The 41st International Symposium of CIB W062 Water Supply and Drainage for Buildings

Healthy Water Environment of Buildings

18-20 AUGUST, 2015

BEIJING, CHINA

Proceedings
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Organizers:
International Council for Research and Innovation in Building and Construction
China National Engineering Research Center for Human Settlements
China Architecture Design Group
China Industry Technology Innovation Strategic Alliance for Housing

Co-organizer:
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Foreword
Work Together to Build a " Healthy Water Environment of Buildings "

Everyone knows that water is the source of all life on Earth. With one of the longest histories in the world, China has studied water in-depth and has grasped a strong understanding of its intricacies. As early as 384 AD, an author from the Northern Wei Dynasty published a famous book on water called "Shui Jing Zhu." During the Ming Dynasty, physician Li Shizhen divided water into roughly 53 types, and listed them in his "Compendium of Herbal Medica"; he analyzed the physical and chemical properties of each type and their compatibility with medicine; from his work we obtained the old Chinese proverbs: "Water is the best food", “Water is the king of all medicine” and "Water is the pinnacle of nutrition".

The 41st International Symposium of CIB W062 Water Supply and Drainage for Buildings has"Healthy Water Environmen of Buildings" as its theme. The symposium will discuss topics such as: security measures of that last mile from water supply source to the tap; prevention of indoor pollution caused by the construction of drainage systems; reliance on carriers in building water systems, including rainwater collection, treatment and reuse; and promotion of sustainable water use and resources. These elements are all important aspects of sustainable development in the industrialization and rapid urbanization of our new historical period. It also presents some of the greatest challenges that emerging economies and developing countries are facing today.

The Chinese government is very concerned about the safety of its drinking water supply. Urban water supply capacity expanded to 650 cities nationwide in 2014, with tap water accounting for 97.64%, and a per capita water supply of 180 liters. Rural water supply has also seen rapid development, from almost none to 61.55% in 2014 in just a few short years. 10 years ago, the Chinese government formulated its "Long-term Scientific and Technological Development Plan", and launched a major "Water Pollution Control" project. The project was to be implemented over 3 five-year plans, investing 30 billion RMB, and focused on control and improvement of water safety of 6 major areas (including rivers, lakes, urban water environment and drinking water, etc.).

Although our efforts have made visible progress, drinking water still suffers from widespread contamination, pipes are old and outdated, and measurements of water quality in that last mile before your home are unknown. In addition, due to economic, social and cultural reasons, China has neglected water drainage issues for far too long; leading to a lack of theory and engineering research in this area.

Health is a universal pursuit; access to safe drinking water and having sanitary drainage facilities are common goals both for China and on a global scale. Buildings have a very close relationship with humans, and serve as the most basic foundation of life, survival and production space; which makes this the most important aspect of our forum and ultimately to achieving our goals of a healthy water environment. Although it isn’t as attractive as economic, social or artistic architecture, it is still the most important. More important than energy-saving! More important than art! We sincerely hope that through this forum, we can strengthen exchanges and cooperation, learn advanced technologies and concepts from abroad and explore new ways of building a healthy water environment together. It is our duty to make due contributions to human health and sustainable development!

A special thanks to the academic committee experts for their guidance in the Symposium, a special thanks to the organizing committee members for all their hard work, and finally a very special thanks to all delegates for their active participation.

Karel De Cuyper
Coordinator of CIB W062

Han Aixing 韩爱兴
Organizing Committee Chairman

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Air Pressure Fluctuation Behaviors in a High−rise Building Drainage System

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Abstract

Air pressure inside the drainage stack is an indicator for the safety retention of water seal. While the excess air pressure destroys water seal of traps and water closets, smell emission from the drainage system will occur and cause health problem. In view of drainage safety, air pressure can be measured for assessment of drainage system in a building. After the SARS outbreak, there are intensive reviews with this respect. A setup has been established to demonstrate how it is assessed. Air pressure fluctuation behaviors in a high-rise building's drainage system (HBDS) is presented by probability density functions (PDF) and statistical analysis of measured data in the drainage stack in a real-life eighteen-floor building, the Li Ka-Shing (LKS), at PolyU of Hong Kong. Three observation points, at the mezzanine (M), 6th, and 12th floors, are arranged to record the air pressure in the primary building stack. The measured data are stored in a personal computer with a sampling period of 1 second(s). Statistical analysis reveals that there is an evident floor dependence of the air pressure in the real-life HBDS.

Keywords

Air pressure; Fluctuation behavior; PDF; Short & long duration of observations

1. Introduction

Building drainage system (BDS) is different from other building services facilities and therefore, it is usually ignored by Building Management System (BMS). There is no automatic monitoring and control with the system. Actually, drainage system is complicate and it is not easy to handle excess positive and negative air pressure inside the system. BDS has an unsteady characteristics causing the air pressure oscillations in the system. Most drainage researches are related to trap which mainly emphasize the importance of water seal retention in the trap. In a drainage stack, the water flow was simply assumed as an annular flow in the vertical stack and partially filled flow in the branch pipes. The purpose to assess the odour and smell removal is to improve the building management.

Cross-contamination via the drainage system may be caused by the depletions of the trap seals and the bathroom floor drain traps. It indicates that the study of BDS is important in safeguarding occupied space and improving building management.

The above researches on air pressure oscillation are usually not carried out in an occupied building's drainage system. Considering this situation, the air-pressure in the high building drainage system (HBDS) of the LKS building in PolyU of Hong Kong was measured and analyzed, to provide information of pressure oscillation for recognizing HBDS operation. LKS building is 18-storeys structure. Offices are located in 5/F to 18F while computer centres and classrooms are located in 1/F to 4/F. Ground floor is a carpark and the drainage stack is bended to horizontal and hang in the ceiling of the car park. The computer centres in 3/F to 4/F have very high utilization rate during day and night time, from Monday to Saturday.

Experimental methods, results and discussion, and final conclusions are covered in the following sections.

2. Experimental Models

The LKS building is the tallest building in PolyU. It is located in the center of the campus. The drainage system of the 18-storeys building was used in the test in April of 2008. The air pressure in the main drainage stack was measured at three survey stations, which were set up on the mezzanine (M) floor, the 6th and 12th floors. It is a unique experiment because data of the air pressure was obtained from a drainage stack in real life operation.

2 surveys were carried out for the test. One is a typical one-day survey and the other is a long one which lasts more than half year.

2.1 Short Duration survey

2.1.1 Analysis

The one day survey was held on 28 April in 2008. Data of the statistical analysis was recorded in daytime from 8:00 AM. The data sampling period was 1s. The aim is to understand the pressure oscillation behaviors so that more useful information can be provided for HBDS operation management.

Pressure sensor IP67 in the type of WIKA was used in the measurement. It has a measuring range of about

± 200mbar, with an accuracy of about 0.25%. Calibration was done using 150mm height U tube manometer, which was connected to the pressure sensor and an air pump. The pressure sensor can detect air pressure in the stack of the test building by providing electric current signals having unit mA, which are transferred to a set of data logger.

The data logger has two parts: an analog input module used to convert mA signals to digital signals, and a programmable logic controller (PLC) used for signal control. The type of the PLC is micrologix-1500. A software named as RS-logix-500 was used for data logging in PLC. Digital signals were sent to the personal computer by using the DH485 communication port and cable.

2.1.2 Result and Discussion

A summary of the statistical analysis of measured air pressure in the main stack of the test building is given in Table 1. The pressure evolutions during 8:00 to 10:00 AM on 28 in April of 2008 are shown in Figs. 1(a-c). Both indicate that the floor dependence of the pressure is quite obvious.

Table 1: Mean pressure, standard deviation, and skewness and flatness factors of pressure fluctuation.

Floor	p_m(mbar)	s(mbar)	C_S	C_F	Record number
M	1.175	0.866	0.899	3.795	38206
6th	-2.28	0.399	-0.52	8.632	38055
12th	-2.05	0.303	-1.10	75.27	32357

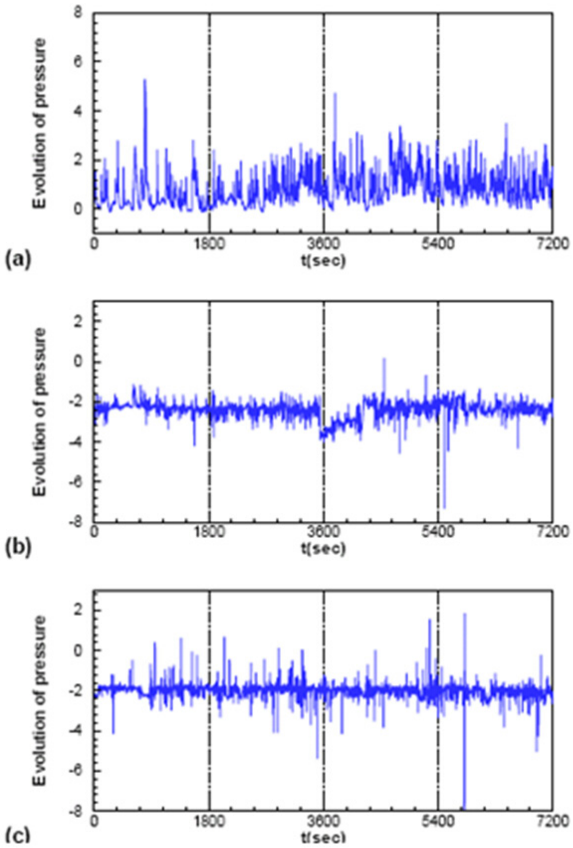


Fig. 1: Evolution of pressure. (a) M floor, (b) 6th floor, (c) 12th floor.

On the M floor, the air pressure in the stack has a positive mean value of roughly 1.2mbar, a larger standard deviation 0.87mbar. The fluctuation of the M floor pressure has a positive skewness factor of about 0.9, and a flatness factor of 3.8, as given in Table 1. The values of these statistical parameters varies in different floors. In particular, the mean air pressure in the drainage stack on the 6th and 12th floors is negative. The standard deviation is roughly three times on the M floor. A fluctuations with lower strength is recommended.

The skewness factors CS of pressure fluctuations on the 6th and 12th floors are less than zero which indicates that fluctuations with larger amplitude is negatively oriented. It means that large amplitude negative pulsations are more common than large amplitude positive pulsations. Evidence can be found in Figs. 2(b-c).

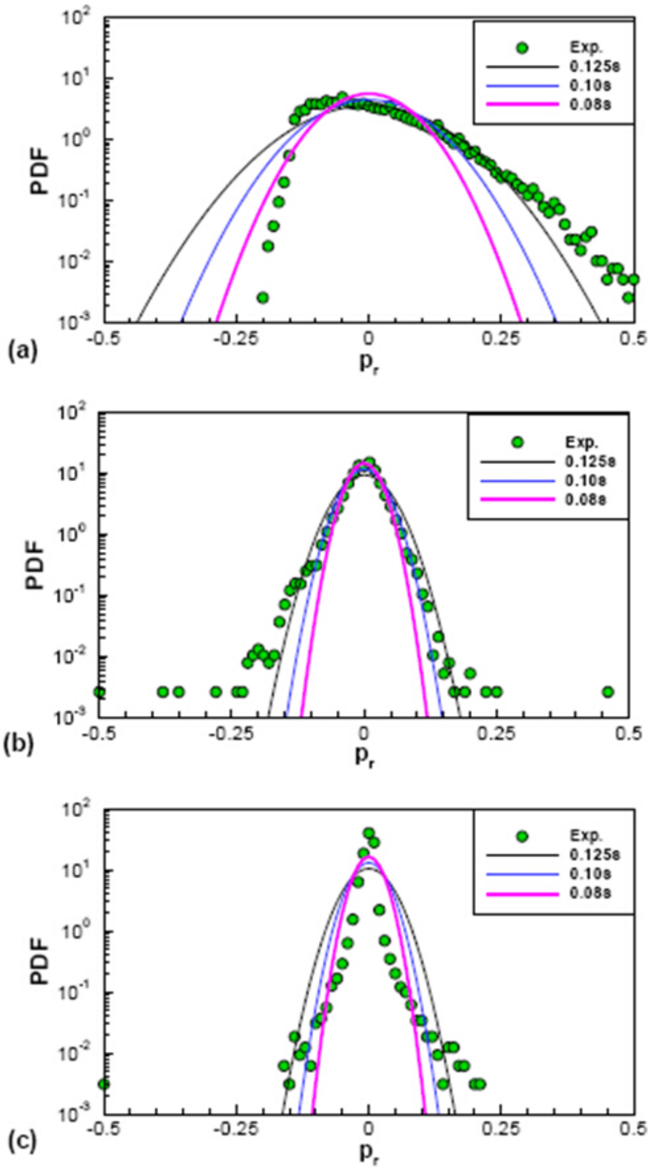


Fig. 2: PDFs of measured pressures and normal distributions with standard deviation Cos. (a) M floor, (b) 6th floor, (c) 12th floor.

The C_S on the 12th floor is about twice of the C_S on the 6th floor, showing that the negative orientation of pulsations with larger amplitude is larger. The flatness factor C_F of the pressure fluctuations in the stack on the 12th floor is about 75, much higher than the C_F on the 6th floor (8.6), implying the re-scaled pressure has a particularly narrowed distribution. As seen in Fig. 2(c), almost all the fluctuation were concentrated in the narrow range of pr from -0.15 to 0.2.

The probability density functions (PDFs) were calculated to assess air pressure in the primary stack of the test building. These PDFs have shown the pressure fluctuation behaviors. The variables demonstrate the re-scaled pressure, which is defined by

$$pr = (p - pm) = [p] \tag{1}$$

and pressure variation range

$$[p] = \max(p) - \min(p) \tag{2}$$

has been shifted so that the midpoint of the range has the mean value pm. As shown in Fig. 2, the pressure fluctuations are less similar to the PDFs (f_p) of normal distributions with standard deviations C_{0s},

$$f_p = \frac{1}{C_{0S}\sqrt{2\pi}} \exp\{-\frac{p_{r2}}{2(C_{0s})2}\} \tag{3}$$

Here the parameter of C_0 was chosen as 0.125, 0.10, or 0.08 (1=mbar). The shape of f_p becomes narrow with the reduction of C_0. In Fig. 2(a), the negative pulsations with amplitude beyond 0.25 were found. The air flow driven by the drained water in the stack is stagnated at the stack bottom near the M/F. This fluctuation behavior determines the standard deviation of normal distribution PDF when the measured PDF will increase with the increase of $1/C_0$. The variation trend is quite different from that of the pressure fluctuations on the 6th and 12th floors [Fig. 3].

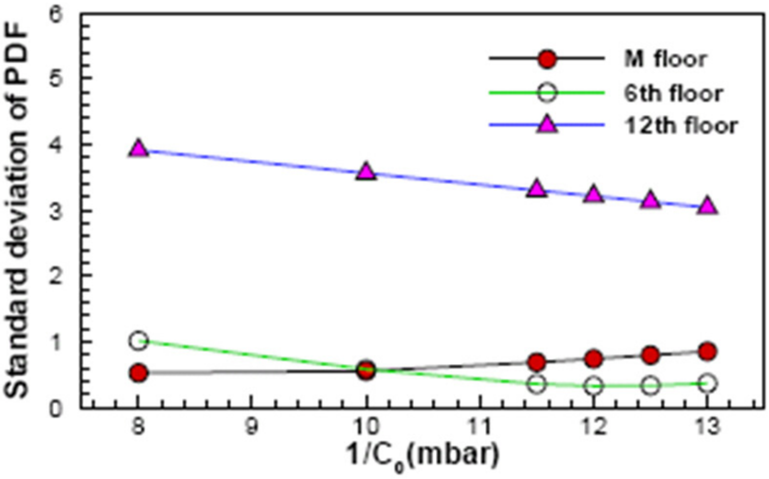


Fig. 3: Standard deviation between the measured PDF and the normal distribution with standard deviation C_{0s}, plotted as a function of $1/C_0$. It denotes the root mean square of air pressure inside the drainage stack.

In Fig. 2(b), the fitness of the normal distribution to the measured PDF is well for small amplitude pressure pulsations while large deviation occurs in the tails representing larger amplitude oscillations. The standard deviation of normal distribution PDF, as shown by the line connected by unfilled circles in Fig. 3, has a minima around $1/C_0$ = 12mbar.

2.2 Long duration survey

2.2.1 Analysis

The long duration survey was held from 3 April to 6 November in 2012. Data of the statistical analysis was recorded during the period. The data sampling period was 1sec. The purpose is to monitor the pressure oscillation behaviors in a longer duration. Comparison of air pressure record is provided for each survey point in different dates. It is very useful information for HBDS operation management.

Pressure sensor IP67 in the type of WIKA was used in the measurement. It has a measuring range of about ± 100mbar, with an accuracy of about 0.25%. Calibration was done using 150mm height U tube manometer, which was connected to the pressure sensor and an air pump.

Based on the continuous data obtained from the system, it is able to estimate how much air pressure oscillation were caused by flushing operation. In this assessment, only the air pressure values would be considered that values were equal or above ± 2.0mbar. The aim of the assessment not only includes general statistical analysis, but also to find out the trend of the air pressure value in the drainage stack. As the probability of malfunction in the stack is related to the reduction of its flushing sectional area, it can be alerted by the increase of the air pressure in the stack. This study is essential and efficient to evaluate the piping condition and possible age of the system.

2.2.2 Result and Discussion

2.2.2.1 Simple Model - Methodology is simple because the purpose is just to collect and compare all the data of ±2.0 mbar air pressure during the period. Probability is evaluated for the occurrence and the trend is assessed. As the amount of losing data is less than 0.2% of total measured data for 32 weeks, thus there is little impact on the analysis.

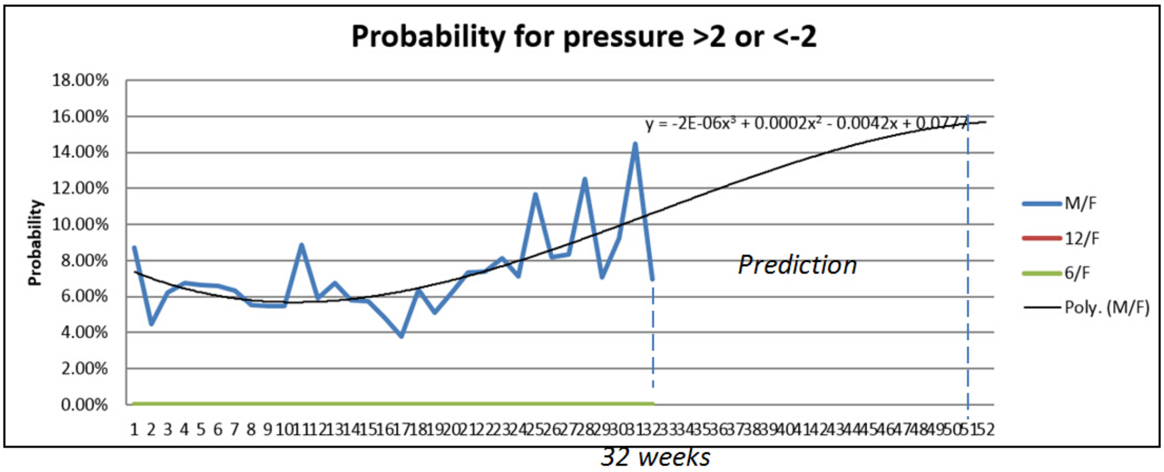


Fig. 4:.As shown in Fig The most suitable formula that % of ± 2mbar = $-2E\text{-}06x^3 + 0.0002x^2 - 0.0042x + 0.0777$ in M/F survey station

The prediction is easy to get but it is open end and no related ranges. ARMA model is applied to solve this question.

2.2.2.2 – ARMA model

Autoregressive integrated moving average (ARIMA) model is a generalization of an autoregressive moving average (ARMA) model, which is to fit the time series data, in order to better describe the data and predict the future values in time series. It is generally denoted as ARIMA(p,q,d), where p is the order of partial correlations, q is the order of correlations, and d is the order of differencing used. It can be expressed as

$$(1-\sum_{i=1}^{p}\varphi_i L^i)(1-L)^d X_t = (1+\sum_{i=1}^{q}\theta_i L^i)\varepsilon_t \qquad (4)$$

where L is Lag operator, d ∈ Z, d>0. φ_i are the autoregressive part of the model, and θ_i are the moving average part. ε_t are error terms, which are generally assumed as independent, identically distributed variables sampled from a normal distribution with zero mean, also called white noise.

R language is utilized to build up model for time series data. It is a free programming language and software environment for statistics and graphics. R console is run with R language. In the exercise, Tuesday is selected to run for 32 weeks from April to November, 2012.

Import data file and plot original data into diagram and check its stationary.

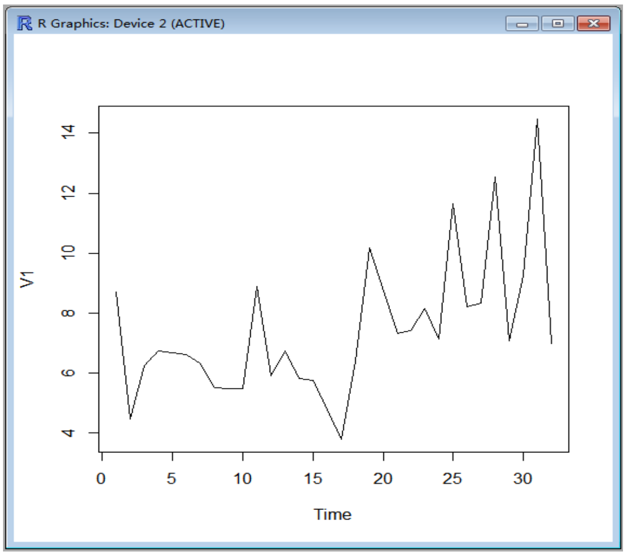


Fig. 5:.As shown in Fig, the probability of ± 2mbar occurrence is increasing

From the diagram, see an increasing trend can be observed, which indicates that it is a non-stationary time series. In order to obtain a stationary time series, we have to “difference” it several times until it becomes stationary. Once the data are correlated and find out the most suitable model is ARIMA(0,1,1).

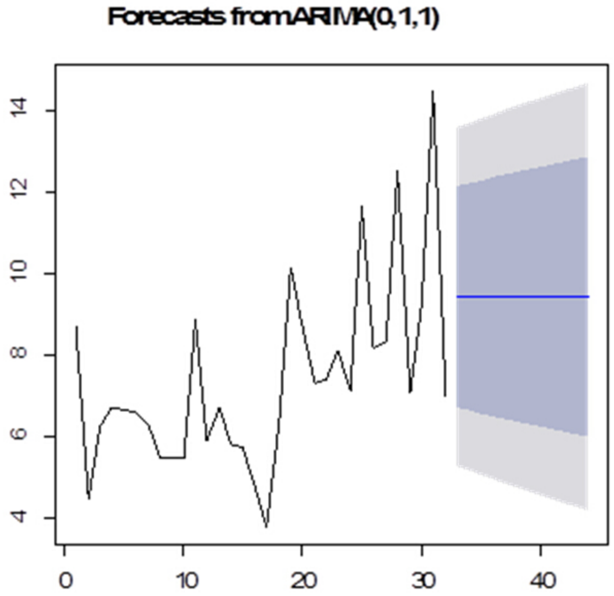
The resulting data are in the table below. They are the possibility of the pipe pressure exceeding 2 mbar (“%” is omitted), which can be regarded the indicator of pipe conditions and will be briefly called “pressure indicator number” or PIN.

In the above predication, PINs of the following 12 weeks are predicted with 80% and 95% prediction intervals respectively.

From table 2, taking week 33 as an example, “Lo 80” and “Hi 80” mean that there is 80% possibility that the PIN is between 6.723219 and 12.16400, and “Lo 95” and “Hi 95” mean that there is 95% possibility that the PIN is between 5.283132 13.60409. The mean predicting PIN is 9.44361.

Table 2: Prediction of ± 2mbar occurrence

Point Forecast	Average	Lo 80	Hi 80	Lo 95	Hi 95
33	9.44361	6.723219	12.16400	5.283132	13.60409
34	9.44361	6.650647	12.23657	5.172142	13.71508
35	9.44361	6.579913	12.30731	5.063963	13.82326
36	9.44361	6.510885	12.37634	4.958394	13.92883
37	9.44361	6.443444	12.44378	4.855252	14.03197
38	9.44361	6.377487	12.50973	4.754379	14.13284
39	9.44361	6.312918	12.57430	4.655630	14.23159
40	9.44361	6.249655	12.63757	4.558878	14.32834
41	9.44361	6.187621	12.69960	4.464004	14.42322
42	9.44361	6.126747	12.76047	4.370905	14.51632
43	9.44361	6.066970	12.82025	4.279484	14.60774



Average = 9.44361

Fig. 6:.As shown in Fig, the probability of ± 2mbar occurrence is increasing within the ranges

For the diagram, x-axis is number of weeks, and y-axis is the number of PIN. Blue line shows the average of PIN. Darker and lighter shades represent possible PIN range with 80% interval and 95 intervals.

Therefore, it is obvious that the possible maximum value PIN is increasing. This means the pipe is tend to lager risk of breaking.

Comparison with result from Excel: Excel gives a rough trend. ARIMA model focus on boundary, with trend as well. They combined together to make a better prediction.

3. Conclusion

Measurements of air pressure on the mezzanine, 6th and 12th floors in the drainage stack of high building drainage system were conducted. Statistical analysis was presented to obtain the following conclusions:

3.1 The air pressure of drainage stack on the mezzanine (M) floor has a positive mean value of about 1.2mbar and a larger standard deviation of about 0.9mbar which is two to three times larger than those on the 6th and 12th floors. The pressure distribution indicated that with respect to the mean value - the pressure has more frequent large amplitude positive fluctuations in lower floors and, more frequent small amplitude negative fluctuations in upper floors. Large amplitude negative fluctuations are not common due to the barrier effect of the stack bottom on the air flow in the stack.

3.2 The air pressures on the 6th and 12th floors have mean values of about -2.3 and 2.1mbar, with comparable standard deviation of roughly 0.3. The corresponding skewness factors are negative, indicating that the pressures have a tendency of large amplitude negative fluctuations. The flatness factor of the pressure fluctuation on the 12th floor is about 75. The value is much larger than that on the M and 6th floors which illustrated that the pressure on the 12th floor has very narrow distribution.

3.3 The air pressure distributions do not satisfy the normal distributions at various standard deviations. The distribution of pressure on the M floor shows the largest deviation from the normal distributions.

3.4 The air pressure in M floor has been monitored for a long duration. It is found that the positive air pressure has an increasing trend due to its age.

3.5 There is a positive trend for positive air pressure which is found in M/F. A risk of smell emission will occur from toilets in 3~4/F of LKS building. Some measures have been planned for the smell emission.

3.6 As drainage monitoring is weak in the Building Management System (BMS) in industry, more analytic methods and devices are used for drainage system in the BMS.

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5. Presentation of Author

Dr Eric S.W. Wong works in Industrial Centre of The Hong Kong Polytechnic University. His expertise is in the design and testing of Plumbing and Drainage systems and products. He is an active consultant and handle a lot of related projects.

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High−rise Testing of Active Drainage System Compared with Conventional Venting on Two Test Towers

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Abstract

Active Drainage Ventilation has been a subject of a number of CIB W062 papers over the years, with the development of the Positive Air Pressure Attenuator and Air Admittance valves. With buildings being built taller each year and many being designed in excess of 400 meters, with mixed use occupation hotels, office and residential all discharging into one stack.

The drainage systems are being subjected to grater loadings in different zones at any one time. The effect of negative transients and positive transients is becoming a greater issue, due to the time it takes for the system to balance. With the vents to atmosphere being further away and the increased communication time for the pressure regime within the pipe leading to the system pressure exceeding 400Pa with the loss of water trap seals.

National codes still do not proved sufficient information to the design engineers for tall buildings due to many being based on steady state flows versus the real inherently unsteady sate discharges that occur.

The paper will present findings of physical testing data carried out on two testing towers. The testing will compare the capabilities of the active drainage ventilation verse conventional venting methods for tall buildings. The testing subjects both systems to unsteady discharges to determine the maximum loadings in both 100mm and 150mm sized pipes systems with the key criteria being that all the traps seals are maintained. Further tests subject the drainage system with solids, wet wipes and sanitary towels. The aim of this paper is to provide data for national code bodies on the capabilities of both systems, to meet the demands of the drainage system to the unsteady discharges in tall buildings so that the water traps seals continue to provide the barrier between the drainage system and the occupied space within the building.

Keywords

Air Admittance Valves, Positive Air Pressure Attenuator, Drainage Ventilation, Water Trap Seals, Unsteady State Discharges, Active Drainage Ventilation

1.Introduction

Throughout the many years of CIB W062 there have been numerous papers on the ability of utilizing air admittance valves to help protect the water trap seals from negative transients. Through these many research papers and tests from around the world air admittance valves (AAV) have been integrated into many national and international codes. In more recent years there have been a number of papers on the causes and the effects of positive transients within the drainage system. Industry still needs to understand the research and how it can guide them towards improving the codes and practises especially for high-rise building designs. When research and industry have worked together it has been possible to develop products to deal with these transients, one example has been the Positive. Air. Pressure. Attenuator. (P.A.P.A. ™)

Fig 1 P.A.P.A. ™

This has progressed into the overall transient protection solution of Active Drainage Ventilation, the combination of AAV’ s and the P.A.P.A ™ working together to help balance the positive and negative transients generated in the drainage system from reaching levels that breach or siphon water trap seals (-+400Pa.)

The development of active drainage ventilation has always been focused on high-rise drainage systems and has been developed from a research basis into a commercialised system.

The use of simulation/modelling has been essential to the development of the active drainage ventilation solution and by using AIRNET developed by Heriot Watt University.

Although the information and research is available and has been for some time, there is still a lack of understanding or acceptance of the research. This may be in part a lack of education or just conservatism within the industry to change their current practice. The only solution to overcome this resistance is a“seeing believes” approach initially by actual projects but access to a completed project is a limitation or the approach to test the system on the tallest facilities available in the world. This paper will look at two testing towers one based in Europe and the other based in China.

2. Simulated Active Air Pressure Transient Control Using AIRNET

Research carried out by the drainage research group of Heriot-Watt University using AIRNET for a 50-storey building produced some surprising results, which are illustrated in Figures 2 and 3, especially considering that the conventional system analysed is very typical of high-rise drainage designs.

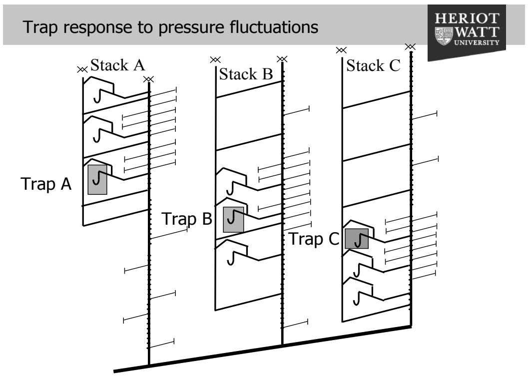


Figure 2 - 50-storey building with 150mm wet stacks and 100mm vent pipe network

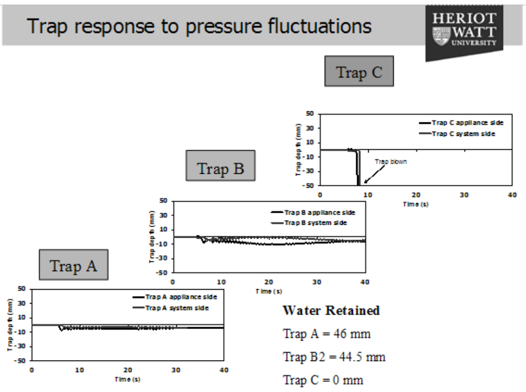


Figure 3 - Results of the trap seals when subjected to a discharge of 12.4L/s over a 35 second period

Trap C has siphoned at 8 seconds, at which point the system has approximately 4.5L/s in the system. This simulation has demonstrated that although the drainage system design is fully vented with a 100mm relief vent pipe and 100mm cross vents with a 150mm wet stack the trap seal at the lowest point of the building is subjected to negative transients that have depleted the trap. It can be assumed that due to the height of the building in the simulation the height of the building has a major impact in the communication times for the system to respond to the pressure needs of the system.

Figures 4 and 5 illustrate the results when the same 50-storey building is vented using AAVs. It can be seen in Figure 4 that when AAVs are installed at the point of need (throughout the system) pressure relief is provided throughout the system. The reason that the system in the simulation now provides protection to the trap seals is due to the fact that AAVs installed on each floor respond typically at around -80Pa to the pressure in the system to relieve the negative pressure and keep the system within -110Pa. This is well below the point that traps will siphon from -400Pa to 500Pa and return the system back to atmospheric pressure.

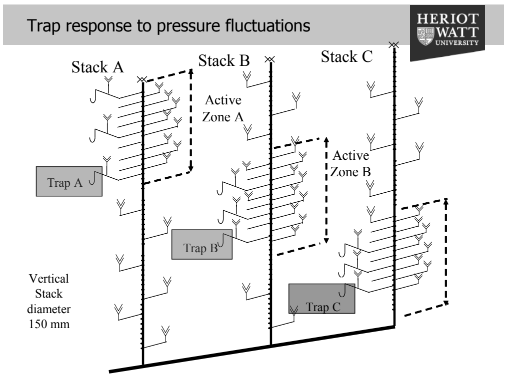


Figure 4 - 50-story building with 150mm wet vent stack and AAVs placed at the point of need in the system

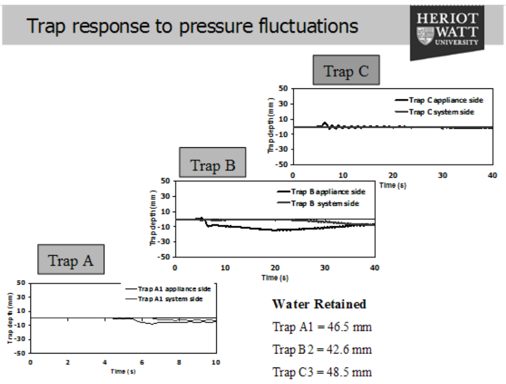


Figure 5 - Results of the trap seals when subjected to a discharge of 12.4L/s over a 35 second period

Figures 6 and 7 below illustrate the results when the same 50-story building is simulated by AIRNET for positive transients with half the hydraulic loading of 6.5L/s. It can be seen by the simulation results at trap C has depleted due to positive transients. This indicates that the 100mm relief vent which is in the design and commonly used is insufficient in diameter to divert the positive transient that is moving at 320m/s away from the trap seals in the system.

When the 50-storey building is designed as an active controlled system it can be seen that protection is provided throughout the system, as illustrated in Figures 8 and 9 below. By using AAVs and P.A.P.A. placed throughout the system the simulation results provided by AIRNET show the provision of the trap seals throughout the system with protection from negative and positive pressures. It is the concept of using AAVs and P.A.P.A. together that keeps the system pressure below -110Pa and thus the trap seals within the system are not subjected to the harmful pressures of over +- 400Pa.

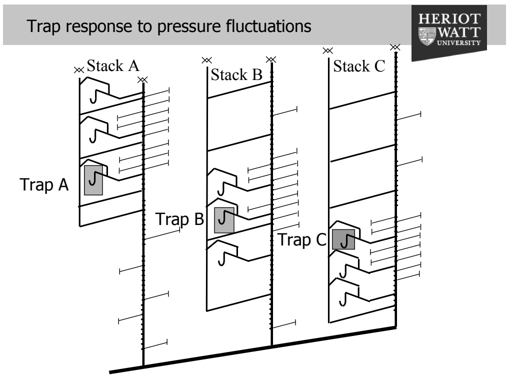


Figure 6 - 50-storey building with 150mm we stacks and 100mm vent pipe network

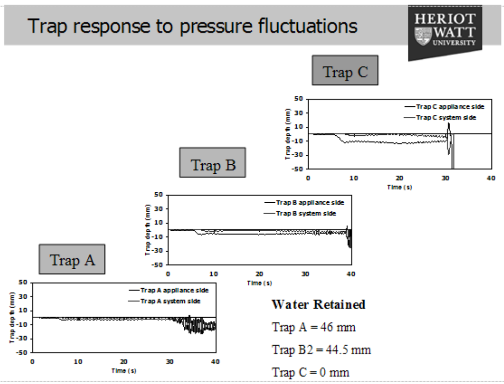


Figure 7 - Results of the trap seals when subjected to a discharge of 6.5L/s over a 35 sec. period and a surcharge placed downstream after a 30 sec. period with the load at that point of 3.5L/s

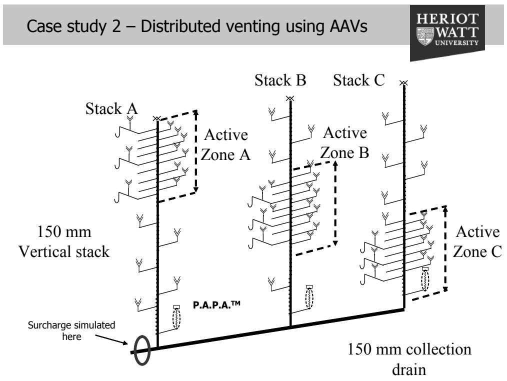


Figure 8 - 50-storey buildings with 150mm stack with a loading of 6.5L/s utilising AAVs and P.A.P.A.

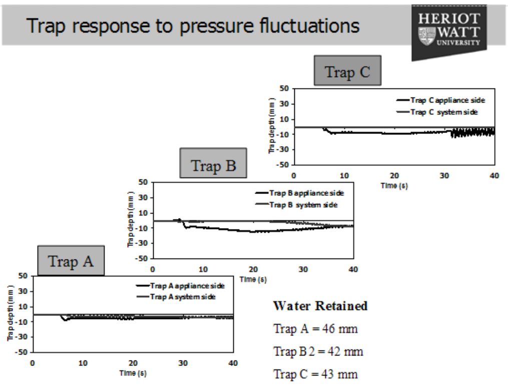


Figure 9 - Results of the trap seals when subjected to a discharge of 6.5L/s over a 35 sec. period and a surcharge placed down stream after a 30 sec. period

The involvement of research has demonstrated two major factors; firstly that high-rise buildings designed conventionally can be affected by negative and positive transients; and secondly that working with the industry there is a safe and practical solution to designing a high-rise building drainage and vent system.

3. Test Towers

Finding suitable facilities to test drainage systems of a suitable height that reflects the types of high-rise construction that is occurring around the world is limited, especially for testing purposes. It is either through testing on buildings at the end of their life as Heriot Watt University undertook at the 17 floor building in Dundee or new construction as Otsuka (2010) 34 floor super high-rise tower or on an existing buildings, Wong and Mui (2009) on actual rather assumed flows on Hong Kong housing tower block. Fernandes and Goncalves (2006) investigated the application of AAV within the Brazilian national codes on the student campus blocks. But in many cases the testing has been undertaken by universities own research facilities for example Otsuka (2012) on the high-rise simulation tower of Kanto Gakuin University Cheng (2008) on the NTUST 13 experimental test tower and 108 meter URA experimental tower mentioned in Sakaue (2014).

In 2012 at the symposium in Edinburgh, CIB W062 was introduced to the Chinese experimental test tower in Dongguan, Guangdong Province operated by the China National Engineering Research Centre for Human Settlements- Vanke Building Research Centre Fig 10.

Fig 10 Chinese Experimental Test Tower

In 2013 and 2014 two papers have been summited to CIB W062 focusing on the instantaneous flows in drainage stacks Z Zhang (2013/2014) L Zhang (2013/2014). In 2015 active drainage is also being tested on this tower, with the aim to provide data to allow the Chinese drainage experts to assess the system into the Chinese building codes.

Within Europe the tallest test tower was 10 floors and in the UK at the British Research Establishment a 5 floors rig. Due to the new building demands in London with over 230 high-rise buildings being constructed over the next 5 years ranging from 20 floors up to 80 floors or more and with floor space costing \$472-\$4720 USD ft^2 major building firms are looking at new solutions to maximise sellable space within these buildings.

Active drainage ventilation has been submitted to the major builders to provide them with an alternative system verse traditional pipe methods. This will give them the space saving in the ducts that they are seeking as well as limiting the roof penetrations of the stacks at the top of the building which the architects do not want to see on their designs. Alongside this the research and project references on why active drainage ventilation should be used as the best technical solution for taller buildings, there has still been a resistance to move away from traditional vent pipe method that is in the building code and traditional methodology even through the systems are at risk of failing due to the nature of the high-rise designs.

In one discussion with the builders of Principle Place a 50 floor project in London Fig 11 they requested that active drainage ventilation be proven to them. The only solution was to find a suitable facility in Europe to back up the research.

Fig 11 Principle Place London

The tower that was used for the testing in Europe is the National Lift Tower in Northampton Fig 12. It is 128 meters tall 14.6 meters at the base and tapers to 8.5 meters at the top of the building.

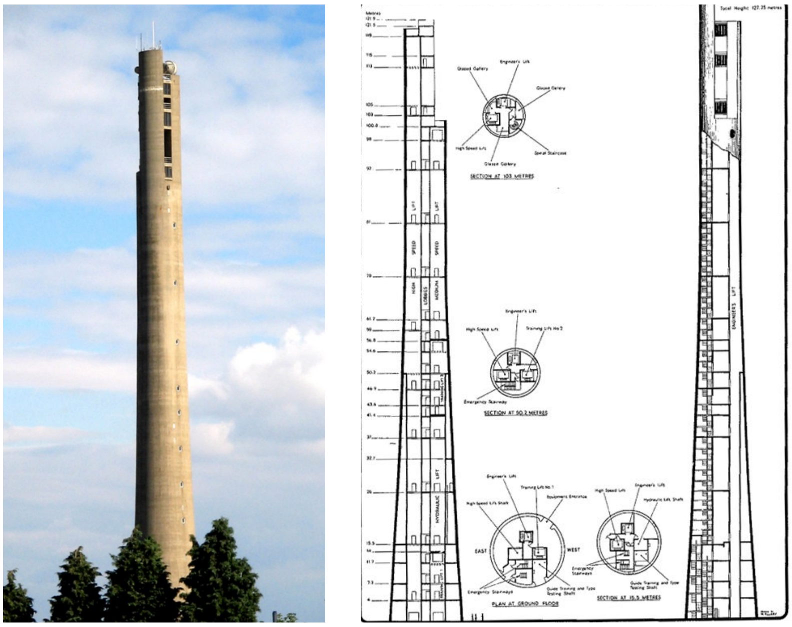


Fig 12 National Lift Test Tower Northampton

4. Testing Aims

Due to the significant amount of existing research that has already been published over the years on negative and positive transients, and on the P.A.P.A ™ and AAV’S the testing has been carried out to see if the physical testing is in line with the researched findings as in Chapter 2.

To compare traditional pipe vented systems designed to national codes to the active drainage ventilation solutions.

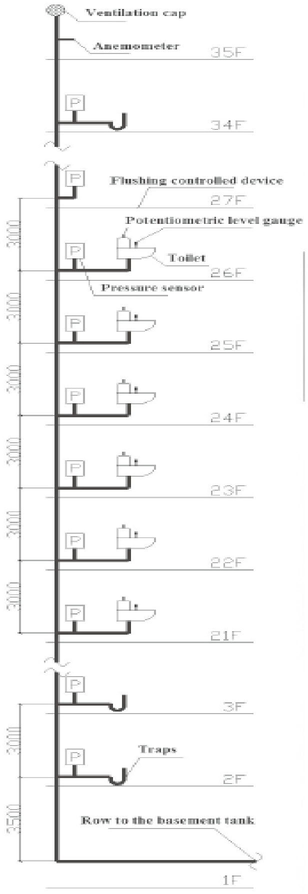
To subject the drainage systems to extreme loadings and usage and introducing waste into the system that a normal high-rise may be subjected too in every day usage. Keeping to the principle of unsteady state discharges verses steady state discharging as this is the reality of the system in a real building.

To focus on the trap seal retention during and after discharging into the system, as this is the main goal of drainage ventilation to ensure that the barrier is maintained.

Focus on dynamic discharges by using WC as the principle discharge route into the system.

5. Chinese Experimental Test Tower

The testing on this tower has been undertaken by contract between Studor and the China Architecture Design and Research Group CNERC for Human settlement. The testing is still ongoing so the full results will be updated at a later date. The test tower base setup is set up as in Fig 13. Water trap seals have been installed throughout the floors, AAV’ s and PAPA ™ have been installed with gate valves Fig 14 so that they can be switched in and switched out as required through the testing phases



Explanation:4F~20F、 28F~33F with 2F

Fig 13 China Test Tower

The testing procedure is being undertaken in table 1 and focuses on proving the active drainage ventilation data to be summited to the Chinese drainage experts for discussion and approval of the system into China building codes. The test sets table 2 are aimed to load the system to a high rate of discharge at different zones to see how the ventilation solution protects the water traps seals in different zones under high loadings as well as introducing toilet paper, wet wipes, sanitary towels and solids to see the effect that they have on the system.

Fig 14

Table 1

	system	method	test set
1	Traditional system , PAPA™, open vent	Appliance flow test method	3 set
2	Single stack, Maxi-Vent™, Mini-vent™, PAPA™	Appliance flow test method	3 sets
3	Single stack, Mini-Vent™, PAPA™ , Open Stack	Appliance flow test method	3 sets
4	Single stack, Mini-Vent™, PAPA™, Maxi-Vent, solid waste	solid waste simulation	4 sets
5	Single stack, Mini-Vent™, PAPA™, Open Stack, solid waste	solid waste simulation	4 sets

Mini-Vent™ Maxi-Vent™ P.A.P.A.™

Fig 15

Table 2

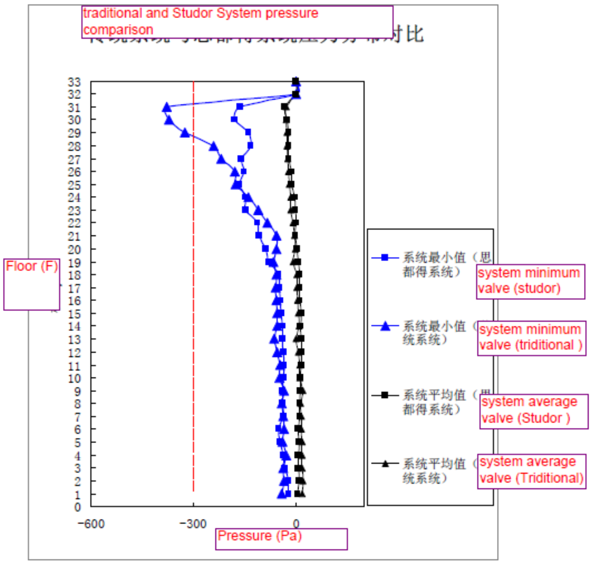
Floor	discharge test set			solid waste tests			
	1	2	3	Toilet paper	Towel paper	Sanitary towel	Solid,TBC
34		x					
33		x		x	x	x water only	x
32		x					
31		x					
30		x					
29		x					
28		x					
27		x					
26		x					
25		x					
24				x	x	x add sanitary towel	x
23							
22			x				
21			x				
20			x				
19			x				
18			x				
17			x				
16			x				
15			x	x	x	x water only	x
14			x				
13			x				
12							
11							
10	x						
9	x			x	x	x water only	x
8	x						
7	x						
6	x						
5	x						
4	x						
3	x						
2	x			x	x	X water only	x
1	x						

6. Chinese Experimental Test Tower Single Test Result

System Description
Two Experimental test of the systems are using DN110 single stack pipe,
Traditional signal stack system with open vent to atmosphere
AAV’ s installed on each branch, P.A.P.A. ™ installed every 3 floors, Maxi-Vent ™ installed at the top of the stack.

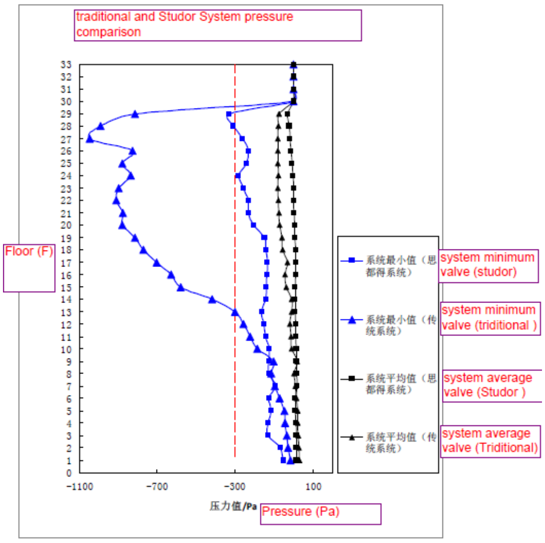
TEST
Discharge (christen 6L) at 30-33F, each floor has 1 unit.
Tests are carried out 2 and 4 units discharge at same time to analyze pressure response.

Result
Under same test configuration, , the maximum negative pressure within the Studor system had significantly smaller than the maximum negative value of the traditional single-riser system. In particular with the 4 discharges Fig 16 without the AAV’ s the system exceeded -1100Pa and loss of the water trap seal. With the AAV’ s the system only went -310Pa and fell within national code limits of -400Pa. In the two discharge test Fig 15 the traditional system exceeded -400Pa with partial loss of the water trap seal but with the AAV’ s engaged the system pressure reached -150Pa and the trap seal was maintained.



2 discharge unit (cristen), pressure profile

Fig 15



4 discharge unit (cristen), pressure profile

Fig 16

7. Europe Experimental Test Tower

The 128 meter National Lift Test Tower proved to be the ideal facility to test in as well as demonstrating drainage system in operation on a tall building. It provided ease of access with minimal health safety requirements and due to the open floors Fig18 the whole system can be observed when testing is carried out.

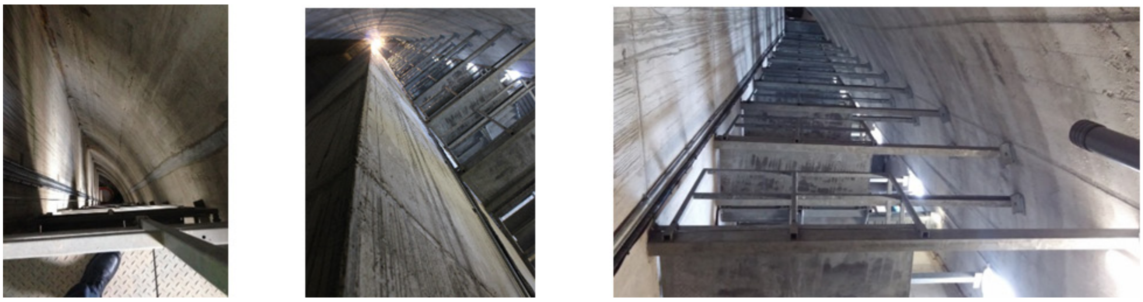


Fig 18

The design of the system was based on standard UK principles based on BS EN 12056-2. Polypipe® Terrain supplied FUZE HDPE 110mm stack and FUZE HDPE 56mm vent pipes. HDPE pipe is the preferred pipe material for commercial high–rise projects in the United Kingdom.

The drainage system tested was 84 meters, with the lower 4 floors discharging in to the main sewer system with office kitchen (1 sink) and bathrooms (two WC and one basin) on floor 1 and 2, which were not monitored as part of the test.

The tested instillation consisted of a stub stack Fig 19 on floor test level 1 to test level 2 with one WC and two 40mm P traps and one 75mm bottle trap. It was connected to horizontal run 3.5 meters downstream of the base of the main stack. The horizontal run at the base of the main stack was 5 meters before it turned via a 90 bend into the original building drainage network picking up the office kitchen and bathrooms on floor 1 and 2.

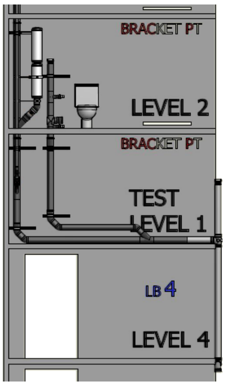
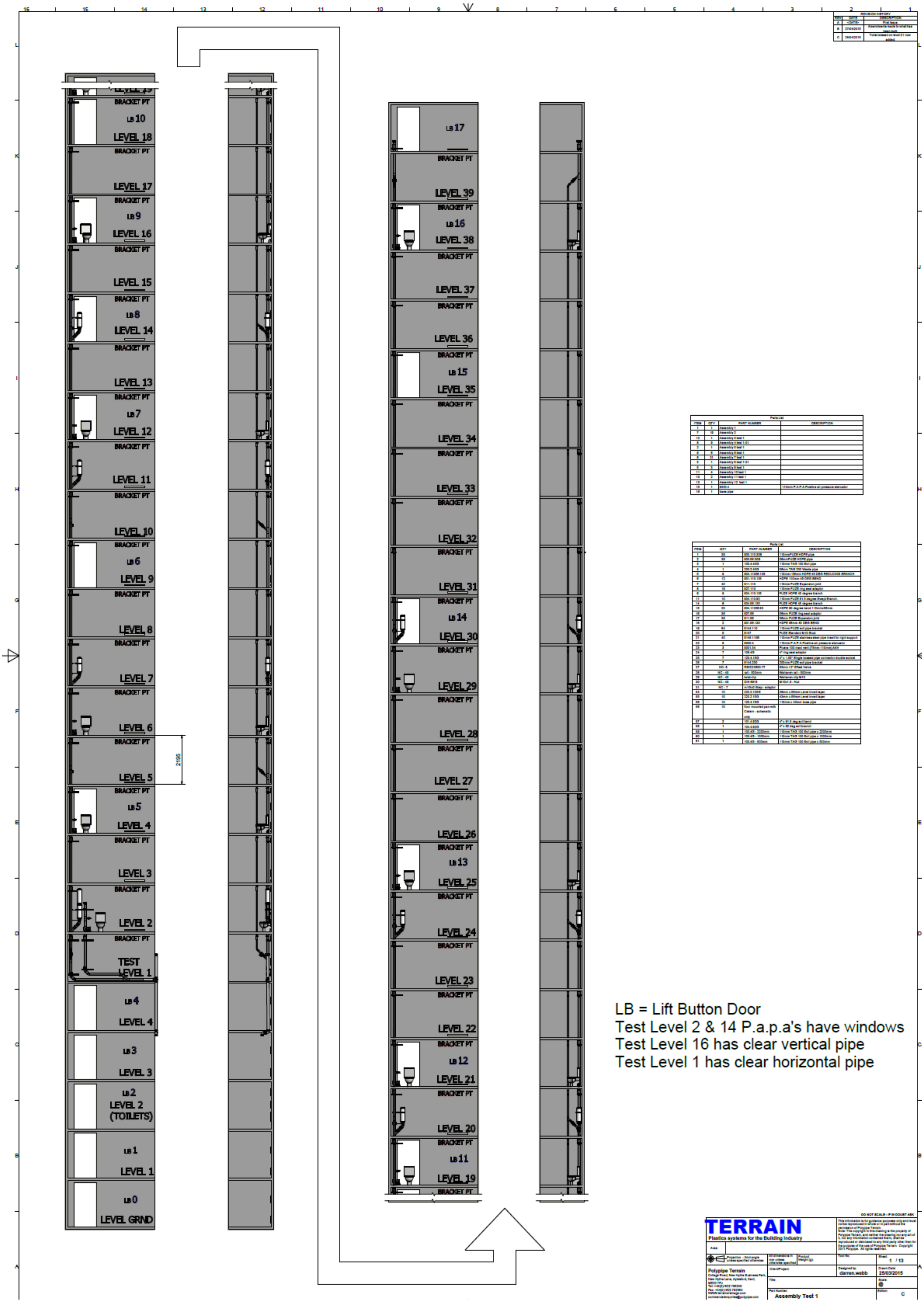


Fig 19

Each test level floor was installed with a 5L WC, two 40mm P traps and one 75mm bottle trap. These were installed on test level floors, 4, 6,12,16,19,21,25,29 and 38 as shown in Fig 20. Each of the test floors were installed with a Mini-Vent ™ AAV that had a gate valve so that they could be selected or isolated from the system. Two P.A.P.A. ™ was installed in series at test level 2 on the main stack. Single P.A.P.A. ™ were placed on test level floors 7,11,14,20,24 and 30 with gate valves to isolate them from the system. The 56mm vent pipe was cross connected at test level floors 1, 5, 10, 14,20,24,30 and 39 these also had gate valves to isolate from the system as required.



LB = Lift Button Door
Test Level 2 & 14 P.a.p.a's have windows
Test Level 16 has clear vertical pipe
Test Level 1 has clear horizontal pipe

Fig 20

Each test level floor with a WC had a manometer connected to the stack and traps were replenished when required before each test. Video was used to monitor different tests on various test levels to record the manometer readings as well as monitor the base of the stack and trap seals. In the testing the Dyteqta® Pressure TEQ ™ Fig21 was used to record the pressure readings at test level 4 and test level 16. Pressure TEQ ™ is a data and analysis system using Sensor Technics CTEM7NO23G7 pressure transducer.

Fig 21

On test level one, clear pipe was installed Fig 22 and on test level 16 clear pipe was also installed Fig 23 this allowed the flow in the pipes to be monitored and recorded. A number of the P.A.P.A.™ were opened so that the action of the balder could be observed when discharging was taking place Fig 24. The installation of the system can be seen in Fig 25

Fig 22

Fig 23

Fig 24

Fig 25

Testing of the system was carried out comapring the active driange ventilation with the vent pipe network isolated and the tested were repeted with the active driange ventilation isolated and the vent pipe network opened.

8. Europe Experimental Test Tower Testing

The first test undertaken were clean water flushes consisting of 3 flushes from test level 12,16 and 38 with the active ventilation open and the vent system closed. The test were repeated with the vent system open, both systems of venting coped well with no loss of water trap seals and the pressures in the system did not exceed more than +- 150Pa which is well within the design limits of the European standard. The terminal velocity was measured and calculated to 2.8 m/s and this measured by discharging the WC on test level 38 and timing it to when it reached the base of the stack 30 seconds.

The testing increased the number of flushes to 3x flushes 5 seconds apart from test levels 12, 16 and 38 that the first trap seal loss on test level 6 that a trap seal had siphoned when the active ventilation was closed and the vent system was opened. It can be seen in Fig 26 that the manometer on the stack and the vent pipe had the same response and oscillations from the video it was recorded that was over 30 mm of movement being 300Pa which was depleting the trap seal due to the 45 seconds period that the discharges were taken place and flowing in the stack at measurable level.

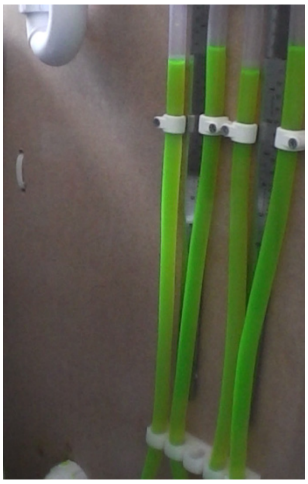


Fig 26

As the failure point of the vent pipe system was found to be at 9 WC flushes over a 45 second period the testing focused on the active ventilation for clean water flush testing to find the limit. The next significant result was 3x flushes from test level floors 12, 16, 19, 21 and 38 with over 75 litres discharge over a 45 second period. The sensors Fig 27 measured positive pressure of over +230 Pa and a negative pressure of -160 Pa. Fig 28 the video captured that hydraulic jump at the base of the stack. It is suspected that the initial positive pressure reading is due to the location of the sensor placement on test floor level 12 and the discharge from the WC. It will be in the next testing phase that different location and placement will be undertaken to see if this is the case. It is also to be noted that no traps were lost in this test with the active venting.

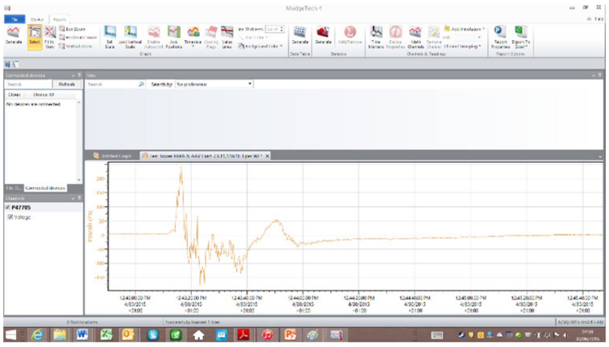


Fig 27

Fig 28

The next phase of testing is to see the effect that solids have on the system. The first test carried out was on the active ventilation engaged and the vent pipe isolated. 9 x sheets of standard toilet paper were placed in the WC on test level 12 and 16. There was no significant finding and the toilet paper obliterated as expected as can be seen in Fig 29 at the base of the stack with no high pressure readings. It was the same when vent piping was engaged.

The second was a testing with 9 x sheets of standard toilet paper and one standard sausage (solid) the speed of the solid was measured at 4-5 m/s and of note in Fig 30 that on this flush the toilet paper attached itself to the solid and only broke up 4 meters further down the pipe, when the velocity was greatly reduced. Again there was no significant findings in regards to pressure readings or trap seal movement and as with the toilet paper flush both systems were measured in the -+ 150 Pa range well with in design limits.

The third tests involved the discharge of a single sanitary towel Fig 31 and again no significant readings were observed or recorded for both active ventilation and vent piped systems and the pressure range was similar to test 2.

The fourth test involved x 4 wet toilet paper sheets placed into the WC pan in Fig 32 it was noted that although they were flushed at the same time in the video the sheets separated as in Fig 33, also in further test of the wet wipes is was seen to catch at the base of the stack momentarily. But as per test 2 and 3 no significant events on both systems was seen.

Fig 29

Fig 30

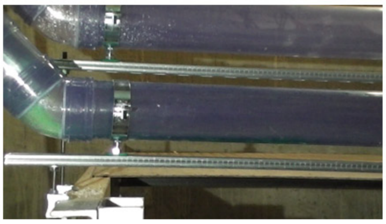


Fig 31

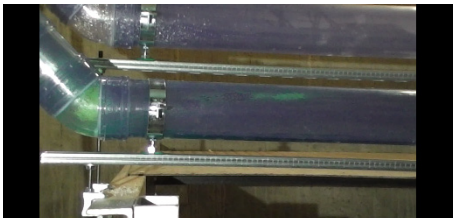


Fig 32

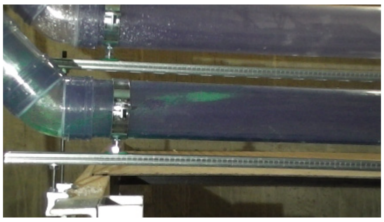


Fig 33

The pervious testing was undertaken to assess if the solids for a single discharge had any effect to the pressure readings or that there was a marked difference between the active ventilation and the piped vent to which there was none. These were controlled tests and come in the realm of steady state testing.

To achieve a more unsteady state testing a random testing approach was carried out to try to reflect worse case events that may occur in actual buildings. To this aim more loaded discharges from different test level floors with a mixed load of toilets paper, sanitary towels, wet wipes and solids placed into the WC Fig 34.

Fig 34

As expected due to the varied loadings and variation of discharge the 7 x 5 litre flushes from test levels 38, 30, 25, 21,19,16 and 12 the system was coming to close to maximum load capacity. The results on the active ventilation with the sensor placed on test level 2 just before the P.A.P.A. ™ a positive pressure reading of +320 Pa and a negative pressure of -150 Pa but the traps were maintained as in Fig 35.

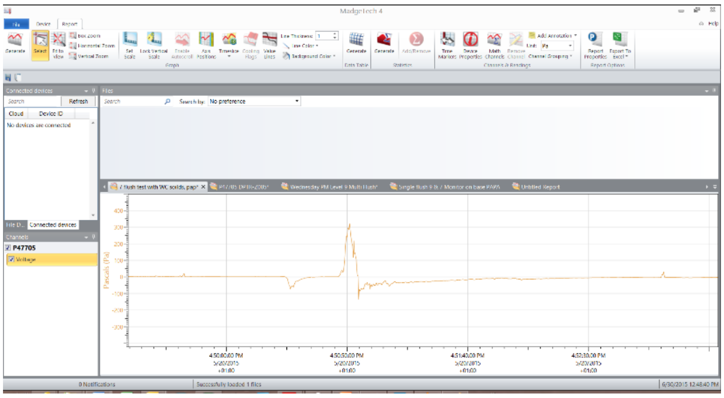


Fig 35

As with the active venting the vent pipe system was subjected to 7 x 5 litre flushes at test levels 38, 30, 25, 21, 19, 16 and 12 with similar loading although not exactly the same, the vent piped system experienced a significantly higher level of positive pressure close to +650 Pa and a negative pressure of -250 Pa as in Fig 36.

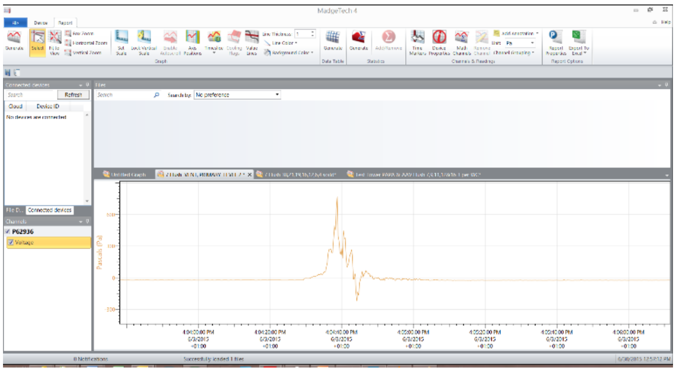


Fig 36

In doing these test in a more random manner the results are in no way perfect and may well be not of any scientific value, but it does highlight that if similar test are carried out the results have a very dissimilar results between the two systems. It also highlights that if the users of the drainage system discharge there systems outside of what is normal usage patterns the possible affects that this has on a communal high-rise drainage could be significant.

To come back to a more scientific approach at the end of each day testing all 10 WC were discharged at the same time 50 litres. This test had a dual purpose, one to see how both systems coped with a large loading. The other is that the buildings drainage system was connected to the main city sewer system and due to the volume of solids that had been flushed from the tower the volume of water from the two 10 WC test would prevent any blockages. Fig 37 is the sensor based just before the P.A.P.A. ™ on test level 2.

The first peak is the discharge on the active drainage system and the measurement of the positive pressure reached too nearly +1000Pa for a very short period then reduced very rapidly.

The 110 mm pipe was fully surcharged at the base of the stack and the WC and traps on the stub stack had major movement although the traps did not blow out or self-siphon.

The second peak is the discharge into the vented pipe system and the measurement of the positive pressure peaked at +1500Pa and was present for a much longer period. The WC connected to the stub stack on test level 2 blew out totally.

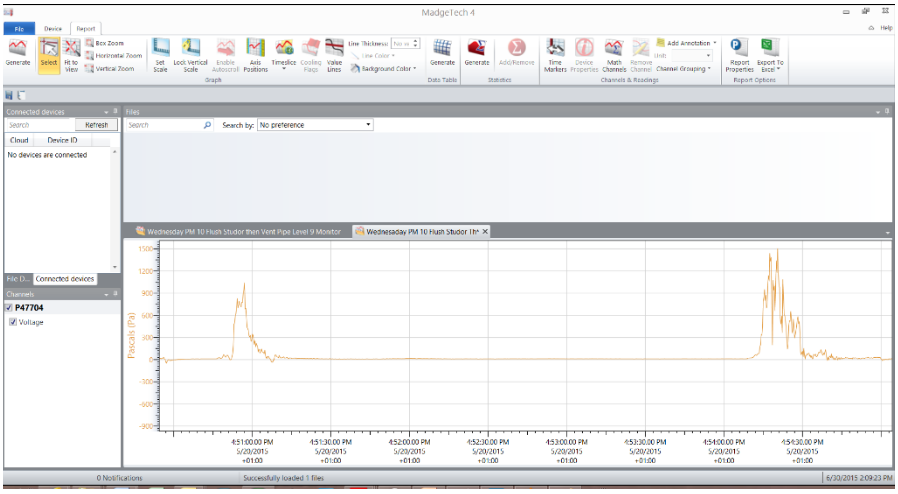


Fig 37

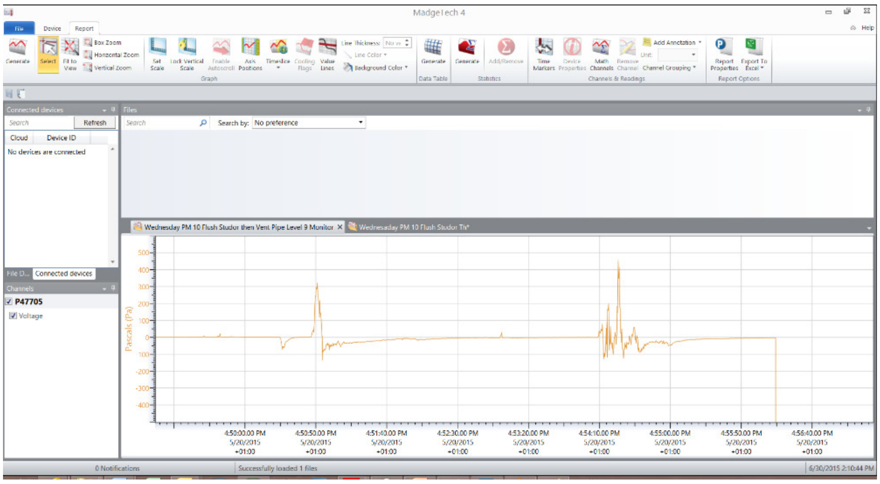


Fig 38

In Fig 38 the second sensor was located on test level 16 connected to the 110mm branch from the WC on that floor.

The first peak is positive pressure of +300Pa on the active drainage system was measured and the positive event lasted for a short period of time.

The second peak of over +400 Pa is on the pipe vented system and the event last a few seconds longer than the first peak.

From this 10 WC discharge the system exceeded the hydraulic loading of the system, there was excessive movement of the traps seals on the active drainage ventilation test but no traps were found to be depleted.

With the pipe vented system designed to the BS EN12056-2 and commonly used in the UK for taller building, when subjected to a major event it did not cope as well as the active drainage ventilation and had suffered loss of the WC trap seal on the stub stack and a loss of the water trap seal on test level 6.

9. Discussion and Conclusion

There is sufficient research already generated to design an international high-rise building code. But the industry is sometimes unwilling to accept the research to change their beliefs and ensure that the national codes that they follow meet the demands for the tall complex designs that are being built all over the world.

In China they have recognised this and in partnership with industry have established a testing facilities that industry can test on to prove that their products or systems meet the demand for China and their people. This is sometimes lost in other regions where it can take years to gain product approval or sometimes decades to change and existing code. The testing of active drainage ventilation is ongoing on the China Experimental Test Tower and the initial feedback of the testing results, that have yet to be released, has followed the expected outcome of the research that have already been published in the past, and the performance of active ventilation using AAV’s and P.A.P.A. ™ performs better than what is the guidance in the existing national codes for taller projects.

Within Europe the need to have a tall testing facility is the same as China and yet there is no third party testing institute able or willing to operate such a project. The need for the test tower has come from a commercial requirement and the need for industry to physically witness the system in operation so in some cases they can accept the research and testing that has already been done.

The test rig in tower was completed in May 2015 and to date over 100 public health engineers have come to witness the testing and also partake in the test themselves. Many have commented that they have never seen a hydraulic jump at the base and what happens when there is a surcharge at the base of the stack. So as a practical tool to help educate convince designer of drainage system and installers who are sometimes unaware of the amount of valuable research is out there to help improve what they do for the clients.

The tower in Northampton is an ongoing project and with more refinement required planned for the next six months is to place an offset in the middle of the system as well as testing square and swept branch junctions into the stack. The Dyteqta ™ monitoring system will be installed in the next few months and this will assist in monitoring the detection of the water trap seals throughout the system as well as providing system analysis when testing is going on.

It also has to be noted that active drainage ventilation has time and again proven to be better in performance than traditional pipe vented design for tall buildings, through research and simulations, through practical testing as on the test towers, through problem solving and untimely by the 1000’s of buildings around the world that already have active ventilation installed upon them

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11. Presentation of Authors

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An Experimental Investigation on the Influence of Different Offset Piping Methods on the Drainage Performance of a Drainage Stack

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Abstract

The study aims to understand the drainage performance of a drainage stack, when different types of offset configurations are installed thereto using different piping conditions, and to obtain knowledge that contributes to a design method for a piping arrangement. To be more specific, an offset having 45 elbows and an offset having 90 elbows are installed and the descending position thereof is moved 1m, 2m, and 3m from the centre of the drainage stack. The influence of the offsets on the drainage performance of the drainage stack is evaluated when loads are applied in accordance with SHASE-S218, and a prediction method is subsequently discussed.

Keywords

Drainage Performance, Offset, Single Stack System, Piping Network Model

1. Background and Objectives

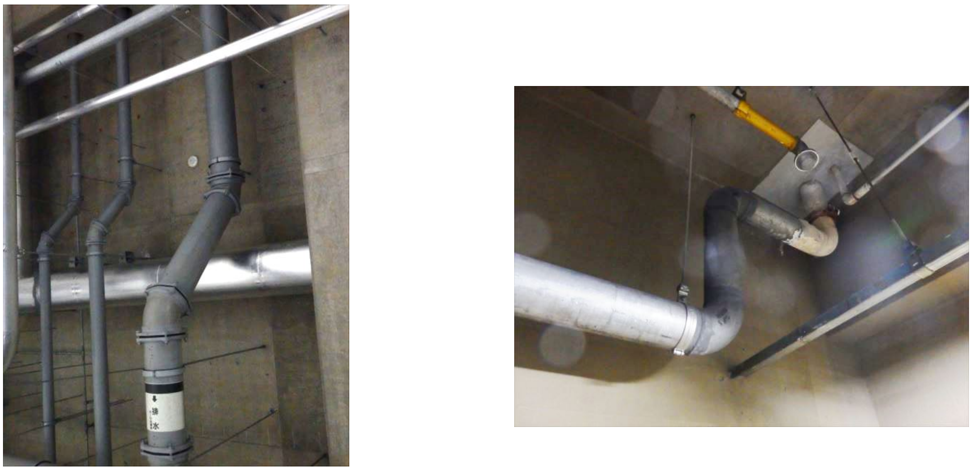
In the case of a multipurpose building comprising a carpark, shops, etc., offsets are often installed on a lower floor for horizontally transferring drainage and ventilation air from an upper floor, as shown in Photo 1. Offsets are generally configured with 45 elbows or 90 elbows depending on the deflection angle of a drainage stack. SHASE-S 206 [1)] provides specific drainage and ventilation methods using an individual vent system and a loop vent system, but does not provide any information or quantitative data that serve as the basis for defining the methods. Furthermore, SHASE-S 206 [1)] prohibits the use of any offset with stack vent type systems and it is necessary to confirm the influence of offsets on stack vent type systems.

Following the previous report [2)] presented at the International Symposium of CIB W062 in 2014, the present report aims to discuss the scope of applicability of offsets with reference to basis data, and examine the influence of an offset on the drainage performance of a stack system when the stack system employs the stack vent system and the offset is installed on a lower floor, which is an arrangement currently prohibited by SHASE-S206. In this instance, the offset is provided with 45° elbows or 90° elbows and is connected to the drainage and ventilation piping system of a high-rise building, and tests are carried out in accordance with SHASE-S218 [3)] with the intention of examining and clarifying the following:

(1) The influence of the offset on the drainage performance of the stack when the offset has 45° elbows and when the offset has 90° elbows and the descending position is moved 1m, 2m and 3m from the centre of the stack.

(2) Proposal and applicability of a drainage performance analysis method, which uses a drainage piping network model, by analysing that identified in (1).

(3) The applicability of offsets to the stack vent system in a comprehensive context.



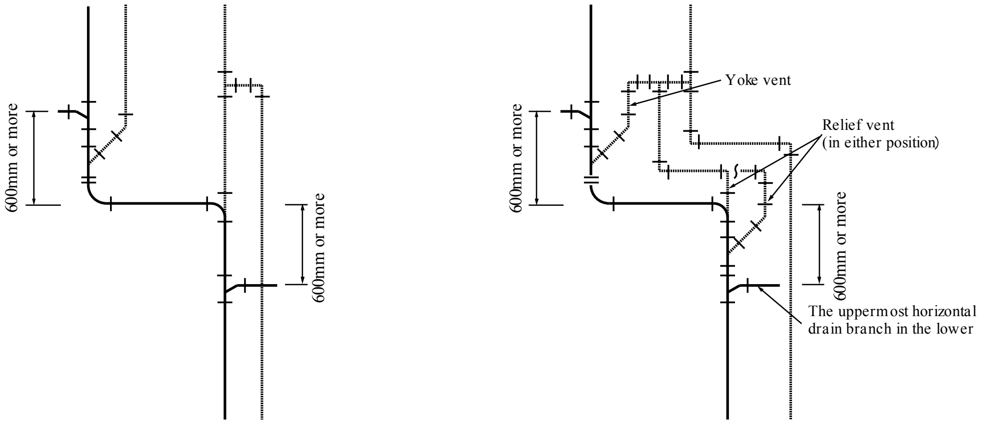
(1) 45°offset (2) 90°offset

Fig. 1 Actual offset examples

Table 1 Offset criteria by SHASE-S206

Drainage/ventilation system	Item	Condition	Specifics consistent with SHASE-S206
Individual system Loop system	Ventilation piping	The offset at an angle exceeding45° from the vertical (except when the offset is set below the lowermost horizontal drain branch)	• Vent pipes are provided in the upper and lower sections of the offset and serve as individual stacks. (See Fig. 1 (1)) • A relief vent is provided in either the rising, extending portion of the stack from the lower section of the offset or a part of the stack above the point where the uppermost horizontal drain branch is connected in the lower section of the offset, and a yoke vent is provided in the upper section of the offset. (See Fig. 1 (2))
	Pipe diameter	At an angle of 45° or less from the stack	• The pipe diameter of the offset is determined the same as that of the vertical stack.
		At an angle of 45° or more from the stack	• The pipe diameter of the stack above the offset is determined as that of the usual stack according to the load flow rate of the stack above the offset. • The pipe diameter of the offset is determined as that of the house drain (one size larger than the diameter of the stack). • The pipe diameter of the stack below the offset is determined according to the diameter of the offset or the pipe diameter determined according to the load flow rate of the entire stack, whichever is the greatest.

(Note) Offsets may not be used in stack vent systems.



(1) Individual ventilation of the upper and lower sections of the offset

(2) The offset with a relief vent and a yoke vent

Fig. 2 Offset ventilation methods consistent with SHASE-S206

2. Experiment Overview

2.1 Experimental single stack system

The experiment uses the nine-storey (approx. 25m above ground) simulation tower set up on the premises of Kanto Gakuin University, which is shown in Photo 2. The tower is installed with a stack vent-type single stack system comprising a stack (pipe diameter 100A) with JIS-DT fittings, horizontal fixture drain branches (pipe diameter 75A, pitch 1/50), and a house drain (pipe diameter 125A, pitch 1/150), as shown in Fig. 2. The single stack system is further equipped with an offset with 45 elbows or an offset with 90 elbows on a lower floor (the 2nd floor), as shown in Photo 3. When using the 90 offset, the length of the horizontally-laid pipe is changed; 1m, 2m and 3m from the drainage stack above the offset. In the descending sections, the 45° offset uses 45° elbow fittings and the 90° offset uses 90° LT fittings. Moreover, three different configurations are applied to the house drain; straight from the base of the drainage stack (hereinafter referred to as ‘straight’), with a horizontal bend formed 1m from the base of the drainage stack (hereinafter referred to as ‘1m bend’) and with a horizontal bend formed 3m from the base of the drainage stack (hereinafter referred to as ‘3m bend’). Table 2 shows all the variations of the experimental drainage stack system used in the experiment.

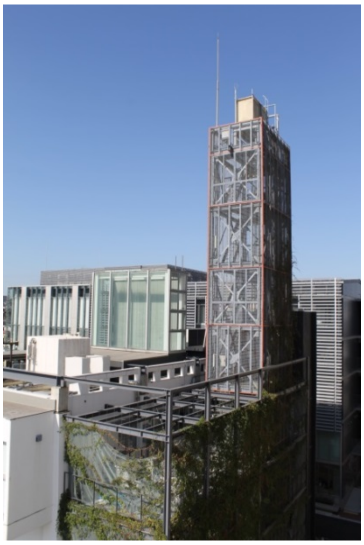
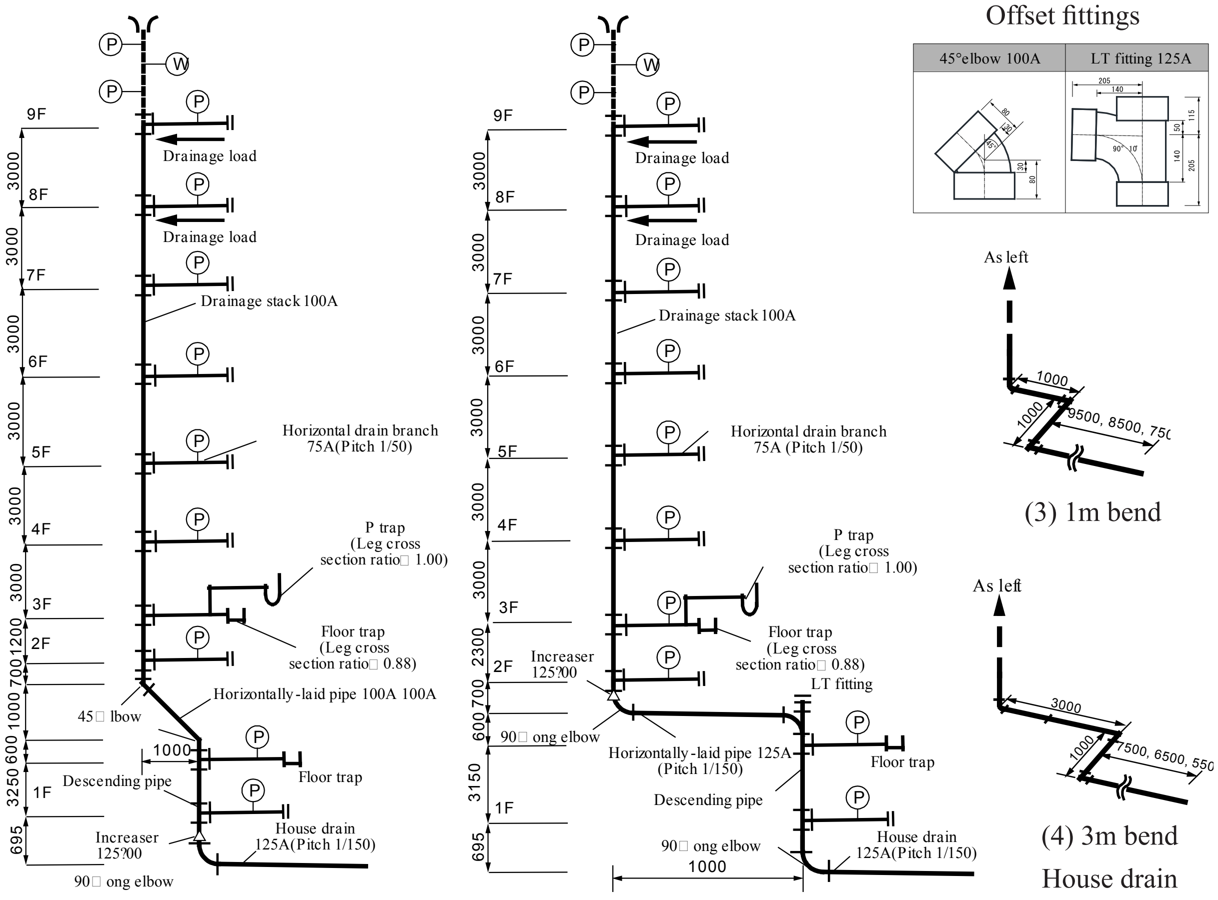


Fig. 3 The simulation tower of Kanto Gakuin University

Sensor	Measurement
Ⓦ Anemomenter	Measure with a hotwire anemometer the flow rate of the air flowing from end of the stack vent.
Ⓟ Pressure senseor	Measure the pressure in the stack vent and the horizontal drain branches on the respective floors.



(1) 45° offset (System [2])

(2) 90° offset (System [3])

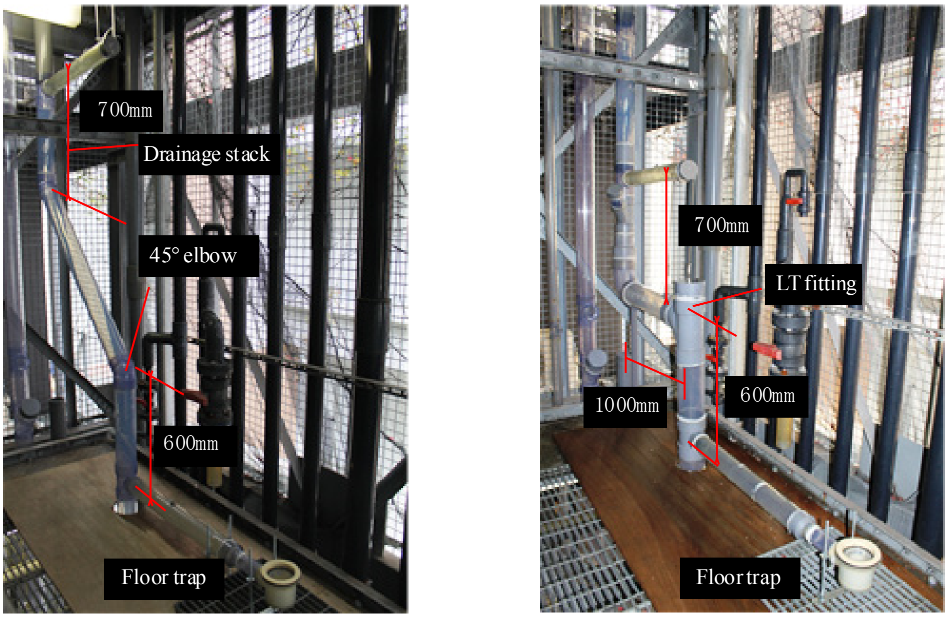
(3) 1m bend

(4) 3m bend

House drain

[mm]

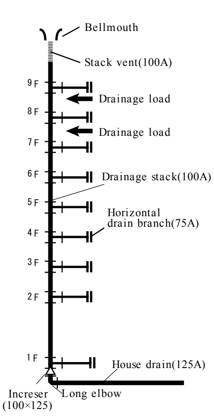
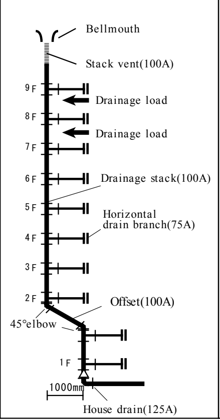
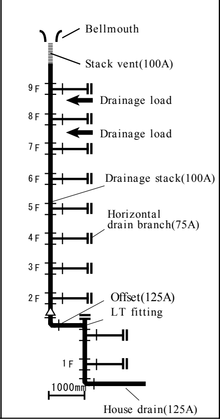
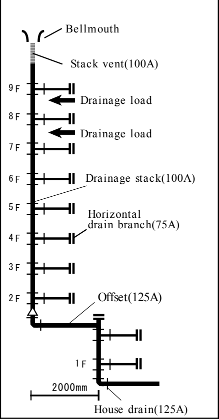
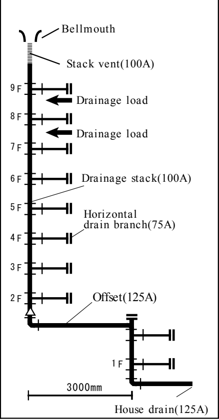
Fig. 4 Experimental single stack system



(1) 45° offset (2) 90° offset

Fig. 5 Offset piping examples

Table 2 Experimental single stack system variations

System[1]	System[2]	System[3]	System[4]	System[5]
Standard	45°offset	90°offset(1m)	90°offset(2m)	90°offset(3m)
				

2.2 Drainage load applications

Table 3 shows the drainage load patterns which are applied during the experiment. Each load is applied at a constant flow rate, which complies with SHASE-S218, according to the pattern. A load is applied from the 9th floor while being increased by 0.5L/s to a maximum of 2.5L/s. While a load of 2.5L/s is being applied from the 9th floor, another load is applied from the 8th floor, which is increased in the same manner as the load from the 9th floor, until the combined load flow rate Qw reaches the maximum of 5.0L/s.

Table 3 Drainage load applications

Floor	Single point application					Two-point application				
9	0.5	1.0	1.5	2.0	2.5	2.5	2.5	2.5	2.5	2.5
8	-	-	-	-	-	0.5	1.0	1.5	2.0	2.5
Total load flow rate[L/s]	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0

2.3 Items to be measured and measurement methods

Table 4 shows the items to be measured, the measurement methods and the reference criteria. The reference criteria apply to internal pipe pressure variations and trap seal level variations. The reference range for internal pipe pressure variations complies with SHASE-S 218, similar to the drainage load applications, and is the range of ±400[Pa]. Meanwhile, the upper floors located above the offset are taken into consideration for the evaluation of drainage performance. Furthermore, the horizontal drain branch on the 3^{rd} floor is provided with a floor trap (leg cross-section ratio: 0.88, seal trap depth: 50mm) and a P trap (leg cross-section ratio: 1.00, seal trap depth: 60mm), and another floor trap is provided to the horizontal drain branch which is located 600mm below the offset on the 2^{nd} floor. Seal variations in the traps are measured using a wave meter, and seal losses are also measured visually with a tape measure. The reference criteria also apply to the presence or absence of seal breakage.

Table 4 Measured items, measurement methods and reference criteria

Measured item	Measurement method	Reference criteria
Inner pipe pressure variation	Measure with a pressure sensor the pressure in the stack vent and the horizontal drain branch on each floor.	Within the range of ±400Pa in accordance with SHASE-S218.
Velocity	Measure, at the pipe centre using a hot-wire anemometer, the velocity of the air flowing from the end of the stack vent.	-
Trap seal variation and seal loss	Attach a trap immediately below the offset, and another trap to the horizontal drain branch on the 3rd floor. Measure the seal water with a wave meter and a tape measure.	The seal loss value is less than half(Note) of the trap depth. No sudden breakage.

(Note) Two types of traps used for the experiment: floor trap for waterproof pan (base cross-section ratio: 0.88, trap depth: 50mm); P trap for washbasin (base cross-section ratio: 1.00, trap depth: 60mm)

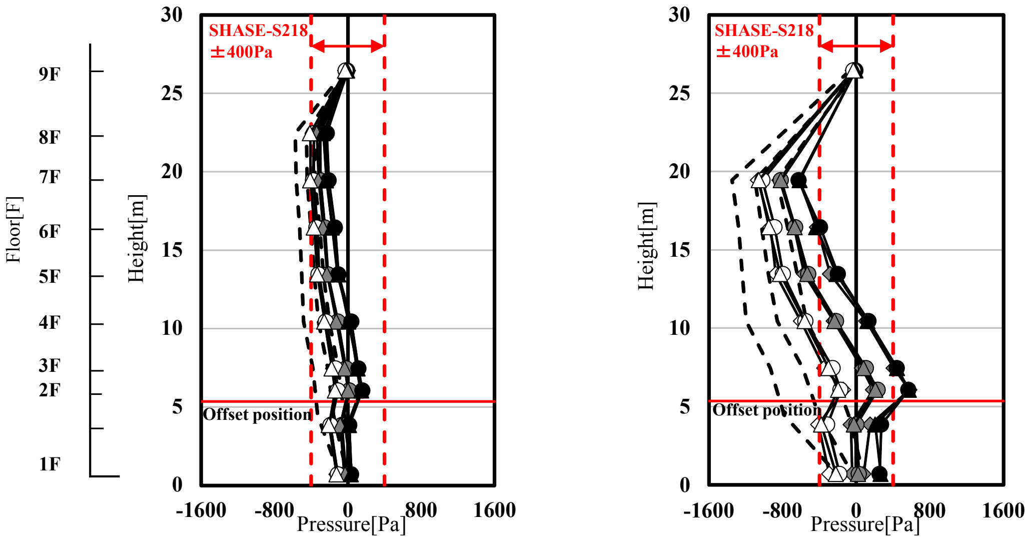
3. Experiment Results and Discussion

3.1 45° offset

(1) Comparison of internal pipe pressure distributions

Fig. 3 compares the pressure distributions of System [1] (the house drain: straight) and System [2]. A drainage load was applied to each system at a constant flow rate, and in each system, the maximum value, Pmax, the minimum value, Pmin, and the average value of internal pipe pressure variations were obtained per floor. In Fig. 3, (1) shows the case of applying a drainage load of 2.5L/s which is a value close to the allowable flow rate value for stack vent systems, and (2) shows the case of applying a drainage load of 5.0L/s which is a value close to the allowable flow rate value (4.15L/s) for house drains, specified by SHASE-S206. Fig. 3 (1) and (2) both indicate that in System [1], the negative pressure is relaxed on the upper floor (the floor immediately below the floor from which the load is applied), whereas in System [2], the positive pressure shows a significant increases immediately above the offset because the offset creates airflow resistance. This suggests that, as in the previous report 2), drainage causes a blockage in the fitting part that joins the horizontally-laid pipe and the descending pipe of the offset together , thus, preventing the air from flowing from the end of the stack vent, and subsequently increasing the positive pressure.

Single stack system	Standard	45°offset		
	System[1]	System[2]		
House drain	Straight	Straight	1m bend	3m bend
Min value : *Pmin*	------	◇	○	△
Ave value : *Pave*	------	◆	●	▲
Max value : *Pmax*	------	◆	●	▲

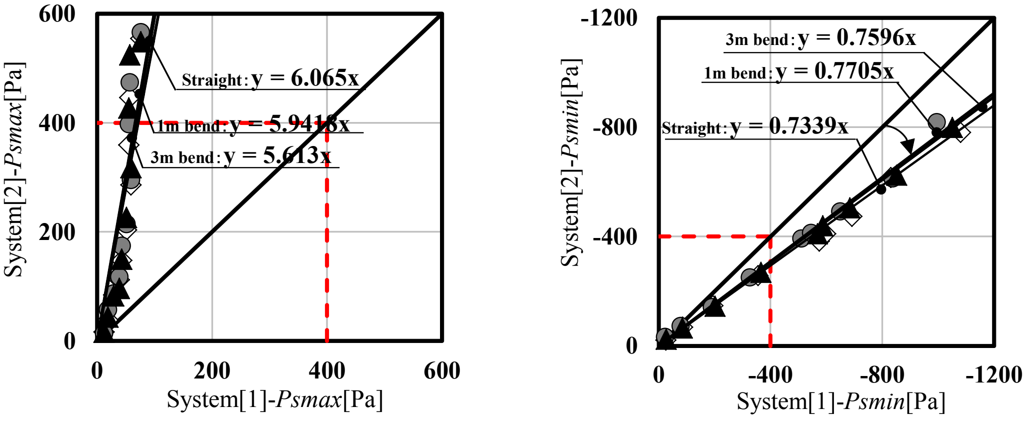


(1)2.5[L/s] (2)5.0[L/s]

Fig. 6 Comparison of internal pipe pressure distributions (Systems [1] and [2])

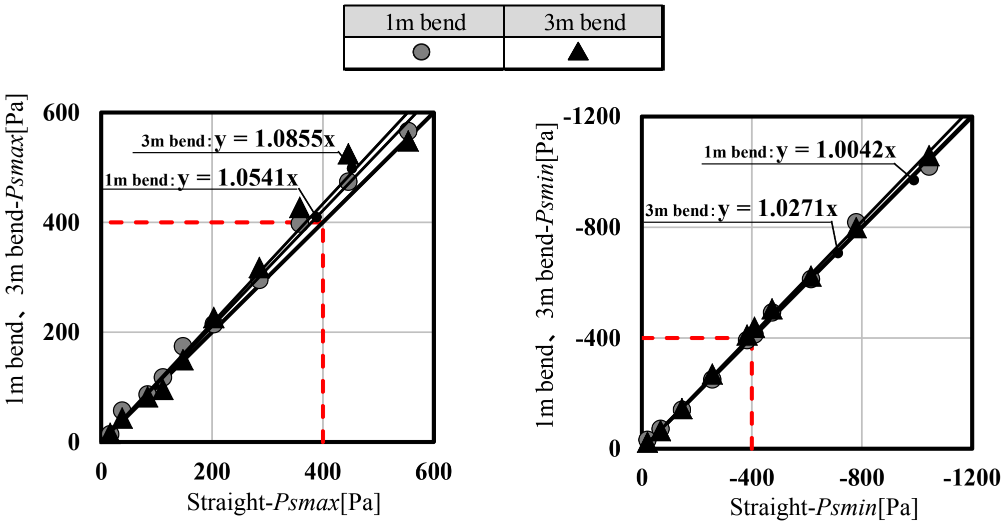
(2) Maximum system value Psmax and minimum system value Psmin
Fig. 4 (1) and (2) compare the maximum system values, Psmax, and the minimum system values, Psmin, between System [1] (the house drain: straight) and System [2] (the house drain: 1m, 3m). These values were obtained from the Pmax and Pmin values which were measured on the respective floors and which were plotted in Fig. 3. Fig. 4 shows the results of using all the drainage load patterns which are shown in Table 3. According to the results, in comparison with System [1], Psmax of system [2] in Fig. 4 (1) increases by 5.6-6.1 times depending on the configuration of the house drain, whereas in Fig. 4 (2), Psmin of system [2] decreases by 23-27%, again, depending on the configuration of the house drain. Meanwhile, Fig. 5 shows Psmax and Psmin of the house drain between the configurations; the 1m-bend and 3m-bend configurations in comparison with the straight configuration. The results suggest that the influence of the house drain configuration on Psmax and Psmin is less significant than the influence of the offset configuration.

Straight	1m bend	3m bend
◇	●	▲



(1) Psmax (2) Psmin

Fig. 7 Psmax and Psmin (in comparison with System [1])

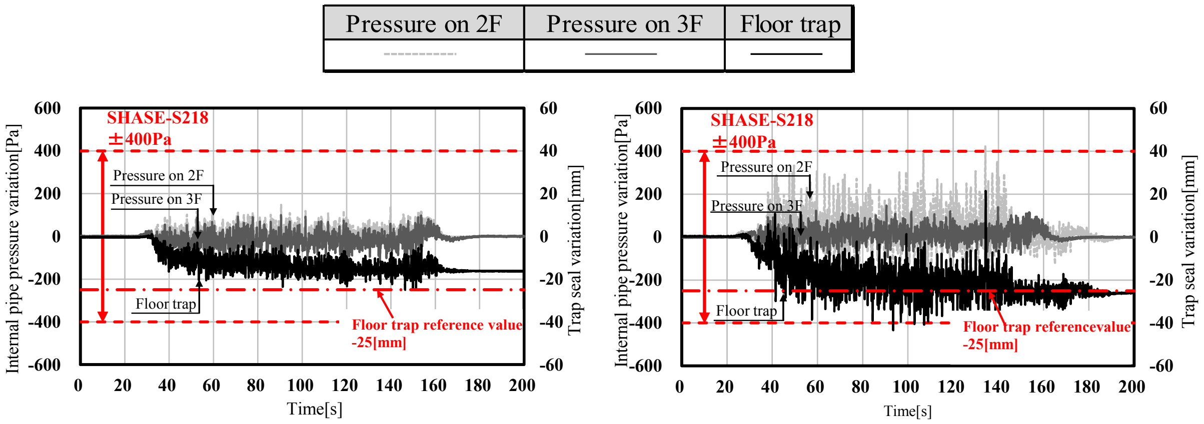


(1) Psmax (2) Psmin

Fig. 8 Psmax and Psmin (in comparison with 'straight')

(3) Trap seal variations

Fig. 6 shows the seal variations in the floor trap installed on the 3rd floor, which were measured when drainage loads of 2.5L/s and 5.0L/s were applied ((1), (2)), using the straight house drain configuration. The graphs confirm that the trap seal level varies more significantly as the drainage load is increased, as shown in (2). Furthermore, the maximum seal variation value was measured to be 11mm, and the minimum seal variation value was measured to be -44mm. This clarifies that although the positive pressure is high on the 3rd floor, the trap seal has a tendency of decreasing, and that the variation value of the trap seal is less than half of the trap depth, which is set as a reference value, when the drainage load of 2.5L/s is applied.



(1) Drainage load 2.5L/s (2) Drainage load 5.0L/s

Fig. 9 Floor trap seal variation waveforms (3F)

(4) Comparison of drainage performance

Fig. 7 shows how the total drainage load flow rate, Qw, with reference to the load patterns in Table 3, relates to Psmax and Psmin. The manner in which the drainage performance of the stack is affected by the presence or absence of the 45° offset was examined through comparison, and it was found that the reference value for negative pressure was exceeded in the case of using the 3m-bend house drain and applying a total drainage load flow rate of 2.5L/s. Meanwhile, when using the other house drain configurations, the pressure value range was -370 to -391Pa, which is more or less the same as in System [1], the drainage performance value of which is 2.0L/s. Moreover, as a result of further increasing the drainage load flow rate, excessive positive pressure was generated, exceeding the reference range, when a load of 4.0L/s was applied. Incidentally, Photo 4 shows the drainage condition of the offset.

System[1]	System[2]		
Straight	Straight	1m bend	3m bend
- -□- -	—◇—	- · ● · -	- -▲- -

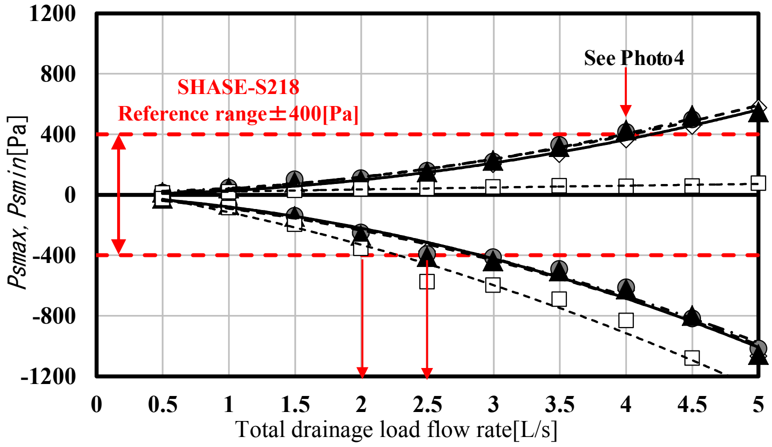


Fig. 10 Total drainage load flow rate, Qw, in relation to Psmax and Psmin

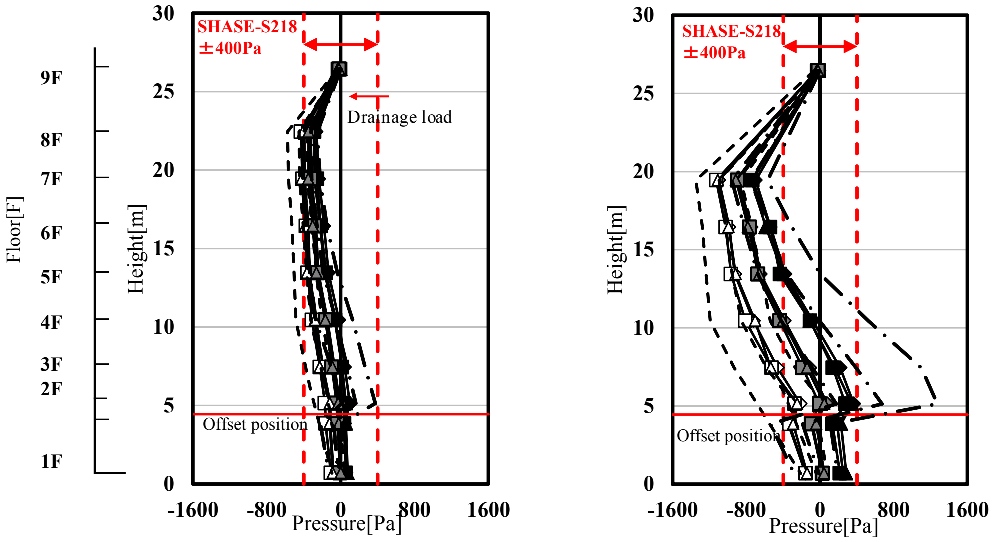
Fig. 11 Drainage condition in the 45° offset (drainage load 4.0L/s)

3.2 90° offset

(1) Comparison of internal pipe pressure distributions

Fig. 8 (1) and (2) compare distributions of internal pipe pressure measured in different systems by using the 90° offset. The length of the horizontally-laid pipe of the offset was changed; 1m, 2m and 3m from the drainage stack. As for the house drain, in comparison with the straight configuration used in System [1], the 1m-bend configuration was used in the other systems. Fig. 8 (1) and (2) show that comparing to System [1], the negative pressure becomes relaxed in the other systems, as in System 2, but the positive pressure increases in the offset. Furthermore, when applying a drainage load of 5.0L/s, the positive pressure in System [5] increases by a maximum of approx. 7%, immediately above the offset, compared to System [3] which is supposed to have an offset configuration with the harshest conditions. This suggests that the length of the horizontally-laid pipe of the offset causes some influence, but is not significant enough to affect the drainage performance. Incidentally, Fig. 8 includes, for reference, the results when a pipe diameter of 100A was applied to the offset, the same pipe diameter as that of the drainage stack, and in this instance, Psmax reached as high as 1273Pa. This confirms, therefore, that as indicated by SHASE-S206, the section below the offset should be treated as a house drain, and providing it with a pipe diameter larger by one size will probably relax the positive pressure, and the effect thereof will be significant.

	Standard	90°offset (125A)			90°offset (100A)
	Straight	System[3]	System[4]	System[5]	System[3]
Pmin	------	◇	□	△	–·–·–
Pave	------	◈	▣	▲	–·–·–
Pmax	------	◆	■	▲	–·–·–

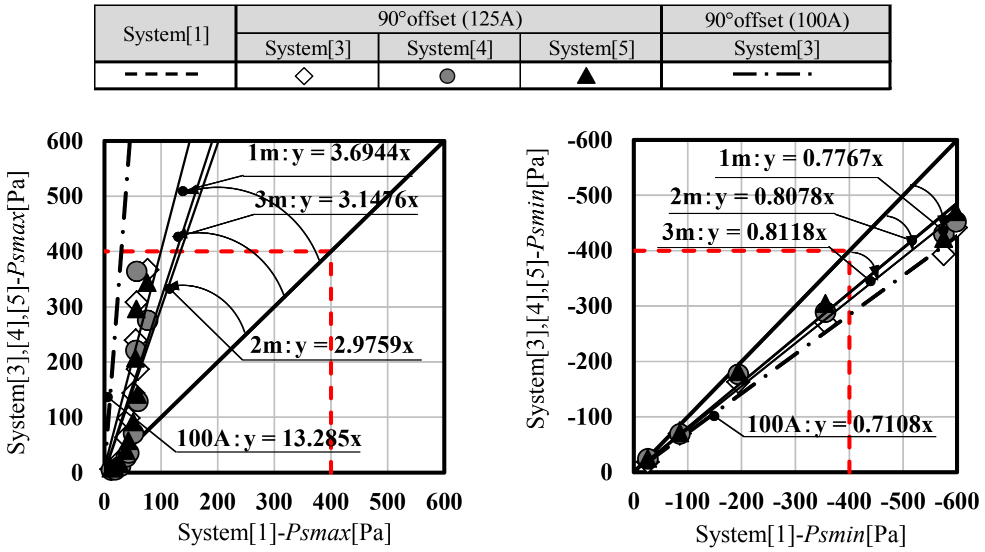


(1)2.5[L/s] (2)5.0[L/s]

Fig. 12 Comparison of pressure distributions (1m bend)

(2) Maximum system value Psmax and minimum system value Psmin

Fig. 9 (1) and (2) compare the maximum system values, Psmax, and the minimum system values, Psmin, of Systems [3]-[5] with Psmax and Psmin of System [1] (the house drain: straight). Fig. 9 shows the results of using all the drainage load patterns in Table 3. Fig. 9 (1) indicates that as a result of changing the length of the horizontally-laid pipe of the offset, Psmax of Systems [3]-[5] increased 2.9-3.7 times as much as Psmax of System [1], and Psmax reached the highest in System [3] which is configured with the shortest horizontally-laid pipe. Meanwhile, it is evident in Fig. 9 (2) that Psmin of Systems [3]-[5] was relaxed by 19-22% compared to Psmin of System [1]. Accordingly, the length of the horizontally-laid pipe somehow affects the positive pressure, especially in System [3] in which said length is the shortest, but the positive pressure is less affected when said length exceeds 2m. Fig. 10 shows the total drainage load flow rate, Qw, in relation to Psmax. Fig. 10 indicates that when applying a drainage load of 2.0L/s, which is also the drainage performance value of System [1], Psmax of Systems [3]-[5] with the 90° offset remained below +100Pa, indicating little influence of the drainage load. However, as the drainage load was increased up to 5.0L/s, while the offset was treated as a house drain, Psmax reached almost +400Pa. Moreover, as shown in Fig. 10, when the offset was used with a pipe diameter of 100A, a high positive pressure of approx. +300Pa was generated at 2.0L/s, the drainage performance value of System [1]. Therefore, it is effective to provide the offset with a pipe diameter that is one size larger than that of the drainage stack.



(1)Psmax (2)Psmin

Fig. 13 Psmax and Psmin

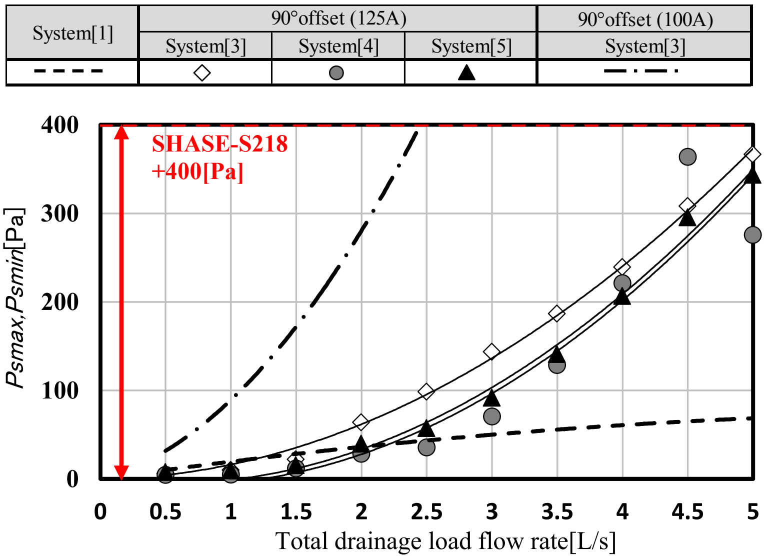
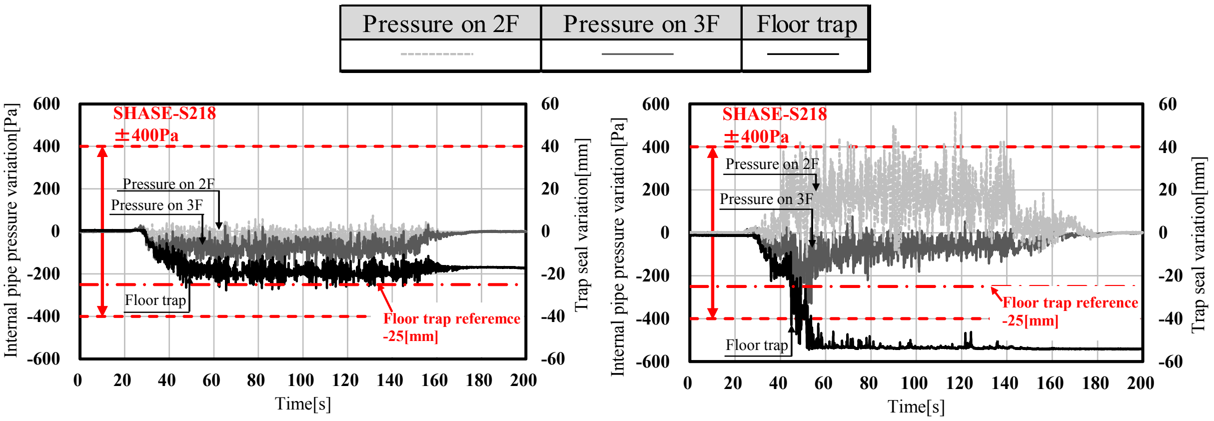


Fig. 14 Total drainage load flow rate in relation to Qw and Psmax

(3) Trap seal variations

Fig. 11 (1) and (2) show the seal variations in the floor trap installed on the 3rd floor, which were measured when drainage loads of 2.5L/s and 5.0L/s were applied to System [3] (straight). As shown in Fig. 11, the seal water rapidly decreased immediately after a drainage load was applied. Fig. 11 (1) indicates that the level of the seal water was slightly fluctuated by rapid decreases therein, and as the waveform indicates, the seal water decreased slightly more than half of the trap seal depth which is set as a reference value. In addition, Fig. 11 (2) indicates that when a drainage load of 5.0L/s was applied, the floor trap broke completely within 48 seconds after starting the measurement. This suggests that an excessive drainage load raises the risk of trap breakage.

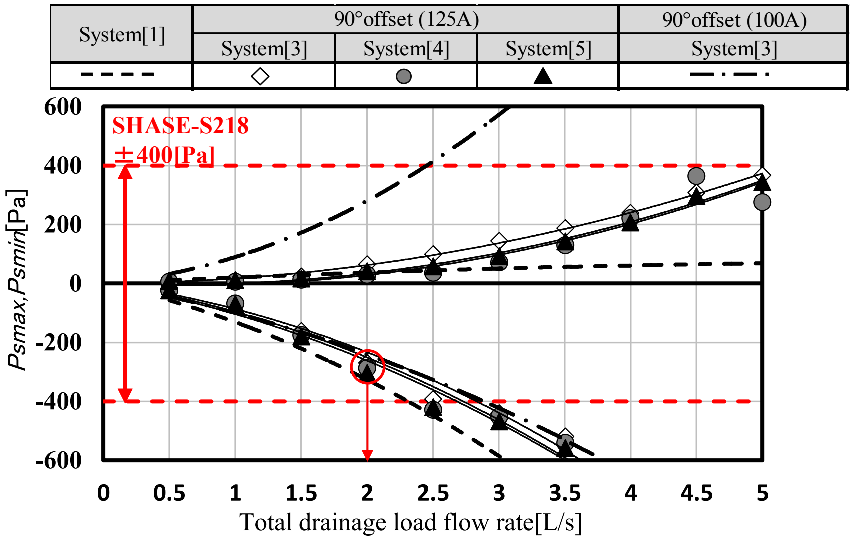


(1) Drainage load 2.5L/s (2) Drainage load 5.0L/s

Fig. 15 Variation waveforms of water seal of the floor trap (3F)

(4) Comparison of drainage performance

Fig. 12 compares the total drainage load flow rate, Qw, against Psmax and Psmin of System [3]-[5] (the house drain: 1m bend). As shown in Fig. 12, it turned out that the internal pipe pressure in most of the systems exceeded the reference range of ±400Pa on the negative pressure side when a drainage load of 2.5L/s was applied, and therefore, the drainage performance values of these systems are considered to be very similar to 2.0L/s, which is the drainage performance value of System [1]; the standard stack vent systems, regardless of various conditions that are applied to the offset. Accordingly, although SHASE-S206 prohibits the use of offsets in stack vent type systems, it is considered to be possible to incorporate offsets in stack vent type systems as long as the drainage performance thereof are similar to that of System [1].

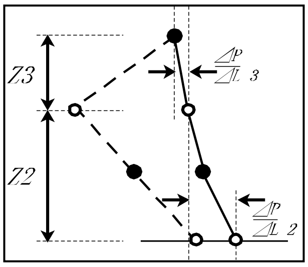


(Note) The upper floors above the offset were taken into consideration for the evaluation of drainage performance (internal pipe pressure variations).

Fig. 16 Total drainage load flow rate, Qw, in relation to Psmax and Psmin

4. A Method for Predicting the Drainage Performance of the Piping Network Model

Fig. 13 and 14 respectively show a classification chart of typical internal pipe pressure distributions of a stack vent system having an offset with reference to the previous report[4)], and a piping network model created on the basis of the classification chart. As shown in Fig. 14, the airflow resistance coefficients are $\zeta_{①}$, $\zeta_{②}$, $\zeta_{③}$ and $\zeta_{⑤}$, plus $\zeta_{⑤}$of, which represents the airflow resistance in the offset, and the suction force in the lower floor descending section, ④ ’, is added to the suction force, (⊿ P/ ⊿ Z), in ④ . Total resistance formulae (1)-(4) each using an air flow rate as a variable and total suction formulae (5) and (6) are balanced to predict an air flow rate. The estimated air flow rate (predicted air flow rate) is then used in formulae (1)-(6) to calculate the average pressure value, $\mathrm{Pave}_{(k)}$, for each floor. The reference criterion is that internal pipe pressure variations are within the range of ±400Pa in accordance with SHASE-S218.



ffset pressure classification chart

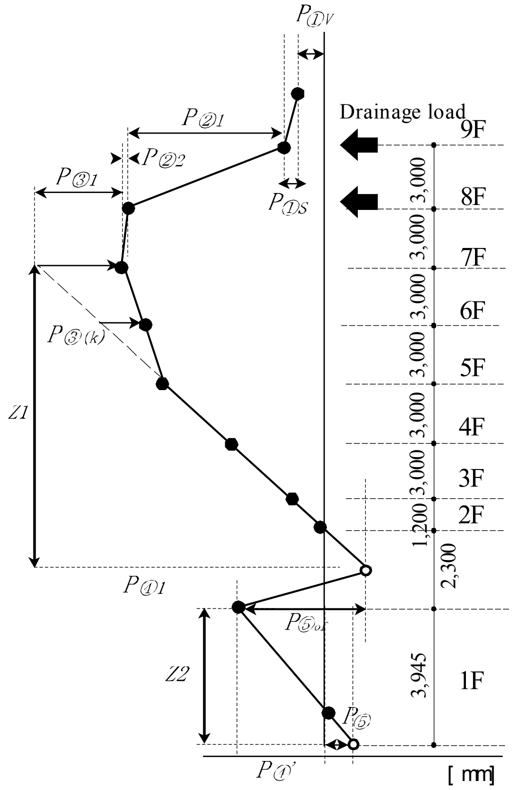


Fig. 17 Pressure classification chart

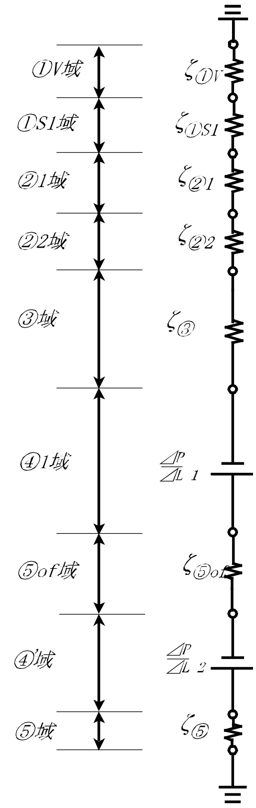


Fig. 18 Piping network model

$$P_{①\sim②}=\zeta_{①\sim②}\times\frac{\rho}{2}\times\left(\frac{Q_a}{A_s}\right)^2 \qquad \ldots(1)$$

$$P_{⑤of}=\zeta_{⑤of}\times\frac{\rho}{2}\times\left(\frac{Q_a}{A_{H1\sim H2}}\right)^2 \qquad \ldots(2)$$

$$P_{⑤}=\zeta_{⑤}\times\frac{\rho}{2}\times\left(\frac{Q_a}{A_{H3}}\right)^2 \qquad \ldots(3)$$

$$P_{③(k)}=e^{-\alpha H}\times P_{③} \qquad \ldots(4)$$

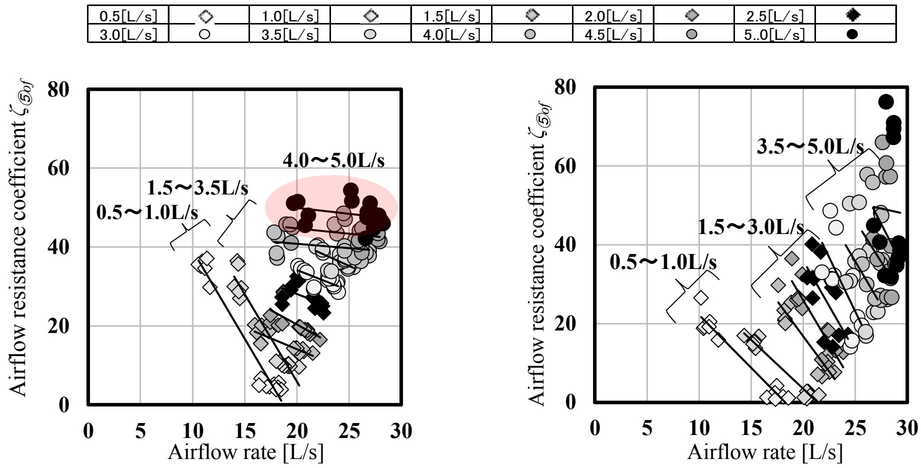
$$P_{④}=\frac{P}{L_1}=\left(\frac{⊿P}{⊿L}\right)_{④}\times Z_1 \qquad \ldots(5)$$

$$P_{④'}=\frac{P}{L_{2\sim3}}=\left(\frac{⊿P}{⊿L}\right)_{④'}\times Z_{2\sim3} \qquad \ldots(6)$$

ζ: airflow resistance coefficient, ρ: air density [kg/m^3], Q_a: air flow rate[L/s],L: length of drainage stack [m], A_s: cross section of stack vent and stack [m^2], $A_{H1\text{-}2}$: cross section of offset [m^2], A_{H3}: cross section of house drain[m^2], $P_{③(k)}$: correction value for average pressure/floor in stack [Pa], $Z_{1\sim3}$: length of stack between floors [m], H: length between Psmin floor and other respective floors [m], (k): floor

4.1 Offset configuration and air flow resistance

Fig. 15 shows the relationship between the air flow rate and the airflow resistance coefficient, per drainage load, in both cases of System [2] using the 45° offset and System [3] using the 90° offset (see Table 2). The airflow resistance coefficient refers to $\zeta_{⑤\ \mathrm{of}}$, as shown in Fig. 13, which is a representative coefficient for analysis purposes. Fig. 15 (1) and (2) both indicate that there is a tendency for the air flow rate to increase as the drainage load is increased. Moreover, Fig. 15 (1) shows that in System [2], the airflow resistance coefficient gradually became constant as the drainage load was increased, especially when a drainage load of 4.0L/s or more was applied. Meanwhile, Fig. 15 (2) indicates that in System [3] using the 90° offset, the airflow resistance coefficient also increased as the drainage load was increased, but more significantly than in System [2], although the drainage load was applied in the same manner as in System [2]. This is considered to be mainly because in System [3], the fluctuation of the pressure generated below the offset is more significant than in System [2].



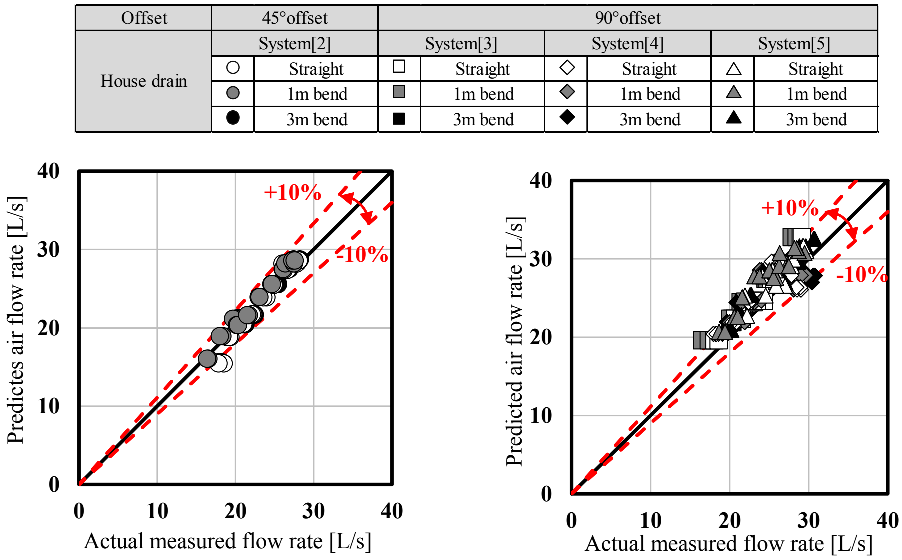
(1) System [2]
(45° offset)

(2) System [3]
(90° offset)

Fig. 19 Air flow rate and airflow resistance coefficient $\zeta_{⑤\ \mathrm{of}}$ (straight)

4.2 Air flow rate prediction

Fig. 16 compares the actual measured air flow rates and the predicted air flow rates of Systems [2]-[5] according to the house drain configuration. Fig. 16 (1) shows the results for System [2], and it is clear that the differences between the actual measured and predicted flow rates are roughly within the range of ±10%. Meanwhile, Fig. 16 (2) shows the results for Systems [3], [4] and [5] each using the 90° offset, and it is clear that the differences between the actual measured and predicted flow rates are also roughly within the range of ±10% when different drainage flow rates are applied, with the exception of when a drainage load of 5.0L/s is applied; the actual measured value is 27.9L/s while the predicted value is 32.8L/s, making the largest difference of approx. 5.0L/s.



(1) System [2]
(45° offset)

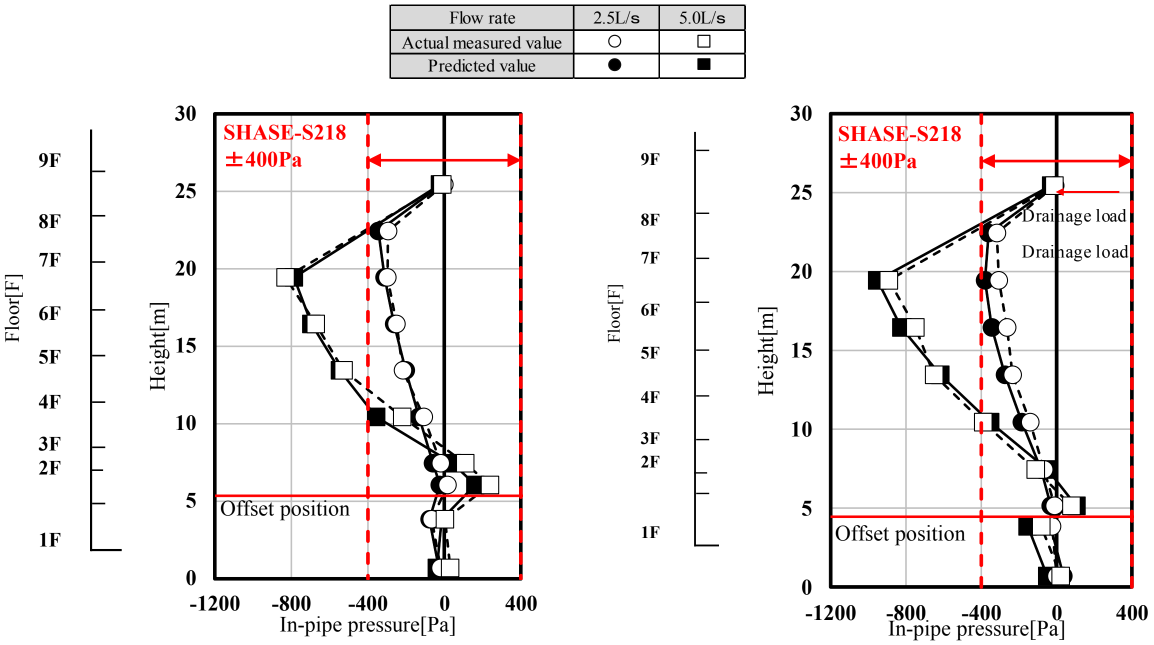
(2) System [3], [4] & [5]
(90° offset)

Fig. 20 Comparison of actual measured and predicted air flow rates

4.3 Comparison of internal pipe pressure distributions

Fig. 17 shows the distributions of internal pipe pressure of System [2] and System [3], using air flow rates, Q_a, which were calculated in 4.2. Drainage load flow rates of 2.5L/s and 5.0L/s were applied to the systems, and the average pressure, $P_{ave(k)}$, per floor was used when the 1m-bend house drain configuration was employed. The distributions of actual measured pressure values are also included in the graphs, which turn out to be similar to the distributions of the predicted pressure values.

In addition to the distributions of average pressure values in Fig. 17, constants, $N1_{(k)}$ and $N2_{(k)}$, which are variable components, and standard deviations, $\sigma 1_{(k)}$ and $\sigma 2_{(k)}$ were included in formulae (7) and (8) to calculate Pmax(k) and $Pmin_{(k)}$, and the predicted *Pmax* and *Pmin* values per floor, when applying drainage load flow rates of 2.5L/s and 5.0L/s, were used to create the distributions of internal pipe pressure of System [2] and System [3], which are shown in Fig. 18. The distributions of actual measured pressure values are also included in the graphs, which turn out to be similar to the distributions of the predicted pressure values.



(1) System [2]   (2) System [3]

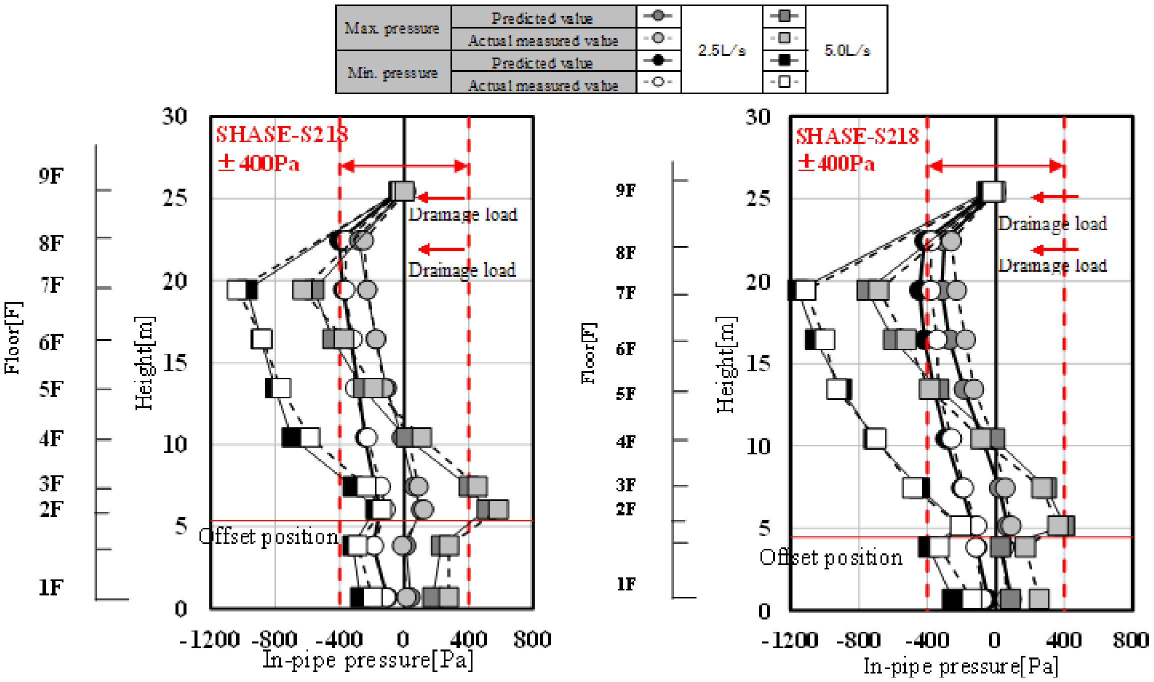
Fig. 21 Comparison of distributions of actual measured and predicted average pressure values (1m bend)

$$Pmax_{(k)}=Pave_{(k)}+\sigma_{1(k)}\times N_{1(k)} \quad \ldots(7)$$

$$Pmin_{(k)}=Pave_{(k)}-\sigma_{2(k)}\times N_{2(k)} \quad \ldots(8)$$

σ(k): standard deviations of the max. and min. values of Pmax and Pmin per floor

N(k): constants of the max. and min. values of Pmax and Pmin per floor



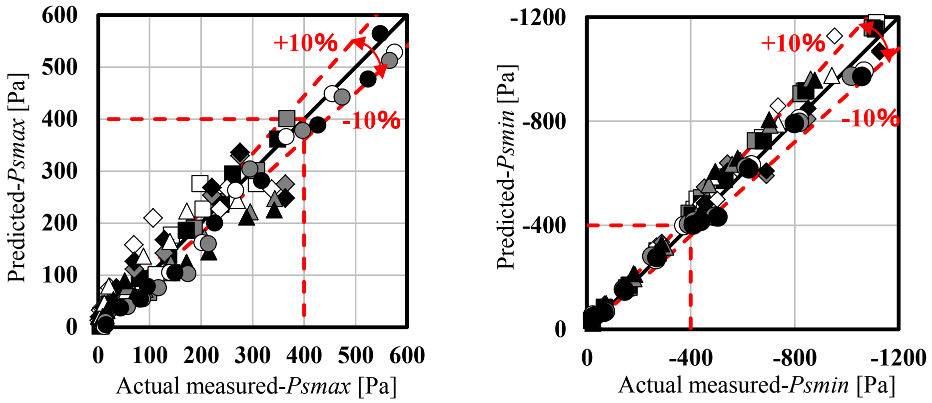
(1) System [2]   (2) System [3]

Fig. 22 Distributions of actual measured and predicted internal pipe pressure values (1m bend)

4.4 Comparison of actual measured and predicted values of Psmax and Psmin

Fig. 19 compares the actual measured and predicted values of Psmax and Psmin among Systems [2]-[5]. Fig. 19 (1) indicates a noticeable difference between the actual measured and predicted Psmax values in System [4] and System [5]. This is inferred to be due to significant pressure variations in the horizontal drain branch on the 2nd floor where Psmax is generated. Meanwhile, Fig. 18 (2) indicates that the difference between the actual measured and predicted Psmin values are roughly within the range of approx. ±10% in all the systems. In this instance, because the drainage performance is within the reference range of ±400Pa and Psmin is determined on the negative pressure side, the predicted Psmin values are so accurate that they do not create too big differences from the actual measured Psmin values, and therefore are considered to be applicable as a means of predicting internal pipe pressure.

Offset	45°offset		90°offset					
	System[2]		System[3]		System[4]		System[5]	
House drain	○	Straight	□	Straight	◇	Straight	△	Straight
	◍	1m bend	▣	1m bend	◈	1m bend	◬	1m bend
	●	3m bend	■	3m bend	◆	3m bend	▲	3m bend



(1)Psmax (2)Psmin

Fig. 23 Comparison of actual measured and predicted values of *Psmax* and *Psmin*

4.5 Prediction of drainage performance

Fig. 20 shows the total drainage load flow rate in relation to the predicted Psmax and Psmin values for each of Systems [2]-[5]. Fig. 20 shows the results when the 1m-bend house drain was used to provide a severe condition. When a total drainage load flow rate of 2.5L/s, which is close to the drainage performance value of System [1], was applied, the reference value of -400Pa was exceeded in all the systems. As a result, with the house drain having a 1m-bend, the predicted drainage performance value was 2.0L/s in every system, corresponding to the actual measured value. Moreover, as the total drainage load flow rate was increased to 4.5L/s, the reference value for positive pressure was exceeded in System [2]. This clearly corresponds to the result obtained in 3. (4), in which the actual measured drainage performance value of System [2] exceeded the reference value when using the 1m-bend house drain configuration and when applying the same drainage load flow rate.

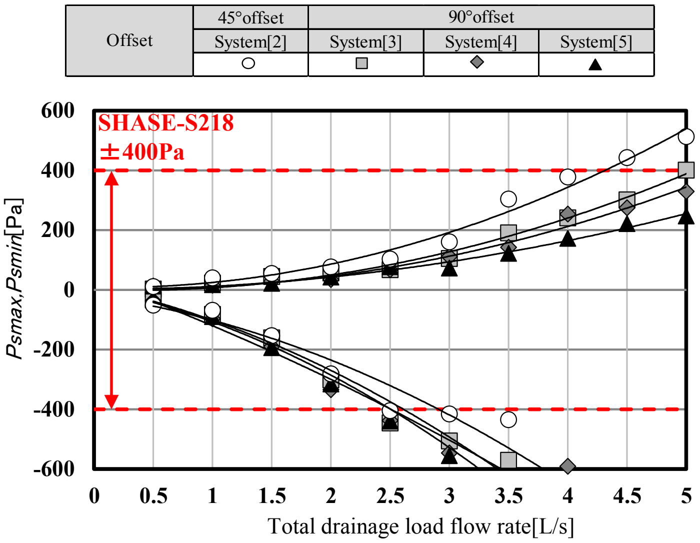


Fig. 24 Total drainage load flow rate in relation to Psmax and Psmin (predicted) (1m bend house drain)

5. Conclusion

A high-rise, stack vent-type single stack system was provided with an offset on a lower floor, and the influence of the offset on the drainage performance of the system was examined in accordance with SHASE-S218. Subsequently, the following knowledge was obtained:

(1) When using the offset with 45° elbows, the drainage performance value is 2.0L/s which is no different from that of System [1] (no offset), but there is a likelihood of generating excessive positive pressure when applying a drainage load of 4.0L/s or more.

(2) When using the offset with 90° elbows, the drainage performance value is also 2.0L/s which is more or less the same as that of System [1], given that the offset is provided with a larger pipe diameter. Moreover, the pipe length from the centre of the stack to the offset position hardly affects the drainage performance. However, there is a likelihood of generating excessive positive pressure around the drainage performance when the pipe diameter of the offset is the same as that of the stack (100A).

(3) In the case of applying the offset to the piping network model of the previous report, it is possible to predict the internal pipe pressure and the drainage performance in consideration of the airflow resistance in the offset.

The above knowledge will be conducive to designs and plans of offset piping for drainage systems with a stack vent.

6. Reference

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7. Presentation of Authors

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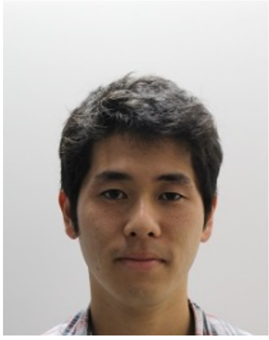

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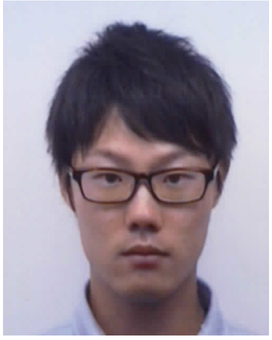

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An Experimental Study on Application of Siphonic Drainage Systems for Washing Machine Drainage

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Abstract

In Japan, washing machine has become a necessity of life, and almost every household is equipped with one. However, in apartment buildings built before the 1970s, washing machines had been installed in a dressing room next to a bathroom, and an extended hose used for drainage through the bathroom because of the absence of drainage pipes for a washing machine in the building. But a sprawling pipe in the dressing room could be cumbersome, sometimes causing leakage. And it is difficult to install a pipe exclusively for drainage from a washing machine. Sphonic drainage system may hold a key to solve this dilemma as its use of pipes with small diameters, no slope or straddling has the advantage over the conventional drainage system. In this study we conducted experiments and analyzed flow characteristics in view to applying siphonic drainage system to washing machine drainage. We also examined how flow characteristics would be affected by detergent discharge and a self-sealing trap connected to prevent self-destruction. Siphon effects were observed under all experimental conditions. It also became clear that the use of self-sealing trap or detergent discharge had little influence on flow characteristics.

Keywords

Drainage system, siphon, washing machine

1. Introduction

In apartment buildings built before the 1970s, there had been no drainage pipes for a washing machine; an extended hose had been used for drainage via the bathroom. However, the existence of an extended hose created a nuisance sometimes causing leakage. It was difficult to install conventional drainage piping with slope in such a situation. The use of siphonic drainage system with small pipe diameters, and no slope or straddling is expected to make a significant improvement.

In the previous study we clarified the flow characteristics and drainage time of spring water and detergent discharges. However, no trap was used in those experiments, and it was thought that the use of water seal trap was likely to cause siphonage leading to self-destruction.

In this study we examined characteristics of flow and pressure in drains when self-sealing traps (referred to as test traps below) were installed at inlet sections.

2. Local Resistance Coefficient of Self–Sealing Trap

2.1 Purpose

The purpose of this section of the study is to obtain local resistance coefficient of test trap as a necessary parameter for calculating the theoretical values of siphonic negative pressure and flow velocity in siphonic drainage system.

2.2 Outline of Self –Sealing Trap

The cross-sectional view of a test trap is shown in Figure 1. The test trap used in the study does not require seal; the trap is closed with a self-sealing diaphragm when no discharge is made and the diaphragm opens automatically to pass water through when discharge is made (Figure 2).

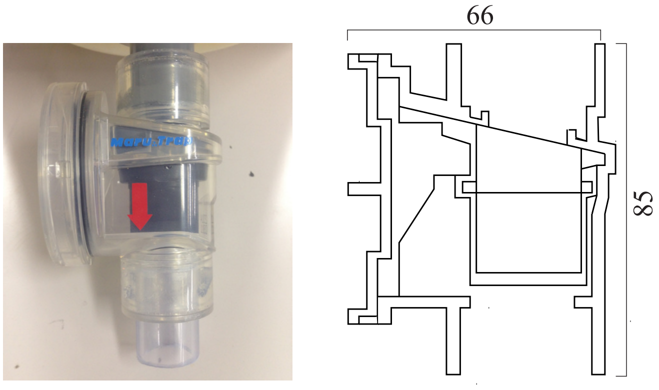


Figure 1-The cross-sectional view of a test trap

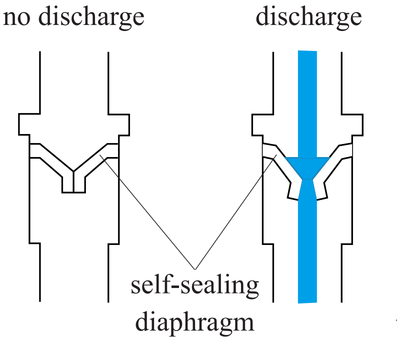


Figure 2-Mechanism of self-sealing diaphragm

2.3 Experimental Apparatus

The experimental apparatus is shown in Figure 3. A 20A pipe made of transparent polyvinyl chloride (referred to as PVC pipe below) was used. Pressure was measured at points A and B, and three flow rates in pipes of 10, 15, and 20 L/min. were applied.

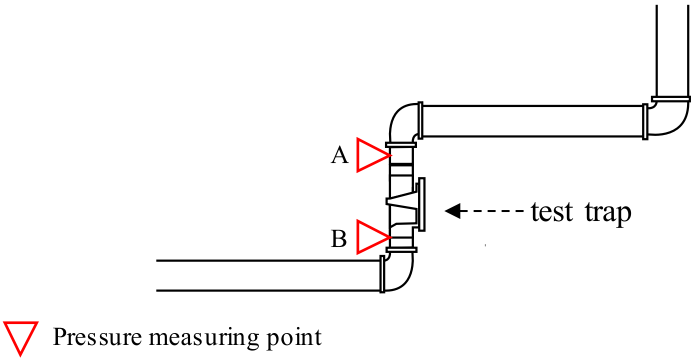


Figure 3 -The experimental apparatus

2.4 Results and Discussion

The pressure difference between A and B was measured, and the pressure loss in the test trap was calculated. Local resistance coefficient obtained with the formula (1) in Table 1 was 6.82 (Table 2).

Table 1-Local resistance coefficient

$$P_{rf} = \zeta \times \left(\frac{1}{2}\rho v^2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

P_{rf}: pressure loss [P_a]
ρ: Density [kg/m^3]
v: Flow velocity [m/s]
ζ: Local resistance coefficient [-]

Table 2-Pressure loss and local resistance coefficient in the test trap

Parameters of test trap	Water supply flow rate [L/min]		
	10	15	20
pressure loss [Pa]	920	1,610	3,050
local resistance coefficient [-]	6.80	6.75	6.90

3. Pressure and Flow Characteristics in Pipe When Self–Sealing Trap Was Installed

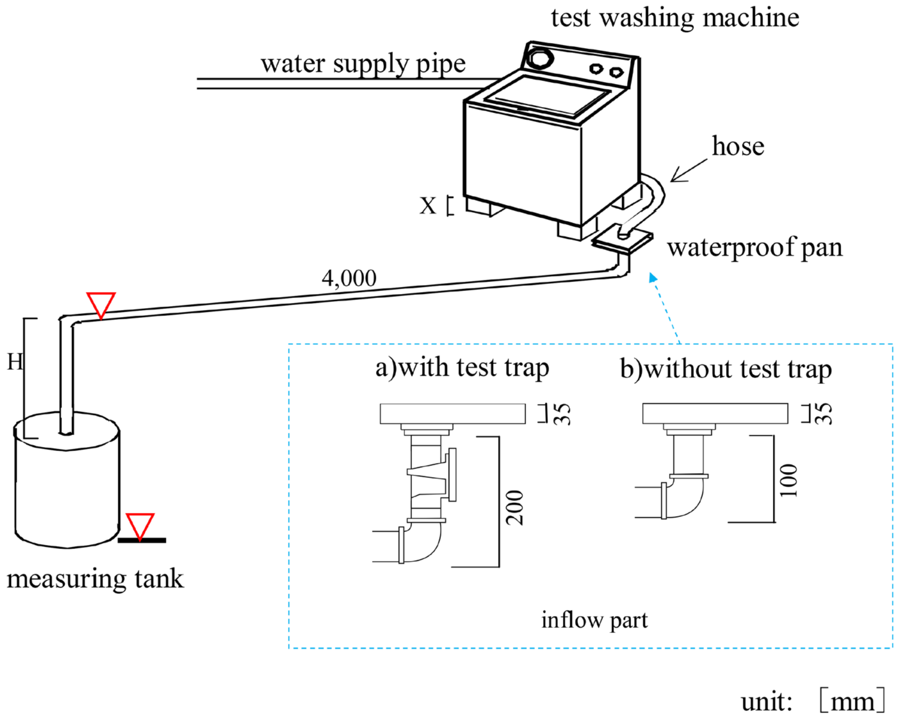
3.1 Purpose

Pressure and flow characteristics in pipe were examined to clarify how siphonic drainage system for washing machine discharge was influenced by test trap.

3.2 Outline of Experiment

3.2.1 Experimental apparatus

The outline of the experimental apparatus is shown in Figure 4. A 4,000 mm long horizontal 20A PVC pipe was used. Two different outflow head of 1,000 mm and 1,500 mm were prepared, and the washing machines were positioned at the height of 50, 100, and 150 mm from the floor. The test trap was installed in the stack pipe that connected waterproof pan with the horizontal pipe. Pressure was measured at two points: near the elbow of the outlet section and in the catch basin to measure discharge characteristics.



▽: Pressure measuring point
H : Outflow head (1,000mm、1,500mm)
X : Height from the floor of the washing machine (50mm、100mm、150mm)
Horizontal paipe length : 4,000mm

Figure 4 -The experimental apparatus

3.2.2 Test detergent

Three types of powder detergent A, B, and C on the market were tested for their bubbles power to select one to be used as test detergent. Table 3 shows the bubbles power of test detergent. As there were no significant differences in bubbles power of the three, detergent A was selected as test detergent. The specifications of detergent A are shown in Table 4. The test method used to measure the bubbles power of detergent is shown in Figure 5. 0.6 times dilution of the standard use volume of each detergent (30 cc) was poured into a test tube with a diameter of 25 mm and length of 200 mm, and shaken vertically 50 times in 15 seconds at a stroke of 20 cm. The bubbles power was measured one minute later.

Table 3- The bubbles power of test detergent

test detergent	A	B	C
bubbles power [mm]	59	58	53

Table 4- Specifications of detergent A

uses	cotton, linen, synthetic fibers
humoral	alkalescent
component	Surfactant (22%,Sodium dodecylbenzenesulfonate,polyoxyethylene alkyl ether),alkali chemicals (carbonate),water softener (aluminosilicate),Process materials (sulphur chloride),dispersant,fluorescent brightening agent,enzyme
bubbles power	59mm

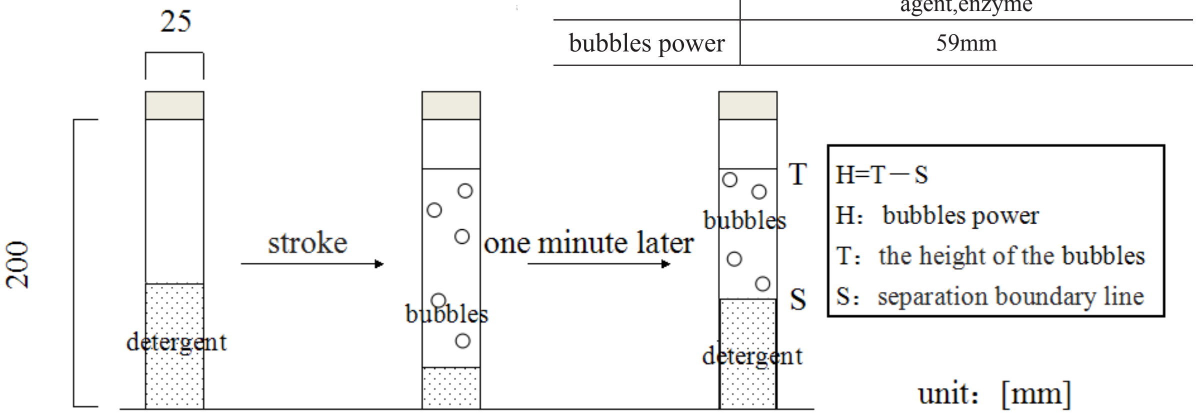


Figure 5-The test method used to measure the bubbles power of detergent

3.2.3 Experimental method

Experimental conditions are shown in Table 5. The amount of water used for a spiral type washing machine was 15, 40 and 55 L, that for a drum type washing machine was 11, 16 and 20 L. Two different outflow head of 1,000 mm and 1,500 mm were prepared, and the washing machines were positioned at the height of 50, 100, and 150 mm from the floor. Following the recommended volume of detergent (47 g per 55 L), 0.85 g per 1 L was considered as a standard volume. The volume of detergent used per each water amount is shown in Table 6. Detergent was put into the tank of a washing machine and stirred for one minute. Measurement was started at the beginning of spinning for dewatering. Three measurements were made for each of 144 patterns of experimental conditions.

Table 5-Experimental conditions

washing machine	water volume [L]	height from the floor [mm]	outflow head [mm]	self-sealing trap	detergent
spiral type	15	50 • 100 • 150	1,000 • 1,500	with • without	with • without
	40				
	55				
drum type	11				
	16				
	20				

Table 6- Water volume and detergent volume

washing machine	water volume [L]	detergent volume [g]
spiral type	15	13
	40	34
	55	47
drum type	11	9
	16	14
	20	17

3.3 Results and Discussion

3.3.1 Flow phase

Siphonage was observed in all of the experimental conditions shown in Table 5. There was no leakage from washing machines. Fill flow was observed at all times in the spiral type washing machines and siphonage occurred continuously. In the drum type washing machines siphonage occurred intermittently as some air was trapped in the pipe. No leakage was found from the filters.

3.3.2 Maximum siphonic negative pressure

As an example of the experimental results, maximum siphonic negative pressure measured spring water drainage with the spiral type washing machine and a water head of 1,500 mm is shown in Table 7. Table 8 shows maximum siphonic negative pressure in spring water drainage with the drum type washing machine and a outflow head of 1,500 mm. It was found that maximum siphonic negative pressure went down by 1,000 ~ 2,000 Pa if test trap was attached. It seems that the resistance of the trap reduced siphonic negative pressure. But it was clearly shown that discharge was made without a problem even when test trap was attached as there was no leakage from the washing machine nor was there any water remaining in the tank. Fluctuations of pressure in drain and water velocity in spring water drainage with the spiral washing machine and water volume of 55 L, a outflow head of 1,500 m, and a height of 50 mm from the floor are shown in Figure 6. Those in spring water drainage with the drum washing machine, water volume of 20 L, a outflow head of 1,500 mm, and a height of 50 mm from the floor in Figure 7.

Table 7- Maximum siphonic negative pressure measured (spiral type)

a) with test trap

height from the floor [mm]	water volume [L]		
	15	40	55
50	-11,700	-11,200	-11,000
100	-12,300	-12,100	-12,500
150	-12,000	-11,700	-11,600

unit:[Pa]

b) without test trap

height from the floor [mm]	water volume [L]		
	15	40	55
50	-13,100	-12,900	-13,000
100	-12,800	-12,700	-12,900
150	-12,800	-12,500	-12,600

unit:[Pa]

Table 8- Maximum siphonic negative pressure measured (drum type)

a) with test trap

height from the floor [mm]	water volume [L]		
	11	16	20
50	-11,700	-11,800	-11,900
100	-11,200	-11,400	-11,100
150	-12,100	-12,100	-12,200

unit:[Pa]

b) without test trap

height from the floor [mm]	water volume [L]		
	11	16	20
50	-12,900	-12,500	-12,400
100	-12,300	-12,400	-12,400
150	-12,200	-12,300	-12,500

unit:[Pa]

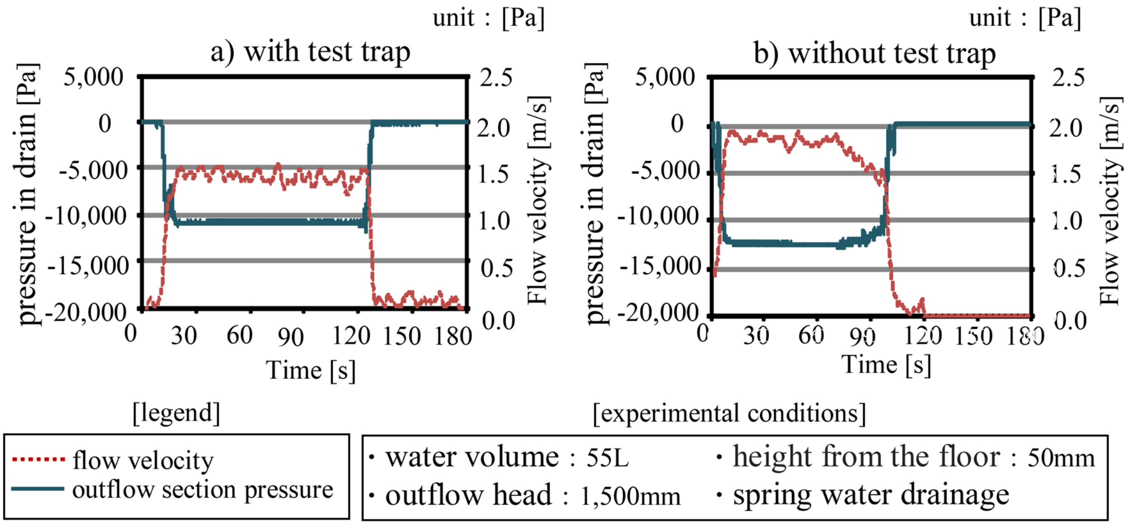


Figure 6- Fluctuations of pressure in drain and water velocity (spiral type)

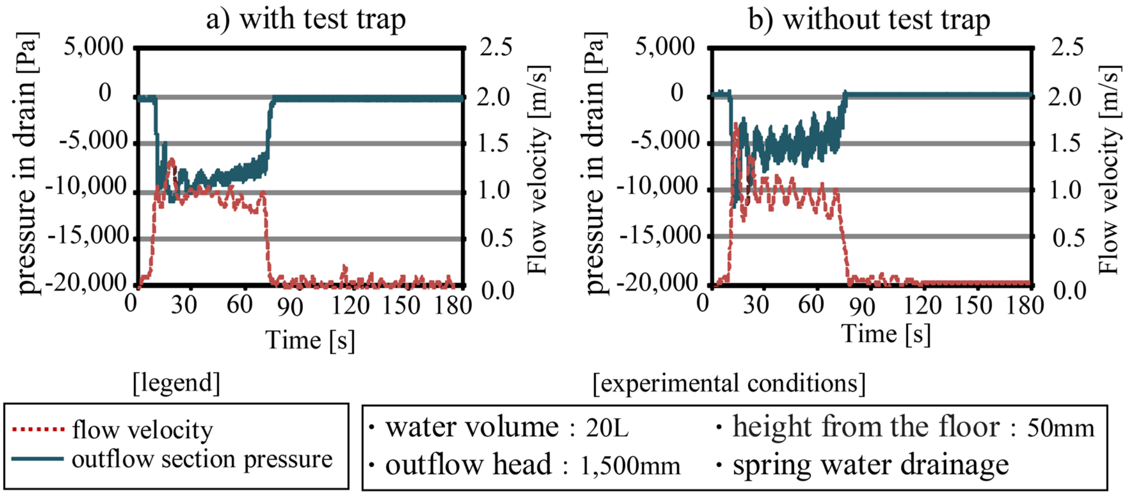


Figure 7- Fluctuations of pressure in drain and water velocity (drum type)

3.3.3 Maximum water velocity

As an example of experimental results, maximum water velocity in spring water drainage with the spiral washing machine and a outflow head of 1,500 mm is shown in Table 9. Table 10 shows maximum water velocity in spring water drainage with the drum washing machine and a outflow head of 1,500 mm. As was the case with maximum siphonic negative pressure, maximum water velocity decreased by 0.1 ~ 0.5 m/s when test trap was attached.

Table 9- Maximum water velocity (spiral type)

a) with test trap

height from the floor [mm]	water volume [L]		
	15	40	55
50	1.47	1.52	1.58
100	1.42	1.61	1.63
150	1.46	1.52	1.59

unit:[m/s]

b) without test trap

height from the floor [mm]	water volume [L]		
	15	40	55
50	1.72	2.11	1.94
100	1.82	1.89	1.97
150	1.86	1.92	2.07

unit:[m/s]

Table 10-Maximum water velocity (drum type)

a) with test trap

height from the floor [mm]	water volume [L]		
	11	16	20
50	0.97	1.10	1.10
100	1.33	1.30	1.32
150	1.00	1.03	1.25

unit:[m/s]

b) without test trap

height from the floor [mm]	water volume [L]		
	11	16	20
50	1.54	1.59	1.62
100	1.56	1.55	1.63
150	1.52	1.56	1.58

unit:[m/s]

3.3.4 Discharge time

Discharge time tended to be longer with test trap than without test trap. This may be attributable to the fact that water velocity decreased when trap was attached. As an example of experimental results, Discharge time in spring water drainage with a outflow head of 1,500 mm and a height of 50 mm from the floor is shown in Table 11.

a) spiral type (spring water)

system condition	water volume [L]		
	15	40	55
with test trap	50	103	124
without test trap	35	75	98

unit:[m/s]

b) drum type(spring water)

Installed test trap or not	water volume [L]		
	11	16	20
with test trap	39	52	62
without test trap	32	44	60

unit:[m/s]

3.4 Siphonic Negative Pressure and Maximum Water Velocity: Comparison of Theoretical Values and Actual Measurements

3.4.1 Maximum siphonic negative pressure

A formula for calculating siphonic negative pressure (referred to as formula P below) is shown in Table 12.

Figure 8 shows a comparison of theoretical values calculated from formula P with actual measurements made in spring water drainage with a outflow head of 1,500 mm and a height of 50 mm from the floor. Under all experimental conditions, the theoretical values approximated to the actual measurements.

Table12–P formula

$$P_o = \left\{ (H_a - Z_m) - \frac{(1+\lambda \frac{L_m}{d} + \sum^{m} \zeta)}{(1+\lambda \frac{L_a}{d} + \sum^{a} \zeta)} H_s \right\} \rho g \qquad \ldots\ldots\ldots\ldots(2)$$

P_0 : Pressure at outflow section [Pa] H_a : Height from base level to water surface [m]
Z_m: Height from base level to pressure measuring point in outflow section [m]
λ: Pipe coefficient of friction [-] L_m: Pipe length to pressure measuring point in outflow section [m]
L_a: Pipe length [m] : Pipe diameter [m] ξ: Partial resistance [-]
H_s: Height from end of outflow section to water surface [m]
ρ: Density [kg/m^3] g: Gravity acceleration [m/s^2]

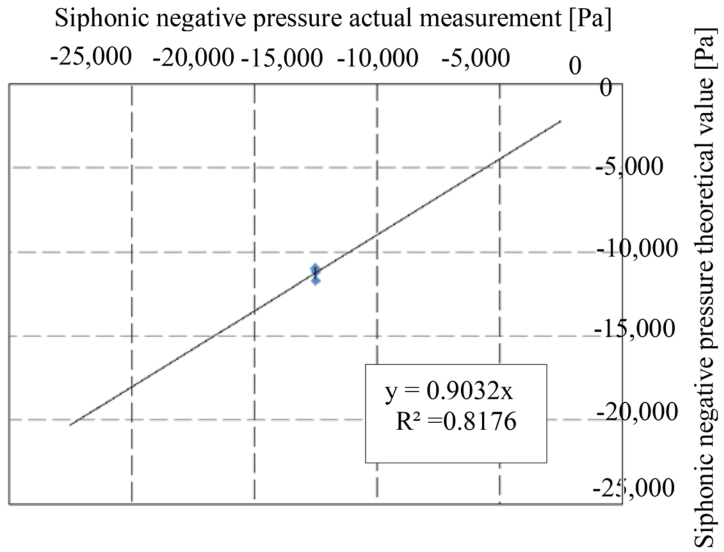


Figure 8-Comparison of siphonic negative pressure measurements and theoretical values

3.4.2 Maximum water velocity

A formula for calculating water velocity (referred to as formula V below) is shown in Table 13. Figure 9 shows a comparison of theoretical values calculated form formula V with actual measurements made in spring water drainage with a outflow head of 1,500 mm and a height of 50 mm from the floor. Under all experimental conditions, the theoretical values approximated to the actual measurements.

Table 13- V formula

$$v = \sqrt{\frac{2gH_s}{\lambda \frac{l}{d} + \sum \zeta + 1}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (3)$$

Equivalent pipe length L_e

By substituting hydraulic gradient $I = H_s/L_e$ and g = 9.8 into the equation, we get

$$v = 4.43\sqrt{I} \cdots\cdots\cdots\cdots\cdots\cdots\cdots \quad (4)$$

v : Flow velocity [m/s] g: Gravity acceleration [m/s^2] H_s: Siphon head [m]
λ : Pipe coefficient of friction [-] l: Total pipe length [m] d: Pipe inner diameter [m]
ζ : Partial resistance [-] L_e: Equivalent pipe length [m] I: Hydraulic gradient [-]

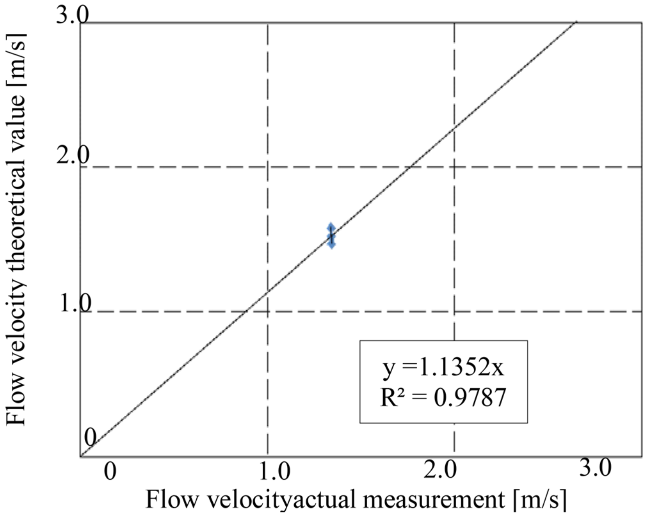


Figure 9- Comparison of flow velocity measurements and theoretical values

4. Conclusion

The results of this study can be summarized as follows:
1) The characteristics of pressure in drains and flow, and discharge time when self-sealing trap was attached to the inflow section have been made clear. The presence of the trap reduced maximum siphonic negative pressure by approximately 1,000 to 2,000 Pa and maximum water velocity by approximately 0.1 to 0.5 m/s. But discharge time tended to be longer. As there was no leakage from the washing machine, it was clearly shown that the presence of self-sealing trap did not hinder discharge in any way.

2) The theoretical values of siphonic negative pressure and maximum water velocity calculated from the formulas P and V roughly approximated to the values actually measured in the experiment.

In the future the authors intend to clarify the effects that the presence of trap exert on discharge by conducting experiments with water seal trap attached in the inflow section, and comparing pressure in drains and flow characteristics with those obtained in the experiments with self-sealing trap.

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6. Presentation of Authors

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Comparison of Pneumatic Pressure and Seal Loss in Constant and Fixture Discharges

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Abstract

There are two types of discharge load to test drainage capability of a drainage system: constant flow discharge load such as bathtub discharge and fixture discharge load such as WC discharge. Constant flow discharge load is mainly utilized in SHASE S218. However, discharge from a bathtub is practiced almost exclusively in Japan while it is not a common practice in other countries. Therefore, it is reasonable that fixture discharge load should be utilized as test discharge load in such countries. In view of this, we conducted discharge experiments to clarify the effects that steady discharge load and fixture discharge load exerted on pneumatic pressure and seal loss.

We measured pneumatic pressure and seal loss of various traps in constant flow discharge load and fixture discharge load experiments using a 15-story drainage system with special drainage fittings.

Constant flow discharge load was shown to have about twice as large effects as fixture discharge load on pneumatic pressure.

Keywords

Drainage system, flow capacity, special drainage fittings, discharge load, pneumatic pressure, seal loss, experiment

1. Introduction

Discharge characteristics of sanitary fixtures are normally indicated as changes in flow rate over time as shown in Figure 1. Discharge time from WCs and urinals tend to be short while that from bathtubs and washing machines is long. Discharge time from wash-basins and sinks fall somewhere in between. Maximum flow rate from sanitary fixtures constitutes an important indication of drainage system discharge load, and probability of simultaneous use is relative to discharge time and discharge intervals. As shown in figure 2, in the plumbing standard of Japan, SHASE-S 206$_{-2009}$, discharge characteristics of fixtures are simulated by the parameters of volume of fixture: w [L], average flow rate of fixture: $q_d(0.6w/t_d)$[L/s], and average discharge time: t_d [s]. Table 1 shows average flow rate of fixture used for calculating discharge load of

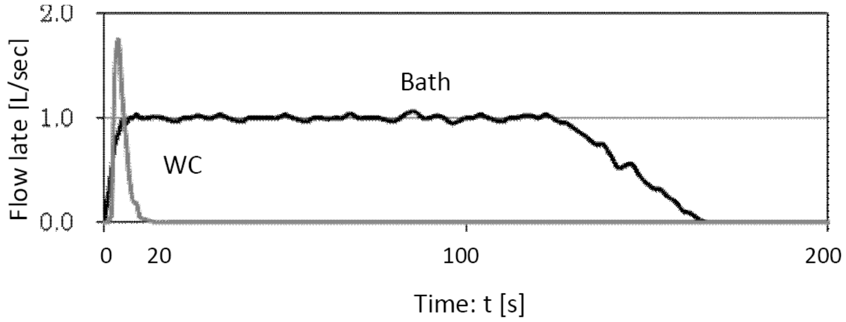
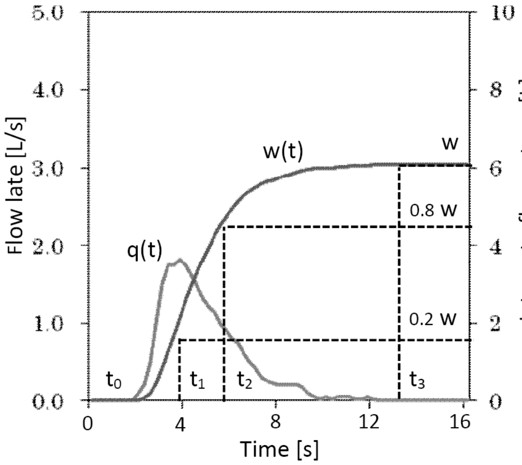


Figure 1 Discharge characteristics of fixtures



$$w(t) = \int_{t_0}^{t_3} q(t)dt$$

$$w_d^{`} = \int_{t_1}^{t_2} q(t)dt = 0.6w$$

$$t_d = t_2 - t_1$$

$$q_d = w_d / t_d$$

Figure 2 Definition of discharge characteristics of fixture

Table 1 Average flow rate of fixtures

fixture		q_d [L/s]	fixture	q_d [L/s]
WC		1.5	Bath tub	1.5
Urinal		0.5	Shower	0.3
Washbowl	Full discharge	1.0	Kitchen sink	0.3, 1.0
	Flowing discharge	0.3	Slop sink	0.3

SHASE-S 206. The question of what type of fixture represents discharge characteristics of a particular building is an important one when testing flow capacity of drainage system in that building. Most frequently used fixtures in office buildings would be WCs and wash-basins; therefore WC should be regarded as a representative fixture. In housing complexes where WCs, wash-basins, kitchen sinks, bathtubs, showers, and washing machines are the main fixtures used, WC with large maximum flow rates and bathtubs with long discharge time can be regarded as fixtures that typify discharge characteristics.

In mid-to-high rise housing complexes and hotels in Japan, stack vent system with special drainage fitting is the mainstream drainage system while loop vent system is mainly used in other types of buildings. Stack vent system with special fitting was introduced in the 1970s as Sovent system in Switzerl and as Sexia system in France. Later some improvements were made in Japan and it has started to be used in super high-rise buildings since the 1990s. The need for performance evaluation to ensure the validity of the system was stressed in the process, and SHASE-S 218-2014: “Testing Methods of Flow Capacity for Drainage System in Apartment Houses” was put out in 1997. Bathtub was used as the testing fixture because it had larger pneumatic pressure and seal loss than WC when discharge flow rate was constant, and because it was found more difficult to make experimental arrangements where simultaneous multiple discharges could be made in drainage stack with WC than with bathtub.

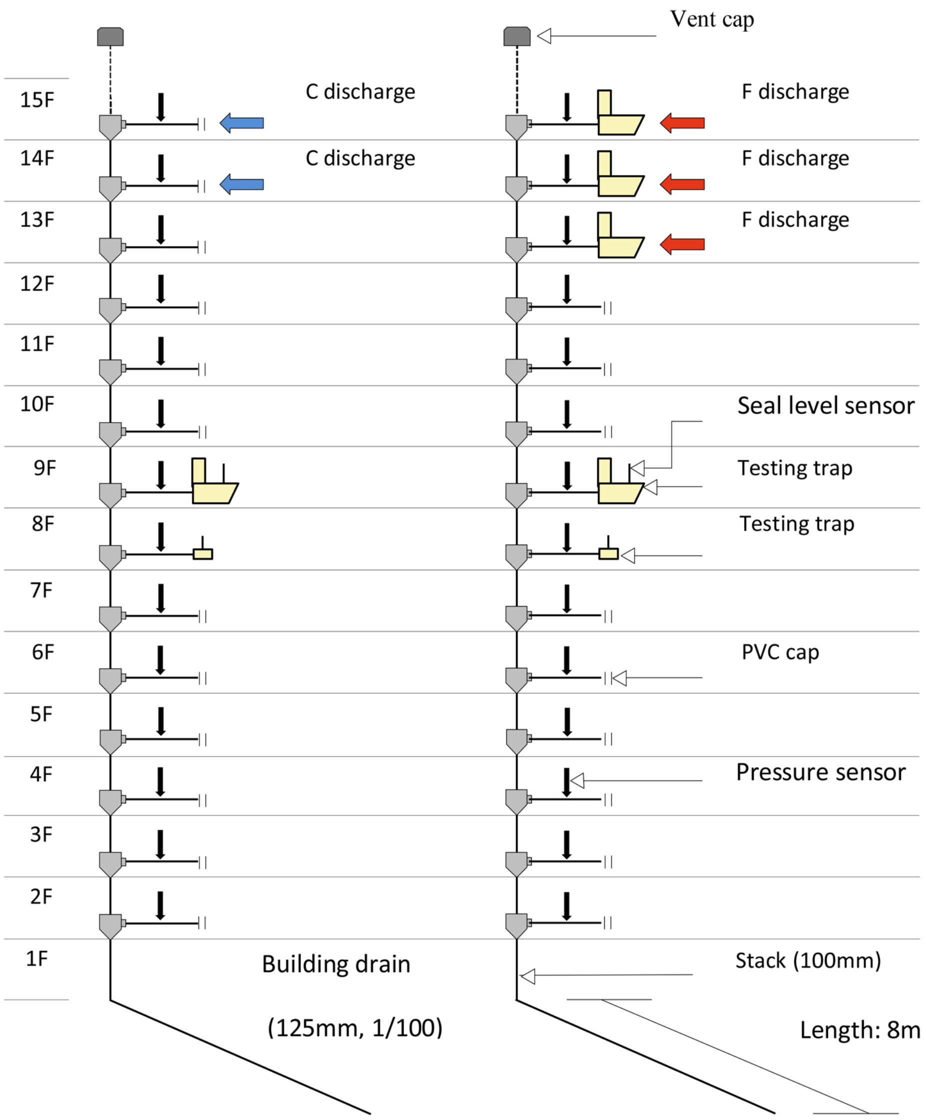
It could be called an ideal discharge from bathtub if water is discharged at a constant flow rate over a given space of time. This type of discharge is called constant flow discharge in this paper. As opposed to this, discharge from WC is called fixture discharge. In Japan soaking in a bathtub constitutes a common practice of taking a bath while taking a shower is a major bathing style in other countries. WC would be a fixture that typifies discharge characteristics in countries other than Japan, and fixture discharge is feasible in office buildings in Japan as well. However, special experimental arrangements must be made to ensure simultaneous discharge when WC is used as a main test discharge fixture.

In this experiment we analysed fluctuations of pneumatic pressure and seal loss using an experimental drainage tower to quantitatively compare pneumatic pressure and seal loss in constant flow discharge load with those in fixture discharge load.

2. Outline of Experiment

2.1 Experimental drainage system

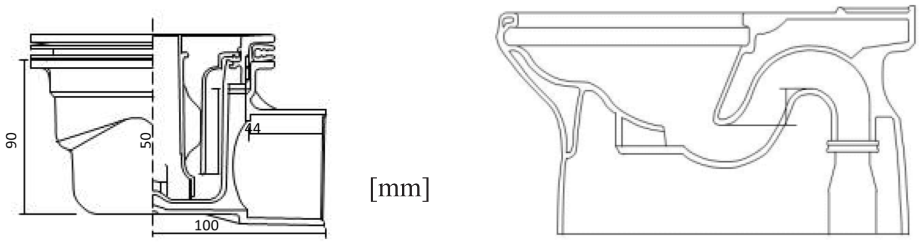
The outline of the experimental drainage system is shown in Figure 3. Stack vent system with special drainage fitting was installed in a 15-stories experimental tower. Test traps were connected on the 8th and 9th floors; PVC caps were attached to the ends of horizontal branches on the 2nd–7th and 10th–12th floors. Discharge was made from the 13th to 15th floors depending on the discharge type and flow rate.



[C discharge (Constant flow discharge)] Flow rate: Max 2.5L/s

[F discharge (Fixture discharge] Volume: 6L/time, Flow rate (q_d): 2.2L/s

Figure 3 Experimental drainage system



Contrary bell trap WC

Figure 4 Cross-section of test trap and test WC

Table 2 Basic parameters of test trap and test WC

Test trap	Setting floor [F]	Seal depth [mm]	Quantity of seal [mL]	Ratio of leg's cross sectional area [-]	natural frequency [Hz]	Average flow rate of fixture [L/s]
Contrary bell trap	8	50	330	1.07	2.23	-
WC	9	58	2,400	0.16	1.27 2.47	202

2.2 Test WC and trap

Water-saving siphonic toilets with "big" flush capacity of 6L were used as a test WC. The contrary bell trap were used as a test trap and installed on the 8th floor and WC on the 9th floor. Cross-sections of test WCs and traps are shown in Figure 4, and their basic parameters in Table 2. q_d (2.2L/s) of test WC is bigger approximately 1.5 times than q_d (1.5L/s) was shown in Table 1. This change depend on saving water of WC.

2.3 Method and measurement

1.5L/s, 3.0L/s, and 4.5L/s discharges at constant flow rate were made from one to three WCs. To simulate simultaneous multiple discharges (discharges from multiple floors), a discharge from the top floor was made first and one second later a discharge from the next floor was made so that discharges from these floors were combined to make up the maximum flow rate in drainage stack on the lowest floor.

Fluctuations of pneumatic pressures and seal loss, and residual seal depths were measured at a sampling period of 20 msec. Measurements were made for one minute after flow rate became stabilized with constant flow discharge, and for 40 seconds with fixture discharge.

3. Pressure Fluctuations and Seal Water Fluctuations

3.1 Purpose and method of analysis

The vertical distributions of pressure (referred to as pressure below) obtained from constant flow discharge were compared with those from fixture discharge. In addition fluctuation wave forms were analysed to clarify the characteristics of pressure fluctuation and seal water fluctuation. The standard deviation and coefficient of variation for seal water fluctuation values obtained from constant flow discharge and fixture discharge were calculated and compared.

3.2 Results and discussion

The vertical distributions of pressure obtained from constant flow discharge and fixture discharge are shown in Figure 5. In the case of constant flow discharge, negative pressure (minimum pressure) tended to dominate on the upper floors and the maximum system pressure on the lower floors. The minimum system pressure on the 11th floor and the maximum system pressure on the 2nd floor at a flow rate of 4.5 L/s were approximately -310Pa and 210Pa. Minimum system pressure is defined as the minimum value of minimum pressure of each floor, and maximum system pressure is defined as the maximum value of maximum pressure of each floor. In the case of fixture discharge, positive pressure (maximum pressure) tended to be larger than negative pressure on all floors. : with pressure reaching maximum on the top floor declining gradually on lower floors. These differences may be explained as follows. Air flows upward in drainage stack before discharging water. In constant flow discharge, measurements were made after pneumatic pressure became stabilized when air inside the stack was moving downward; thus making negative pressure dominant. On the other hand, in fixture discharge, air flowing upward collided with discharged water making positive pressure more dominant and the largest pneumatic pressure was seen on the top floor.

An example of pressure fluctuation waveforms and seal loss fluctuation waveforms are shown in Figure 6. While seal loss fluctuation corresponded with pressure fluctuation in both constant flow discharge and fixture discharge, their waveforms varied considerably depending on the discharge type. In constant flow discharge, seal water was already being lost corresponding with pressure fluctuation when flow rate became stabilized (when measurements started). In fixture discharge, seal water started to fluctuate in correspondence with pneumatic pressure when maximum pressure was created right before discharged water passed through. Seal water fluctuation was greater with contrary bell traps than with WC. This can be clearly seen in standard deviation and coefficient of variation of seal water fluctuation shown in Table 3. Standard deviation of contrary bell trap was twice as large as that of WC. This difference may be attributed to the structure of traps and seal water volume.

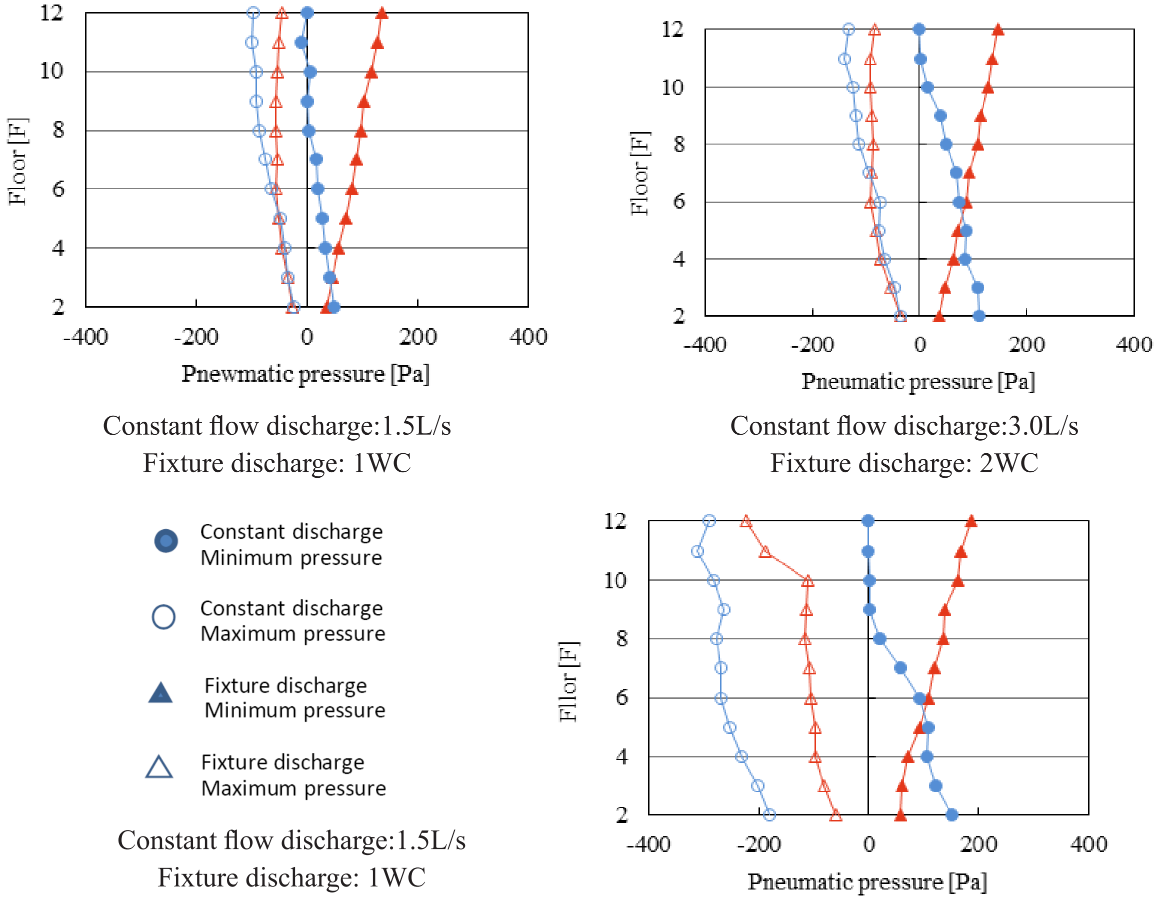
4. Discharge Flow Rate and Minimum Pressure

4.1 Purpose and method of analysis

We examined the relationship between discharge flow and minimum pressure in constant flow discharge and fixture discharge to shed light on the effect of discharge type on minimum pressure. A scatter plot was used to indicate the relationship between discharge flow and minimum pressure based on pneumatic pressure fluctuation data with 3 Hz LPF (low pass filter) applied, and the primary regression equations were compared. The relationship between discharge flow rate and system minimum pressure was also examined using average fixture discharge flow rates.

4.2 Results of analysis and discussion

An example of how discharge flow rate in each discharge type relative to minimum pressure is shown in Figure 7, and coefficient of determination R^2 in Table 4. Coefficient of determination R^2 in both constant and fixture discharges fell in the range of 0.64 ~ 0.93 indicating a high correlation between discharge flow rate and minimum pressure. Regression coefficient “a” of the primary regression equation for each discharge type and the ratio of regression coefficient “α” of constant flow discharge relative to fixture discharge are shown in Table 5. The ratio of regression coefficient “α” was found to be 194 ~ 268 From this it is predicted that the system minimum pressure (negative pressure) produced in constant flow discharge, as is the case with minimum pressures on each floor, should reach twice larger than that produced in fixture discharge.



Constant flow discharge:1.5L/s
Fixture discharge: 1WC

Constant flow discharge:3.0L/s
Fixture discharge: 2WC

Constant flow discharge:1.5L/s
Fixture discharge: 1WC

Figure 5 Cross-section of test trap and test WC

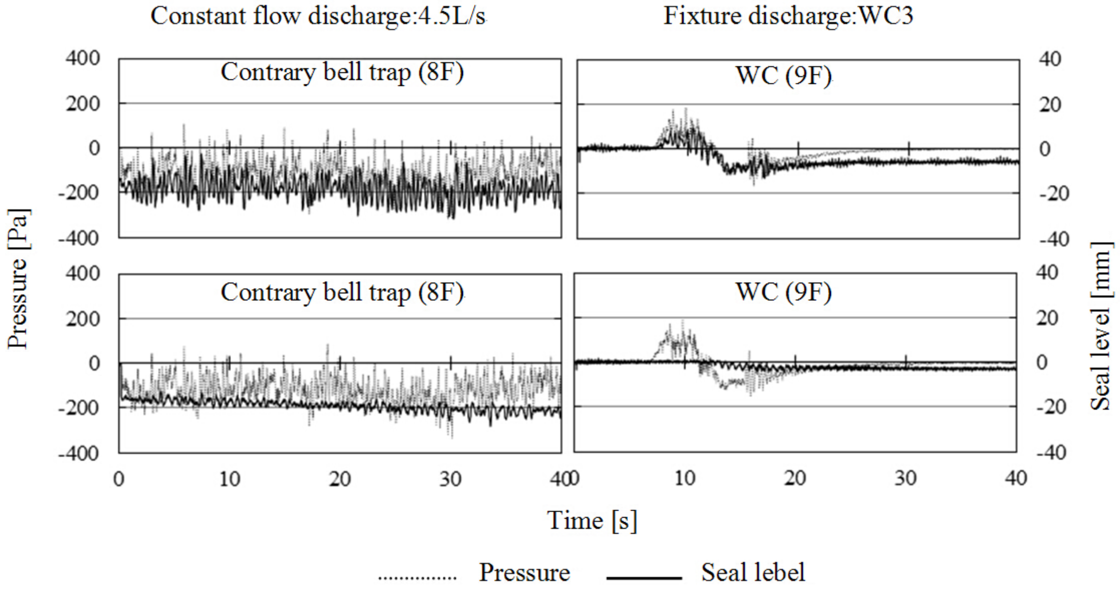


Figure 6 Pressure fluctuation and seal water fluctuation

Table 3 Standard deviation and coefficient of variation of seal water fluctuation

Discharge type		Standard deviation [mm]		coefficient of variation [-]	
		Contrary bell trap (8F)	WC (9F)	Contrary bell trap (8F)	WC (9F)
Constant discharge	1.5L/s	1.4	0.6	0.19	0.09
	3.0L/s	2.7	1.4	0.27	0.15
	4.5L/s	4.8	2.3	0.25	0.12
Fixture discharge	1WC	2.1	0.7	0.23	1.10
	2WC	3.0	1.5	1.03	0.71
	3WC	4.3	1.8	0.90	0.75

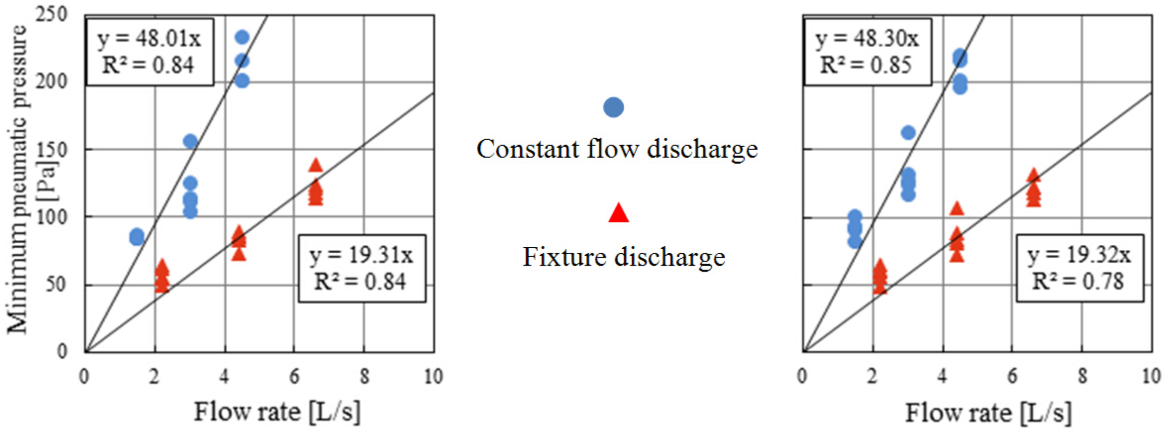


Figure 7 Relationship between flow rate and minimum pressure

Table 4 Coefficient of determination R2 of flow rate and minimum pressure

Dischargetype	Floor [F]										
	2	3	4	5	6	7	8	9	10	11	12
Constant flow Discharge	0.64	0.70	0.78	0.77	0.77	0.81	0.84	0.85	0.89	0.88	0.91
Fixture discharge	0.74	0.93	0.84	0.75	0.70	0.79	0.84	0.78	0.77	0.83	0.81

Table 5 Ratio of regression coefficient of constant flow discharge relative to fixture discharge

Floor [F]	Regression coefficient“a”		Ratio of regression coefficient“ α”
	Constant flow discharge	Fixture discharge	
12	53.62	27.57	1.94
11	55.18	24.92	2.21
10	51.52	19.19	2.68
9	48.30	19.32	2.50
8	48.01	19.31	2.49
7	43.67	19.14	2.28
6	41.58	18.67	2.23
5	37.82	17.32	2.18
4	35.89	15.33	2.34
3	27.99	12.98	2.16
2	24.53	9.93	2.47

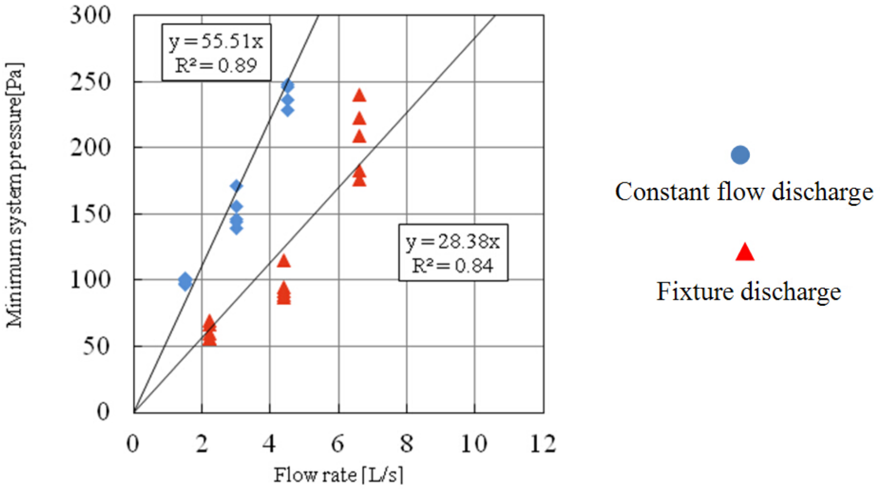


Figure 8 Relationship between flow rate and minimum system pressure

The relationship between discharge flow rates and system minimum pressures is shown in Figure 8. As the ratio of regression coefficient“α” is 1.96, the system minimum pressure (negative pressure) occurring in constant flow discharge, when the discharge flow rates are constant, is expected to be approximately twice as large as in fixture discharge just as the same as minimum pressure that occurs on each floor.

5. Minimum Pressure and Seal Loss

5.1 Purpose and method of analysis

We examined the relationship between minimum pressure and seal loss in constant flow discharge and fixture discharge to shed light on the effect of discharge type on seal loss. Minimum pressures on the 8th and 9th floors where traps were placed were obtained from pneumatic pressure fluctuation data with 3 Hz LPF applied, and their relationship to seal loss was compared.

5.2 Results of analysis and discussion

Seal loss of traps on the 8th and 9th floors is shown in Table 6. Seal loss in constant flow discharge was larger than that in fixture discharge. While seal loss of WC in constant flow discharge was larger than that of contrary bell traps on the 8th floor, in fixture discharge, contrary bell traps showed larger seal loss than WC. This seems to indicate that pressure resistance of trap varies depending on the discharge type.

Figure 9 shows a scatter plot expressed in the primary regression equations, which indicates the relationship between minimum pressure and seal loss in each of the discharge types. Coefficient of determination R2 in both constant and fixture discharges was 0.64 ~ 0.90 indicating a high correlation between minimum pressure and seal loss. Regression coefficient “α” of the primary regression equation and the ratio of regression coefficient “α” of constant flow discharge relative to fixture discharge are shown in Table 7. The ratio of regression coefficient “α” for contrary bell traps on the 8th floor was 1.32 and that for WC on the 9th floor was 2.91. It can be assumed that seal loss in constant flow discharge should be approximately 1.3 times as large as that in fixture discharge with contrary bell traps and approximately 3 times larger with WC when the minimum pressure values are the same. As the ratio of regression coefficient “α” of minimum pressure and seal loss varied considerably depending on the type of trap, it seems difficult to make any generalization.

Table 6 Seal loss of traps

Test trap (Floor)	Constant flow discharge			Fixture discharge		
	1.5L/s	3.0L/s	4.5L/s	1WC	2WC	3WC
Contrary bell trap (8F)	6mm	9mm	16mm	2mm	4mm	7mm
WC (9F)	8mm	12mm	22mm	1mm	3mm	4mm

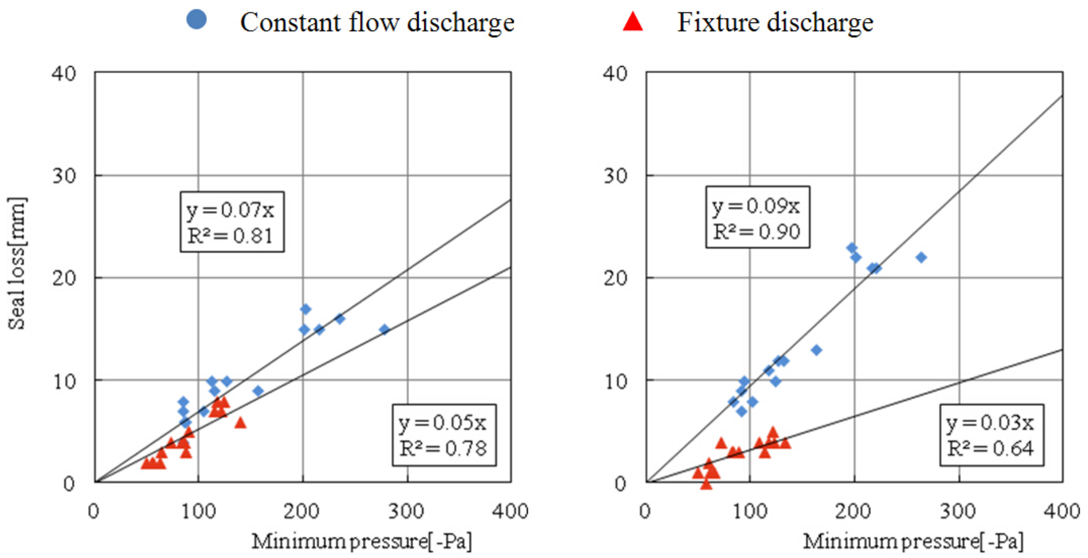


Figure 9 Relationship between seal loss and minimum pressure

Table 7 ratio of regression coefficient " α " of constant flow discharge relative to fixture discharge

Floor [F] (trap)	Regression coefficient"a"		Ratio of regression coefficient"α"
	Constant flow discharge	Fixture discharge	
8F (Contrary bell trap)	0.069	0.053	1.32
9F (WC)	0.095	0.033	2.91

6. Conclusion

The results of this experiment can be summarized as follows.

(1) Pneumatic Pressure and Seal Fluctuation

The vertical distributions of pneumatic pressure indicated that negative pressure was more predominant on upper floors and positive pressure on lower floors in constant flow discharge. On the other hand, positive pressure prevailed over negative pressure on each floor, but gradually dwindled on the lower floors in fixture discharge. Seal fluctuation varied more markedly with contrary bell traps than with WC with the standard deviation of contrary bell traps being approximately twice as large as that of WC.

(2) Discharge Flow Rate and Minimum Pressure
It was clearly shown that there was a high correlation between discharge flow rate and minimum pressure. Minimum pressure (negative pressure) in constant flow discharge is predicted to be about 2 to 2.5 times as large as that in fixture discharge when there is no change in discharge flow rate.

(3) Minimum Pressure and Seal Loss
Seal loss in constant flow discharge was larger than in fixture discharge. This seems to indicate that pressure resistance of trap varies depending on the discharge type. It was shown that there was a high correlation between minimum pressure and seal loss. Seal loss in constant flow discharge was approximately 1.3 times larger with contrary bell traps and 3 times larger with WC than in fixture discharge.

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Research on the Back Flow into the Branch from the Soil Stack

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Abstract

Various of branch fittings for flushing system including venting stack system and special single stack system have been developed in recent years and it is noticed that there is some back flow into the branch from the soil stack in some cases that will likely result in the blocking in the branch. It is necessary to study the possibility of back flow into the branches with various branch fittings for determination of application of different branch fittings.

Key Words

Back Flow, Branch Fittings, Soil Stack

Experiments in Hunan University and Ningbo Spec Global Sanitaryware Co., Ltd. show that back flow from soil stack happens into the some kinds of branches in the branch fittings in some cases. It is very well known that back flow into the branch will bring solid waste into the branch resulting in blocking when the waste gets dried and stick to the wall of the branch pipes.

So we make a lot of investigation into the relationship between the back flow into the branch and the flow rate in the stack as well as in the upstream branch for the toilet with various types of the branch fittings including special branch fittings and the conventional ones. We hope our research will be helpful to determine the application of different branch fittings in various flush systems to make sure of the quality of life with our bathrooms and kitchens.

1. Flow from Various Types of Upstream Branches

Both conventional branch fittings and special branch fittings for connecting the stack to the branch are in the test. For the fitting with only one branch, only the water from upstream in the above floors is used to test the back flow. For the branch fittings with more than one branch, the water from the branch for discharging of toilet is also used to test in addition to the water from upstream of the stack.

The back flow into the branch can be defined as continuous flow back into the branch from the gate of the stack. It is believed that solid objects in the waste water in the soil stack can drop into the branch and accumulate there resulting in blockage when back flow appears.

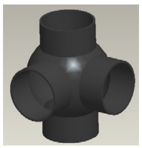
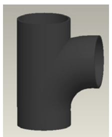
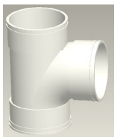
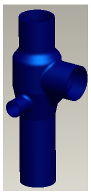
No matter the back flow water is from the soil stack for the upper floors or from the nearby branch for the toilet on the same floor, the dirt contained in the waste water flowed back into the branch will be very likely to be left on the wall of the branch.

2. Branch Fittings in the Experiment

There are various types of branch fittings in the markets including conventional branch fittings and special ones. The most commonly applied branch fittings in HDPE or PVC or cast iron are selected for the tests.

Here we mainly provide the performance of the samples and the test method for further study on the variety of the branch fittings.

Table 1 Branch fittings in the experiment

Conventional Branch fittings			
	4-way ball	Tee, swept-entry	Tee, swept-entry
Special Branch fittings			
	Sovent	Cyclone	Cyclone

3. Conventional Branch Fittings for the Soil Stack

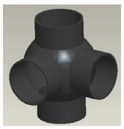
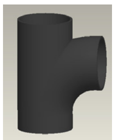
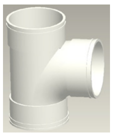
Conventional branch fittings for the soil stack are tested for back flow by adjusting the flow rate in the soil stack from the upstream gradually until continuous back flow appears into the branch.

With the 4-way ball in the experiment, the waste water from the upstream in the soil stack starts to splash at the gate of the branch and some water gets into the branch when the flow rate in the stack reaches 2.2L/s. When the flow rate increases, the splash at the gate is more serious with more water splashed back into the branch.

With the test on the Tee with swept-entry, the waste water from the upstream in the soil stack starts to splash at the gate of the branch and some water gets into the branch when the flow rate in the stack reaches about 4.0L/s and 4.4L/s.

The test result is as the following table.

Table 2 Flow rate in the stack at which Splash starts at the gate

Conventional Branch fittings			
	4-way ball	Tee, swept-entry	Tee, swept-entry
Flow rate in the stack L/s	2.2	4.4	4.0
Start to splash in			

4. Special Branch Fittings for the Soil Stack

(1)Sovent Fitting
So far all Sovent fittings available in the markets have the same amount of branches, three upper branches in DN110 and three lower branches in DN75. Each branch of the Sovent fitting meets the main body in the right angle instead of any swept-entry structure to sweep the dropped water back into the stack.

When there is a constant flow into one branch of DN110 at a constant flow rate of 1.5L/s that is nearly the same as a toilet discharges, there is back flow almost in every lower branch as shown in the following table. When the flow rate reaches 2.5L/s, back flow becomes very serious.

There has been no back flow found in any of the branches when there is only flow from upstream in the above floors in the soil stack.

(2)Cyclone Fitting
There are various types of cyclone fittings available in the markets and the distribution of branches is

quite different. Tests on different cyclone fittings give very different results. We provide the tests on some samples that play important roles in the markets especially the cyclone fittings with more than one branch.

Table 3 Back flow with Sovent Fitting

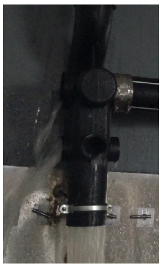
Sovent fitting		
Descriptions	At flow rate of 1.5L/s	At flow rate of 2.5L/s

Table 4 Back flow with Cyclone Fittings

		
At flow rate of 2.0L/s from both Stack and toilet	At flow rate of 2.5L/s from Stack	At flow rate of 1.5L/s from Stack

Some cyclone fittings in the tests show no significant back flow into the branch at very high flow rate up till 4.5L/s either from the stack for the upstream or from the nearby branch for the toilet in the same fitting. So far as the tests have been performed, all the cyclone fittings with upper and lower branches must have such character that the branches need to connect the cyclone body tangentially or there will be back flow into the smaller branches.

Test on some sample cyclone fittings shows that back flow into the lower branch is serious even at very low stack flow rate of 1.5L/s and the back flow is much more serious at stack flow rate of 2.5L/s as shown in the following table.

5. Codes and Regulations

Nearly all over the world, the discharging capacity of the soil stack depends upon the pressure fluctuation figures no matter at the constant flow rate or at instantaneous flow rate. When the pressure in the soil stack reaches positive or negative 400 Pa as the flow rate increases, the maximum flow rate is regarded as the discharging capacity of the soil stack.

So far there have been no reports about any standards restricting any branch fittings to application due to the back flow into the branches from the stack. But the back flow into the branches is very harmful to the piping system.

6. Conclusions

1. In addition to the pressure fluctuation in the soil stack, back flow into the branches should also be the criteria to determine the maximum discharging capacity of the soil stack.
2. In addition to the pressure fluctuation to define discharging capacity, the back flow should also be the critical factor to determine how many toilets can be connected to the same branch fitting with more than one branch.
3. Sovent fittings should be applied with either upper branches or lower ones instead of both at the same time.
4. Cyclone fittings should have all the branches meet with the main body tangentially instead of vertically.

7. Presentation of Authors

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Pressure Characteristics of Water Seal and Tests on Flow of Drainage System– A Discussion on Testing Philosophy of Water Drainage Capacity of Drainage Riser

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Abstract

Based on latest research and experiments on water seal, this paper contains thorough analysis on worldwide technologies and philosophies concerning maximum water drainage capacity of drainage riser in buildings. Objections are brought forward against existing Assessment Criteria, for instance, “internal pressure fluctuation below ±40 mmH_2O”, “water seal loss depth not exceeding 25 mm” and etc. The paper proposed a new testing philosophy that testing on the maximum water drainage of drainage riser in buildings should comply with the pressure characteristic pattern of water seal, and vacuum suction of drainage system prior to positive pressure confirmation, and positive calibration after testing.

Keywords

Water Drainage Capacity of Drainage Riser; Pressure Fluctuation; Assessment Criteria; Water Seal Loss; Pressure Characteristic; HES Ratio

1. Introduction

An overall view of the field of building drainage system in the world indicates that higher buildings are being built with the development of science and technology, therefore, stricter requirements are imposed on water drainage capacity of drainage riser in buildings.

To determine water drainage capacity of drainage riser in buildings, numerous methods have been instigated ranging from experience-based estimation, theoretical solution, on-site testing to professional testing by means of drainage test tower at present. Among them, drainage technology achieved great progress. Especially, the professional and high class full-scale testing by means of drainage test tower provided a strong technical support or reference for industrial standards and codes of drainage technology.

2. Problem Raised

As technology researches further develop on water seal in building drainage system, drainage test facilities and techniques in many countries are continually improved and enhanced, but the basic testing philosophy of water drainage capacity of drainage riser, or the “Assessment Criteria” in testing maximum water drainage capacity of drainage riser in buildings remains unchanged, for instance, the so-called typical Japanese "internal pressure fluctuation below ±40 mmH_2O"[7] and European/American "water seal loss depth not exceeding 25 mm", as well as Chinese “water seal residual depth should be at least 20mm”[3][6] and etc.

Demonstrated by theoretical research and relevant experiments on water seal, objections are brought forward against assessment criteria imposed on maximum water drainage capacity of drainage riser, which include “internal pressure fluctuation below ±40 mmH_2O” and “water seal loss depth not exceeding 25 mm”. Results resulting from these standard criteria are only ostensibly correct. More specifically, inconsistency is observed in case of various HSE ratio [1] (note: originally termed “water seal ratio”; hereinafter “HSE” ratio), thus results under these criteria are unrepresentative.

The “Assessment Criteria” are originally purported to test the maximum water drainage capacity on condition that water seals within the system remains safe. However, all water seals in the system are fulfilled with water prior to testing drainage riser with maximum “Testing Flow”. After pressure fluctuation (due to alternative draining via drainage riser and horizontal branches) and maximum flow test, it is uncertain that whether the water seals could withstand internal positive pressure (e.g. standard 400 mmH_2O) followed by another draining in the riser and branches. Traditional approaches ignored these facts, which is the deep-down defect of traditional “Assessment Criteria”. The cause of this defect is due to “Misunderstandings” [2] on water seal pressure characteristics.

It has been ignored in real life projects that, water seals in horizontal branch of positive section of riser, prior to draining riser, may be subject to negative pressure suction when branch is drained; and conversely, water seals in the branch of negative section of riser, after draining branches, may be subject to negative pressure suction when riser is drained. In both cases, the residual depth of water seals in positive and negative section could no longer withstand positive pressure resulted respectively from draining of riser and horizontal branches. These problems are significant provided that length of horizontal branch is amply long and number of lavatories is large enough. This is also the reason for necessitating loop and fixture vents as in Code [4] and Specification [5]. Although length of lavatory branches and number of fixtures in residential buildings is insufficient and can be treated distinctively. Nevertheless these phenomena do exist and therefore must not be neglected.

A building drainage system, designed in accordance with codes and standards, could still result in water seals that failed under internal pipe positive pressure, causing positive break-through/bubbling or foul odor in bathroom. Besides from obvious causes of poor installation and dried-out water seals, deeper causes should attract more attention from professionals.

In addition, I am looking forward to having a systematic, thorough and comprehensive discussion with the author of the Textbook [8].

3. Analysis and Discussion

In order to test flow capacity of the riser of drainage system, it is crucial to understand status of drainage system and water seals before and after experiencing maximum water flow and their impact on test results.

3.1 Status of Drainage System before Experiencing Maximum Water Flow

Pressure fluctuation is generated while draining horizontal branches, thus influencing their water seals. Moreover, pressure fluctuation generated by draining riser will apply a composite effect on these water seals, and vice versa.

For pressure profile while draining horizontal branches, check descriptions on Page 151 of Textbook [8].

Pressure variation of horizontal branches is dependent on branch position (upper or lower section of riser) and whether other branch is draining simultaneously. The branch is connected to A, B and C lavatory. If lavatory B, the middle one, starts draining suddenly and the branch is located in the upper section of riser, and other part(s) along the branch is draining simultaneously, water level in the trap of all A, B and C lavatories would decline during the final stage of drainage of B. However, pressure fluctuation as a result of self-draining of horizontal branch is small, thus declination of water seal height inside trap is also small. In this case, water seal is normally unaffected.

In worse case, when branch length is relatively long, and larger number of lavatories (4 or more and length exceeds 12m, or at least 6 toilets) are connected (refer to Page 168 in aforementioned textbook), pressure fluctuation as a result of self-draining of horizontal branch is no longer negligible. It becomes necessary to arrange loop vents, as stipulated in Code 4.6.3[4].

Assume horizontal branch is connected with 4 or more lavatories, total pipe length is 11.5m, and there is no loop vent, which is not violating the Code. Under this threshold condition, what is the magnitude of critical pressure fluctuation when one or two lavatories are draining? Whether other water seals on the same branch, after previous critical pressure fluctuation, could still withstand internal positive pressure caused by alternative draining of riser and branch pipe?

Now assume the horizontal branch is connected with 5 toilets and there is no loop vent, which is not violating the Code. Under this threshold condition, what is the magnitude of critical pressure fluctuation when one or two toilets are draining? Whether other water seals on the same branch, after previous critical pressure fluctuation, could still withstand internal positive pressure caused by alternative draining of riser and branch pipe?

It is reasonable to set magnitude of “Critical Pressure Fluctuation” to commonly accepted or default ± $40mmH_2O$. In order to calibrate the system, we should and it is necessary to simulate alternative drainage of riser and branch prior to testing flow capacity of drainage system, i.e. perform -40 mmH_2O suction, followed by applying +40 mmH_2O. The drainage system must pass this simulation to proceed to next flow test, otherwise the system can be deemed failure.

3.2 Status of Drainage System after Maximum Water Flow

In engineering practice, for drainage system of any building, its drainage risers and horizontal branches will individually experience continuous, multi-times and alternating “Maximum Flow”. Calibrated drainage system, when risers passed maximum flow test, it is unavoidable to determine whether all water seals within the system are able to withstand piping pressure (say 40 mmH_2O) as testing data is required to govern design of building drainage system and to achieve long-term safe operation.

For negative section of riser, water seals of horizontal branch must have residual depth that is able to withstand a pressure of +40 mmH_2O when draining the branch, which happens after they were subject to a maximum suction (-40 mmH_2O) when riser is drained.

Similarly, for the positive section of riser, water seals of horizontal branch must have residual depth that is able to withstand a pressure of +40 mmH_2O when draining the riser, which happens after they were subject to a maximum suction(-40 mmH_2O) when branch is drained.

These require us to perform positive and negative calibration to drainage system before testing flow capacity of riser. After test, verify the system by applying +40 mmH_2O positive pressure.

3.3 Pressure Characteristics of Water Seal

The HES Ratio theory [1] can be used to analyze and evaluate quality of water seals, and more importantly to evaluate safety of entire building drainage system.

According to HES ratio theory, all drainage water seals can be classified into three types: HES ratio $n < 1$ (Figure 1), HES ratio $n = 1$ (Figure 2) and HES ratio $n > 1$ (Figure 3).

Now we will discuss problems associated with “Assessment Criteria” by analyzing performance and pressure characteristics of the three types of water seals above under ± 40 mmH_2O and 25mm seal loss.

Figure 1

Figure 2

Figure 3

To facilitate discussion, Figure 4, 5 and 6 below are illustrating five status points for the above three types of water seals. Assumption is made that outer water level area A is identical for each water seal.

Five status points are:

a. Water seal is full, and depths of the all seals are standard 50mm[3-6];
b. Full water positive pressure withstand, maximum tolerable positive pressure of water seal at standard depth;
c. Water seal is subject to multiple or continuous suction of -40 mmH_2O (eg, 10s as stipulated in Standards[3][6]), outer water level A lowered by 40 mm, thus total water seal loss volume equals A × 40mm;
d. Pressure vanished, a volume of B × 40mm under inner water level B is relocated. Part of the water returned to outer compartment so that water level is even again. Now water seal is balanced, water level B is lowered to a height that is determined by "height loss" due to standard negative suction, viz. "Residual Depth" after standard negative suction;
e. Maximum tolerable positive pressure of "Residual Depth" of water seal.

Figure4 below shows a simplified water seal that corresponds to Figure 1 (American type floor drain). Assuming the diameter ratio between inner and outer compartments is d/D=1/2, then HES ratio of this seal is n=B/A=1/4=0.25.

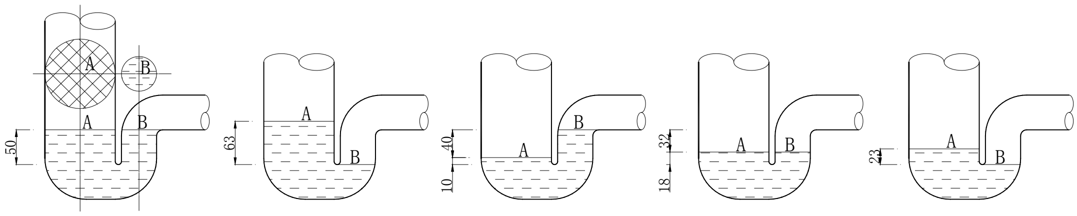

Figure 4

Figure 5 below represents a water seal (commonly known as S-Shaped Trap) that corresponds to Figure 2. Assuming the diameter ratio between inner and outer compartments is d/d=1/1, then HES ratio of this seal is n=B/A=1/1=1.

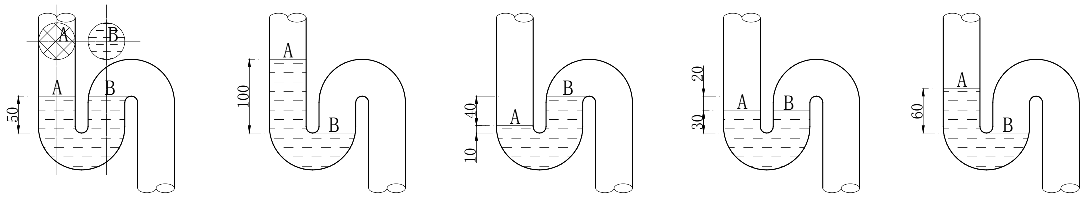

Figure 5

Figure 6 below represents a water seal (bottle type)that corresponds to Figure 3. Assuming the diameter ratio between inner and outer compartments is D/d=2.5/1[5], then HES ratio of this seal is n=B/A=(6.25-1) /1=5.25 ≈ 5.

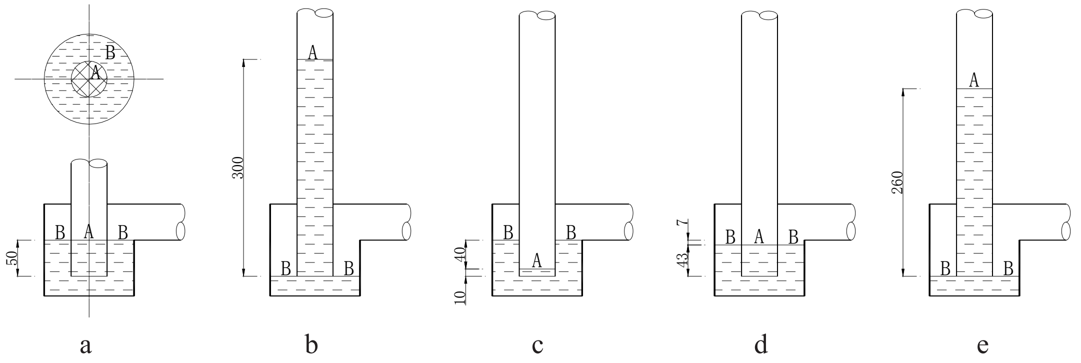

Figure 6

Comparing the performance of the above water seals at different status points, we observed that seals of various HES ratios show distinctive pressure characteristics under the same external condition.

Full water positive pressure withstand (status point b). Gradually apply positive pressure to inner compartment (outlet) of every water seal, till exceeding threshold of seal, as shown in point b of each figure. Measure maximum positive pressure P_{50qy} of water seal at full water condition:

Figure 4-b $P_{50qy}= (n+1) \times H= (0.25+1) \times 50=62.5 \approx 63$ (mmH_2O)
Figure 5-b $P_{50qy}= (n+1) \times H= (1+1) \times 50=100$ (mmH_2O)
Figure 6-b $P_{50qy}= (n+1) \times H= (5+1) \times 50=300$ (mmH_2O)

For the same water seal of standard depth 50mm, its capability to withstand positive pressure depends on its HES ratio n. Water seal with larger n value has greater capability to withstand positive pressure.

Negative suction (status point c). Apply-40 mmH_2O slowly to inner compartment of every water seal for 10s. Outer water level A is lowered by 40 mm, thus a volume of A × 40mm water is sucked into pipe and lost, and it is not influenced by value of n.

Water seal height loss (status point d).
After internal pressure is vanished, a volume of B × 40mm is refilled into both compartments of water seal till water level is even. Water level at this stage should differ from that when water was full, which is the "height loss" h_{40ss} after standard negative pressure suction.

Figure 4-d $h_{40ss}=40/(n+1) = 40/(0.25+1) = 40/1.25 = 32$ (mm)
Figure 5-d $h_{40ss} =40/(n+1) = 40/(1+1) = 40/2 = 20$ (mm)
Figure 6-d $h_{40ss} =40/(n+1) = 40/(5+1) = 40/6 = 6.7 \approx 7$ (mm)

Therefore, although the same suction is applied, amount of water loss from seal is A × 40 mm, which is not influenced by value of n. However this amount does impact on water seal, and it is dependent on HES ratio n: the larger n, the smaller "height loss".

Water seal residual depth (statue point d).
"Height Loss' of water seal occupied upper part of 50mm water seal. The remaining part is "Residual Depth" h_{40sy} after standard negative suction.

Figure 4-d $h_{40sy} =50-32=18$ (mm)

Figure 5-d h_{40sy} =50-20=30 (mm)
Figure 6-d h_{40sy} =50-7=43 (mm)

However this amount does impact on water seal, and it is dependent on HES ratio n: the larger n, the smaller “height loss”.

Positive pressure withstand of water seal “Residual Depth” (statue point e).
Gradually apply positive pressure to inner compartment of every water seal, till it exceeds threshold of seal, as shown in point e of each figure. Measure maximum positive pressure P_{40sy} of water seal after standard negative suction.

Figure 4-e $P_{40sy}= (n+1) \times 18 = (0.25+1) \times 18 \approx 23$ (mmH_2O)
Figure 5-e $P_{40sy}= (n+1) \times 30 = (1+1) \times 30 = 60$ (mmH_2O)
Figure 6-e $P_{40sy}= (n+1) \times 43.3 = (5+1) \times 43 = 260$ (mmH_2O)

Maximum tolerable positive pressure of “Residual Depth” of water seal after negative suction is dependent on HES ratio n, the larger n, the greater positive pressure tolerable by “Residual Depth”.

Table1 Summarized Data

Figure	Figure 1	Figure 2	Figure 3	Remarks
Full water depth mm	50	50	50	Standard depth
HES Ratio n	0.25	1	5	Ratio of water level: inner/outer compartments.
Full positive withstand mmH_2O	63	100	300	Varies with n
Suction pressure mmH_2O	-40	-40	-40	Same negative pressure
Height loss mm	32	20	7	Varies with n
Residual depth after suction mm	18	30	43	Varies with n
Residual depth after dynamic negative pressure mmH_2O	10	10	10	Safe under pressure
Residual positive pressure withstand mmH_2O	23	60	260	Varies with n
Note	Common for floor drain, bathroom drain and toilet	Common for S, U, P shaped traps	Common for bottle and simple traps	

3.4 Analysis and Summary

Based on the above data, we can summarize the following items:

3.4.1 At the same 50mm standard depth, subject to the same suction of -40 mmH_2O and resulting the same A×40mm water loss, it can be observed that “Height Loss” varies with n. Water seals with smaller n value will experience larger “Height Loss”, smaller “Residual Height” and thus are vulnerable to positive pressure. In some instances, they even fail under +40 mmH_2O. On the contrary, water seals with larger n value will result smaller “Height Loss”, larger “Residual Height” and be able to withstand greater positive pressure. Therefore, safety of water seal should not be determined by so called 50 mm “Standard Height” alone.

3.4.2 Regarding European/American standard “Seal Loss 25mm” (or “Residual Depth 25 mm”, and referring to previous figures (status point e), the positive pressure withstand value P_{sy25} for various HES ratios under 25mm residual depth are:

Figure 4-e P_{sy25}= (n+1)×25 = (0.25+1)×25 ≈ 37.5 (mmH_2O)
Figure 5-e P_{sy25}=(n+1)×25= (1+1)×25=50 (mmH_2O)
Figure 6-e P_{sy25}=(n+1)×25= (5+1)×25=150 (mmH_2O)

Under 25mm “Residual Depth”, some water seals are able to withstand +40 mmH_2O pressure whereas other seals with much smaller HES ratio fail to. This illustrates that, safety of water seal should not be determined by 25 mm “Residual Depth” alone. Hence it is deficient to determine maximum water drainage capacity of drainage riser by criteria “Height Loss 25 mm” or “Residual Depth 25 mm”.

Again refer to previous figures (status point e), we will examine the maximum positive pressure withstand value Psy20 for various HES ratios under 20mm residual depth as specified in Chinese standards[3][6]for floor drains are:

Figure 4-e P_{sy20}= (n+1) ×20 = (0.25+1) ×20 ≈ 25 (mmH_2O)
Figure 5-e P_{sy20}= (n+1)×20= (1+1) ×20=40 (mmH_2O)
Figure 6-e P_{sy20}= (n+1) ×20= (5+1) ×20=120 (mmH_2O)

For water seals with HES ratio greater than and equals to 1, A “Residual Depth” of 20mm is able to withstand +40 mmH_2O without positive break-through. Water seals with HES ratio below 1 cannot withstand +40 mmH_2O. Thus 20 mm “Residual Depth” cannot guarantee safety of water seal.

3.4.3 Fundamental expectation on water seal is such that external water can easily flow into pipe through it, and turbid air inside pipe must not escape water seal at any time.

A. With the same 50mm standard depth, after subject to -40 mmH_2O suction, residual depth of some water seals are able to withstand +40 mmH_2O pressure, some failed to withstand. And some water seals break through during suction yet they are still able to withstand +40 mmH_2O.

From March to May 2014, I conducted a drainage capacity test for “HES water seal of single riser no-top DN110 drainage system” at Wanke Tower, Dongguan, China. The system had a total of 34 levels, basically identical to other conventional single-riser drainage system, but depth of water seals was only 7.2mm and HES ratio ranged from 40 to 80. Both negative suction and positive pressure calibration were performed prior to testing the system, and many water seals observed break-through and massive air intake when riser drainage capacity reached 10 L/s, yet the “Residual Depth” of water seal and tested drainage system were able to pass positive pressure calibration above 150 mmH_2O. This is far beyond normal seals with 50 mm depth.

In November 2009, another drainage capacity test for "HES water seal of single riser no-top DN110 drainage system" was performed at Drainage Test Tower, Hunan University, China. The system had a total of 12 levels, basically identical to other conventional single-riser drainage system, and depth of water seals was 10mm and HES ratio was 20. Both negative suction and positive pressure calibration were performed prior to testing the system. When riser drainage capacity reached 10 L/s, the "Residual Depth" of water seal and tested drainage system were able to pass positive pressure calibration above 110 mmH_2O. This is also beyond normal seals with 50 mm depth.

In actual fact, safety of water seal does not rely on whether it is able to withstand -40 mmH_2O. Therefore definite and single result cannot be obtained when -40 mmH_2O is the sole "Assessment Criteria" for determining maximum drainage capacity of drainage system due to its major deficiency.

B. For water seal with 25 mm "Residual Depth", some can withstand +40 mmH_2O whereas others cannot. Thus it is inappropriate to determine maximum drainage capacity of drainage system by using 25 mm "Residual Depth" as "Assessment Criteria".

C. Safety of water seal cannot be precisely determined by -40 mmH_2O of "Internal fluctuation within ± 40 mmH_2O". Accordingly drainage capacity of riser measured at -40 mmH_2O is not valid. Similarly, safety cannot be determined by "Water Loss 25 mm" (or "Residual Depth 25 mm"), and the drainage capacity measured is not valid either.

3.4.4 It is also uncertain to determine safety of water seal and drainage system by using both “Withstanding -40 mmH_2O” and "Water Loss 25 mm" (or "Residual Depth 25 mm") together, and further derive maximum drainage of the riser of drainage system. This is because that even both criteria are satisfied, in addition to HES ratio of water seal $n \geq 0.6$, it is also required that seal depth should be at least 50 mm. Among global projects, there is vast number of drainage systems with HES ration $n < 0.6$. In addition to the floor drain illustrated in Figure 1, water seals of many toilets, urinals have very small HES ratio.

3.4.5 Objections are posed against clauses "Water seal depth no less than 50 mm" in standards [3-6] and "Residual Depth 20 mm" in Floor Drain [3][6].

3.4.6 Essentially, among Japanese and American/European criteria ± 40 mmH_2O and "Water loss 25 mm or (Residual Depth 25 mm)" respectively, only "Pipe pressure $\geq$ 40mmH_2O" condition is directly related and significant to determine maximum drainage capacity of drainage riser. For water seals, regardless of initial depth, water loss and residual depth, safety is ensured as long as they can withstand an internal pressure of least 40 mmH_2O.

New testing philosophy should be proposed to test on the maximum water drainage of building drainage system: after consecutive and alternative drainage of riser and horizontal branches, all water seals within the drainage system must be able to withstand an internal pressure of at least 40 mmH_2O.

The true principles that water seals should be able to withstand a pipe pressure of +40 mmH_2O at any time (free of foul air escape).

The author of this paper did an interesting test in the level 34 Wanke Test Tower:
Using "Pipe Pressure ± 40 mmH_2O" as criterion and the maximum drainage capacity of a normal PVC-U

single riser drainage system at level 33 was 2.0 L/s. One toilet was chosen among several types. After calibrating pressure characteristics and -40 mmH_2O suction, it was discovered that its maximum pressure withstand was merely 32 mmH_2O at "Residual depth". This pressure was corresponding to a drainage flow of only 1.6 L/s when matched to the capacity curve of drainage riser. This verified the fact that the drainage system was already crashed. This is because when riser flow exceeds 1.6 L/s, positive pressure resulted from draining will cause "Residual Depth" of some toilet water seals to suffer from " Positive Break-through". This typical "Cask Effect" of drainage system was evident enough to demonstrate that the so-called 2.0 L/s maximum drainage derived from "Pipe Pressure ±40 mmH_2O" criterion was inaccurate, vague and invalid.

4. Conclusion

4.1 Pressure characteristics of water seal can be used as “Assessment Criteria” to analyze and evaluate quality of water seals, and more importantly as “Assessment Basis” when evaluating maximum drainage capacity of building drainage system.

4.2 Prior to testing maximum drainage capacity of building drainage system, first perform -40 mmH_2O suction, followed by standard +40 mmH_2O calibration. The drainage system must pass this step before proceeding to next flow capacity test, otherwise the system can be deemed failure.

4.3 For drainage system passed negative suction, positive calibration and riser flow capacity test, positive pressure verification at 40 mmH_2O should be immediately performed to the entire system. If this pressure is successfully tolerated, testing data is valid. Otherwise reduce pressure and test again.

4.4 Neither “Pipe Pressure -40 mmH_2O” nor “Water Loss 25 mm” is able to ascertain safety of drainage system and water seals, thus cannot be used as “Assessment Criteria”.

4.5 Using “Pipe Pressure -40 mmH_2O” and “Water Loss 25 mm” together is also not valid to ascertain safety of drainage system and water seals.

4.6 Maximum drainage capacity of drainage system determined by so-called “Standard Water Seal” or “Special Type Water Seal” does not comply with complexity of real projects with respect to water seals within the drainage system, thus it is inadequate for project discussion.

5. Reference

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6. Presentation of Author:

He Chuanzheng, Senior Engineer, Registered Equipment Engineer, Commissioner of Building Water Supply and Drainage Committee ASC (Architectural Society of China), developed “HES Water Seal Theory” for building drainage,as well as a system of “HES Building Drainage Technologies” including:HES shallow water seal single riser no-top drainage system,HES high water seal building drainage technologies, HES low water seal building drainage technologies,and HES building override pipe & water-film penetration for drainage and ventilation technologies.

Factors and Analysis of Drainage Aapacity within Special Single Stack Drainage Systems

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Abstract

Flow method tests are done according to the "Residential drainage system vertical stack drainage capacity testing standards"; after confirmation of pipe diameter, and under heavy flow conditions, we changed the height of the vertical stack system, the strengthening parameters for the helical pipe, the helical noise reduction pipe dimensions and the deflecting noise reduction elbow parameters at the bottom; after these drainage capacity tests were conducted, we found new phenomenon. A summary of these phenomena gives us new laws to adhere to, and thus we are able to analyze the reasons for such behavior.

Keywords

Special single vertical stack; Drainage capacity; System height; Pipe dimensions; Inner pipe helical parameters; Bottom Most Elbow; Cause Analysis

As the system height increases in high-rise buildings with special single vertical stack drainage systems, the ability to decrease drainage capacity does not comply with existing attenuation coefficients. By adjusting the structure and parameters of the horizontal branch and vertical stack pipes, we obtain drastic changes in drainage capacity.However, water seal observation exhibits a relatively stable vacuum state.Adjusting the bottom most elbow parameters can effectively regulate the range of pressure changes. With the increasing capacity of the drainage system, the differences between positive and negative pressure values arenoticeably reduced.

1. Testing Method

The experiment took placeat theVanke Research Center for high-rise building system experiments. Figure 1 shows a piping system with dn110 hard PVC special single vertical stack. We used an enhanced noise reduction hydro-cyclone pipe for the horizontal branch pipes; enhanced internal helical pipe for the vertical stack; deflecting noise reduction elbow for the bottom part; dn160 optical walled tube for the discharge pipe. Height between building levels is 3m. Vertical stack is extended top ventilation. Water adding level is configured according to testing standards, starting with the 34th floor; horizontal branches on these levels have universal slope gradients; discharge pipe slopes toward the outside; and a transparent dn50 "S" curved water seal was installed at the pressure stress points.

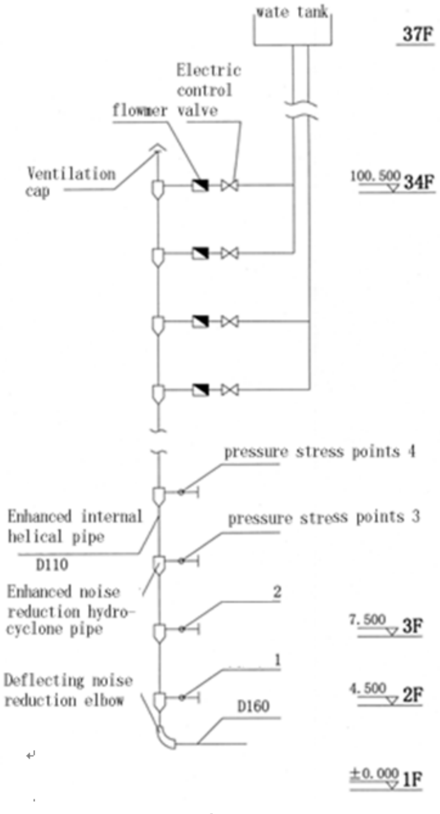

Figure 1 Test System Diagram

2. Drainage Capacity

(1) Ⅰ -type noise reduction hydro-cyclone pipe as in Figure 2; Ⅰ -type internal helical pipe(12 helical ribs, with a 1000 mm lead, helical ribs protrude 3mm at an equilateral triangle); Ⅰ -type deflecting noise reduction elbow as in Figure 3(with a curvature radius of 330). The system starts the experiment by adding water to the 34th floor; system flow rate is 4.0L/s. See Figure 4 for average pressure analysis.

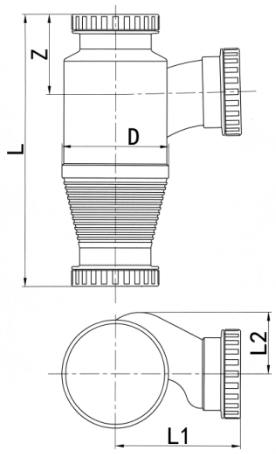

Figure 2 Ⅰ -type noise reduction hydro-cyclone pipe

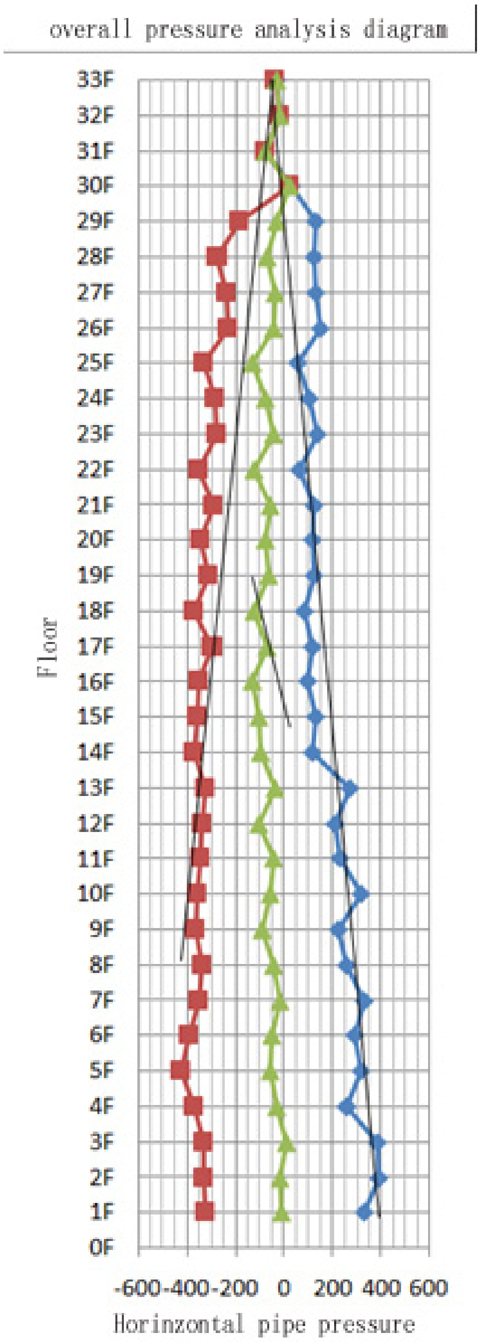

Figure 5 Pressure analysis diagram

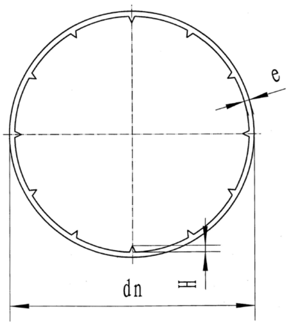

Figure 3 Ⅰ -type Enhanced internal helical pipe

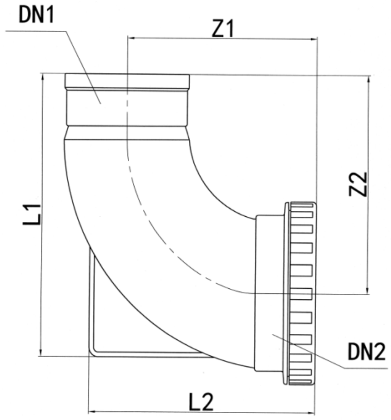

Figure 4 Ⅰ -type deflecting noise reduction elbow

（2） Ⅱ -type noise reduction hydro-cyclone pipe as in Figure 6; Ⅰ -type internal helical vertical pipe; Ⅰ -type deflecting noise reduction elbow. The system starts the experiment by adding water to the 34th floor; system flow rate is 6.2L/s. See Figure 7 for average pressure analysis.

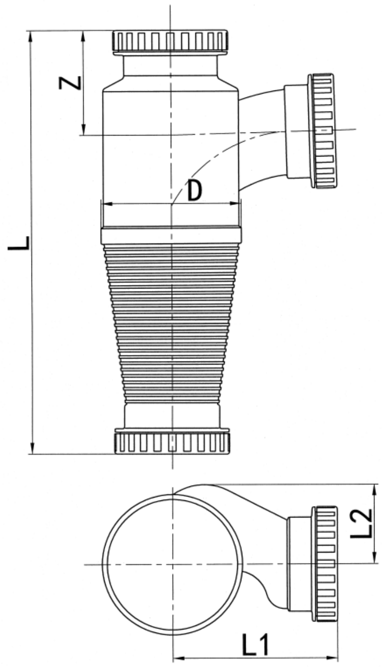

Figure 6 Ⅱ -type noise reduction hydro-cyclone pipe

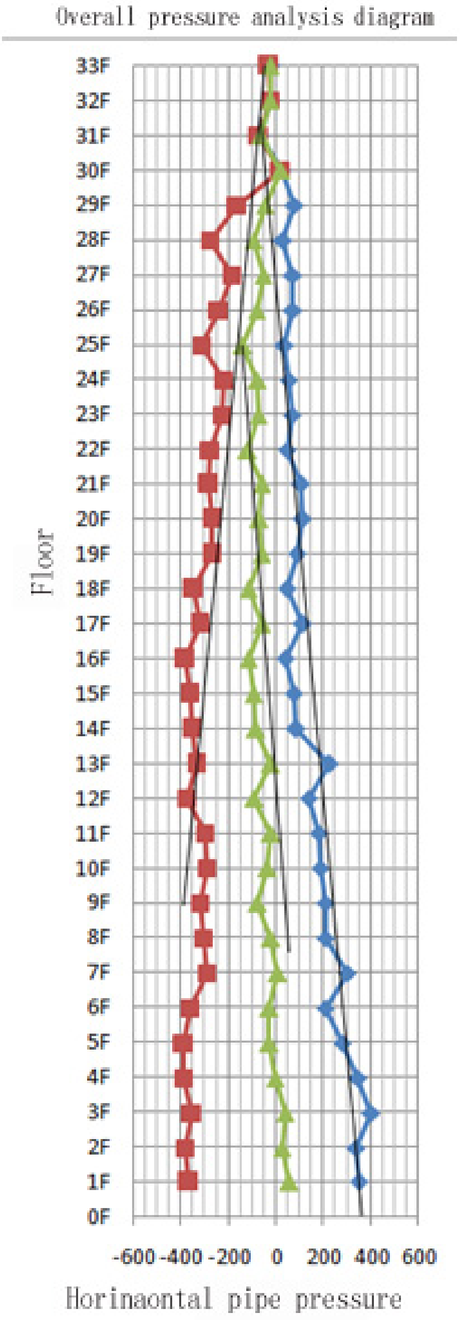

Figure 7 Pressure analysis diagram

(3) Ⅱ -type noise reduction hydro-cyclone pipe; Ⅱ -type internal helical pipe（12 helical ribs, with a 800 mm lead, helical ribs protrude 4mm at an equilateral triangle）; Ⅰ -type deflecting noise reduction elbow; The system starts the experiment by adding water to the 34th floor; system flow rate is 8.0L/s. See Figure 7 for average pressure analysis.

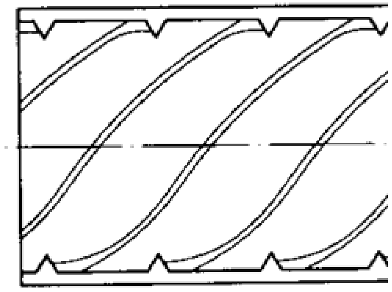

Figure 8 Ⅱ -type Enhanced internal helical pipe

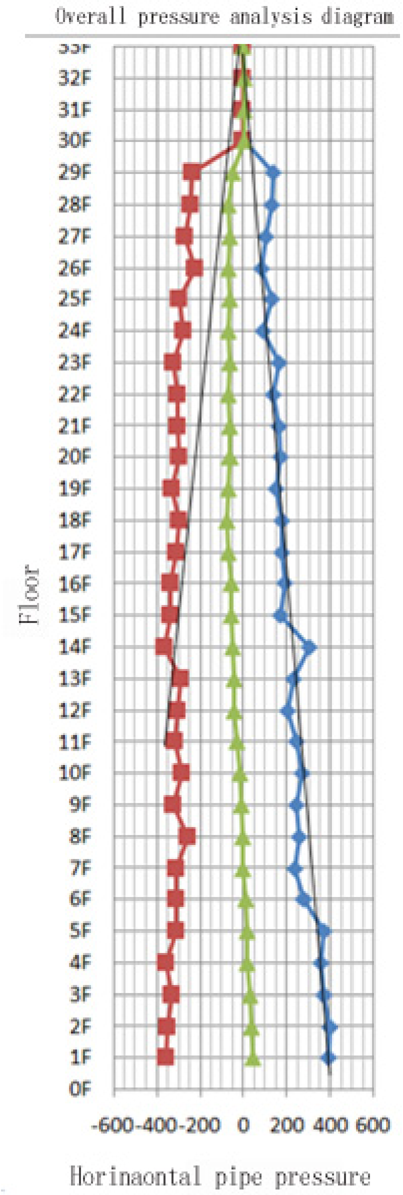

Figure 9 Pressure analysis diagram

(4) Ⅱ -type noise reduction hydro-cyclone pipe; Ⅱ -type internal helical pipe; Ⅱ -type deflecting noise reduction elbow as in Figure 8 (with a curvature radius of 260); The system starts the experiment by adding water to the 34th floor; system flow rate is 7.6L/s. See Figure 7 for similar average pressure analysis. Positive pressure exceeds 400MPa within the bottom three floors; negative pressure change is minor.

(5) From observing the transparent water seal since the experiment start time, it is apparent that the system seal remains in a vacuum suction state;at maximum drainage capacity, all water seal test points are in a negative pressure state, with maximum negative pressure values of the water column in the range of 23 to 25 mm.

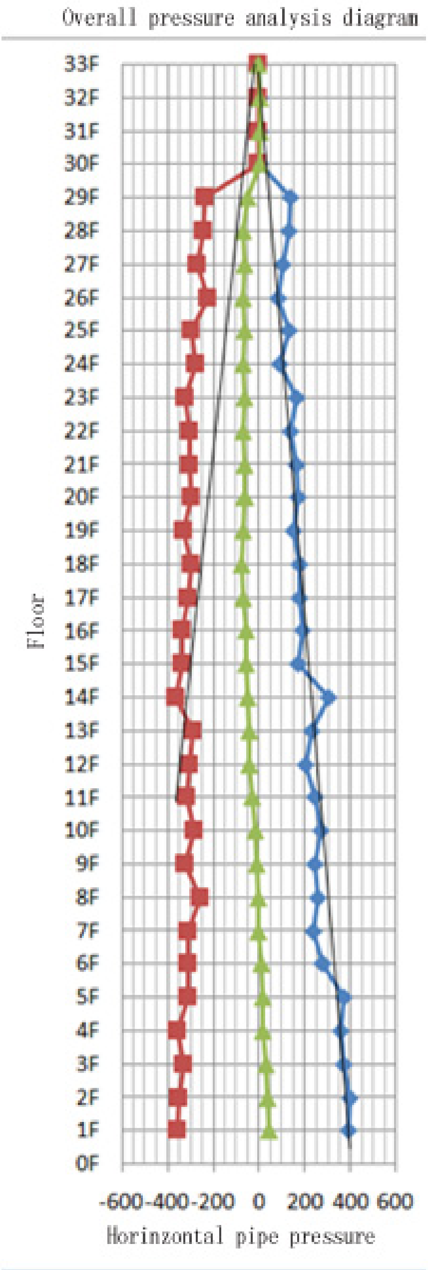

Figure 11 Pressure analysis diagram

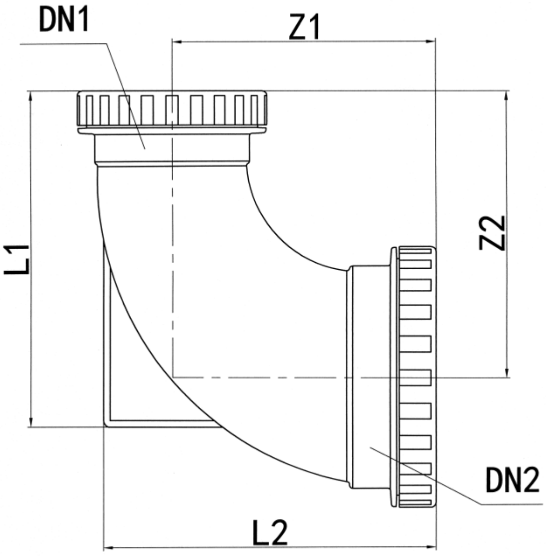

Figure 10 Ⅱ -type deflecting noise reduction elbow

3. Drainage capacity variations

(1)As the system height increase, so does the difference between positive and negative pressure values; and volatility increases along with the increasing gap between the positive and negative pressure difference.

(2)By changing the structure and size of the noise reduction hydro-cyclone pipe, the system’ s drainage capacity changes accordingly; but the trendremains that positive and negative pressure value volatility is still the largest at the places where the gap difference is greatest.

(3) By changing the parameters of the internal helical pipe, we obtain drainage capacity changes; however, the trend remains the same.
(4) While changing the parameters of the deflecting noise reduction elbow at the bottom, the changes to drainage capacity are minimal when the radius of curvature is 3 times or higher than the radius of the vertical stack; the changes mainly affect the gap between positive and negative pressure values of the 5th floor and down. When the radius of curvature is 2 times or higher than the radius of the vertical stack, there is a significant impact on the drainage capacity of the system.

4. Cause Analysis

（1）Air flow resistance within the pipe system increases as system height increases; the ability to usher in air into the system’ s extension stack decreases as system height increases. There is a proportional relationship between the length of the pipe and air flow resistance within the pipe.
（2）Air flow resistance within the pipe receives greater loss as air flow velocity increases; this also reduces the ability to usher in air into the pipe.
（3）Airflow velocity changes along with water flow velocity; the faster the water flows, the faster air flows; this increases air resistance loss, and is prone to turbulence, which further increases air resistance loss.
(4) Flow velocity fluctuates under the changes to the internal structures of horizontal branch pipe and vertical stack; air flow also changes under water flow fluctuations within specific velocity ranges.Changes in the system’ s pressure gap are due to both volume changes and air velocity fluctuations.
（5）As water flows downward, the frequency of water membrane resistance formations increases as flow and system height increase; this leads to increased loss of air resistance and instability.

By adjusting the structures and size of the enhanced noise reduction hydro-cyclone pipe, the enhanced internal helical pipe and the deflecting noise reduction elbow at the bottom; we form a proportional coordination between the 3. The smaller the water jets formed by controlling water flow velocities of the horizontal branch pipes, the larger the volume of water flow that remains rotating on the pipe walls; this maintains fluctuation within a specified range of water flow. By reducing turbulence and the increase of water membrane resistance formation it causes, we effectively reduce the loss of air resistance caused by excessively fast water flow; at the same time, we maintain a decrease in membrane resistance caused by the water plug and membrane thickness. Adequate membrane resistance is lost and we maintain a specific range of velocity fluctuations when air is suctioned in through the extension stack and discharged via the horizontal dry pipes. Drainage capacity is increased, while air pressure within the pipeline is decreased and kept stable.

Experiment Study on Drainage Capacity of Specific Vent Stack System by Using Instantaneous Flow

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Abstract

This experiment uses instantaneous flow generator drain away water on 34-floor tower. Investigate the different drainage pressure in each specific vent stack system, explore the relationship between the pressure and flow rate, and confirm the corresponding drainage capacity. The results show that: when using instantaneous flow，the maximum positive and negative pressure occurs in the intermediate floor of specific vent stack system. Compared with the maximum standard capacity value of building water supply and drainage design specifications (GB50015-2009), it is found that when the joining pipe setting with the same mode, the drainage capacity of instantaneous flow testing (joining pipe is connected in each floor) is DN110mm × DN110mm> DN125mm × DN110mm> DN110mm × DN75mm, when joining pipe is connected in each two floors，the drainage capacity of instantaneous flow testing is DN110mm × DN110mm> DN110mm × DN75mm> DN125mm × DN110mm.

Keywords

Specific Vent Stack System; Instantaneous Flow; Drainage Capacity

The specific vent stack system is composed of a drainage stack and a vent stack. The vent stack connects the drainage pipe with the conjugation pipe. It' s better to set vent stack for the sewage pipe which in multistory buildings, public buildings and more than ten and ten floors high buildings[1]. In order to further study the drainage capacity of each specific vent stack system, the research group made a series of systematic research on three kinds of specific vent stack systems which commonly used in engineering. In order to provide references for engineering application.

1. Test Method

1.1 Test stack system

This experiment carries out in the research and development base of high rise building device system in equal proportion, China National Engineering Research Center for Human Settlements –Vanke building Research Centre. The drainage systems all use PVC-U specific vent stack system，the horizontal pipe of each floor is DN110mm PVC–U pipe. The drainage stack connects the horizontal pipe with 90° three link. Table 1 shows the settings of pipes for specific vent stack system.

Tab.1 Settings of pipes for specific vent stack system

System number	Specific vent stack system category /mm	Conjugation piping layout	Drainage stack/mm	Vent stack/mm	Discharge pipe /mm
1#	DN110×DN75	Connected in each two floors	DN110	DN75	DN110
2#	DN110×DN75	Connected in each floor	DN110	DN75	DN110
3#	DN110×DN110	Connected in each two floors	DN110	DN110	DN110
4#	DN110×DN110	Connected in each floor	DN110	DN110	DN110
5#	DN125×DN110	Connected in each two floors	DN125	DN110	DN125
6#	DN125×DN110	Connected in each floor	DN125	DN110	DN125

1.2 Test installation and instrument

U.S. GE DruckPTX610 (±10 KPa, PTX) Bi-type pressure sensor is installed on the horizontal pipe of each floor in addition to the drainage floor. It' s set at a distance of 500 mm to the center of the drainage vertical pipe. Its measurement range is ±10000 Pa, its measurement accuracy is ±0.08% and the acquisition cycle is 20 ms. Collecting data and transferring to the server to detect pressure fluctuation. The one or two instantaneous flow generators installed on every drainage floor from top to bottom discharge water in the test. Figure 1 shows the test system of instantaneous flow drainage system.

The instantaneous flow generator simulates the common siphon toilet to discharge water. Each time of discharge is 6 L, the peak of drainage flow is 1.8L/s. Discharging water by electronically controlled pressing. GE Druck RTX1930 input type level gauge is set in the instantaneous flow generator, the measurement range is 0~50kPa（0~5 mH_2O）, the measurement accuracy is ±0.06%. Using measuring cylinder to measure the instantaneous flow convergence displacement. The diameter of measuring cylinder is 0.72m. The test equipment is composed of rectifier disc, pressure sensors, input type level gauge, etc [2].

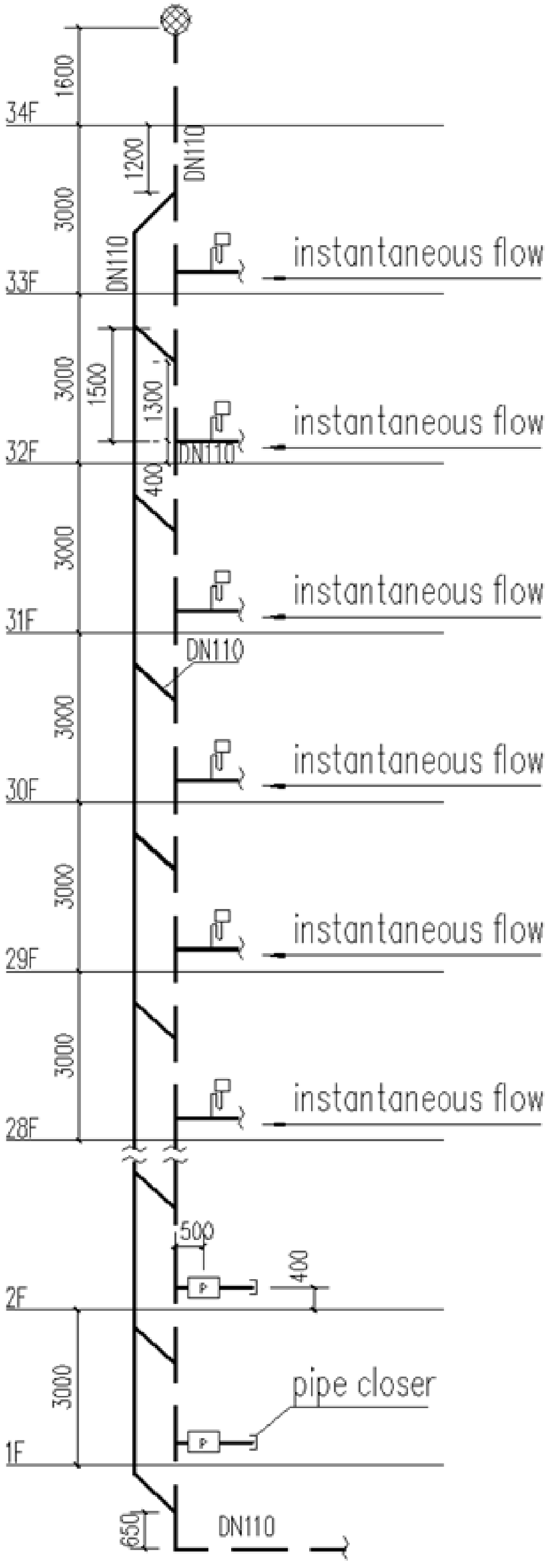


Fig.1 Test system of instantaneous flow drainage system

（DN110mm × DN110mm，Connected in each floor）

1.3 Test procedures and decision condition

Figure 2 shows the test procedures.

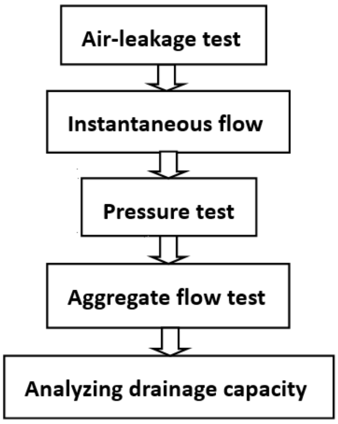


Fig.2 Experimental procedure

The maximum positive and negative pressure automatically measured by pressure sensor is the maximum positive and negative pressure of this floor. As show in figure 3 (DN125mm×DN110mm, Connected in each floor; 6 instantaneous flow generators drain water). According to the national industry standard “Test standard for capacity of vertical pipe of the domestic residential drainage system” (the examination and approval of draft). The determination conditions for this test is: the maximum pressure of drainage system should not be larger than +300Pa when using instantaneous flow, the maximum negative pressure should not be less than -300Pa. The drainage flow is the drainage capacity of the system when the maximum pressure achieving the maximum decision value.

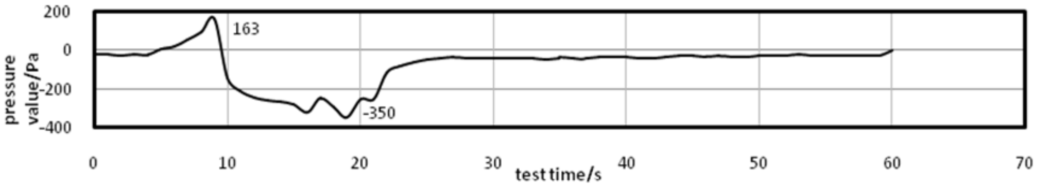


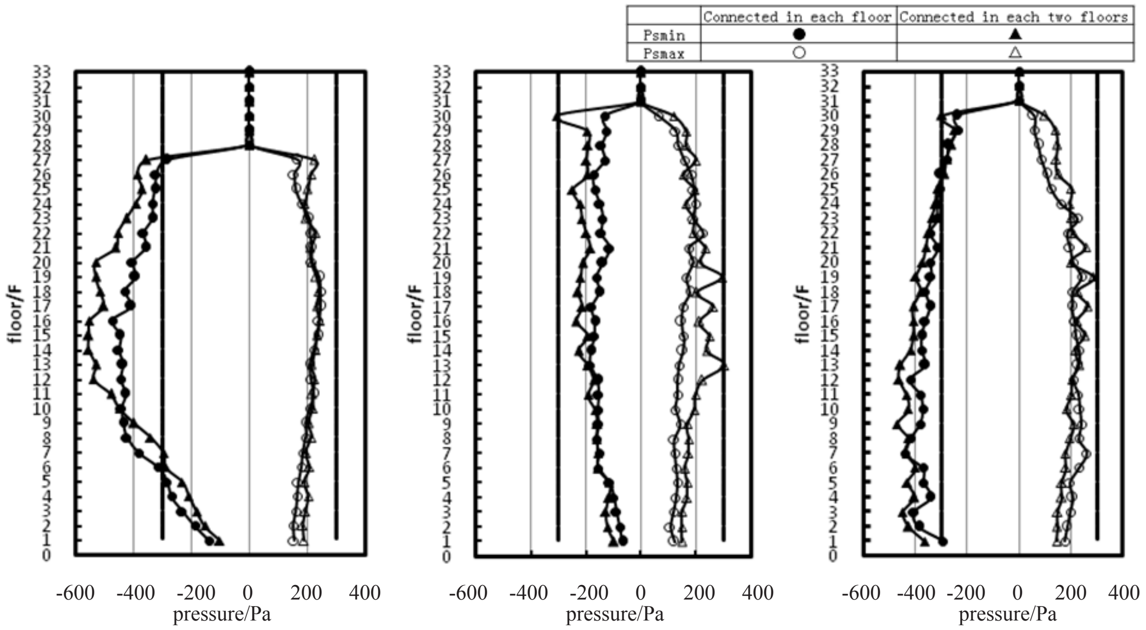
Fig.3 Pressure distribution of horizontal branch pipe of 29th floors

2. Test Result

2.1 Pressure test for specific vent stack drainage system

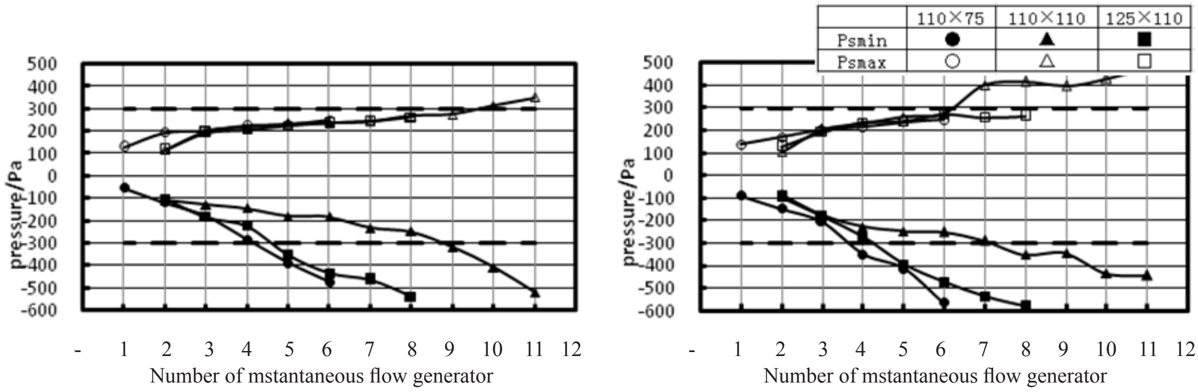
Measured pressure of each specific vent stack drainage system by using instantaneous flow. The pressure value of each system by using 6 instantaneous flow generators is shown in figure 4. It can be seen that the maximum positive and negative pressure occurs in the intermediate floor of specific vent stack system. When the same number of instantaneous flow generator discharge, the negative pressure of intermediate floors is DN110mm × DN75mm> DN125mm × DN110mm> DN110mm × DN110mm, the positive pressure is DN110mm × DN110mm> DN125mm × DN110mm> DN110mm × DN75mm. The maximum positive and negative pressure of intermediate floors for conjugation pipes connected in each two floors is larger than which for conjugation pipes connected in each floor.

The maximum positive pressure and negative pressure within each drainage system increase with the increase of the number of instantaneous flow generators. The positive and negative pressure distribution of each specific vent stack system when instantaneous flow generators drain with different numbers is shown in figure 5. When the same number of instantaneous flow generator discharge, the positive pressure is DN110mm × DN110mm> DN125mm×DN110mm> DN110mm × DN75mm, the negative pressure is DN110mm × DN75mm> DN125mm × DN110mm> DN110mm × DN110mm. Regardless of individual pressure situation, The maximum positive and negative pressure for conjugation pipes connected in each two floors is larger than which for conjugation pipes connected in each floor when the pipe’s diameter is same.



a. DN110mm×DN75mm b.DN110mm×DN110mmc.DN125mm×DN110mm↵

Fig.4 Positive and negative pressure distribution of each specific vent stack system when six instantly stream generators drain



a.Connected in each floorb.Connected in each two floors↵

Fig.5 Positive and negative pressure distribution of each specific vent stack system when instantaneous flow generators drain with different numbers

The situation of the maximum pressure achieving the maximum decision value first for each drainage system is shown in table 2.

Tab.2 The situation of first to achieve maximum determining pressure value for each system

Drainage system	Positive pressure	Negative pressure
DN110mm×DN75mm，Connected in each floor		√
DN110mm×DN75mm，Connected in each two floors		√
DN110mm×DN110mm，Connected in each floor	√	
DN110mm×DN110mm，Connected in each two floors	√	
DN125mm×DN110mm，Connected in each floor		√
DN125mm×DN110mm，Connected in each two floors		√
Note：√ means the pressure of the system to achieve the maximum pressure decision value.		

2.2 Drainage capacity analysis of specific vent stack drainage system

When the maximum pressure value is within ±50Pa of decision value, the measured flow value is the drainage capacity of the system. All the drainage capacity of each specific vent stack system in this test are measured values.

Compared with the maximum design flow capacity value of building water supply and drainage design specifications (GB50015-2009) table 4.4.11, it is found from Figure 6 that the drainage capacity of specific vent stack system by using instantaneous flow is similar to the standard value. The drainage capacity (joining pipe is connected in each floor) is DN110mm × DN110mm> DN125mm × DN110mm> DN110mm × DN75mm, when connected in each two floors，the drainage capacity is DN110mm × DN110mm> DN110mm × DN75mm> DN125mm × DN110mm. The drainage capacity of joining pipe connected in each floor is larger than which connected in each two floors for the same drainage system, but is less than the corresponding standard value. The drainage capacity of joining pipe connected in each two floors is little larger than the corresponding standard value.

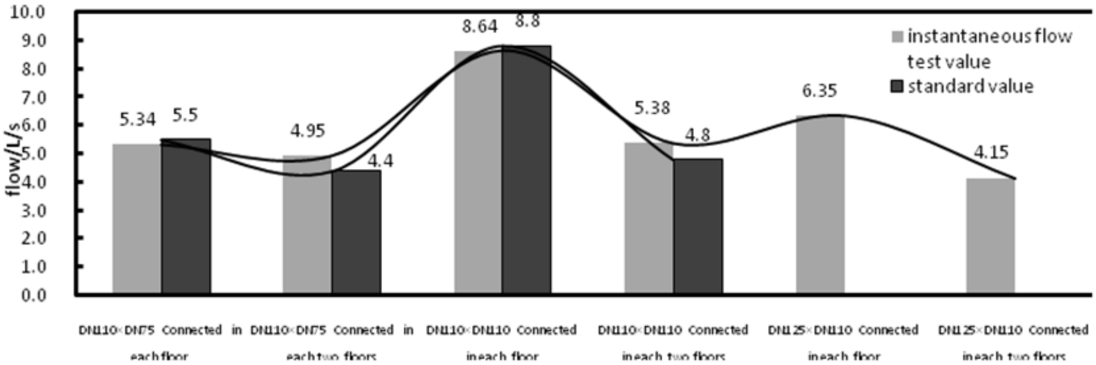


Fig.6 Tendency of drainage capacity for specific vent stack system

3. Conclusion

When using instantaneous flow，the maximum positive and negative pressure occurs in the intermediate floor of specific vent stack system. Compared with the maximum design flow capacity value of building water supply and drainage design specifications (GB50015-2009), it is found that when the joining pipe setting with the same mode, the drainage capacity of instantaneous flow testing (joining pipe is connected in each floor) is DN110mm × DN110mm> DN125mm × DN110mm> DN110mm × DN75mm, when connected in each two floors，the drainage capacity of instantaneous flow testing is DN110mm × DN110mm> DN110mm × DN75mm> DN125mm × DN110mm.

4. References

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5. Presentation of Authors

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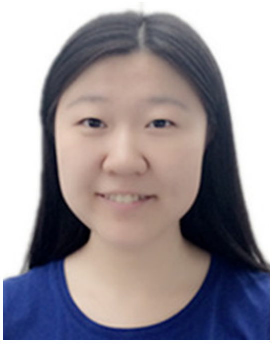

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Masayuki Otsuka is the Professor at Department of Architecture and Environmental Design, Kanto Gakuin University. He is a member of AIJ and SHASE.His current research interests are the performance of plumbing systems, drainage system design with drainage piping system for SI housing, development of building energy simulation tool and the performance evaluation of water saving plumbing systems.

Public Restroom in a Tourist Area in Case of Kawagoe, Japan

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Abstract

Because man is an animal, the excretion is indispensable. It's indispensable to reserve the excretory place regard of a place with time as public service. When it can't be achieved, we will also have the restrictions of movement. Senior citizens, children and people with disabilities also need public restroom making all people can use without discrimination and the basic request of safety and cleanness is also necessary.

Kawagoe that is selected as a target area of a study is the city where few historical streets are left at the metropolitan area more than 6,000,000 tourists visit in the year, and a foreigner tourist visits a lot, too. Summer Olympics of golf is performed in the city in 2020, domestic and abroad, more tourists will come to visit.

There are various problems to make sure that the tourist can use a restroom surely, and many opinions are heard about the number of sanitary fixtures, the location and equipment.

So the number of facilities in a city and leading sign the current state of the public restroom in a tourist spot by this research, and field research is performed from the number of sanitary fixtures and the equipment in each facility. It's also investigated about a practicable restroom at private facilities such as a convenience store. I do the exercise for grasp of a problem and a solution of a problem clearly by hearing to an administrator and the user.

Keywords

public restroom, sanitary fixture, tourist area, field work, interview

1. Introduction

When present-day man lives, the existence in the restroom is necessary, and it's necessary to carry on a cultural life also maintain a hygienic city healthily. It's use in the restroom when going out, to become a big problem. It's very important to be a number appropriate to the place where the restroom that can be used certainly is appropriate in the situation that I have to use a public restroom. When this doesn't exist, the restrictions occur to movement.

When commuting, a restroom exists in the station, a public building and in a commutation location. They're also able to avoid trouble from happening for the most part because it's possible to arrive in the destination getting accustomed to these basically, and without wavering, and the congestion degree and the sanitary conditions can be grasped in the living pattern.

It's difficult that a restroom in a strange place looks for its location, and even if I arrive, congestion is intense, and the sanitary conditions are bad, and use is often difficult.

So I have for my object to get basic material about maintenance in the restroom in future's tourist spot by investigating about the situation of the maintenance and the use in the restroom in a tourist spot by this study.

2. Methodology

2.1 Kawagoe City

Kawagoe City, Saitama Prefecture is taken up as a target of a study. Kawagoe is the city of 350,000 people of population where it's from Tokyo in about 30 km of distance. Kawagoe City which are my address and a commutation place was a castle town, and streets of the building a warehouse which are Japanese traditional streets taking the Kawagoe conflagration in 1893 as a start were formed. Many merchant houses are also built after that, and historical streets are left at each place even at enough present for about 120 years (Figure-2). A tourist of about 7,000,000 people a year is recognized as a tourist spot before an about quarter of a century, and visits Kawagoe and increases a foreigner tourist, too (Figure-3).

Figure-1 The location of Kawagoe City [1)]

The Bell of Time **Kawagoe Ichibangai Street**

Figure-2 Historical streets in Kawagoe

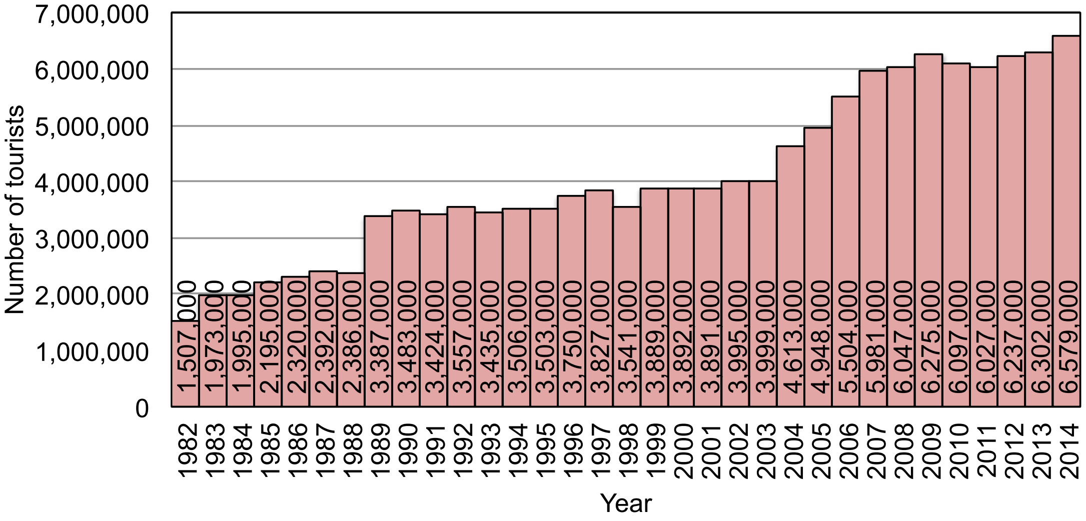

Figure-3 The Number of Kawagoe's tourist

2.2 Investigation

The sightseeing department of Kawagoe City office is maintaining 11 public restrooms for tourists in Kawagoe City centre. An implementation investigation was performed focusing on May 2 and the situation was grasped about these equipment, use conditions and sanitary conditions. It was also checked about the installation situation of the guide map and the sign and linguistic transcription. The arrangement in the restroom on the map and the situation of the emporium and the public facilities that a restroom can be used freely were confirmed by doing a plot. An installation time, the installation area, the number of fixtures, an equipment and future's introduction in the restroom you offer material to the sightseeing department of Kawagoe City office, and which is managed, expected, I made it clear by offered data and interview.

3. Results

3.1 Public restroom managed by the sightseeing department of Kawagoe City

The outline of the public restroom in the Kawagoe City center, managed by the sightseeing department of Kawagoe City office is indicated in table-1. The great difference is equipped with an installation time (Figure-4), the area, other multipurpose restrooms and equipment (Figure-5) and Japanese style toilet or Western style toilet (Figure-6,7), in the specification. Influence by an installation time is big for this reason.

A Japanese-style toilet has been used originally in Japan, but only a Western-style toilet is installed in recent years. The reason that consideration to a senior citizen and the child who has not used a Japanese-style toilet, consideration to a foreigner are various can consider this.

The case that the person who doesn't like touching a toilet seat by an aspect of good hygiene decreases also seems to be a factor. There isn't soap in a wash hand basin about the restroom managed by the sightseeing department (Figure-8). Repair is scheduled during this fiscal year about a restroom of No.7. It's said that the restroom with the high use frequency as well as an installation time are made the repair target.

Table-1 The outline of the public restroom in the Kawagoe City center, managed by sightseeing department of Kawagoe City office (2)

		Number of Fixtures							Equipment of Multi Purpose						
		Male			Female										
No.	Name	Japanese style	Western style	Urinal	Japanese style	Western style	Multi Purpose	Warm water cleansing	Baby bed	Large Bed	Ostomy Toilet	Braille toilet signs	Floor Area (m^2)	Installation year	Open hour
7	Renkeiji Temple	1		4	2	1			/	/	/	/	19.98	1976	24hr
8	Motomachi (Takazawabashi Bridge)	1		3	3				/	/	/	/	17.62	1982	24hr
1	Otemachi	1	1	4	3	1	1			1			64.91	1990	24hr
5	Saiwaicho		1	2	1	1	1			1			18.39	1994	24hr
2	Matsuecho Pocket Park	1		1	1		1			1			13.25	1995	24hr
10	Kawagoe Festival Museum Parking	1	1	4	2	2	1			1			50.35	2003	24hr
3	Naritasan Betsuin Temple		2	3		4	1	1		1			48.03	2008	From April to October: 8:00-18:00 From November to March; 8:00-17:00
9	Kawagoe City Hall North		2	4		6	1			1			46.37	2009	From April to October:8:00-18:00 From November to March; 8:00-17:00
6	Renjakucho Crossing		1	2		2	1		1		1	1	47.47	2014	24hr
4	Kitain Temple		2	4		6	1	1	1		1		51.1	2015	Multi Purpose: 9:00-16:00
A	Motomachi Resting Space		1	2		2	1	1	1		1		69.56	2015	From April to October:9:30-18:30 From November to March; 9:30-17:30
	Total	5	11	33	12	25	9	3	3	6	3	1			

No.6 No.A

Figure-4 External appearance of restroom

Multipurpose toilet (No.6)

Handrail for handicapped person (felt: No.A, right: Kawagoe station west)

Pictogram of toilet (No.10) Floor map (No.6)

Figure-5 Multipurpose restrooms and toilet equipment

No.1 (left) No.7 (right)

Figure-6 Japanese style toilet

No.5 old style No.A modern style

Figure-7 Western style toilet

Commercial building Sightseeing Department managed

Figure-8 Wash hand basin

3.2 Location of restrooms

Figure-9 shows a location of each restroom in Kawagoe City center. The location of the restroom managed by the sightseeing department of Kawagoe City is green circle, and other public facilities are red circle, and the commercial facilities is blue circle, and a convenience store is the light-blue circle. Each center of circle is the location of restroom.

A circle is radius 160m. When there is a road in a pin grid array format, it'll be about 224 m at which you can arrive within 3 minutes. The restroom managed by the sightseeing department of Kawagoe City is arranged in an interval roughly 3 minutes on foot.

A restroom is concentrating around the station, but time which can be used is limited to public and commercial facilities.

A restroom is installed in a convenience store in Japan, and the store side also tends to recommend use. And there are no chip systems and pay restrooms in Kawagoe.

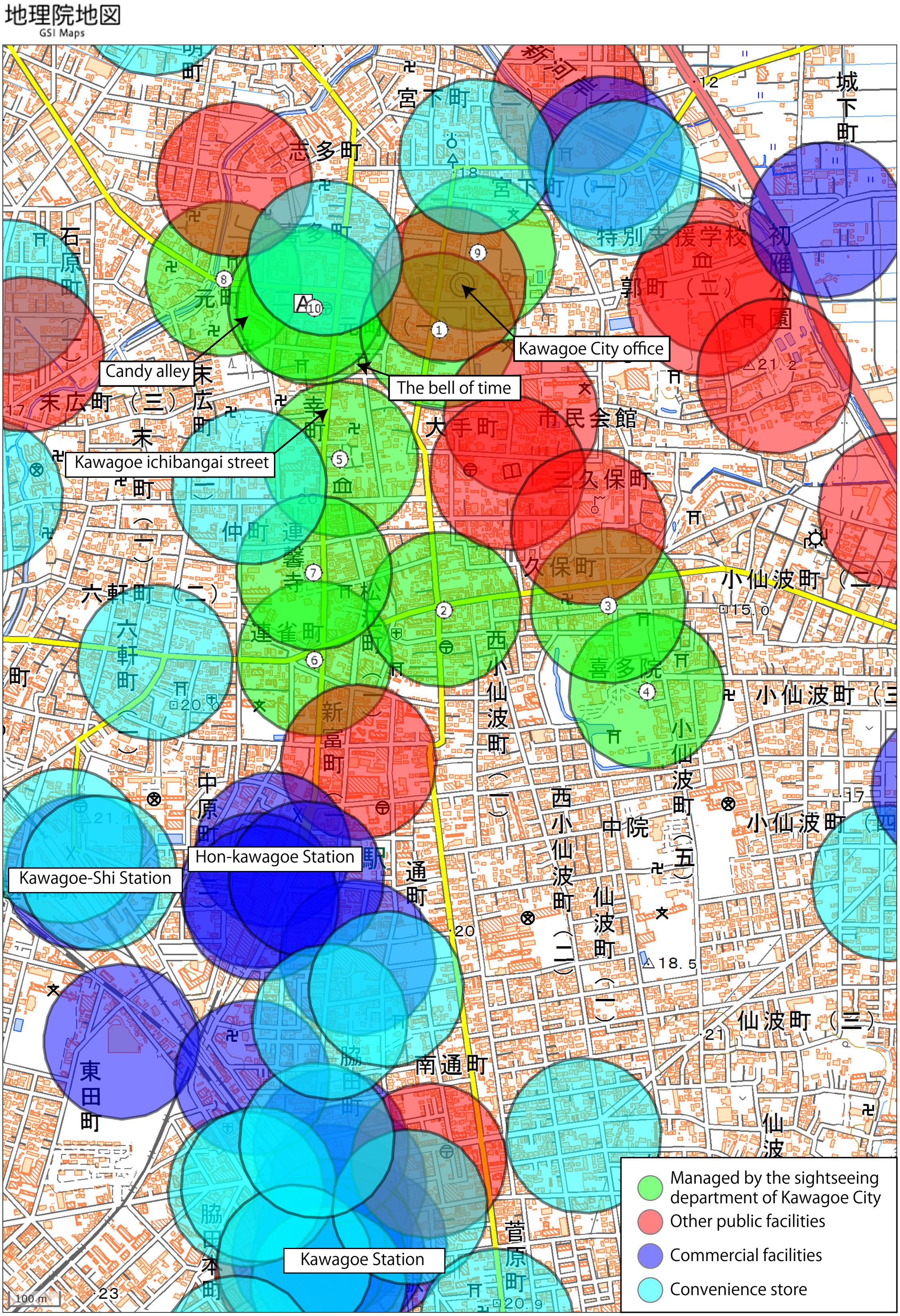

Figure-9 Location of each restroom in Kawagoe City center (3)

3.3 State of the waiting line by field research

There are a lot of people who ask the location of the restroom in front of the station according to hearing to the Kawagoe City tourist information. The location of the restroom is incomprehensible by a sightseeing guide map and a sign board (Figure-10). When a sightseeing bus arrives, it's heard that a waiting line forms in the female restroom. Field research was performed about a public restroom of No.A and a restroom in Kawagoe and Hon-Kawagoe station of commercial facilities to confirm its situation and sanitary conditions.

As a result, the waiting line was confirmed in the female restroom in each facilities (Figure-11). A restroom in a commercial establishment tends to have a high rate of utilization in past study (4), so it's guessed at that arrival rate is expensive. There are a lot of tourists and I'm going to visit around the No.A (right of Figure-4). There is a possibility used selectively because an installation time is new in this restroom.

Figure-10 Sightseeing map (left) and signature (right)

Figure-11 Waiting line in front of the female restroom (Hon-Kawagoe Station building)

4. Discussion

The function and the performance necessary to a public restroom are changing by a time, and installation equipment in the multipurpose restroom is also increasing. The area necessary to a restroom is also increasing with this.

In Japan, a Western style toilet tends to be permitted gradually, and the restroom established in recent years is only Western style already.

Public and commercial facilities as well as a public restroom complement it, and a restroom in the city of center is formed. But these are enough for an installation point to a visitor and the number of fixture but aren't because there are also restrictions in the business hours and the place is also difficult to know.

Grasp of specification of place and the location is difficult by information on a restroom in a guide map and a sign board. There is little transcription by a language, so a pictogram will be often the only information.

5. Conclusions

I made it clear by doing a literature search and field research about the current state and a problem of the public restroom in Kawagoe City center. An investigation and analysis will be also advanced from the user's behavior and degree of satisfaction from now on, and would like to advance a study in order to propose the state of the public restroom in a city.

6. References

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Influence of Type of Discharge Load on Pressure Vibration in Pipes and Seal Water Vibration

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Abstract

In Japan, SHASE-S 218 (Heating, Air-Conditioning, and Sanitary Standard) stipulates the method for evaluating the performance of drainage system. The standard exclusively makes use of steady discharge load, and two test criteria have been laid out: one that allowable pressure in pipe should be ±400Pa, and the other that allowable seal loss within 25 mm. However, discharge made from actual drainage system such as WC is mainly fixture discharge load, and as a result of recent development in water-saving fixtures, average discharge flow rate and time began to vary greatly depending on the type of fixture. Therefore, the existing method based on steady discharge load is far from being practical although it provides evaluation of systems on the safe side.

In view of this, we carried out an experiment with a real-scale drainage tower to clarify the effects that steady discharge load and fixture discharge load exerted on pneumatic pressure vibration and seal water vibration.

As a result, pressure vibration waveforms and power spectrum distributions have been found to vary depending on the type of discharge load.

Keywords

Drainage system, trap, induced siphonage, vibration reply phenomena

1. Introduction

SHASE-S 218 (Heating, Air-Conditioning, and Sanitary Standard) stipulates the method for evaluating drainage system with special fittings. Steady discharge is mainly used as test load, and the test criteria are based on two conditions: one that allowable pressure in pipe should fall within ± 400Pa, and the other that allowable seal loss should be less than 25 mm. However, in real life conditions, discharge from drainage system such as WC is exclusively fixture discharge load. Though a number of studies have been conducted on steady discharge and fixture discharge and their effects on and relationship with pressure in drain and seal fluctuation, the results of those studies may not be applicable to all situations as more and more advanced water-saving fixtures with varied drainage capacities and discharge time have been developed. In addition, SHASE-S 218 does not specify criteria for selection of fixture discharge that is exclusively used in the performance test as part of a completion inspection.

In view of this, we conducted discharge experiments in a real-scale drainage tower and analyzed pressure vibration in pipe data to clarify the correlation between conventional steady discharge load and fixture discharge load from water-saving WC.

2. Outline of Experiment

2.1 Experimental drainage system

The outline of the experimental drainage system is shown in Figure 1. The system consists of a 15-floor equivalent drainage system with special fittings, which makes possible steady discharge flow rates of 1.5 L/s, 3.0 L/s, and 4.5 L/s based on SHASE-S 218. We collected data of pressure vibration in pipe and seal water fluctuations when fixture discharge load equivalent of one, two or three 6L WCs were applied. We also examined the effects of filth discharge on pressure in drain by measuring pressures when substitute filth was discharged form test WCs.

2.2 Conditions of measurement

Based on SHASE-S 218, discharge load was applied from the top floor and pressure fluctuation data in horizontal drainage branches (at the top of the pipe 500 mm from the center of stack pipe) on each floor were collected. Measurements were made with sampling intervals of 20 msec. (50 Hz) for one minute after discharge rate became steady for steady discharge, and 40 seconds (discharge starting 5 seconds after the beginning of measurement) for fixture discharge. No low-pass filters were used. Measurements were made 5 times under each condition. Substitute filth was discharged from a WC located on the 15th floor.

2.3 Test WC and Test Trap

Cross-sectional views of a test WC and a test trap are shown in Figure 2, and parameters in Table 1. The same types of 6 L WCs were used as a test WC in fixture discharge and in steady discharge. The trap was installed on the 8th floor, and a WC on the 9th floor, both filled with water. The setup of a WC and a trap is shown in Figure 3.

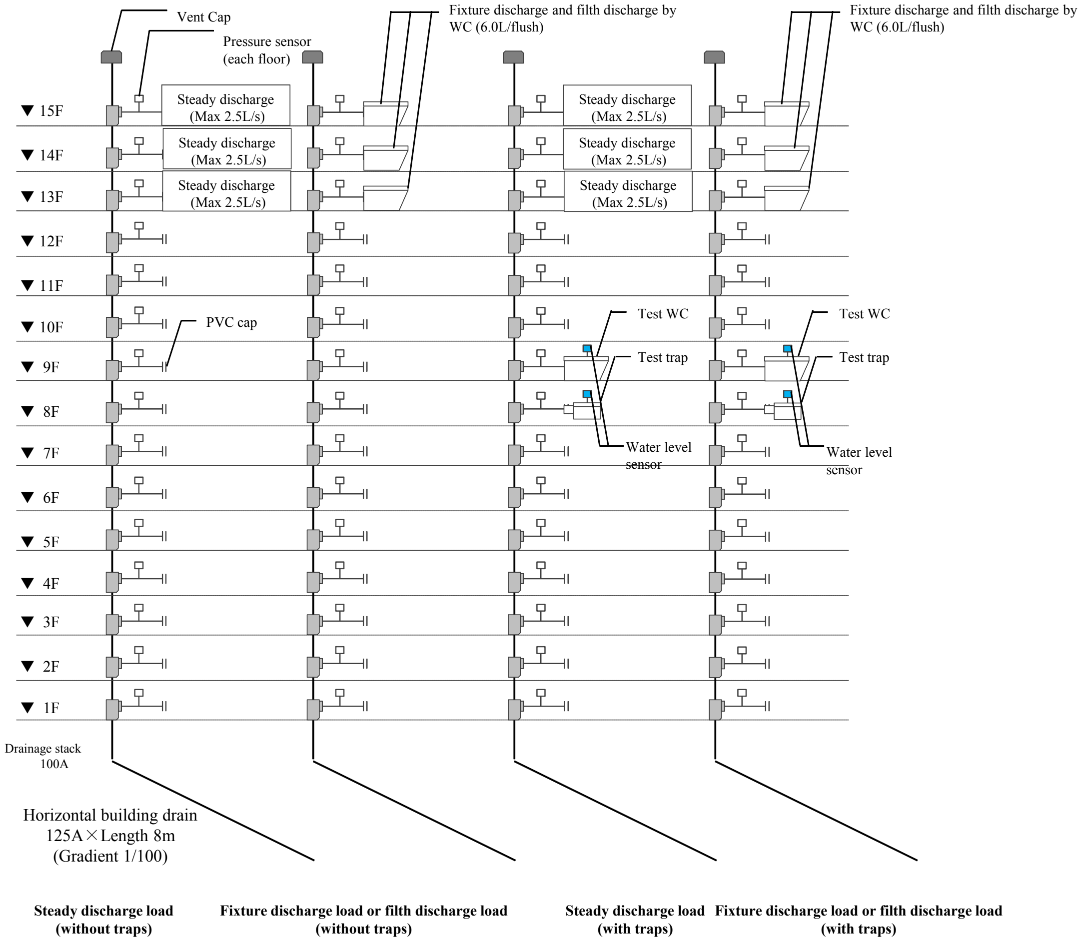
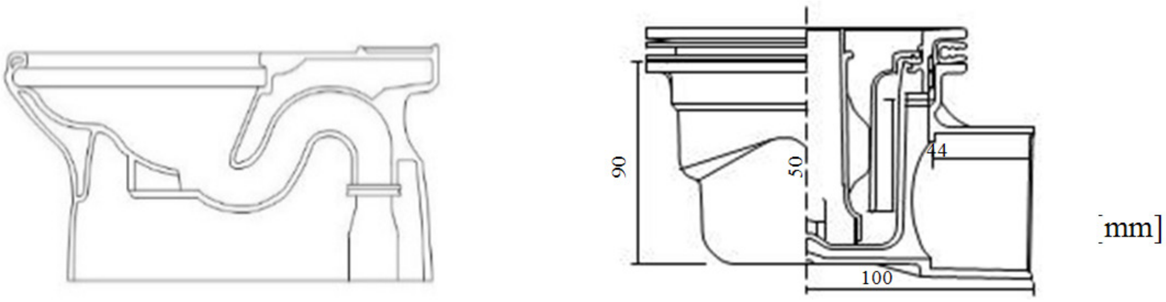


Figure1 Outline of the real-scale drainage tower



WC

Contrary bell trap

Figure2 Outline of test trap and test WC

Table1 Parameters of test traps and test WC

	Ratio of leg’s sectional areas [-]	Seal depth [mm]	Seal volume [mL]	Natural frequency [Hz]	Average flow rate of fixture [L/s]
WC	0.16	58	2,400	1.27、2.47	2.2
Contrary bell trap	1.07	50	330	2.34	-

WC Contrary bell trap

Figure3 Installation conditions of the test WC and test trap

2.4 Substitute Filth

As stipulated in JIS P 4501, four 90 cm long toilet tissues were folded and bundled together to make a standard substitute filth (referred to as a standard below). A standard was placed in the center of the WC where water is half full with the substitute's cut side facing the front of the WC. After the first bundle soaked in, the second one was thrown in; when all four of them were in, discharge was made with a "large flush." Another set of experiments using bundles 1.5 times the size of a standard (six tissues folded and bundled, referred to as a standard × 1.5)) was conducted to examine the effect of filth on pressure in drain.

3. Analysis of Pressure Vibrations in Pipes

3.1 Pressure Vibration Waveforms

3.1.1 Purpose

Steady discharge and fixture discharge are significantly different in their discharge time and instantaneous maximum discharge flow rate. Therefore, we compared pressure vibration data obtained from steady discharge, fixture discharge and filth discharge.

3.1.2 Method

Based on the data of pressure vibration obtained in a real-scale discharge tower, we examined steady discharge flows with 1.5 L/s, 3.0 L/s, 4.5 L/s, fixture discharge flows from one, two, and three fixtures, and standard and standard × 1.5 filth discharge flows by superimposing their waveforms.

3.1.3 Results

An example of pressure vibration waveforms from steady discharge and fixture discharge superimposed on graphs is shown in Figure 4.

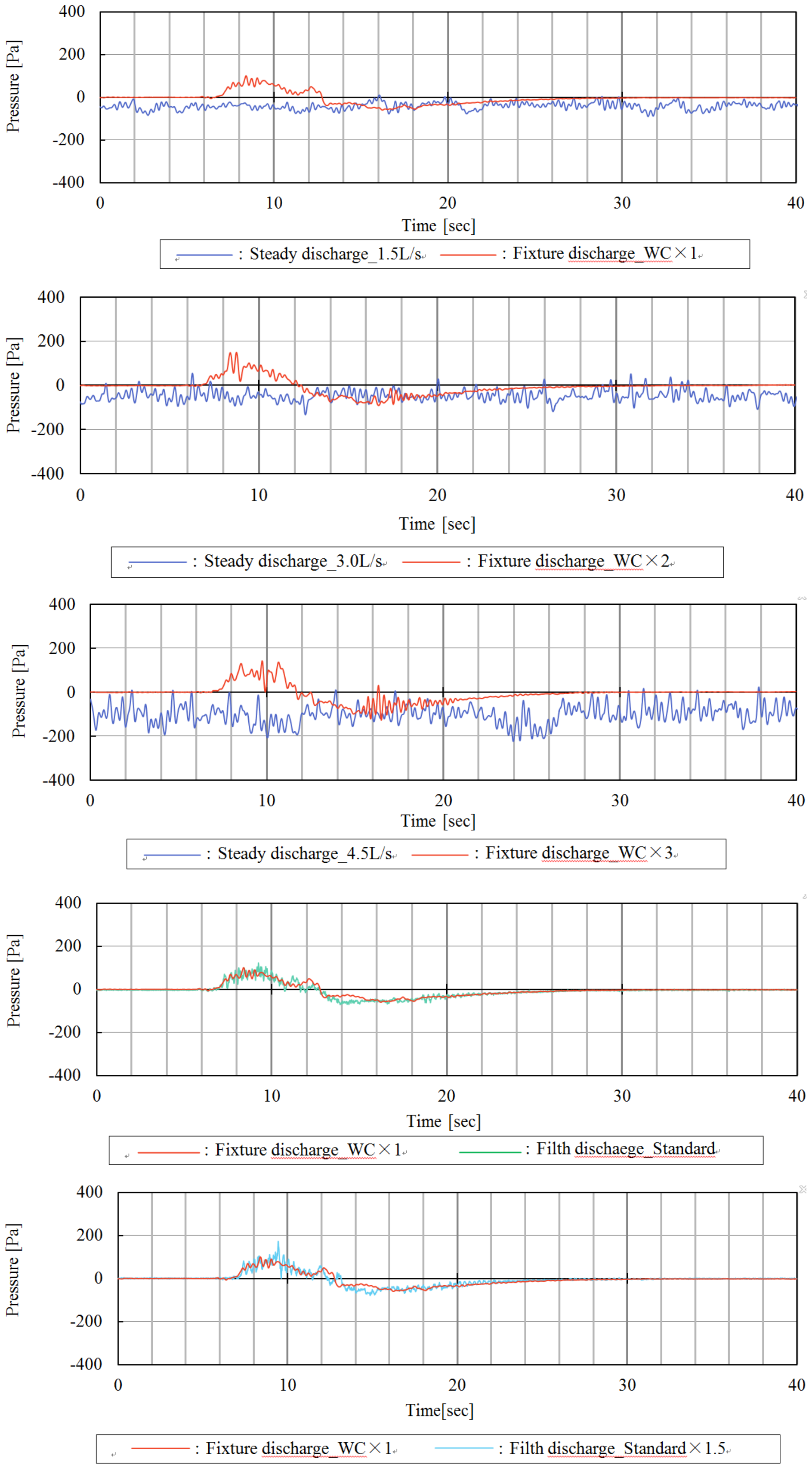


Figure4 Comparison of pressure vibration waveforms from type of discharge load （An example）

Form Figure 4, it can be seen that average pressure values tended to continue vibrating on the negative side in steady discharge while in fixture discharge considerable positive pressures were produced first and then they made a large sudden swerve to the negative side before becoming stable near "0." This can be explained by the fact that in fixture discharge water passes through the drain pipe only for a moment recording a positive pressure on a measuring device and then pressure dies down quickly while set amount of water continues to flow through the pipe in steady discharge. It has also been observed that pressure fluctuation went up in tandem with increase in discharge load from 1.5 L/s, 3.0 L/s to 4.5 L/s in steady discharge while the maximum and minimum pressures in pipes rose as the number of fixture increased in fixture discharge. The minimum pressure of steady discharge was larger than the minimum pressure of fixture discharge, but the maximum pressure was smaller than that of fixture discharge. In filth discharge larger maximum pressures were recorded as the number of filth increased, but no significant changes were observed in the negative pressures. This may be attributable to small amount of filth matter.

3.2 Pressure Profile

3.2.1 Purpose

Previous studies have demonstrated that pressure in drain decreased when test traps were attached (referred to as with traps below) to drainage systems compared with when PVC caps were attached (referred to as without traps below). In view of this we compared pressures in drain with traps and without traps.

3.2.2 Method

We compared pressure in drain profiles with traps and without traps by applying 3 Hz low-pass filters to the data obtained from the experiments and making graphs by the type of discharge load.

3.2.3 Results

Pressure in drain profiles by the type of discharge loads are shown in Figures 5 ~ 7. In this experiment test traps were installed on the 8th and 9th floors, but there have been no differences between pressure in drain with and without traps. It can be assumed that relatively small discharge flow rates applied in the experiment produced only minimal pressure in drain, which wasn't large enough to create fluctuations in pressure attributable to the presence or absence of traps. The fact that test traps were installed only on two floors may also have contributed to the less than significant differences. It has been observed that fixture discharge load produced larger maximum positive pressure than steady discharge load. Generally speaking, upward air flow occurs inside drainage stack while no discharge is being made due to temperature differences. Large positive pressure can occur when this upward air flow comes in contact with downward air flow produced by fixture discharge.

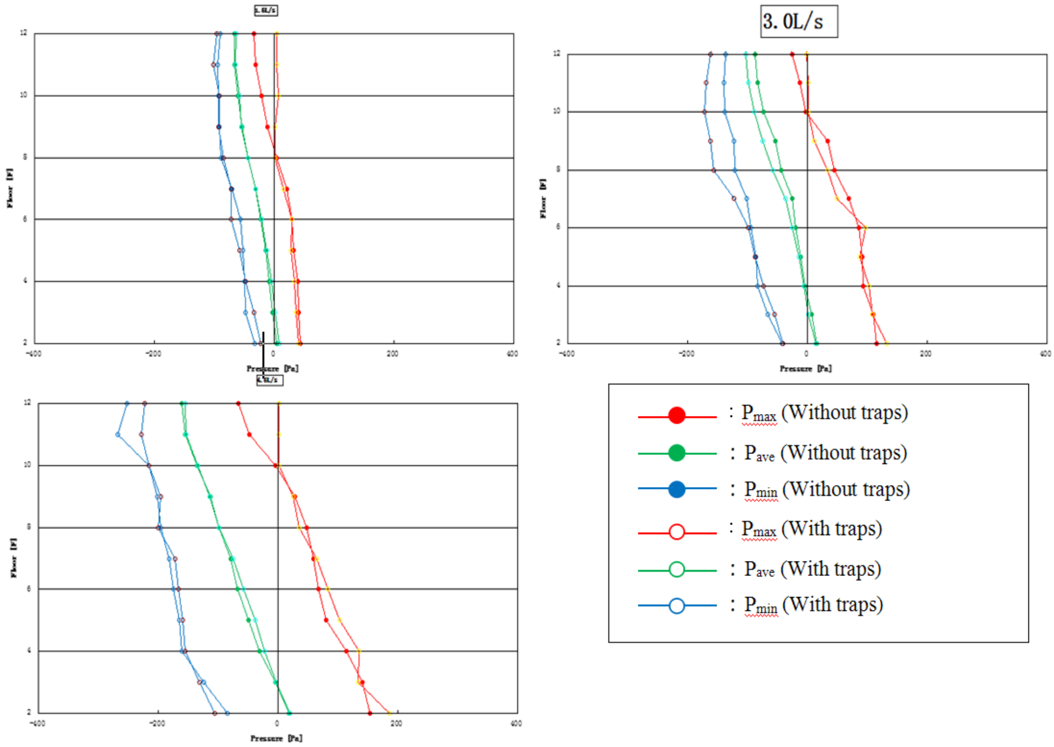


Figure5 Pressure profile by steady discharge load

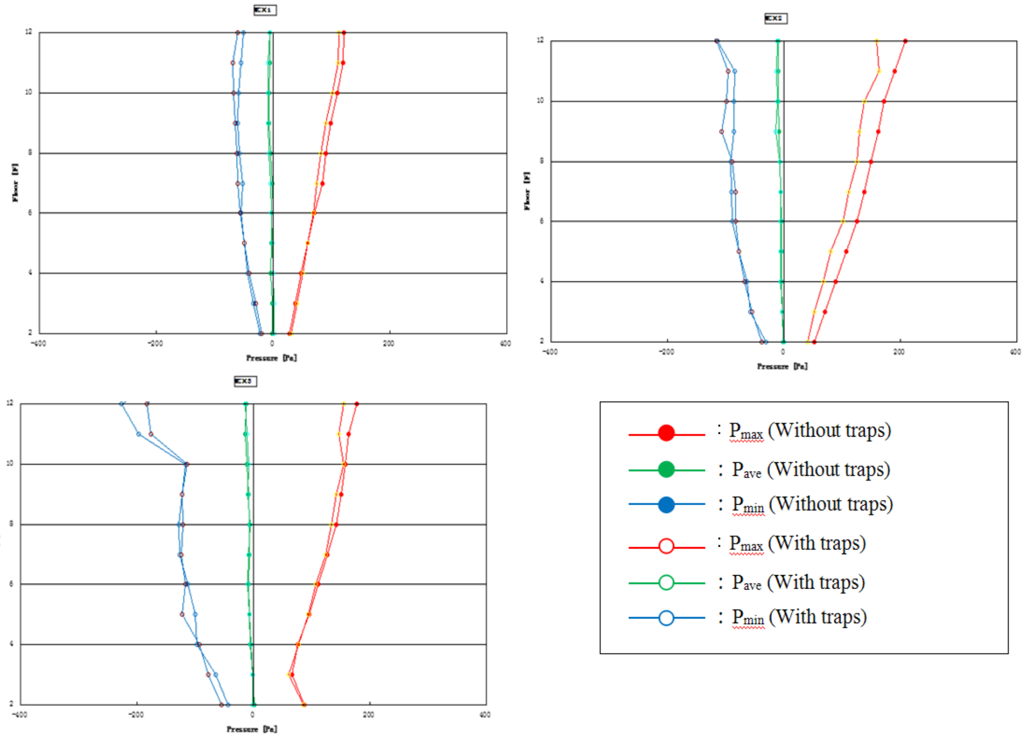


Figure6 Pressure profile by fixture discharge load

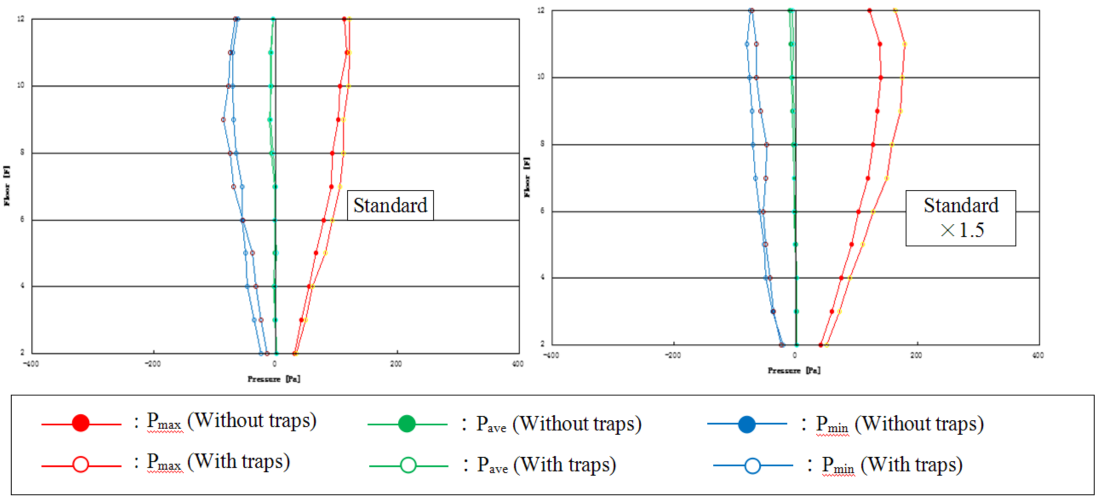


Figure7 Pressure profile by filth discharge load

4. Power Spectrum Analysis

4.1 Purpose

Power spectrum analysis was conducted on the pressure vibration in pipe with and without traps, and the distributions of dominant frequencies were examined.

4.2 Method

Power spectrum analysis was conducted on the pressure vibrations in pipe with traps and pressure vibrations in pipe without traps. As shown in Figure 8, the largest peak in the power spectrum density distribution is called the first dominant power spectrum (referred to as First PS), and the second and third largest peaks Second PS and Third PS respectively.

4.3 Results

The dominance order and frequencies of pressure vibrations in pipe in steady discharge and fixture discharge are shown in Figures 9 and 10.

As can be seen in Figure 9, there have been no significant differences in First PS distribution with or without traps on both 8th and 9th floors at discharge loads of 1.5 L/s and 3.0 L/s. However, at a discharge load of 4.5 L/s, first dominant frequencies aggregated in the 1 ~ 3 Hz range without traps while no prominent patterns in distribution were seen with traps. The characteristic frequencies of the traps connected may have been in that range in the first place.

Figure 10 indicates that there were no differences in distribution of first dominant frequencies with or without traps in fixture discharge load. However, second dominant frequencies showed similar tendencies to those in steady discharge load at a discharge load of 4.5 L/s.

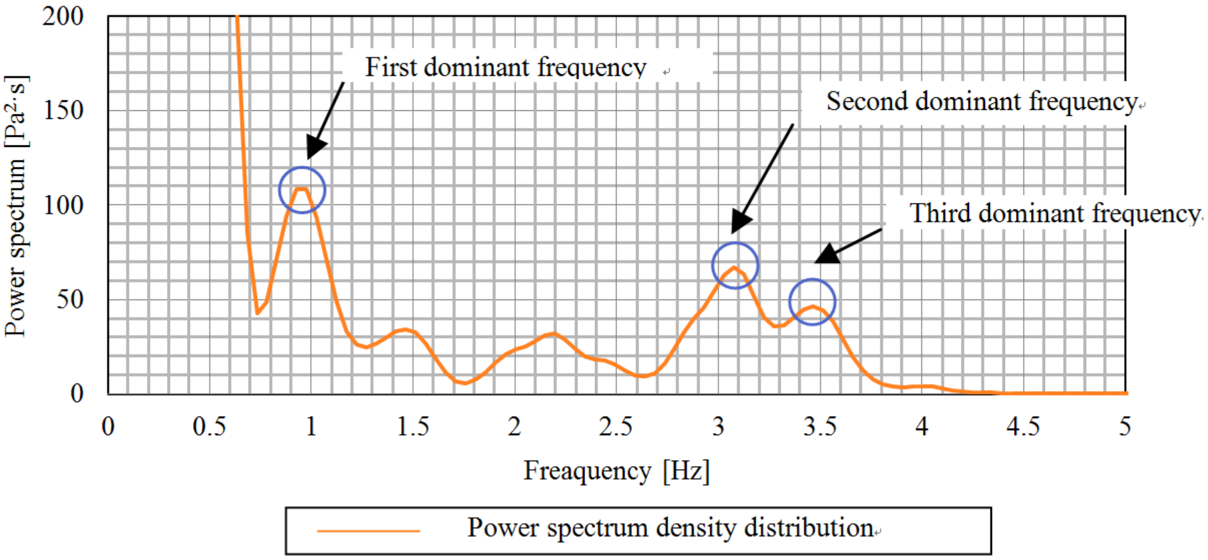


Figure8 Concept of dominant frequencies

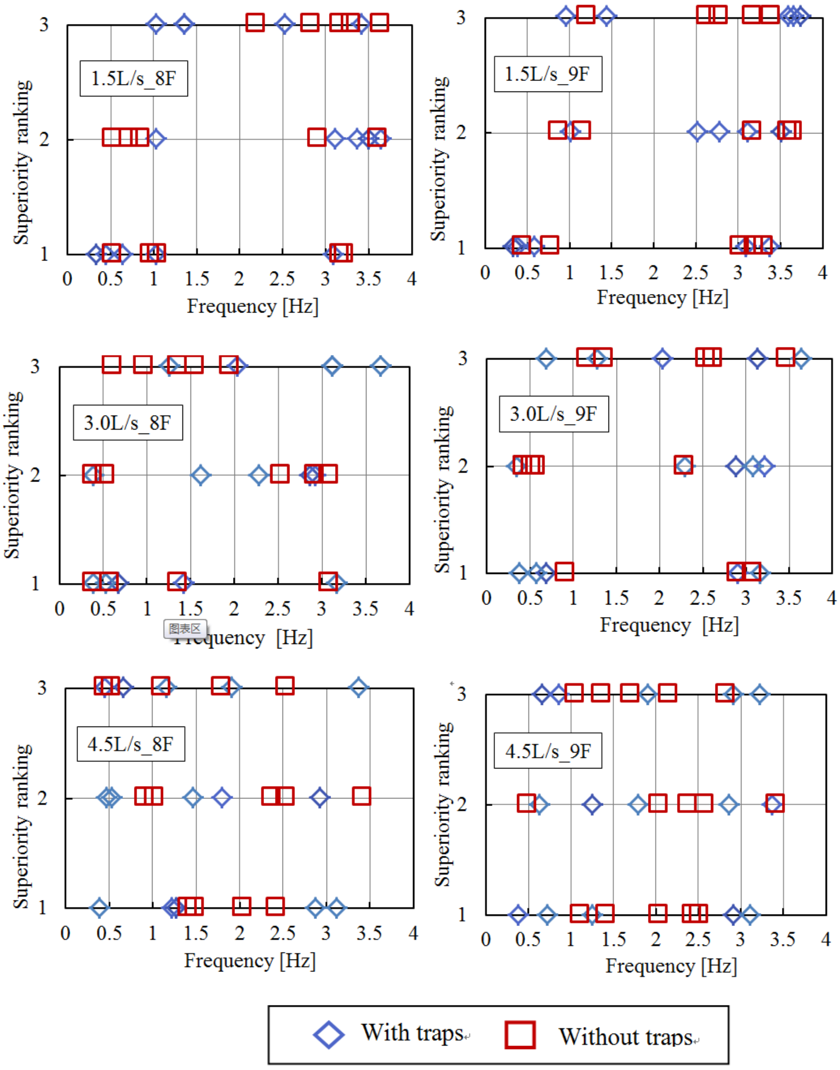


Figure9 Dominant frequency by steady discharge load

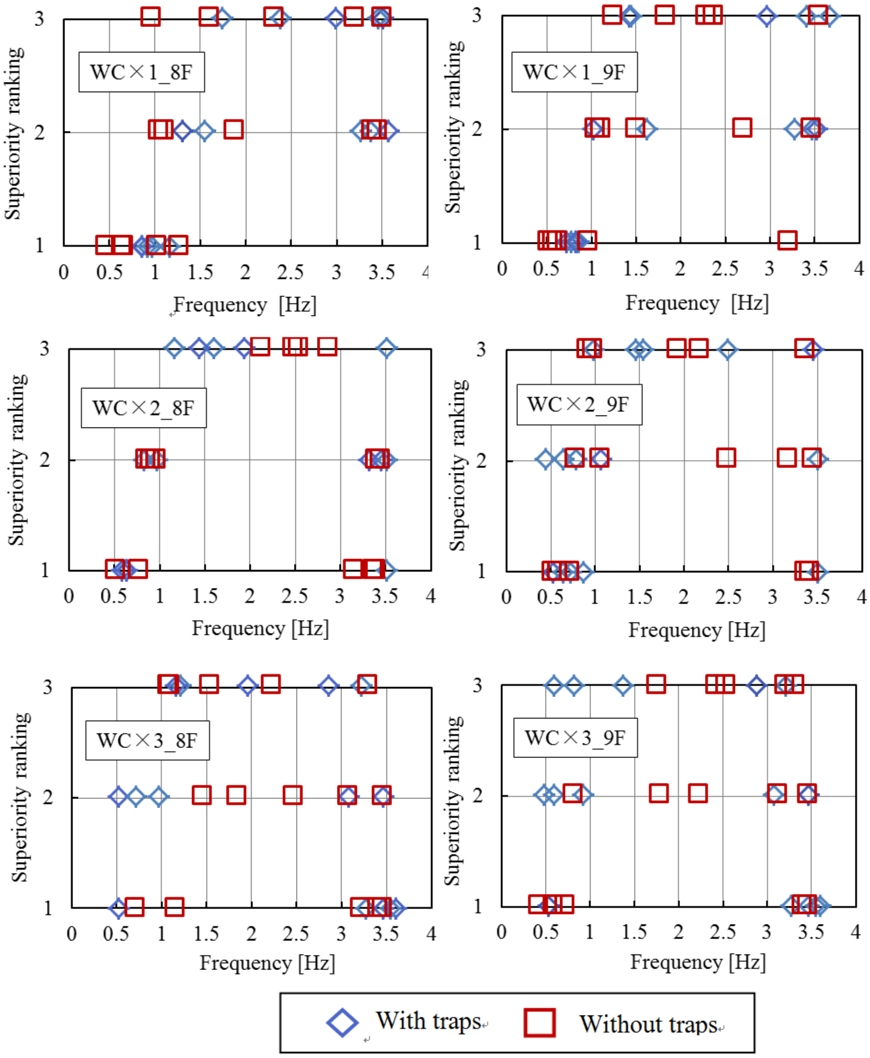


Figure10 Dominant frequency by fixture discharge load

5. Conclusion

In this study, we have analyzed pressures in pipe and seal water fluctuations measured in experiments conducted in a real-scale drainage tower. The results can be summarized as follows:

1) There have been no differences in pressure in pipe with or without traps as discharge loads applied in the experiment were not large enough pressure to produce noticeable effects.

2) As a result of power spectrum analysis conducted on pressure vibrations in pipe, the distribution of first dominant frequencies with trap in steady discharge load showed some difference from those without traps at a discharge load of 4.5 L/s. There has been no such tendency seen in fixture discharge load.

Further experiments with various types of test traps are called for in the future to quantitatively assess fixture discharge and steady discharge.

6. Reference

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Study on the Performance and Application of Integrated Unit Trap in Bathroom

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Abstract

Building drainage system is one of the most essential facilities in building service engineering. Trap seal water in a drainage system acts as an integral part of a hygiene system in existing residential buildings, and provides an essential component in order to minimize the possible infection risk due to the transmission of contaminants and to safeguard occupied space from stench and vermin from the drainage network. Therefore, the building Technical regulations require that all sanitary equipment must install the trap. In order to enhance the performance of building drainage system, a confluent device of Integrated Unit Trap (IUT) is verified as a better substitute for individual trap of floor and washbowl and bathtub in bathroom through investigation and experiment. The practicability and relevant technical issues would be validated in this research. The regulation proposal and certification process would be verified and proposed. A technique which can improve seal depletion of trap problem and enhance people's quality of life will be proposed and presented in this paper.

Keywords

Trap, Building drainage system, Air pressure, Building drainage system, Trap seal depletion

1. Introduction

Drainage system is one of the most essential facilities in building service engineering, the relevant technology used today was developed decades ago. However, little progress has been reported for building drainage systems. Inappropriate design of the drainage system within existing buildings can result in sanitary problems including air transient caused by discharges in the drainage stack and trap seal depletion.

Nowadays, people are more aware of the importance of drainage system design and maintenance due to the SARS epidemic experience in 2003. The rapid spread of the SARS virus at Amoy Garden housing complex in Hong Kong provides a great lesson in the potential health risks attributed to a drainage system by highlighting the cross-contamination route caused by the appliance trap seal depletion. Afterward, Influenza A virus subtype H7N9 and recent MERS-CoV (Middle East Respiratory Syndrome Coronavirus) continuously evoke the panic and serious concerns about inflection issues from building drainage system. Therefore, the fundamental requirement of a building drainage system is to carry away sanitary appliance drainage and preventing foul odors into the habitable space from drainage network, which is important for the healthiness and comfort of living environment.

Trap seal water in a drainage system acts as an integral part of a hygiene system in existing residential buildings, and provides an essential component in order to minimize the possible infection risk due to the transmission of contaminants and to safeguard occupied space from stench and vermin from the drainage network. Therefore, the building Technical regulations require that all sanitary equipment must install the trap. A trap seal is a plumbing term where water is used to both seal a pipe of drainage airborne and assure the movement of drain water.

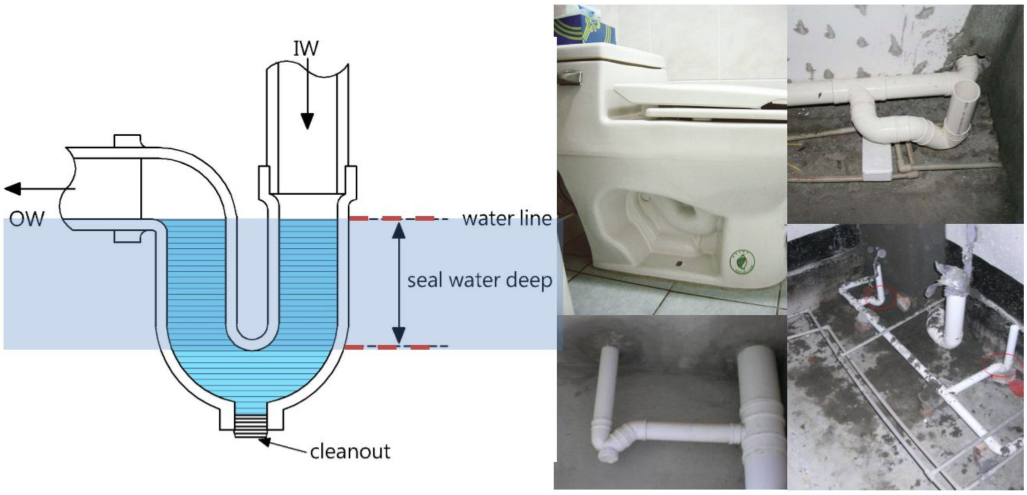

Figure 1 diagram of trap seal device and application

In order to enhance the performance of building drainage system, an innovation of new technique of building water drainage equipment was developed. A confluent device of Integrated Unit Trap (IUT) is verified as a feasible concept and substitute for individual trap of floor and washbowl and bathtub in bathroom. This compact device IUT is conducted by manufactures and applied to residential buildings for recent years in Taiwan. However, the practicability and relevant technical issues are remained and its performance should be validated. In order to avoid the inadequate device be used in market, the certification process for device performance should be established and link to regulation review.

2. Technical Review

2.1 Mechanism

The concept of IUT is from Grease and oil interceptor which is the device within drainage systems to capture grease and oil from the discharge of drain water. This is an associated device to help prevent excessive buildup of grease and solidified oil into building drainage system. The grease and oils are trapped inside the grease trap by using a system of baffles or plates. Most grease systems have a trapped grease indicator which indicates the level of trapped grease. When a level of grease has accumulated within the greases trap, the trap would be cleaned out as the annual maintenance. Figure 2 shows the concept of the IUT from oil/grease interceptor

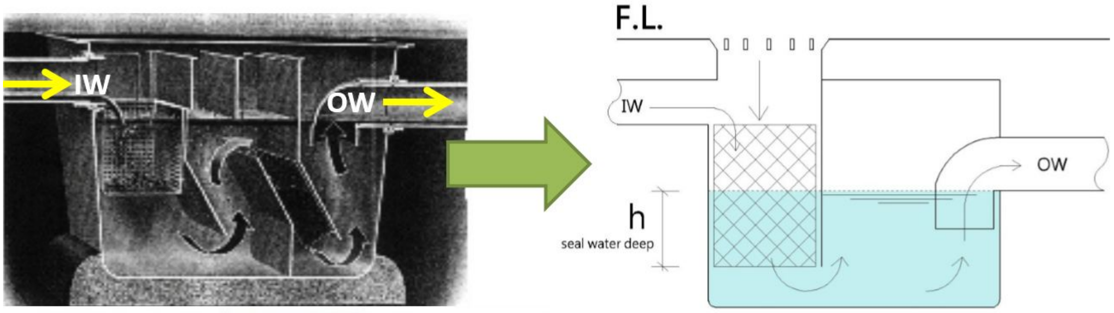

Figure.2 the concept of the IUT from oil/grease interceptor

Currently, several types of the IUT device have been developed and used in buildings. This device adopts centralizes water supply mechanism by collect the sewage from all sanitary equipment. For solve blocked drains pipes problem and cleaning needs, this device also has screens designed to filter impurities. The water outflow when the surface of the water reaches the line effluence out of the system. All sanitary equipment only needs install one trap device which can avoid problem of complicated drainage system, reduce waste materials and assures the water-tightness According to the development prototype of oil/grease interceptor theorem, the advantages of the new style seal trap are water supply immediately and the drainage system simple as shown in Figure 3. It can improve the seal depletion problem and suitable for bathroom space use in house.

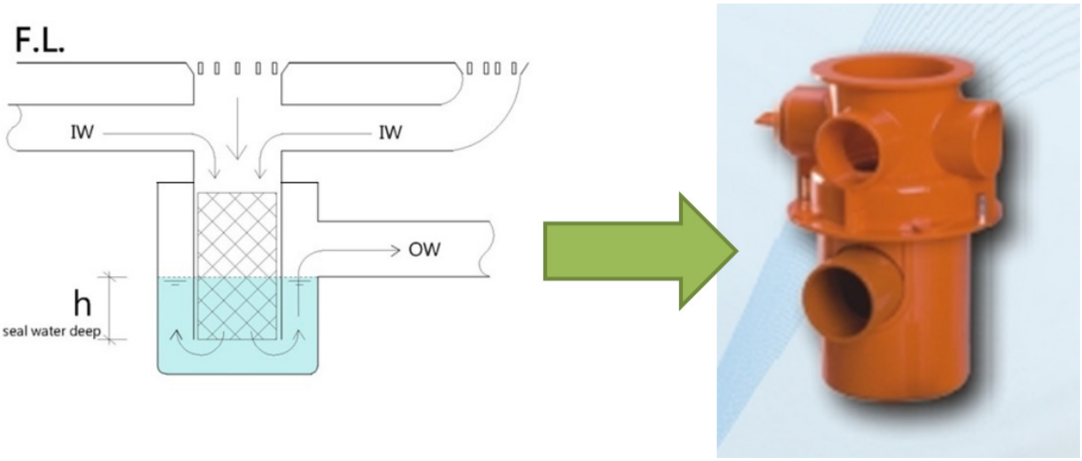

Figure.3 The mechanism and prototype of IUT

2.2 Trap device and piping system

Figure 4 shows the plumbing drainage design for toilet which was usually adopts "one sanitary with one trap" following technical regulation. There are some issues including the seal depletion and the complexity of fitting construction, it would causes the sewage odor into the interior environment through the building drainage system. Figure 5 shows the improved fitting for IUT applying in bathroom, which allows all sanitary equipment used one trap in a bathroom. IUT device adopted centralizes water drainage mechanism by collect the sewage from all sanitary equipment for improve the seal depletion problem. This device has steady seal water and simple drainage system design.

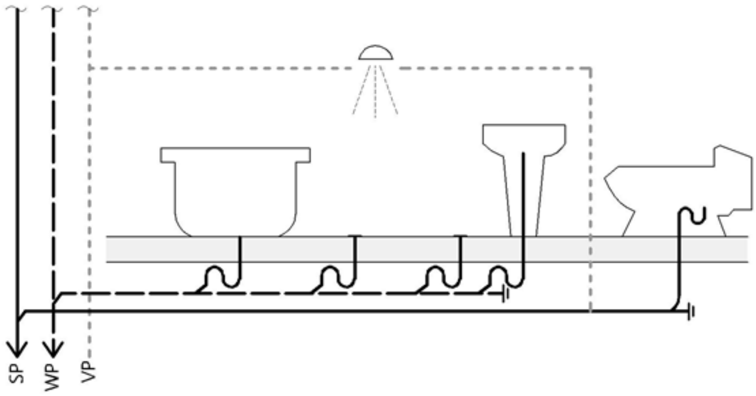

Figure 4 Traditional plumbing configuration in bedroom(11)

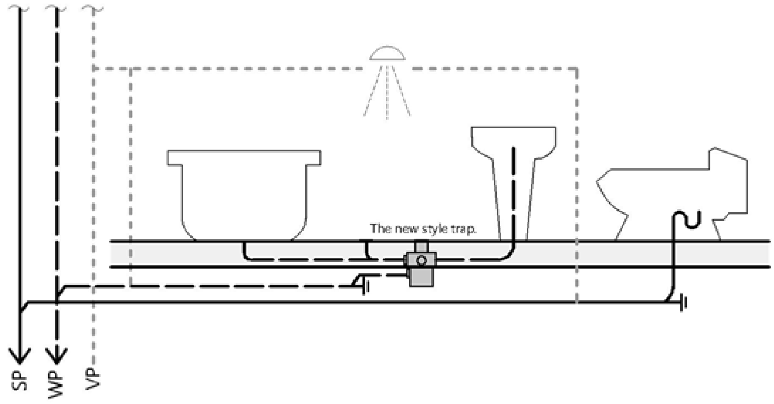

Figure 5 the plumbing configuration of the new style trap in bedroom(11)

2.3 Operation and structure

According to the conditions of building construction, there are four installed type IUT which can be applications for engineering options. Designer can take into account overall drainage system design for the IUT in planning. First, the construction of the embedded type which is must increase the thickness of floor and the new style trap shall be installed among the floor as type 1. Second, construction adopts the double-floor and the trap can be installed above the second floor. The second floor can be as partition for the householder in one story below. So, in order to assure the performance of drainage system, the floor drain cover can be opened to make routine maintenance which would not affect the residents in one story below. It's more suitable for householder with high indoor environmental quality space and more frequent interior design updates. Third, the construction adopts the suspended piping and the IUT can be installed under the floor. Forth, the half-buried type which is similar with the suspended type can be with half part of trap installed among the floor. It's more suitable for residence house use.

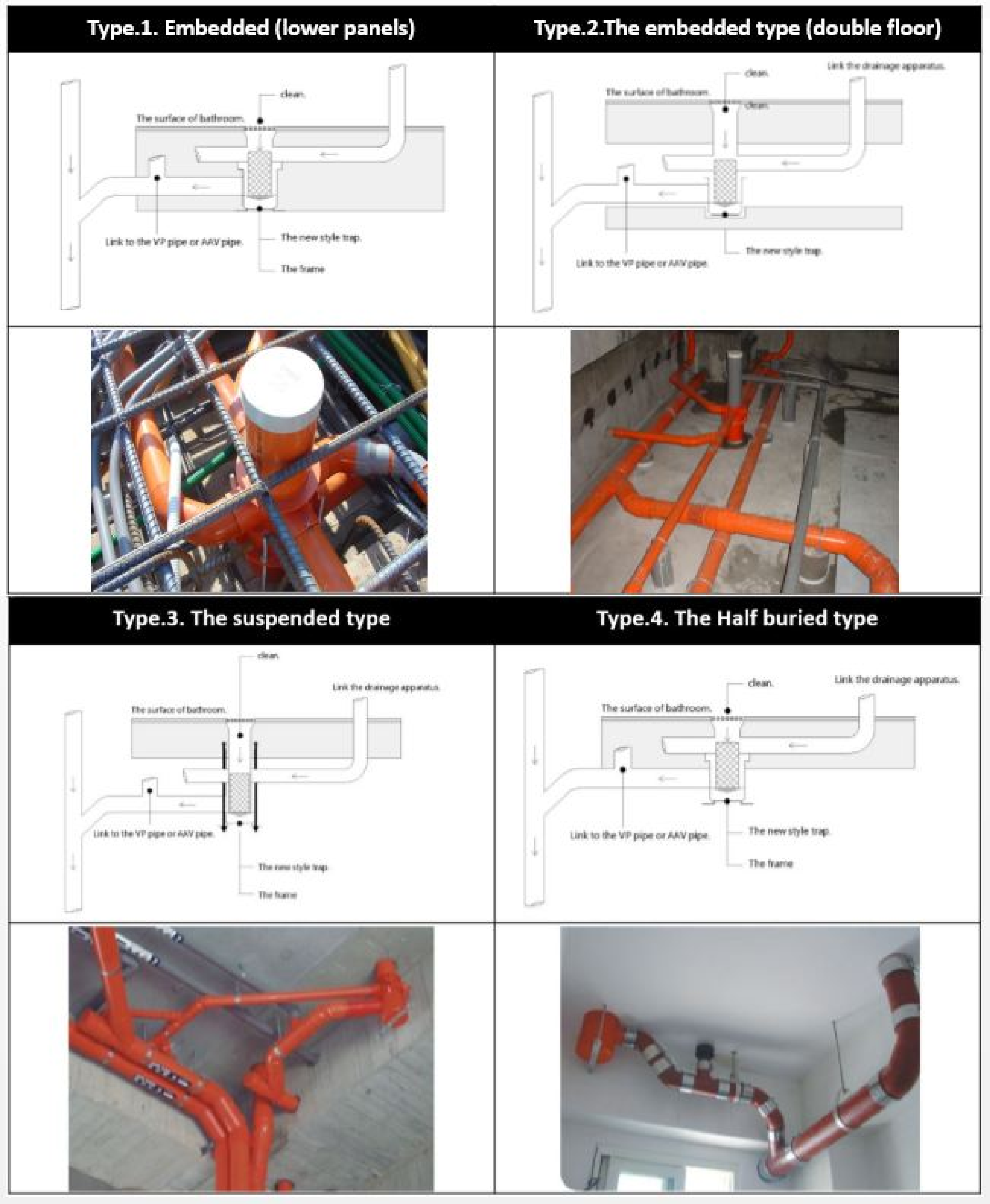
Type.1. Embedded (lower panels)
Type.2.The embedded type (double floor)
Type.3. The suspended type
Type.4. The Half buried type

Figure 6 The four types of IUT for construction

The IUT is an influent device integrated multiple equipment and its trap to be one facility, the operation and structure of IUT is as shown as figure 7.

Figure 7 the operation and application structure of IUT

3. Certification for Performance

3.1 Materials

Due to the variation of building drainage temperature and flow patterns, the material of product and relevant device needs to be regulated. As the function requirement of trap, a fluent transportation in drainage system is necessary. The main body of device should be product of same material and the subsidiary fittings including coverings should be stainless, copper alloy or engineering plastic materials. Table 1 shows the material requests for IUT. The outlook of product should be glossy and smooth without bobble, crack, hollow or any physical defect. The color should be even and decomposition indication is not allowed.

Table 1 the material requests for IUT

Item	ABS	PVC-U
Variant temperature (^{o}C)	≧ 85	≧ 75
Brocken test in low temperature (0 ± 1^{o}C)	none	none

3.2 Physical composition

The device structure should be composited by main body and subsidiary fittings, the depth of seal water should be above 50 mm. In order to clear up the junk of trap, a potable filter which is with hole diameter of 4-6 mm and total area with 2.5 times of drain out section is necessary to be set up in the device. The IUT device should prevent the back water into drainage system or indoor. Multi access unit should be adequate sizing and connect to facility piping and the central line of inlet piping should be higher than seal water surface. The structure should be strength and no leakage or deformation, total high of device should be less than 250 mm for maintenance access. All the section of flow way in device should be no less than drain out piping section.

3.3 Performance

The product including main body and subsidiary fittings should be no deformation or leakage under condition of water temperature 75℃ and during 30 minutes. The conditions of higher temperature drainage in some utilities should be considered for durability of suitable materials.

The package IUT for bathroom is a confluent device which collects the individual facility drain water including commode, sink and floor gutter. All the function of building drainage and sanitation issues must be guaranteed and assured for the healthy indoor environment. Due to structure limitation, the inlet piping connections should be under 4 junctions and piping length from each facility should be under 2.0 meter. In order to converge the flow from all facilities, the IUT capacity of flow rate should allow the maximum flow rate from all facilities. As the minimum performance, the permit flow rate capability for IUT device should be not lower than 1.25 liter per second.

The permit flow rate should be validated by experimental device and certification process. The testing device includes piping system with 1/10 slope and height of 120 cm from equipment to trap which can offer steady flow of 1.0~1.75 L/s. The setting of gutters and timer measurement are as shown as figure 8.

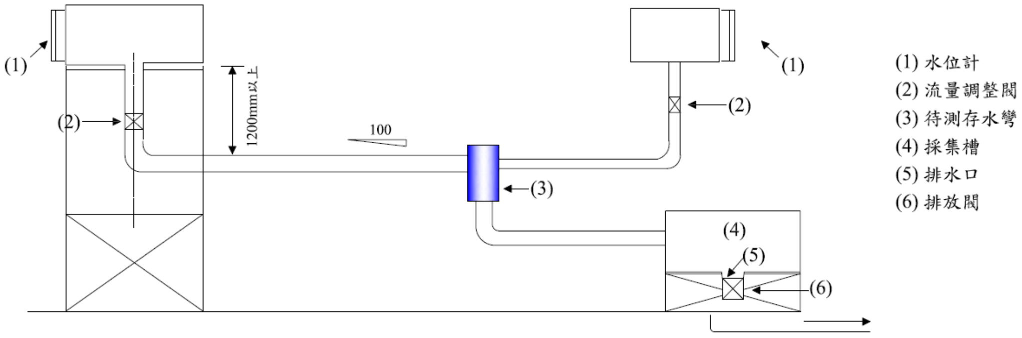

Figure 8 the measurement of permit flow rate

On the other hand, the IUT device should have the self-cleaning ability and certificated by testing device with 80% level. The proposed standards for self-cleaning ability are discharge test with very small balls of 100 pcs of Φ1.9 mm pp balls. Ink test is proposed with no trace of ink after discharge. The depth of seal water should be not less than 50 mm for pressure resistance from drainage stack.

4. Application and Discussion

The IUT device has been used in new buildings since 2006 Taiwan. One of the composition of IUT device as shows in figure 9 which is setting within the bathroom space. According to the field observation, the seal water depth is steady when sewage discharges from sanitary equipment. In this case, the new style tarp has been installed in bathroom space. The trap seal water can be avoid the depletion by centralizes water supply design. Besides, this device has screens design to filter impurities which can help us maintain drainage system more easily. The overall drainage system design is simpler as shows in figure 10. It can reduce the complication of drainage system and be more reasonable in cleaning and maintenance for residential buildings.

Figure 9 Observation of the new style trap

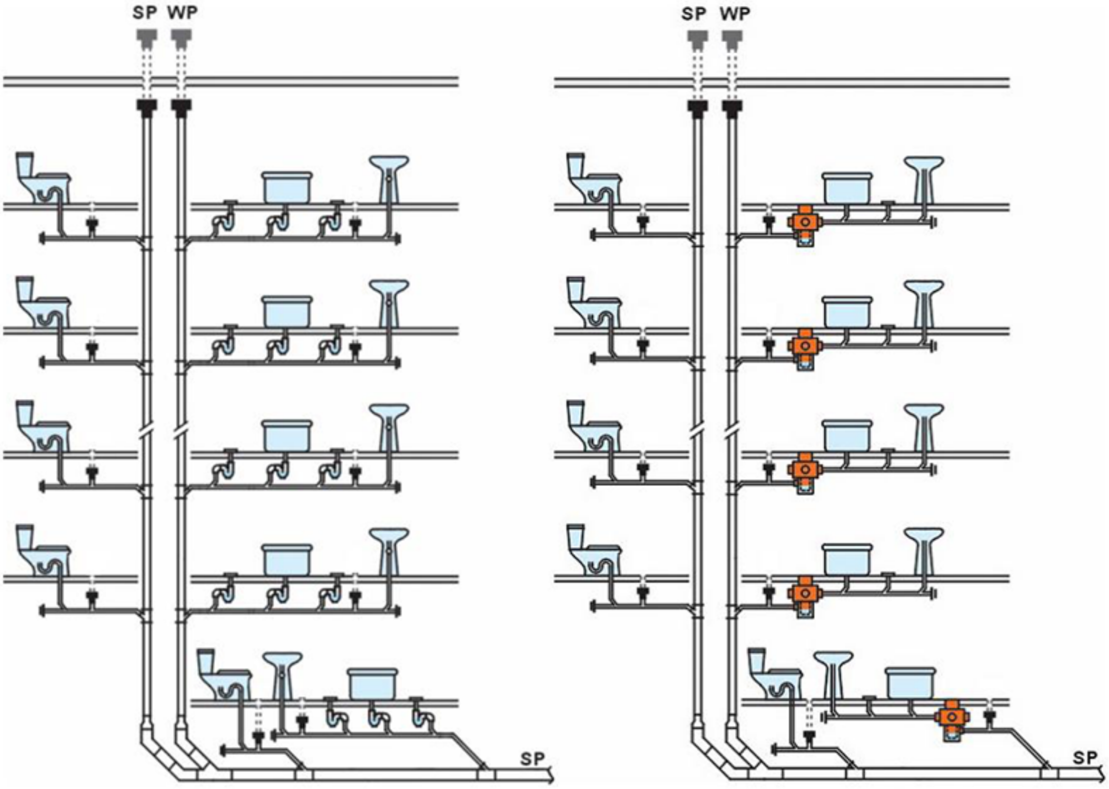

Figure 10 Comparison of differences of the plumbing design between the trap and new style trap(11)

The max flow rate of sanitary equipment is the bathtub in the bathroom. In order to assure the performance of the new style trap, the bathtub is used with full water and bubble to test the performance of trap seal when full drainage load in drain. The result shows that the IUT has the steady seal water depth and the bubble has not backflow in low-rise building. Besides, the trap installation and cleaning is more easily than conventional equipment.

Owing to the IUT device with compact design, it can improve performance of the building drainage system including to simplify the complex plumbing and seal water protection. Besides, this device has screens design to filter impurities for solve the problem of drains pipes blocked which without damage to the floor. But designer must take into account overall drainage system design for the IUT device in planning. Therefore, a guideline and regulation to assure the performance of IUT is necessary to be conducted in the near future.

5. Conclusion

The major function of the building drainage system is to ensure proper operation and to keep a clean and health interior space for human's life. Therefore, there usually exists an interior health problem from trap seal depletion in general building in Taiwan. The IUT device has been developed and preliminary confirmed the performance in bathroom unit of buildings. This paper proposes a basic requirement of guideline and certification process for performance including seal water depth and permit drainage flow. All research results will be the contribution and guideline of legalization procedure which can assist to development of new technique and new construction method.

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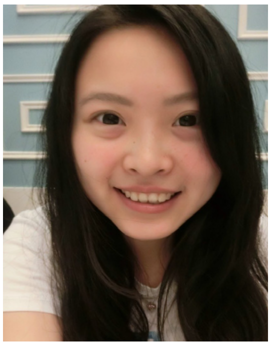

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Introduction of China Test Standard for Capacity of Domestic Residential Drainage System

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Abstract

This article describes the test methods (including constant flow method and instantaneous flow method) of China's first national industry standard(called The Test Standard for short), Test standard for capacity of domestic residential drainage system, introduces the test instrument and installation, test methods and criterions of the two different kind of test methods in detail. The implementation of the Test Standard will provide a comparable test standard for research and development of China's residential drainage system, and it is of great importance to improve the performance of drainage system, enhance the overall level of China's residential design and construction of water supply and drainage system and improve people's livelihood.

Keywords

Test standard, Constant flow method, Instantaneous flow method, Criterion

1. Introduction

In China, researches and experiments on water supply and drainage system for buildings live through some different stages:

(1)experiments at the scene of project

1)experiments on Sovent drainage system of Qian San Men high-rise residential building(the year of 1973, with both constant flow method and instantaneous flow method)

2)Tsinghua University Mechanics Laboratory did experiments on circulator and the whirlcone and the specifical single stack drainage system with whirlcones in Furong Hotel, Chang Sha Province (the year of 1985, the method is unknown)

(2)experiments in test tower

1)drafting group of “Code for design of building water supply and drainage” and “Technical specification for specifical single stack drainage system” did the experiments on some different kinds of specifical single stack drainage system(the year of 2005, with constant flow method)

2)Tongji University did experiments on capacity of the drainage system in high-rise building with PVC-U vertical pipe(the year of 2006, with instantaneous flow method)

3)Hunan University did the experiments on fullness ratio α of drainage system in building(around the year of 2005, with constant flow method)

4)China National Engineering Research Center for Human Settlements did experiments on the capacity of different type of drainage systems(around the year of 2014, with constant flow method and instantaneous flow method)

In the past, we Chinese researchers did a lot of experiments on drainage system for buildings with different kind of testing methods and different criterions which lead to that all the results cannot be compared. Thus, it is necessary to work out our test standard for capacity of domestic residential drainage system according to China’s national conditions and water usage habits.

“Test Standard for Capacity of Domestic Residential Drainage System” is the first industry standard by conducting a 1:1 ratio simulation on the drainage system testing tower and worked out according to its results. The Test Standard is from the Notice of 2013 construction plans to formulate and revise standards” announced by Ministry of Housing and Urban-rural Development of the People’s Republic of China. It is the first national level industry standard for drainage system. China National Engineering Research Center for Human Settlements is the editor in chief.

Capacity of vertical pipe is the drainage flow rate which will lead the pressure in the system to reach the criterion. Currently, the constant flow drainage method is the most extensively studied. This method is the standard in many countries, including Japan’s " Testing Methods of Flow Capacity for Drainage System in Apartment Houses "(SHASE-S218-2008)[1; 2], Europe’s EN12056-2:2000[3], Germany’s DN1986-2[4], United States’ National Specifications ICC-2003[5].

Instantaneous flow method realizes of instantaneous toilets to drain with a certain drainage time interval between the layers and in the different height, by using it to imitate actual working conditions in a residential drainage system which has multiple floors to drain and peak instantaneous drainage characteristics.

During the inventory work, we did experiment research with both constant flow method and instantaneous flow method. As constant flow method is a kind of proven test method, we just adjust the method according to our usage and habits in this Test Standard. While the instantaneous flow method involves a lot of difficulties, such as the accuracy of the automation control system, test method, the selection of the equipment and so on. However, there is no good solutions all around the world. According to our particular condition, using our high-rise test tower which is 122.9 meters high, we spent almost 2 years and did nearly 25000 times experiments on different type of drainage system and working conditions, the Test Standard was finally worked out.

2 Constant Flow Method

2.1 Testing instrument and installation

Testing instrument and installation is outlined shown in Figure 1. Testing instrument and installation contains water supply system and testing pipe system, the testing pipe system contains drainage layers and testing layers.

Circulating water supply system is used in this test tower, with an elevated tank at the top of the tower and pumps and circulating collecting tank at the bottom of the tower. Water goes through the pumps and mingles in the elevated tank, then goes to the drainage instrument of constant flow method with gravity. On the drainage layers, drainage instrument of constant flow method is made up by a regulating valve and a flow-meter. The on and off of the valve would control the flow rate which ranges from 0 to 3.0 L/s. The flow-meter would have a real-time display function and its measuring range is from 0 to 3.0 L/s and the accuracy is 0.06L/s. The drainage instrument of constant flow method would be controlled by an electric control device. The drainage time will be no more than 140s and the flow rate will meet the default value within 40s after the experiment begins. The data of the value from the time of 40s to 120s will be analyzed.

In order to decrease the nappe behavior caused by the water go through in the pipe system and impact on the tee joints, sets a dividing tank to convert pressure flow to gravity flow. The dividing tank is shown in Figure 2. After energy dissipation in the dividing tank, water goes through to the testing pipe system.

The pressure sensors are installed up the horizontal branch with a distance of 500mm to the center of the vertical pipe in drainage layers and its accuracy is 10Pa, acquisition period and storage cycle time is 20ms. A water seal is set at the beginning of a certain horizontal branch for observation. The distance between the outlet of the discharge pipe and the vertical pipe is at least 8 meters and can only be in a line.

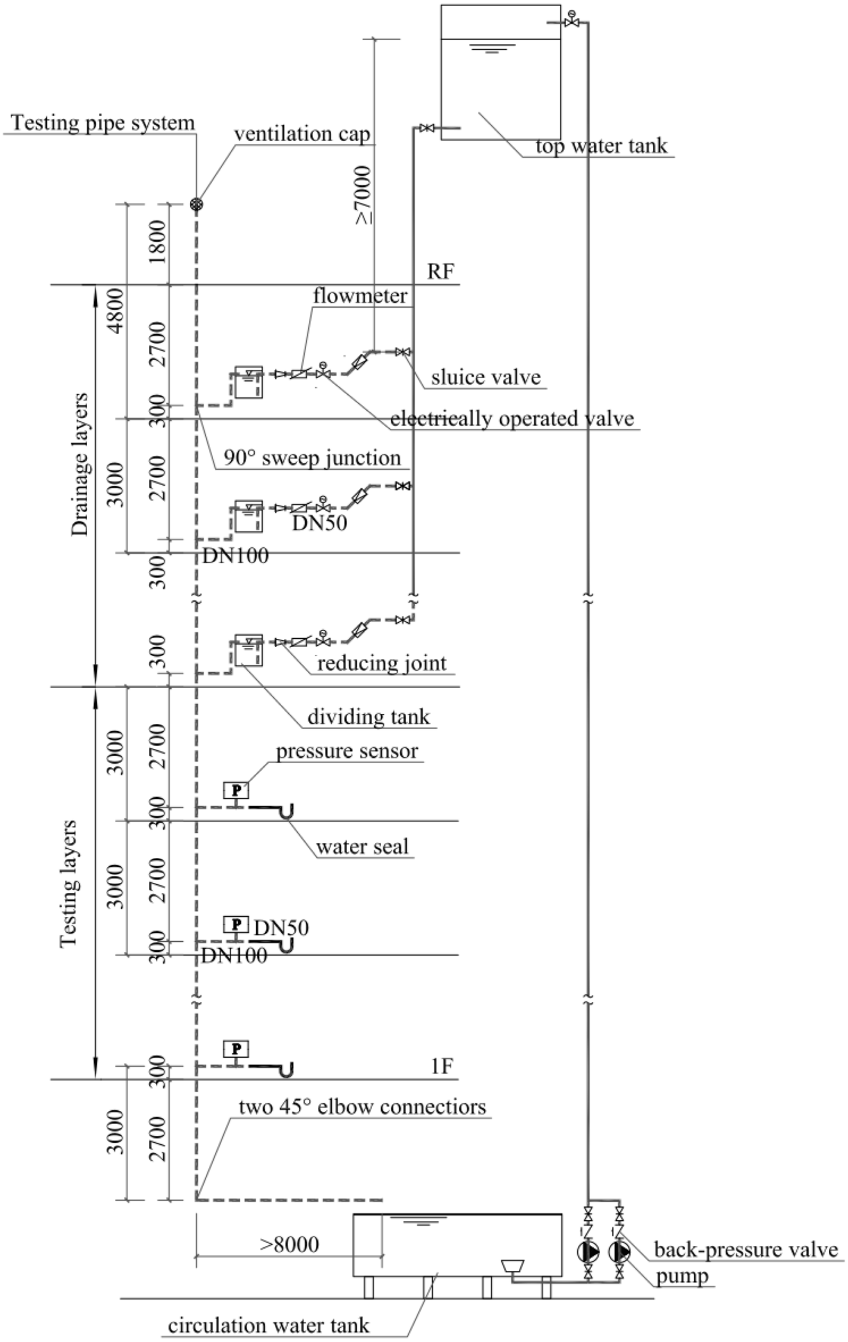

Figure 1 Test instrument of constant flow method

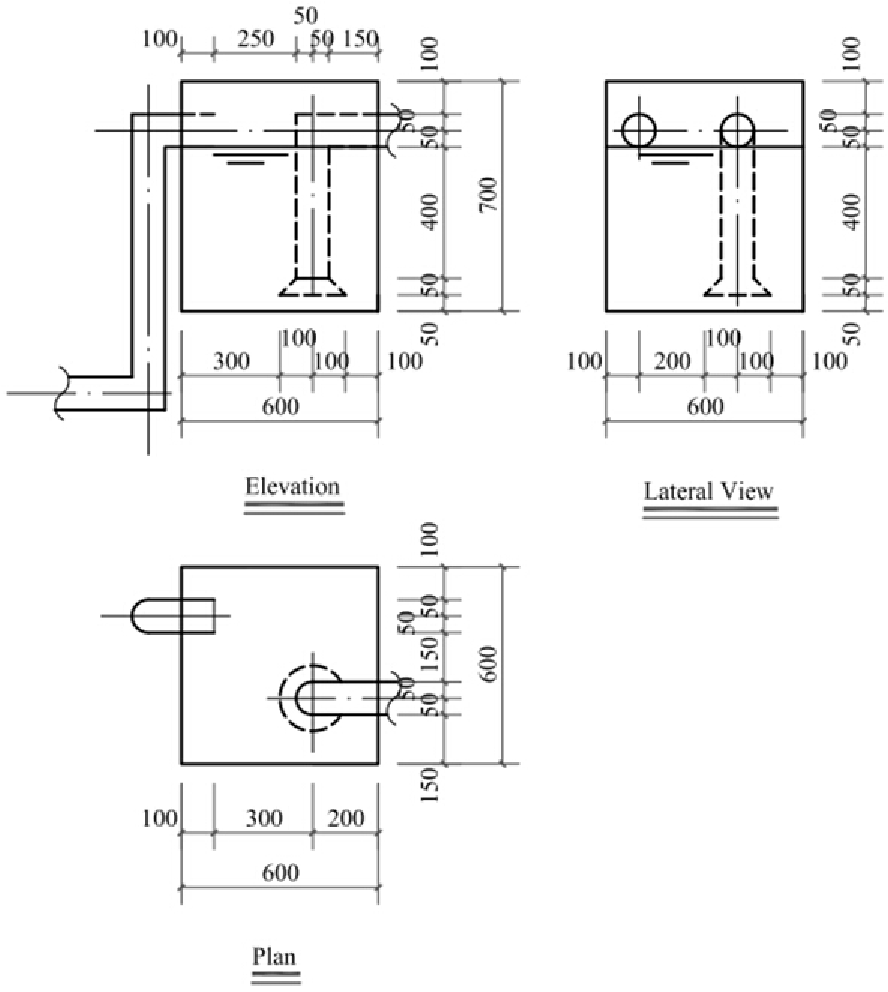

Figure 2 Dividing tank

2.2 Test method

When using the constant flow method, the drain should be started at the top of drainage layers. The flow rate is from 0.5L/s to 2.5L/s in each floor with an increasing degree of 0.5L/s. When the flow rate of one floor is up to 2.5L/s, adds another floor just beneath it to drain. The maximum flow rate of each floor is 2.5L/s. When the pressure in the testing system is around the judging standard, the increasing degree changes to 0.1L/s.

In the constant flow method, the maximum positive pressure is not more than +400Pa and the minimum negative pressure is not less than -400Pa.

3 Instantaneous Flow Method

The biggest difference between the instantaneous flow method and the constant flow method is that there is no pre-set flow rate in the instantaneous flow method. The flow rate in the instantaneous flow method (call it aggregate flow, is the aggregation of flow in the pipe system) is caused by different drain apparatus' combinations, and the aggregate flow will cause the positive and negative pressure pulses and influence on the drainage system.

3.1 Testing instrument and installation

Similar to the constant flow method, testing instrument contains water supply system and testing pipe system, the testing pipe system contains drainage layers and testing layers. The difference is the drain apparatus, the instantaneous flow method uses some instantaneous flow generators as the standard pattern to drain. The instantaneous flow generator (shown in Figure 3) is a standard drainage apparatus and is developed in accordance with one kind of Siphon toilet.

Figure 3 The instantaneous flow generator

The instantaneous flow generator is made up of a standard tank and a drain valve. It uses 6L flushing water for each time and its peak flow rate is 1.8L/s. The characteristic curves of water displacement and flow rate is shown in Figure 4. The instantaneous flow generator is controlled by an electric actuator and it takes1 second to make a stroke of the electric actuator.

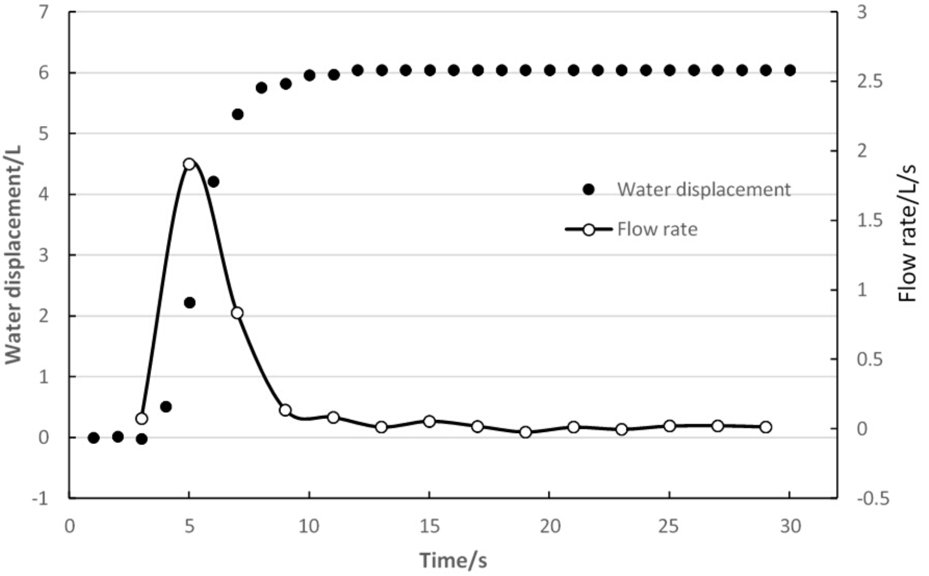

Figure 4 The characteristic curves of water displacement and flow rate

As related before, there is no pre-set flow rate in the instantaneous flow method, its flow rate, the aggregate flow, is realized by instantaneous toilet drainage as the standard pattern. However the aggregate flow rate should be quantified in order to analysis. Referring to Testing Methods of Discharge Characteristic for Plumbing Fixtures (SHASE-S 220-2010), we design the measuring cylinder as shown in Figure 5 And using the measuring cylinder to measure the aggregate flow of different kinds of apparatus combinations in drainage system.

Figure 5 The measuring cylinder

According to the experimental results of different kinds of drainage system, the maximum aggregate flow appears when the drainage time interval between the layers is +1.0s, so the drainage time intervals should be +1.0s.

3.2 Test method

The test sequence of instantaneous flow method should be in accordance with the order of pressure testing at first and following the aggregate flow rate.

3.2.1 Pressure testing

Test instrument of pressure testing in instantaneous flow method is shown in Figure 6. When testing, it should drain from the top floor where is set the instantaneous flow generator, and keep a record of the pressure at the same time.

The drainage time interval is +1.0s. When needs to add the flow rate, adds the apparatus amount to drain layer by layer. The amount of the instantaneous flow generator should be decided by the judging standard.

In the instantaneous flow method, the maximum positive pressure is no more than +300Pa and the minimum negative pressure is no less than -300Pa.

3.2.2 Aggregate flow rate testing

The amount of instantaneous flow generator and the drainage time intervals should be the same with pressure testing when doing experiment on the aggregate flow rate.

Aggregate flow includes the minimum aggregate flow rate (q_{min}) and the maximum aggregate flow rate (q_{max}). When doing experiment on the minimum aggregate flow rate, the measuring cylinder should be set at the bottom of the testing pipe system and the pipe should be cut off to make the water go through into the measuring cylinder (shown in Figure 7). While doing experiment on the maximum aggregate flow rate, the measuring cylinder should be set at the floor which is beneath the lowest-lying drainage floor (shown in Figure 8).

A pressure sensor is set in the measuring cylinder, its accuracy is 10Pa and its acquisition period and storage cycle time is 20ms. When testing, records the valves from the beginning to the 60th second. The data should be analyzed according to The Least Square Method, calculation formula is as follows:

$$q = k = \frac{(100\sum x_i y_i - \sum x_i \sum y_i)}{100\sum x_i^2 - (\sum x_i)^2}$$

Where x_i is time, y_i is the water discharge measured.
According to the result, get the curve diagram of the water discharge and flow rate in testing pipe system with instantaneous flow method and the peak valve is the aggregate flow rate.

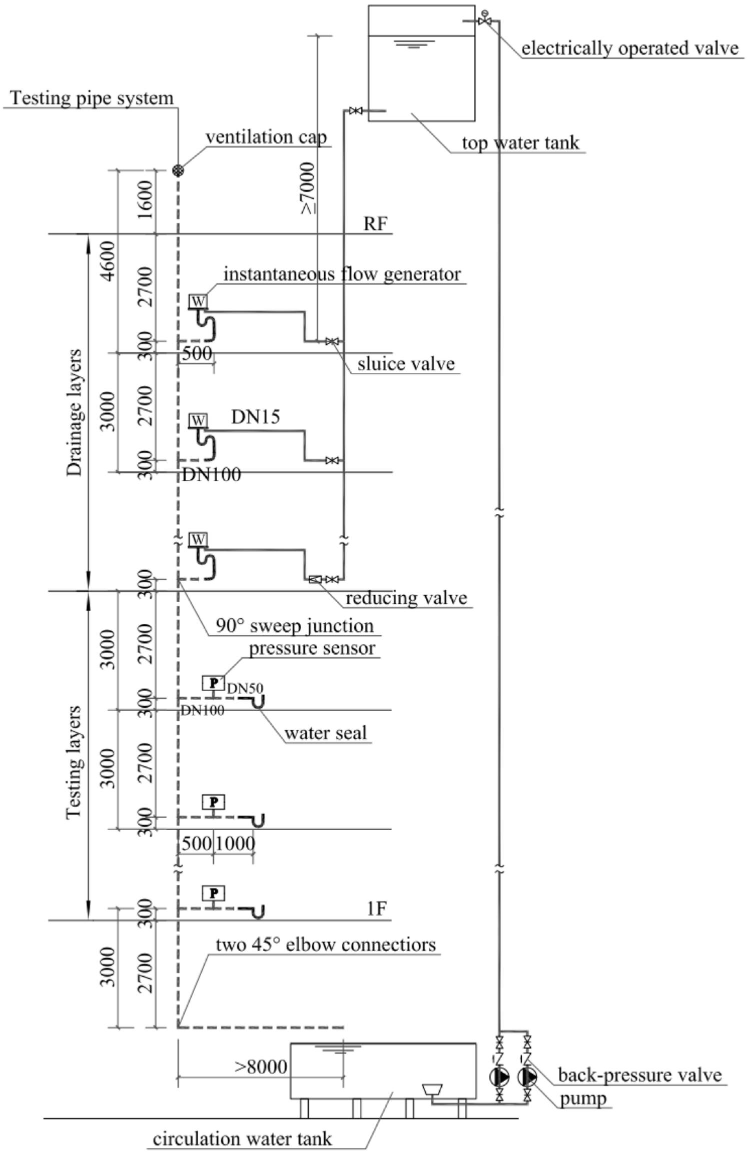

Figure 6 Pressure testing of instantaneous flow method

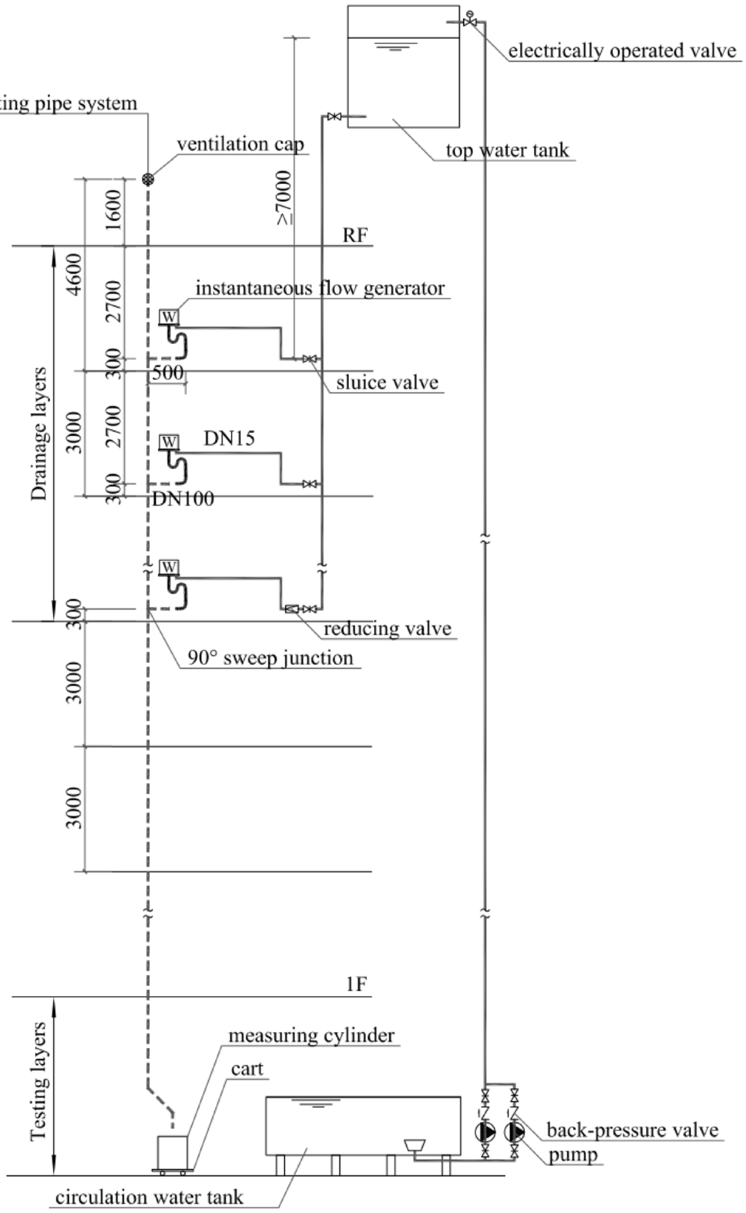

Figure 7 Aggregate flow testing (1)

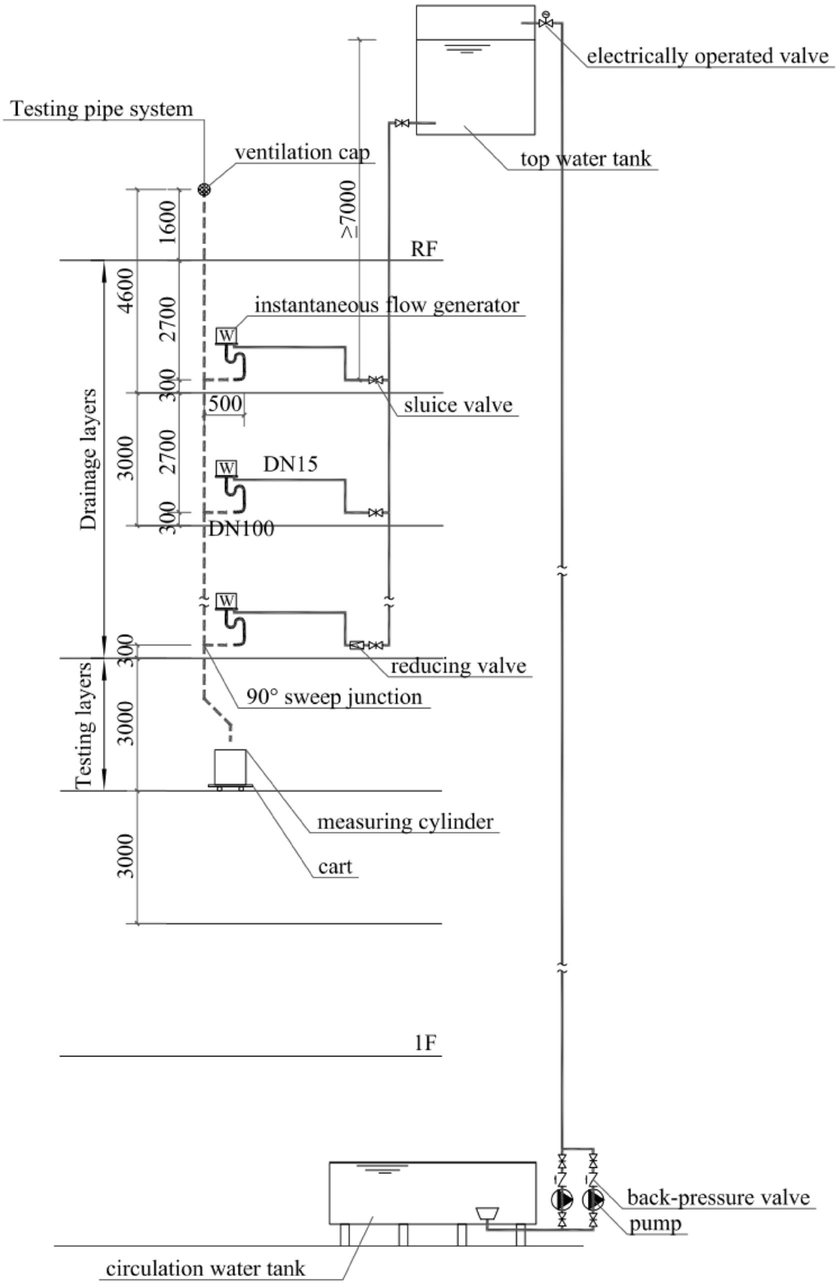

Figure 8 Aggregate flow testing (2)

4. Conclusions

Test for capacity of domestic residential drainage system should use a testing method which is based on the most unfavorable conditions and the pressure in the testing pipe system should break the judging standard. However, due to the existing techniques, we cannot take tracking and monitoring into actual projects. This Test Standard do experimental researches on both constant flow method and instantaneous flow method. Especially, we did a lot of basic researches on instantaneous flow method and partial adjustment the constant flow method combined with the current researches and development conditions. Finally, we take both the two test method in the Test Standard according to the testing results and applied range.

The capacity of drainage system in buildings has a crucial role and is an important parameter to guide the designers. Reasonable design will influence on comfort, experience feeling, and safety. Nowadays, odor-back-to-toilet occurs frequently, SARS in Taoda Gardens, Hong Kang, is the most extreme example which shocked the whole world.

Implementation of Test Standard will provide a standard for development of residential drainage system, and it is significant to improve the performance of drainage system, enhance the design of overall lever housing and the construction of water supply and drainage system, and improve people's livelihood.

5. Presentations of Authors

Zhao Zhenyi is a member of CNERC for Human Settlements. She has designed 4 construction designs for water supply and drainage system. She has been a member in the full scale experiments in the full scale experimental tower of housing performance for a long time in doing building drainage experiments.

Zhang Zhe is an Engineer of CNERC for Human Settlements. He is a member of the water supply and wastewater Association, ASC(Architectural Society of China),mainly engaged in building water supply and Drainage and health housing work. He completed construction work of experimental system for full scale experimental tower of housing performance, and will be responsible for operations.

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Research of Air−Pressure in Building Drainage System Under Windy Weather Conditions

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Abstract

In building water environment, the water seal in drainage system is important barriers to block poisonous gases and insects inside drains into the room. At present, the back smelly phenomena caused by water seal damage become common. In particular, most residents reflect the back smelly phenomenon of floor drain in the top layers of the building is serious, and it occurs more frequently in summer. Experiment was done in stack vent single vertical pipe system. At first, the experiment was done in special weather condition with instantaneous flow. This experiment showed that the biggest influence factor was the wind speed of the external environment. The influence range was the top floors of the building drainage system. After that, in common weather condition weather, use fan for simulating the windy weather condition, and study the air-pressure change in vertical pipe. By simulating different ventilation flow from the top of the vertical pipe and the angle of the wind, analyze and research the air-pressure change of each floor. After the experiment, found that installed a non-return valve on the top floor of the drainage system or properly reduce the top ventilate area of the vertical pipe could ease the influence from wind to the drainage system available.

Keywords

Building water environment; Windy weather; Stack vent; Steady flow; Pressure distribution; Ventilation flow.

1. Introduction

In drainage system, water-sealed joint is a kind of pipe attachment which could form the water seal, and is settled at the outlet of the sanitary apparatus or inside the sanitary apparatus (like toilets). Once the water seal is broken will cause the bubble up, overflow or slopping, and this will lead to the poisonous and smelly gas from the drainage system back into the room, and small insects climb inside the room, which will influence the indoor hygienic security.

Nowadays, the back smelly phenomena widely happened. Some residents reflect that in windy and rainy days, in other words in special weather conditions, the back smelly phenomenon was highlighted at the top of the high-rise buildings. This phenomenon was mostly happened in summer[1].

Special weather conditions included windy and rainy days. In special weather conditions, influence factors like wind, temperature, humidity and rainfall might cause this phenomenon inside the building drainage system. However, which factor will cause worse influence to the building drainage system, and where is the influence range to the building drainage system? Until now, there was no series of research about the above situations.

During truly special weather conditions, experimental tower had done drainage experiments with 2 toilets, and the drainage time interval was -3s. (Draiang time interval is -3s means that the lower floor drainage 3s before the higher floor.) After that, in the next day, with common weather condition, the experimental team did a serious of contrastive experiment.

As the special weather condition could not steady appear for a long time, so the target of the experiment during the special weather conditions was to find the influence factor and influence range to the building drainage system. After that, in common weather conditions, repeated the drainage experiments while imitating the biggest influence factor during the special weather conditions. Through the experiments, found the influence rule of that influence factor, and found the way to release or remove the influence from that factor to the drainage system.

2. Experimental System

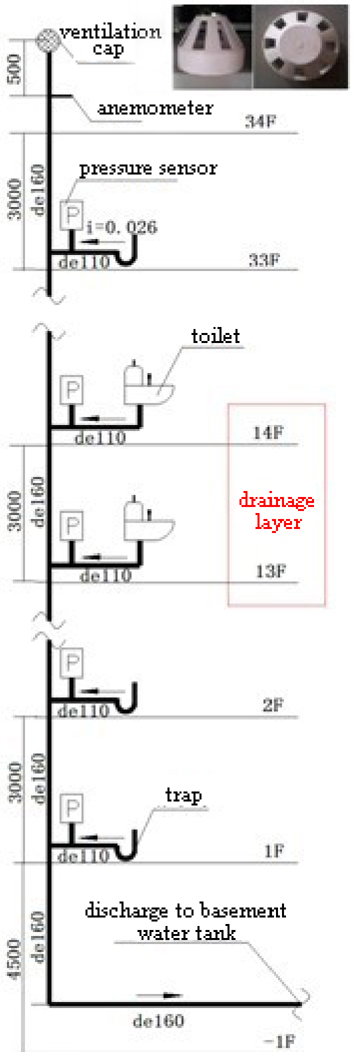
This experiment carried out in the research and development base of high rise building device system, China National Engineering Research Center for Human Settlements –Vanke building Research Centre(see figure 1). The drainage system experiment test system was self-designed, and could fully control the experiment in the central control room. In the experiment the staff controlled the electric control valve to drain water through the main control panel in the central control room, and the electromagnetic flowmeter would feedback the actual water discharge and maximum, minimum pressure data to the test interface.

Fig. 1 Super high-rise equal proportion experimental tower

3. Drainage experiments during special weather conditions

3.1 Experimental installation

The installation for the experiment is assembled by DN150 PVC-U single vertical transparent pipes with 90° three links. There are 33 of transverse branch pipes, the spaces between them are kept as 3.0m and the vertical distance between the lowest branch transverse pipes and general transverse pipe is 3.5m. The bottom of vertical pipe is connected with two of 45° of elbow pipes. The vertical pipe is set up vertically and the transverse pipes are set up according to standard slope i=0.026 toward to the vertical pipe while outlet pipe keeps its slope going to the reuse water tank in the basement. Drainage stack is set up well meeting the requirements of 4.6.10 and 4.6.15 of “The Code for Water Supply and Drainage Design” GB50015-2003 (2009 edition). The testing device is shown in figure 2.



Explaination:3F-12F,15F-32F
are the same as 1F.

Fig. 2 Schematic diagram of experiment installation

In this experiment, both 13th and 14th floor were installed with one toilet; other floors are installed with one trap. The lavatories were assembled by DN100 transparent pipes, and kept its slope toward the vertical pipe. Toilets used in this experiment was a kind of elongated piece toilet, with a siphon jet flushing methods, and its wash water for each time was 6L. Every toilet water seal was installed with a VEGA CAL63 type potentiometer type level gauge which has a range of 0 to 400mm, and its accuracy was ± 1mm.

In this study, the pressure change in the pipes was measured by pressure transmitter sewer system which is US GE DruckPTX610 (10KPa, PTX) Bi-type pressure transmitter. This kind of pressure transmitter has a measurement range of ± 10000Pa, and its measurement accuracy was ± 0.08%. The horizontal pipe of each floor in the drainage vertical pipe system was installed with a pressure transmitter, which was set at a distance of 500mm to the center of the vertical pipe, and above the horizontal pipe. The pressure transmitter was connected to the control cabinet by a wire, then collected and sent data to the server.

The anemometer (DEKTA OHM HD2937T02 type) in the text system was installed 620mm below the ventilation cap. Its measurement range is 0 ~ 20m/s, and its accuracy was 3%. Figure 3 shows the installation site of the anemometer. The experimental test system setup capture duration as 40s, and the acquisition cycle is 20ms. In order to obtain more stable data in the experiment, data analysis begin time is the 5th second, and the end time is the 30th second.

Fig. 3 Installation photo of the anemometer

3.2 Experimental methods

In this experiment, two toilets on the 13th and 14th layer drained. The drain interval is -3s. The experiment had a total of 3 times. The experiment in the exceptional weather conditions was recorded as test1 and test 2. The experiment in the normal weather conditions was recorded as test3. During the test, the anemometer below the ventilation cap collected current real-time wind speed, and transmit the data to the server. The server calculated the current vent flux in the vertical pipe in daemon, and drew real-time curve about the vent flux. At the meantime, the server recorded the real-time values of the pressure change of each layer measured by pressure transmitters.

3.3 Experiment results

The environment weather condition of experiment 1, 2, 3 could be seen in table 1. The weather data came from the weather station settled on the 32th layer. Experiment 1 and experiment 2 were done in special weather conditions, and experiment 3 was done in common weather condition.

Table 1 Experimental meteorological condition

Item No.	1	2	3
Environment temperature（℃）	25.1	24.8	28
Environment humidity（%RH）	92.5	93.3	82.4
Average wind speed in 2 minutes（m/s）	2.5	1.4	0.8

The maximum in experiment 1, 2, 3 was shown in figure 4. The floor which caused the maximum positive pressure and the negative pressure in each experiment was shown in table 2.

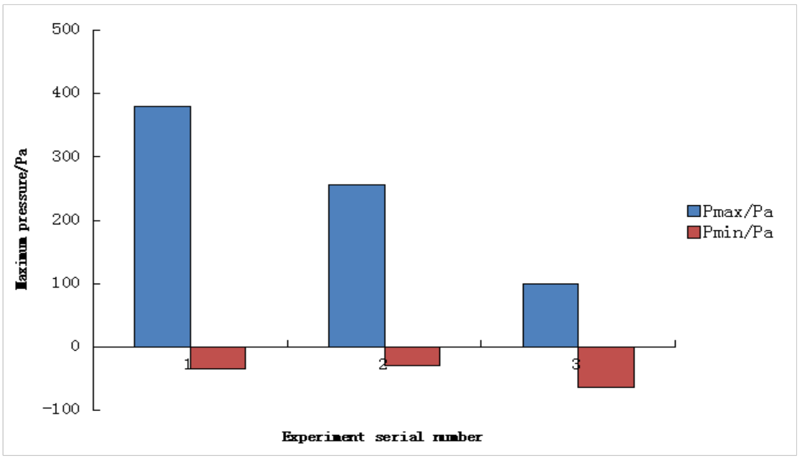


Fig. 4 Maximum positive and negative pressure in special weather condition

Table 2 Floor which caused the maximum and minimum pressure in special weather condition

No. Floor	Experiment 1	Experiment 2	Experiment 3
P_{max} floor/F	33	33	26
P_{min} floor/F	5	5	32

It was shown in figure 4 that with the decrease of the wind speed, the maximum positive and negative pressure of the drainage system was also decreasing. So we could say that wind speed was the biggest influence factor for the drainage system during the special weather conditions.

Table 2 showed that, in different weather condition, the maximum pressure and the minimum pressure could appear at the different floors. Also combined it with figure 4, we could find that, the wind mostly influence the building drainage system at the top range of the building drainage system.

4. Drainage Experiment with Fan Imitated the Windy Condition

As wind speed was the biggest influence factor to the building drainage system, in the following experiments, experimental team use fan to imitate the wind weather.

4.1 Experiment installation

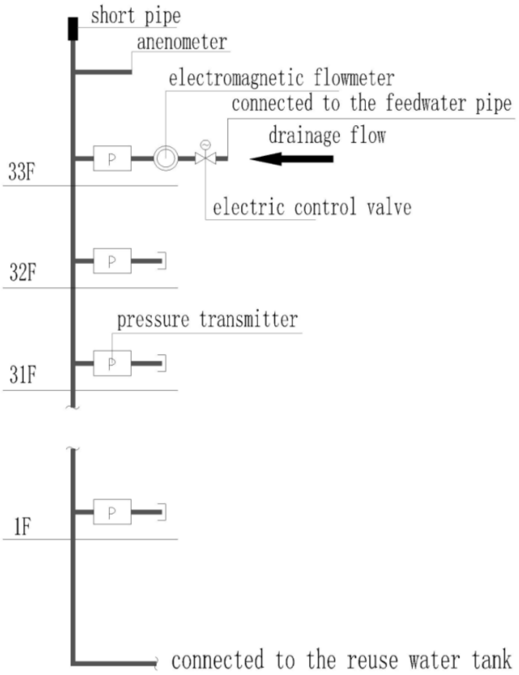


Fig . 5 Diagram of the drainage system

The installation for the experiment is assembled by DN150 PVC-U single vertical transparent pipes with 90° three links. There are 33 of transverse branch pipes, the spaces between them are kept as 3.0m and the vertical distance between the lowest branch transverse pipes and general transverse pipe is 3.5m. The bottom of vertical pipe is connected with two of 45° of elbow pipes. The vertical pipe is set up vertically and the transverse pipes are set up according to standard slope i=0.026 toward to the vertical pipe while outlet pipe keeps its slope going to the reuse water tank in the basement. The drainage vertical pipe stretches to the top of the building, and do not set the ventilation cap. Different diameters of short pipes were installed on the top of the vertical pipe in this experiment. Figure 5 shows the schematic of the drainage system.

In the experimental tower, set a steady flow drainage equipment included one electric control valve and one electromagnetic flowmeter on the 33th floor. The electric control valve used VAG-DURA-DN50 which was made in Germany. Its pressure rating was PN10, recommended flow was 0L/s ~ 3.0L/s, corresponding valve opening was 0% ~ 73%, maximum flow was 4.09 L/s, and with Schneider smart regulation with electric actuator SND-ZTD8T-18S. The electromagnetic flowmeter used optiflux4300C which was made in Cologne. Its measurement range was 0.3~12m/s and measurement accuracy was ±0.5%. Figure 6 shows the steady flow equipment.

The flow rate of the model of the fan used in the experiment was 3000~4800m/h, total pressure was 1032~900 Pa and rotation speed was 1420r/min. The blast pipe of the fan used 5 different angles connected to the top of the vertical pipe, the angles between fan duct outlet and the horizontal direction are 0° , 30° , 45° , 60° , 90° . Both the schematic diagram and the connection way of blast pipe and the vertical drainage pipe can be seen in figure 7. The variable diameter short pipes used in this experiment can be seen in figure 8. The installation of the short pipes on the top of the vertical pipe can be seen in figure 9.

Fig . 6 Steady flow drainage equipment

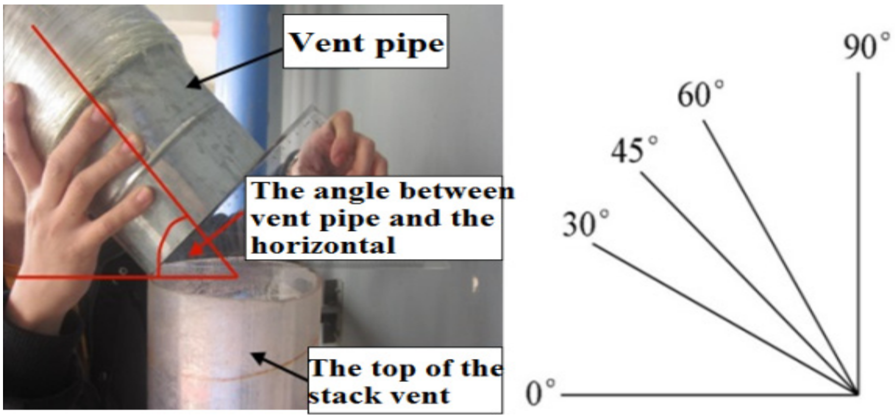


Fig . 7 Connection method of vent pipe and the vertical drainage pipe

Fig . 8 Variable diameter short pipes on the top of vertical pipe

Fig . 9 The installation diagram of variable diameter short pipes on the top of vertical pipe Experiment instrument

4.2 Experimental procedure

(1) Installed the test device, experimented on tightness test of the system, and verify the effectiveness of the steady flow installation.

(2) Experimented on different steady flow and variable diameter short pipes. The fan used 5 different angles to connect with the top of the vertical pipe.

(3) Analyzed the experimental results under different diameter short pipes, different connection ways and different flow.

In order to change the ventilation flow delivered by fan duct, used different diameter short vent ducts in this experiment.

The vent duct of the fan used 5 different angles connected to the vertical pipe in each diameter short pipes, the angles between vent duct and the horizontal direction are 0°, 30°, 45°, 60°, 90°. The fan delivered a certain amount of wind, the wind speed of the fan duct outlet is 9~11m/s, equivalent to the 5~6 levels of wind. The steady drainage flow increments of 0.5L/s to 2.5L/s by 0.5L/s. Carried out 3 parallel tests under each steady drainage flow, and calculated the average value of two of the tests as the test result.

4.3 Experimental results

4.3.1 Pressure situation within the drainage system

This experiment was using fans to simulate windy conditions; it carried out by changing the drainage flow, the angles between vent duct and the horizontal direction and the diameter of the short pipe on the top of the vertical pipe. Drained from 33F of the drainage system. The maximum pressure and the minimum pressure by changing the above-mentioned three conditions can be seen in figure 10 and figure 11.

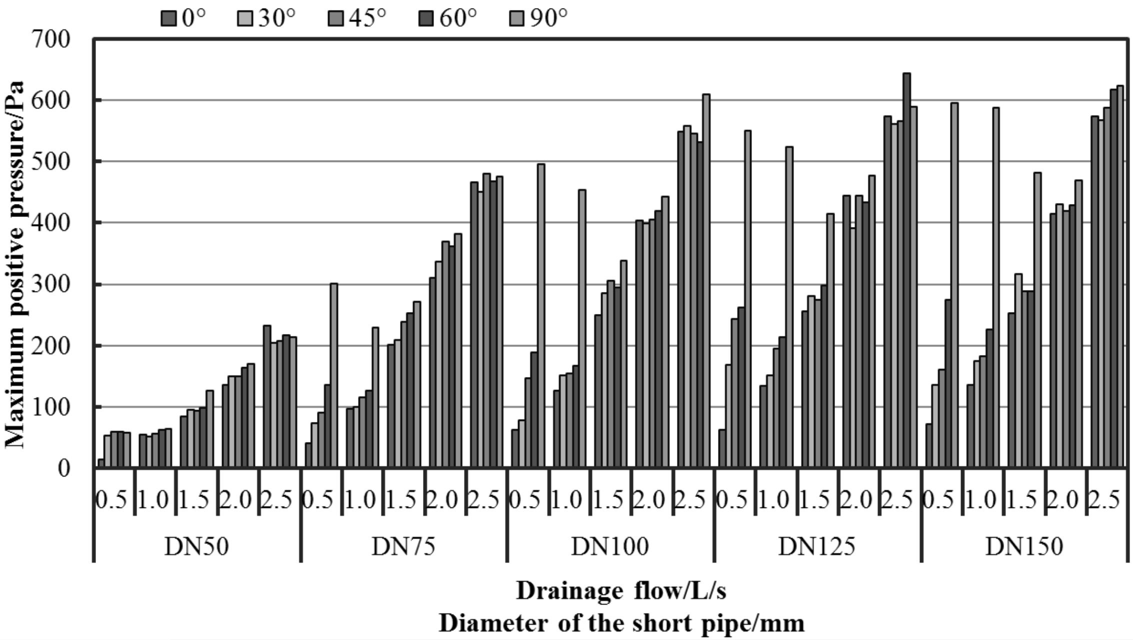


Fig. 10 Maximum negative pressure in the drainage system

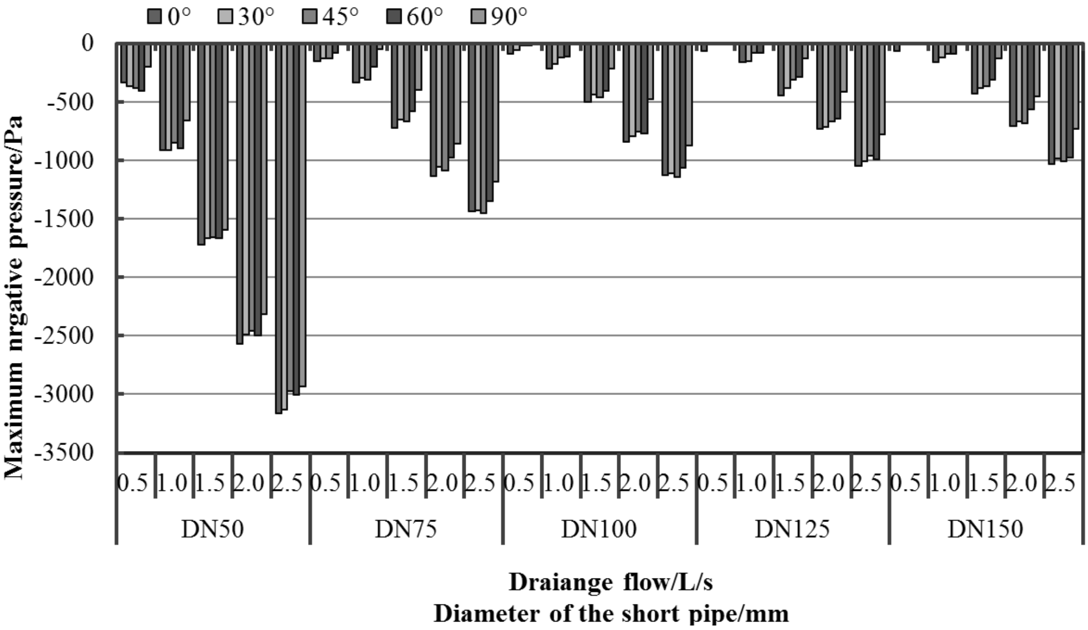


Fig . 11 Maximum positive pressure in the drainage system

Figure 10 and figure 11 show that the maximum positive pressure and negative pressure within the system would increase with the increase of the drainage flow for the same angle of vent pipe and the same short pipe's diameter. The maximum positive pressure is particularly large when the angle of vent pipe is 90°, i.e., vertical vent blown into the vertical pipe, especially for the low flow. This is because the maximum positive pressure appears on the top of the drainage system not at the bottom of the system. That is, these positive pressure values are caused by wind blowing.

Figure 10 and figure 11 show that the maximum positive pressure within the system would increase with the increase of the short pipe's diameter, and the maximum negative pressure within the system would decrease with the increase of the short pipe's diameter for the same angle of vent pipe and the same drainage flow. However, the maximum positive pressure for DN50 short pipe is much smaller than other short pipe diameters, and the maximum negative pressure is much larger than others. And the pressure values of DN75~DN150 these four kinds of short pipe diameters are very close.

The decision pressure value of water seal damage within the drainage system is ±400 Pa [6]. That is the water seal will be broken when the pressure is greater than +400 Pa or less than -400 Pa. Figure 10 and figure 11 show that the negative pressure value within drainage system is larger than positive pressure value, and negative pressure reaches more water seal damage. So the negative pressure is the main factor of water seal damage. According to the negative pressure analysis, the water seal damage of the drainage system is the most serious when using DN50 short pipe, DN75 second.

These two figures also show that the maximum positive pressure within the system would increase with the increase of the angle between vent duct and the horizontal direction, and the maximum negative pressure within the system would decrease with the increase of the angle between vent duct and the horizontal direction for the same the same drainage flow and the same short pipe's diameter.

Based on the above analysis, should reduce the drainage flow or appropriately increase the diameter to reduce the chance of water seal damage in the drainage system. It's better to increase the vent pipe's diameter on the top of drainage pipe and reduce the angle between vent duct and the horizontal direction, don't let wind vertically enter the vertical pipe or through large angle for windy weather. It's also better to install a check valve on the top of the vertical pipe. In order to reduce the positive pressure caused by windy weather, open the check valve when the positive pressure on the top of the vertical pipe is too large.

According to the before steady flow test conclusion [5] that the pressure within the drainage system cannot make the water seal easily be damaged after installing DN100 or DN125 short pipe on the top of the vertical pipe to reduce the ventilation area. It can be inferred that no matter whether it's steady flow or instantaneous flow, it's better to install DN125 short pipe on the top of the vertical pipe.

4.3.2 Ventilation flow on the top of the vertical pipe

This experiment measured the pressure of the horizontal branch pipe at each layer and the wind speed form the bottom of the short pipe 0.68m on the top of the vertical pipe. The test results can be seen in figure 12.

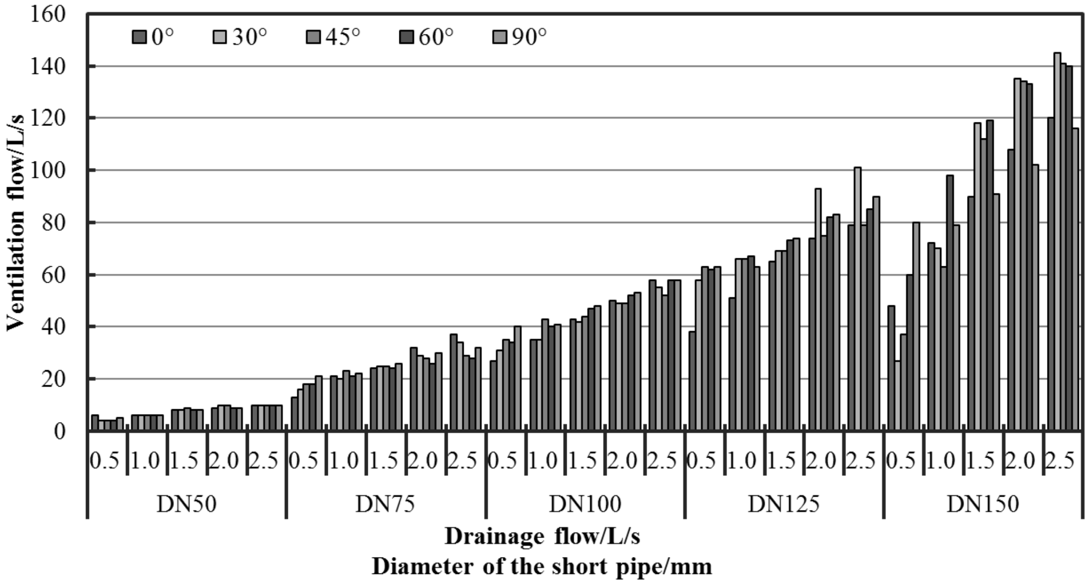


Fig . 12 Ventilation flow at the top of the vertical pipe

Figure 12 shows that the ventilation flow within the vertical pipe would increase with the increase of the short pipe's diameter and the ventilation area on the top of the vertical pipe. While the drainage flow within the vertical pipe increases, the ventilation flow within the vertical pipe also increases when the ventilation area at the top of the vertical pipe is certain. But the angle between fan duct outlet and the horizontal direction has little influence on the ventilation flow at the top of the vertical pipe. The ventilation flow will not change much when just change the wind-entry angle.

When the short pipe on the top of the vertical pipe is DN150, the ventilation flow for the wind-entry angle of 90° is smaller than other angles. It can be inferred that the ventilation flow is decreased because the large drainage flow at the top of the system can make a big nappe to prevent wind from vertically entering the vertical pipe.

The comparison between figure 10 to 12 shows that the maximum negative pressure would decrease with the increase of the ventilation flow, and the maximum positive pressure of the system would increase. But the drainage flow has the largest effect on the maximum positive and negative pressure value within the system.

Therefore, it's necessary to control the ventilation flow on the top of the vertical pipe for a certain drainage flow. The maximum negative pressure would decrease and the maximum positive pressure at the bottom of the vertical pipe would increase when the ventilation flow is large. It's necessary to find a suitable ventilation area which not only can reduce the negative pressure in the drainage system, but also can make the positive pressure in the drainage system does not exceed the broken value of water seal.

4.3.3 Wind speed of the horizontal branch pipe on the top of the vertical pipe

This set of fundamental tests is based on the installation of check valve at the horizontal branch pipe on the top of the vertical pipe.

This set of tests conducted at the horizontal branch pipe on 33 F which is the drainage floor. Made a 32 mm round hole in the middle of the horizontal branch pipe at the upper part which is 50 cm away from the vertical pipe, so that the outlet or inlet wind speed can be measured by anemometer at here. This can be seen in figure 13.

The positive value of wind speed in the figure mains blow air out of the horizontal branch, and the negative value of wind speed in the figure mains suction air into the horizontal branch. Since the value of wind speed exceeded the range of anemometer when the wind-entry angle was 90°, there was no data be recorded.

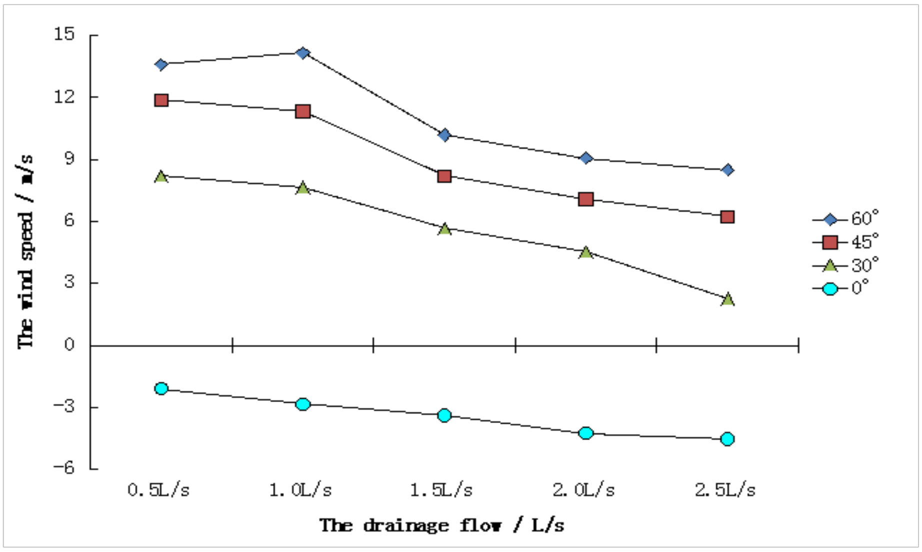


Fig . 13 Wind speed of horizontal branch pipe at 33 F

The figure 13 shows that the outward wind speed of horizontal branch pipe at 33 F would increase with the increase of the angle between vent pipe and the horizontal direction. And the outward wind speed would increase with the decrease of drainage flow. The large positive pressure at the top of the vertical pipe would be reduced by installing a check valve for windy weather.

5. Conclusions

(1) Compared with environment temperature and humidity, outside wind speed has the most serious influence to the high-rise building drainage system.

(2) In high-rise buildings, the bigger the outside wind speed, the bigger influence would cause to the drainage system. The influence range is mostly at the top of the vertical pipe.

(3) The maximum positive pressure and negative pressure within the system would increase with the increase of the drainage flow for the same angle of vent pipe and the same short pipe's diameter.

(4) The maximum positive pressure within the system would increase with the increase of the short pipe's diameter, and the maximum negative pressure would decrease for the same angle of vent pipe and the same drainage flow.

(5) The maximum positive pressure within the system would increase with the increase of the angle

between vent pipe and the horizontal direction, and the maximum negative pressure would decrease for the same the same drainage flow and the same short pipe’s diameter.

(6) The ventilation flow within the vertical pipe would increase with the increase of the short pipe’s diameter and the ventilation area on the top of the vertical pipe. While the drainage flow within the vertical pipe increases, the ventilation flow within the vertical pipe also increases when the ventilation area at the top of the vertical pipe is certain.

(7) It’s better to reduce the chance of water seal damage in the drainage system by reducing the drainage flow or appropriately increase the diameter. It’s better to increase the vent pipe’s diameter on the top of drainage pipe and reduce the angle between vent pipe and the horizontal direction, don’t let wind enter the vertical pipe vertically or through large angle for windy weather. It’s also better to install a check valve on the top of the vertical pipe. In order to reduce the positive pressure caused by windy weather, open the check valve when the positive pressure on the top of the vertical pipe is too large.

(8) It can be inferred from this experiment that no matter whether it’s steady flow or instantaneous flow, it’s better to install DN125 short pipe on the top of the vertical pipe.

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7. Presentations of Authors

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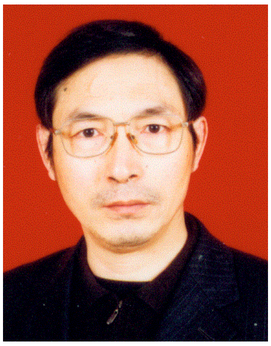

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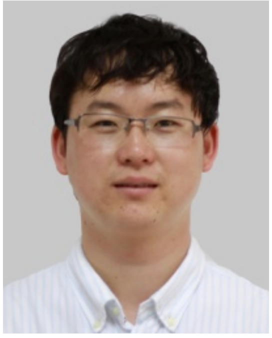

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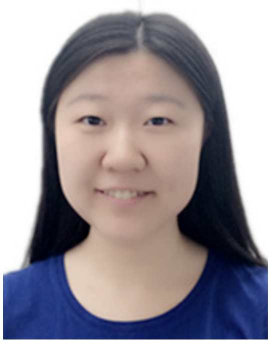

Drainage Performance Evaluation of an Apartment House Drainage System with a Nursing Care Pump−to−flush Toilet Applied thereto

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Abstract

The study looks at a toilet system with a pump-to-flush function, which can be placed at the bedside, and examines the applicability of the toilet system to drainage systems of apartment houses by evaluating the drainage performance of a piping system model with the toilet system incorporated therein.

First, in the piping system model in which a nursing care pump-to-flush toilet and other types of sanitary fixtures are connected to respective horizontal fixture drain branches in a dedicated section of an apartment house, pressure variations in the horizontal fixture drain branches and variations in the sealing condition of the fixture traps are identified as wastewater is drained from each fixture. Next, in the piping system model in which the horizontal fixture drain branches are connected to a drainage stack in a common section of the apartment house, the variation of pressure in the horizontal fixture drain branches and the influence of said pressure variation on the sealing water of the fixture traps are examined. The findings obtained are then used for discussing the applicability of said toilet system to apartment houses.

Keywords

Pump-to-flush toilet system, bathtub, hand wash basin, washbasin, combined draining, apartment house

Introduction

In recent years, Asian countries including Japan and China have been faced with the serious problem of a rapidly aging society. Fig. 1 illustrates the ratio of the elderly to the total population of Japan and China. It is estimated that by 2050, the ratio of the elderly aged 65 and over will reach 35.6% in Japan and 25.6% in China; both countries will have a society in which 1 in 3 to 4 is an elderly person. This also means the creation of serious social issues in terms of the increasing number of care recipients, and increasing mental and physical burdens on both care recipients and their carers. Meanwhile, as shown in Fig. 2, it has been revealed that excretion care is a most burdensome task of nursing care at home. This is because bowel movements are irregular and frequent in the elderly, and they lack the ability to control their bowel movements.

There are expectations for the development and practical application of hygienic and highly user-friendly bedside toilets; tools for easing burdens on care recipients and their carers by assisting care recipients with daily toilet activities. Fig. 3 shows a portable toilet provided at a nursing home in China. There are problems with this arrangement from both the carer's and the care recipient's viewpoints in terms of bad odour and sewage disposal; in reality, it imposes a rather unpleasant task on the carer and imposes a sense of restriction on the care recipient as to how much to eat in order to lighten the unpleasant task for the carer. In response, a nursing care pump-to-flush toilet has been developed, as shown in Fig. 4. As illustrated in Fig. 5, the nursing care pump-to-flush toilet discharges sewage by means of a pressure pump, and is easy to install in a variety of locations. The nursing care pump-to-flush toilet does not cause bad odour at all, which is associated with portable toilets.

In pursuit of the practical application of an easy-to-install, bedside toilet system with a pump-to-flush function to apartment houses, this study evaluates drainage performance by using a piping system model that simulates an actual drainage system with said toilet system incorporated therein. The simulation results will contribute to clarifying the following points:

(1) Evaluation of the influence of the pump-to-flush toilet on other types of sanitary fixtures within the same drainage system and the drainage performance of the horizontal fixture drain branches to which the toilet and the other fixtures are connected.

(2) Evaluation of the influence of the pump-to-flush toilet on the drainage performance of the drainage stack to which the toilet is connected.

(3) Verification of the safety and applicability of the pump-to-flush toilet, on the basis of (1) and (2), when installed to an apartment house drainage system.

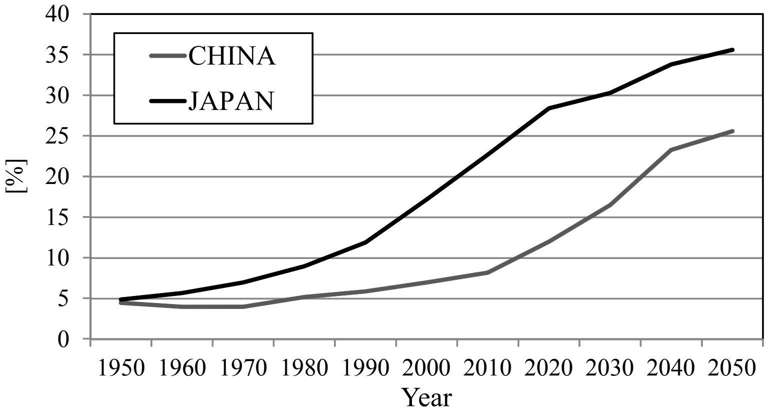


Fig. 1 The ratio of the elderly to the total population of Japan and China

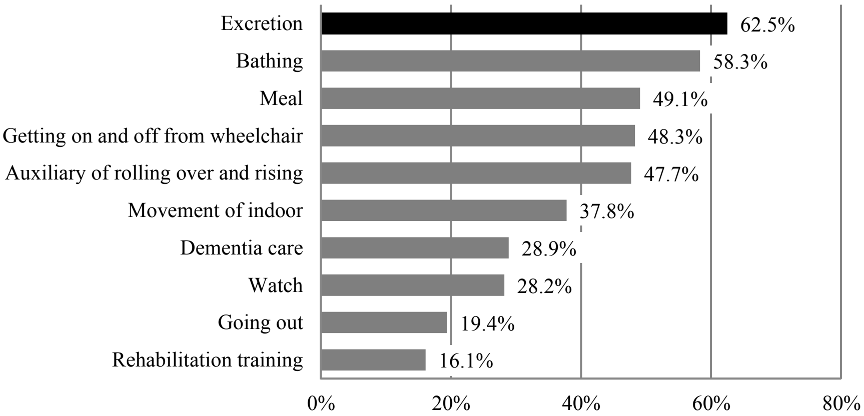


Fig. 2 Problems encountered during nursing care at home

Fig. 3 Portable toilet at a nursing home in China - example

Fig. 4 Nursing care pump-to-flush toilet - example

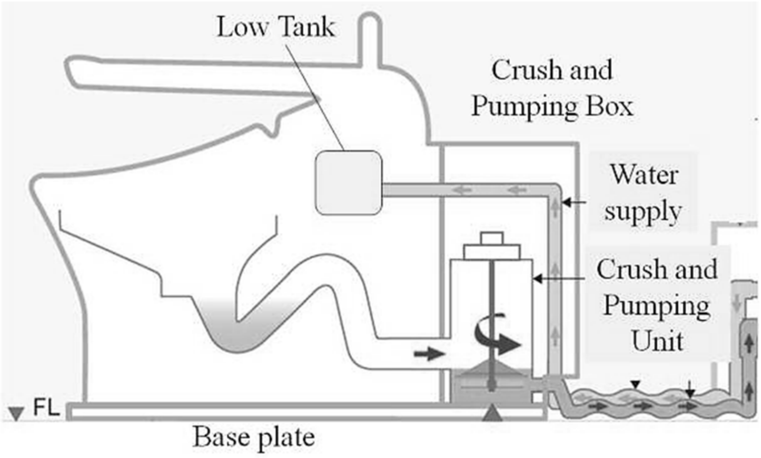


Fig. 5 Schematic image of the nursing care pump-to-flush toilet

1. Experiment overview

The experiment breaks down into two experiments; a horizontal fixture drain branch performance experiment and a drainage stack performance experiment. The former assumes a configuration in which a nursing care pump-to-flush toilet and other types of sanitary fixtures are connected to respective horizontal fixture drain branches in a dedicated section of an apartment house, and examines how the drainage from the fixtures affects the pressure in the horizontal fixture drain branches and the sealing water of the fixture traps. Meanwhile, the latter assumes a configuration in which the horizontal fixture drain branches are connected to a drain stack installed in a common section of the apartment house, and evaluates the drainage performance in the same manner as in the former experiment.

1.1 Experimental drainage system

Experimental sanitary fixtures are connected to respective horizontal fixture drain branches. The types of sanitary fixtures include 5.5L pump-to-flush toilets (hereinafter referred to as 'BFT'), 6.0L gravity water-saving toilets (hereinafter referred to as 'Tg'), washbasins (hereinafter referred to as 'L'), washing machines (hereinafter referred to as 'WM'), bathtubs (hereinafter referred to as 'B') and hand wash basins (hereinafter referred to as 'Wh'). Table 1 shows the drainage characteristic values of the experimental sanitary fixtures, and Fig. 6 shows the flow rate curves of the fixtures.

Table 1 Fixture drainage characteristic values

Fixture	Drainage discharge	Average drainage time	Average flow rate	Max flow rate
	W[L]	td[sec]	qd'[L/s]	qmax[L/s]
BFT	5.4	8.2	0.4	0.4
Tg	6.0	1.5	2.4	3.2
L	5.6	5.9	0.6	0.6
WM	39.5	27.7	0.9	1.0
B	145.8	94.9	0.9	1.5

(Note) BFT: pump-to-flush toilet WM: washing machine Tg: gravity water-saving toilet
B: bathtub L: washbasin

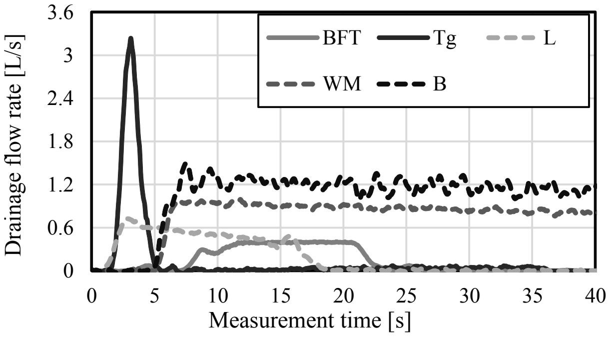


Fig. 6 Fixture flow rate curves.

(1)Horizontal fixture drain branch system

Fig. 7 shows the detailed configuration of the experimental horizontal fixture drain branch system on the assumption that the system is accommodated in a dedicated section of an apartment house. The system comprises four subsystems; a pump-to-flush toilet and a hand wash basin, a gravity toilet, a washing machine and a washbasin, and a bathtub. The drainpipes of these subsystems are connected through respective drain headers to a drainage stack. A flexible, metal pipe (length 2m) extends from the pump-to-flush toilet and connects to a polybutene pipe (pipe diameter 20A, length 16m) which connects to the merging section between the pump-to-flush toilet and the hand wash basin. The piping has no pitch under the floor. Meanwhile, the other subsystems are plumbed using rigid polyvinyl chloride pipes; a pipe diameter of 75A and a pitch of 1/100 for the gravity toilet system, and similarly, 50A and 1/50 for the washing machine/washbasin system, 40A and 1/50 for the hand wash basin system, and 50A and 1/50 for the bathtub system. Incidentally, Fig. 8 shows how the experimental fixtures are connected to the respective horizontal fixture drain branches.

(2)Drainage stack system

Fig. 10 is a schematic diagram of the experimental drainage stack system on the assumption that the system is accommodated in a common section of an apartment house. The initial evaluation assumes a low, four-storey apartment house, and the 2nd to 4th floors are provided with horizontal fixture drain branches which are installed as shown in Fig. 7. The stack system employs a stack vent system. Rigid polyvinyl chloride pipes are used for the drainpipes. The drainage stack has a pipe diameter of 100A, the horizontal fixture drain branches have a pipe diameter of 125A, and the pipe diameter at the connected area of the drainage stack and each horizontal fixture drain branch is 75A. The drainage stack system is also provided with a house drain which has a total length of 7.6m when measured from the centre of the stack, has the first horizontal bend 2.9m away from the centre of the stack, and then extends 4.7m linearly before its end opens into the atmosphere.

1.2 Drainage load patterns

(1)Horizontal fixture drain branch performance experiment

Table 2 shows the drainage load patterns that are applied in the horizontal fixture drain branch performance experiment. The draining from the pump-to-flush toilet is set as a reference, and draining is carried out from a maximum of five fixtures, individually or in a combined manner. In the case of combined draining, different fixtures have different drain times and are installed at different distances from the drainage stack, as illustrated in Fig. 7, and therefore, rather strict conditions are applied and a time lag is set so that the heads of drainage flows from multiple fixtures reach the drainage stack at the same time. To be more precise, with reference to the drainage load patterns in Table 2, the pump-to-flush toilet is flushed first, then the gravity toilet is flushed and the washbasin is drained (4 seconds later), followed by draining the washing machine (3 seconds later), and finally, the bathtub is drained (6 seconds later). In addition, the drainage load patterns involving the toilets contain clean water and/or an experimental waste substitute. As shown in Fig. 9, the experimental waste substitute comprises six pieces of 2-ply paper, each of which is in a length of 1m and folded three times, which are layered together. The waste substitute is placed in the toilet bowl, soaked in the water for 15 seconds and then flushed away.

(2)Drainage stack performance experiment

During the drainage stack performance experiment, in addition to the drainage load patterns No.1-15 in Table 2, the drainage load patterns shown in Table 3 are also applied. Similar to the horizontal fixture drain branch performance experiment, draining is carried out with reference to the draining from the pump-to-flush toilet, which is installed on the 4th floor. The time lag is also set, similar to that described in 1.2 (1), for draining from the fixtures connected to the horizontal fixture drain branches. The timing of draining from the fixtures on the 4th and 3rd floors and the fixtures on the 4th and 2nd floors is: 0 sec., 1 sec., 2 sec., 3 sec., 4 sec., and 5 sec., in this order, after the drainage flow from the 4th floor reached the stack, and a time lag test is conducted to calculate the largest time difference at which the pressure variation in the stack (system minimum value Psmin) reaches a maximum.

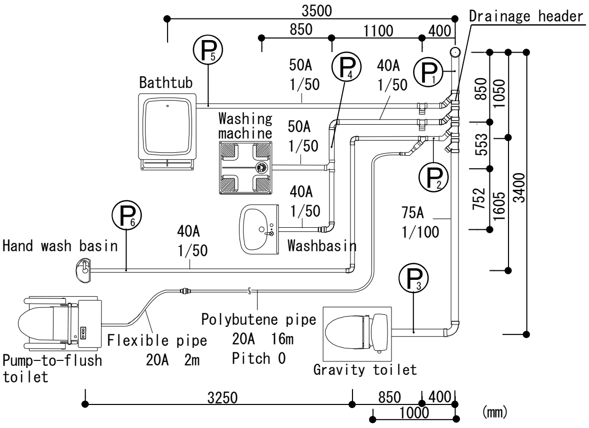


Fig. 7 Experimental horizontal fixture drain branch system

Table 2 Drainage load

	Pattern No.	BFT	Tg	B	WM	L
Individual draining	No.1	○				
	No.2		○			
	No.3			○		
	No.4				○	
	No.5					○
Combined draining	No.6	○	○			
	No.7	○		○		
	No.8	○			○	
	No.9	○				○
	No.10	○	○	○		
	No.11	○	○		○	
	No.12	○	○			○
	No.13	○		○	○	
	No.14	○		○		○
	No.15	○	○	○	○	

○: fixture subjected to testing

(Note) Drainage time lag: the pump-to-flush toilet followed by the other fixtures

Tg: 4sec., B: 6sec., WM: 3sec., L:

Fig. 8 Experimental horizontal drain branch system

Fig. 9 Experimental waste substitute

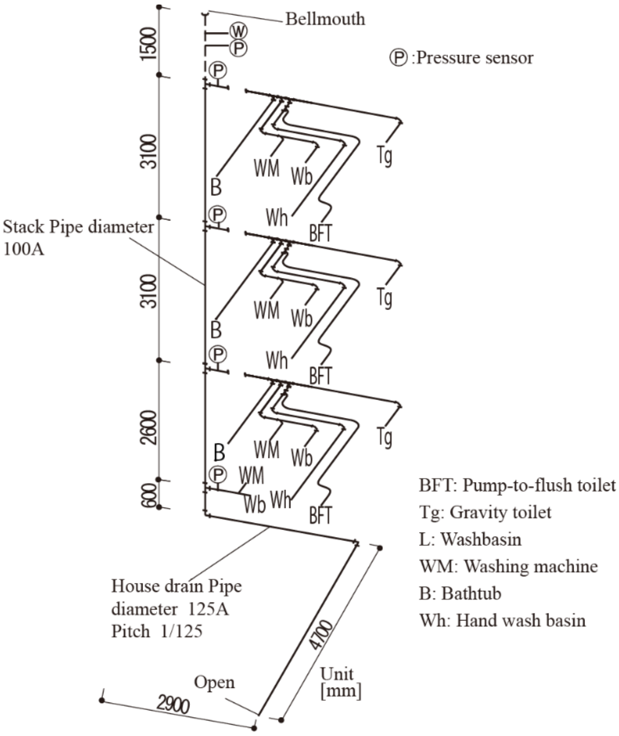


Fig. 10 Experimental drainage stack system

Table 3 Drainage load patterns

Pattern No.	Floor	BFT	Tg	B	WM	L
No.16	4	○				
	3	○				
	2					
No.17	4	○				
	3					
	2	○				
No.18	4	○	○			
	3	○				
	2					
No.19	4	○	○			
	3	○	○			
	2					
No.20	4	○	○			
	3					
	2	○	○			
No.21	4	○	○		○	
	3	○				
	2					
No.22	4	○	○	○	○	
	3	○				
	2					
No.23	4	○	○		○	
	3	○	○			
	2					
No.24	4	○	○		○	
	3	○	○		○	
	2					
No.25	4	○	○	○	○	
	3	○	○			
	2					
No.26	4	○	○	○	○	
	3	○	○	○		
	2					

○: fixture subjected to testing

1.3 Items to measure and measurement methods

Table 4 lists the items to measure and the methods for measuring the items. Meanwhile, Table 5 shows the details of the fixture traps used for the experiments.

Table 4 Items to measure and measurement methods

Item	Unit	Method	Reference Value
Pressure variation in the drainpipe P	[Pa]	Pressuer sensor in Fig.5 and 6	±400Pa according to SHASE-S 218
Fixture trap seal water loss ⊿h	[mm]	Visual measurement	½ of the depth of each trap

Table 5 Traps used for the experimental sanitary fixtures

Trap type	Toilet trap	Floor trap		S trap	
Fixture	Gravity toilet	Bathtub	Washing machine	Wash basin	Hand wash basin
Photo					
Leg cross-section ratio		0.88		0.83	
Seal water depth	55mm	50mm		100mm	
Reference value	27.5mm	25mm		50mm	

2. Results and discussion

2.1 Horizontal fixture drain branch performance experiment

(1)Pressure variations in the horizontal fixture drain branches
The pressure was measured at measuring points P1-P5 shown in Fig. 7. The minimum values, Phmin, and the maximum values, Phmax, of fixture systems, other than the fixture systems used for drainage load testing, were obtained, and the maximum values among these values were defined as the minimum system value, Phsmin, and the maximum system value, Phsmax, of the horizontal fixture drain branches, as shown in Fig. 11. Phsmin was 16 to 68Pa and Phsmax was 11 to 272Pa when only clean water was drained, and Phsmin was 26 to 101Pa and Phsmax was 13 to 175Pa when clean water and the waste substitute were drained together. It turned out that in both cases, these values were all within the reference range of ±400Pa. This outcome suggests that when installed in the dedicated section of the apartment house, combined draining from four fixtures (the pump-to-flush toilet, the gravity toilet, the bathtub and the washing machine) hardly affects the pressure in the horizontal fixture drain branches and is not likely cause any problem. Moreover, it was also observed that the pressure variation in the horizontal fixture drain branches was likely to become greater as the number of fixtures for combined draining increased. However, the pressure values which were measured when combined draining was applied from three fixtures (the pump-to-flush toilet, the bathtub and the washbasin) (pattern No. 14), were very similar to the pressure values which were measured when simultaneous draining was applied from two fixtures. This relates to whether or not the merging sections in the horizontal fixture drain branches become completely full. It is inferred that even when a large amount of water is drained from the bathtub, if it is combined with small amounts of water drained from the pump-to-flush toilet and the washbasin, the combined draining does not fill up the horizontal fixture drain branches, thus, not causing too much variation in the pipe pressure.

Furthermore, among the drainage load patterns in Table 2, with the exception of individual draining from the gravity toilet (pattern No. 2), combined draining from the pump-to-flush toilet and the washbasin (pattern No. 9), and combined draining from the pump-to-flush toilet, the gravity toilet and the washbasin (pattern No. 12), it was found that all the Phsmax values were measured higher when clean water and the waste substitute were drained together than when only clean water was drained. This suggests that the horizontal fixture drain branches were blocked somewhat by the water-waste mixture, and the suction action increased slightly. Phsmax was often measured at P5 near the washbasin, and it is considered that the draining of the experimental waste substitute from the pump-to-flush toilet slowed down the flow velocity slightly, thus suppressing the generation of positive pressure.

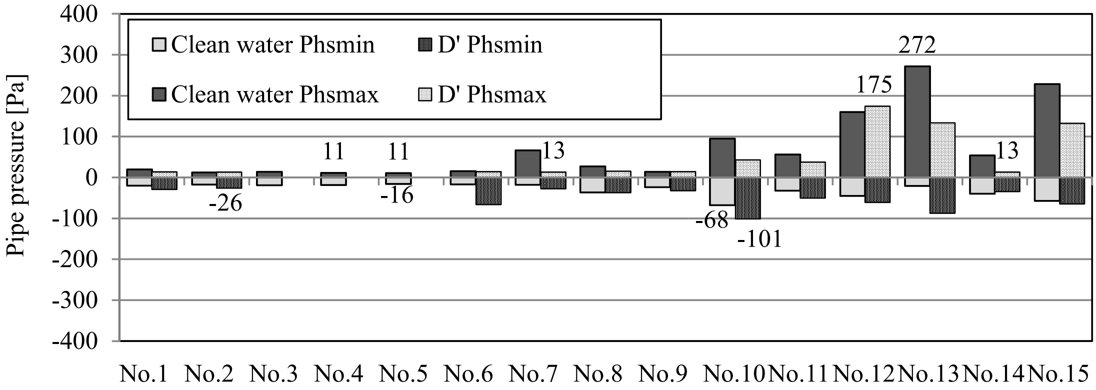
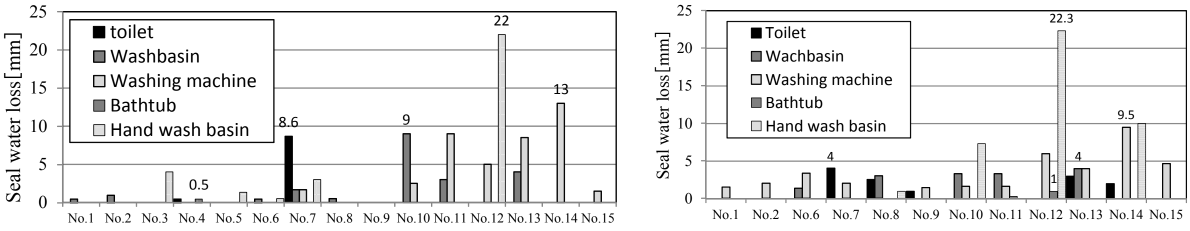


Fig. 11 Pressure variations in the horizontal fixture drain branches (No.1-No.15 refer to Table 3)

(2)Loss of trap seal water

Fig. 12 shows seal water losses in the respective fixture traps, ⊿h, measured during the horizontal fixture drain branch performance experiment. With all the drainage load patterns applied, the seal water in the respective traps was lost by more than half of 50-100mm, but there was no incident during the experiment where any trap broke suddenly. The comparison of (1) and (2) in Fig. 12 indicates that as shown in Fig. 11, in the case in which positive pipe pressure was generated to a significant level when clear water was drained from the pump-to-flush toilet at the same time, in combination, from the bathtub, the gravity toilet and the bathtub, the gravity toilet and the washing machine, or the bathtub and the washbasin, the seal water loss was also likely to increase more than when the water-waste mixture was applied.



(1)Clean water (2)Clean water and waste substitute

Fig. 12 Loss of seal water in the traps(toilet 55mm, bathtub and washing machine 50mm, washbasin and hand wash basin 100mm)

2.2 Drainage stack performance experiment

(1)Pressure variation in the stack

The pipe pressure was measured using the pressure sensor Ⓟ at multiple points as shown in Fig. 10. Among the obtained Pmin and Pmax values, the maximum values are defined as the minimum system value, Psmin, and the maximum system value, Psmax, respectively, of the drainage stack.

The time lag test revealed that after the drainage from the fixtures on the 4th floor flowed into the stack, Psmin reached the highest level in 1 second on the 3rd floor and in 3 seconds on the 2rd floor, and therefore, the combined draining tests were carried out on the stack on the basis of the obtained time lag.

The drainage load patterns No. 1-26 listed in Tables 2 and 3 were applied, and as shown in Fig. 13, the minimum system value, Psmin, per pattern and per drainage content, was identified from the Pmin values measured on the respective floors. The reference value was exceeded only when pattern No. 26 was applied using seven fixtures, i.e., when the water-waste mixture was drained from the pump-to-flush toilet, the gravity toilet, the bathtub and the washing machine on the 4th floor, and subsequently from the pump-to-flush toilet, the gravity toilet and the bathtub on the 3rd floor. This confirms that the pressure variation in the stack is not affected greatly by simultaneous draining of the water-waste mixture from a maximum of six fixtures even when the fixtures are installed on two consecutive floors, i.e., when the pump-to-flush toilets, the gravity toilets and the washing machines on the 4th and 3rd floors are flushed and drained (pattern No. 24) in a combined manner, and when the pump-to-flush toilet, the gravity toilet, the bathtub and the washing machine on the 4th floor are flushed and drained followed by flushing the pump-to-flush toilet and the gravity toilet on the 3rd floor (pattern No. 25). Moreover, in Fig. 13, pattern No. 15, where the pump-to-flush toilet, the gravity toilet, the bathtub and the washing machine on the 4th floor were used for combined draining, and pattern No. 24, where the pump-to-flush toilets, the gravity toilets and the washing machines on the 4th floor and the 3rd floor were flushed and drained, each indicate a significant Psmin difference between when clean water was applied and when the water-waste mixture was applied. Meanwhile, pattern No. 20, where the pump-to-flush toilets and the gravity toilets on the 4th floor and the 2rd floor were flushed, indicates Psmin with clean water being greater than Psmin with the water-waste mixture, which is a reverse case to most of the others, and pattern No. 26, where seven fixtures were used for combined draining, indicates Psmin exceeding the reference value. Fig. 14 shows distributions of pipe pressure values measured on the respective floors when these patterns were applied, according to which the Psmin characteristics, as explained above, are evident around the 2rd level. This suggests that no matter from which floor a drainage load is applied, drainage from multiple horizontal fixture drain branches flows into the stack around the 2rd floor level in a concentrated manner, thus, pulling the air in the stack before dispersing, and this behaviour causes the negative pressure to increase to a maximum on the 2rd floor but decrease to almost nothing around the 1st floor level. Meanwhile, Psmax in the drainage stack is approximately 9.3-120.0Pa which is not considered to be problematic.

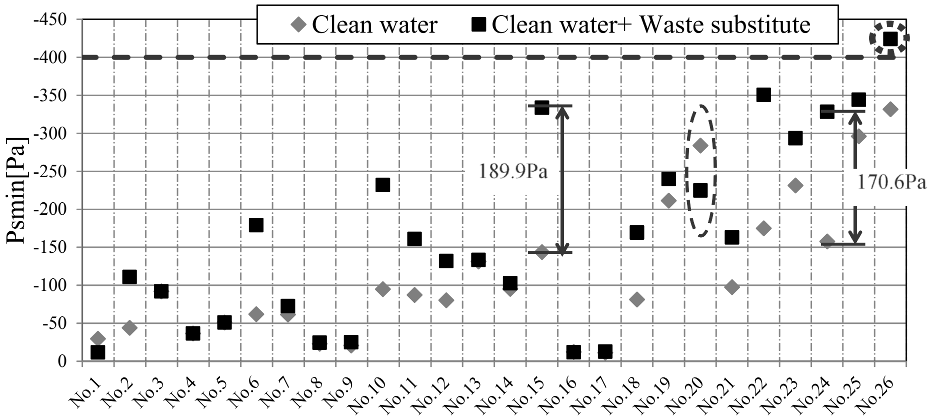
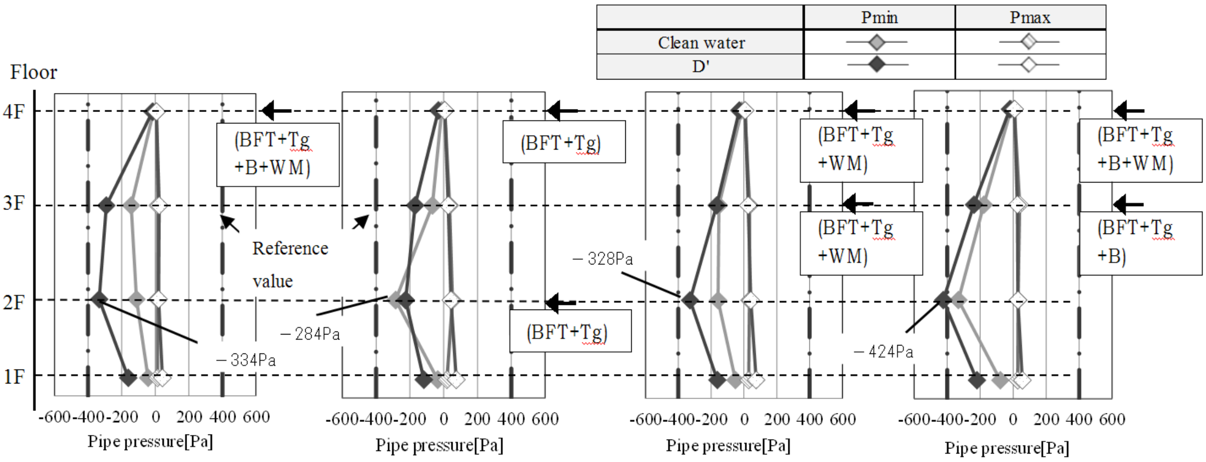


Fig. 13 Psmin values in relation to the drainage load patterns



(1) No.15 (2) No.20 (3) No.24 (4) No.26

Fig. 14 Drainage stack pressure distributions

(2) Loss of trap seal water

Pattern No. 26 refers to combined draining from seven fixtures, which creates the largest drainage load, i.e., the pump-to-flush toilet, the gravity toilet, the bathtub and the washing machine on the 4th floor are flushed and drained, and the pump-to-flush toilet, the gravity toilet and the bathtub on the 3rd floor are flushed and drained subsequently. Fig. 15 compares the seal water losses in the traps and Psmin which were measured on each floor when pattern No. 26 was applied. The seal water loss values, ⊿h, during the drainage stack performance experiment also indicate that the seal water of each trap was lost by more than half of its depth. This suggests that simultaneous draining from a maximum of seven fixtures on two consecutive floors is not likely to cause any problem in terms of seal water loss. As for the pressure variation in the drainage stack, Psmin is 220Pa and the seal water loss of the hand wash basin is 7mm on the first floor, and Psmin is 238Pa and the seal water loss of the hand wash basin is 13.3mm on the 3rd floor. The link between the two confirms that among the experimental fixtures, the hand wash basin, which is connected to the pump-to-flush toilet system, is most likely to be affected by the pressure variation in the drainage stack. Therefore, attention is required for prevention of an induced siphon action.

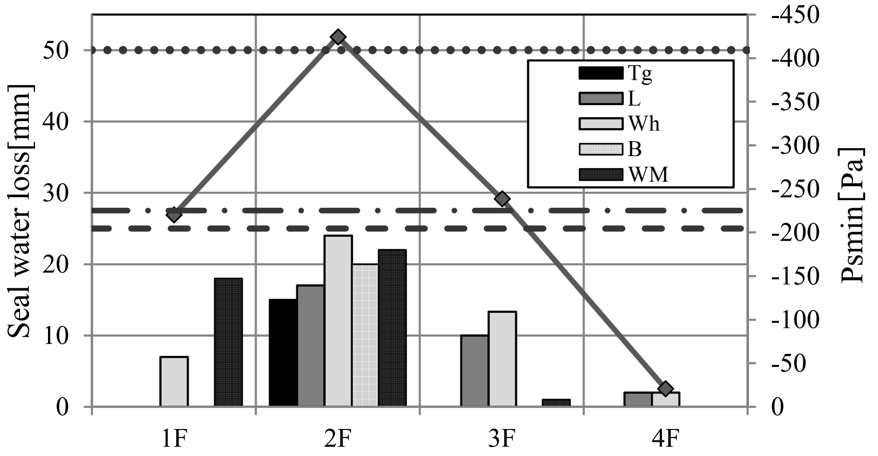


Fig. 15 Seal water losses and Psmin per floor in the case of No.26

3. Conclusion

By using a toilet with a pump-to-flush function, drainage performance experiments were carried out on horizontal fixture drain branches and a stack, and subsequently, the following have become clear:

(1) The drainage performance evaluation of the horizontal fixture drain branch system indicates that combined draining from 1 to 4 sanitary fixtures does not cause any problem. However, in the case in which a hand wash basin is connected to a pump-to-flush toilet system, the loss of trap seal water is significant and therefore, the hand wash basin is likely to be affected by the variation of pipe pressure. During the experiment, the variation of pipe pressure was measured to be 101Pa to 272Pa, and the maximum losses of trap seal water are: approximately 8.7mm in the toilet trap, approximately 4.7mm in the floor trap, and approximately 22.3mm in the S trap, yet these values remained within the reference range.

(2) The drainage performance evaluation of the drainage stack system of a low apartment building indicates that combined draining from approximately six fixtures, which may be installed on two consecutive floors, does not cause any problem. However, in the case of combined draining from seven or more fixtures, there is a risk that the variation of pipe pressure exceeds a reference value of 400Pa, and therefore, attention is required. During the combined draining experiment using six fixtures, the variation of pipe pressure was measured to be approximately 350Pa to 120Pa. Meanwhile, the losses of trap seal water, when combined draining was applied from seven fixtures, were: approximately 15mm in the toilet trap, approximately 22mm in the floor trap and approximately 24mm in the S trap, which all remained below the reference value.

(3) On the basis of the above findings, unless a pump-to-flush toilet, a gravity toilet, a bathtub and a washing machine on an upper floor and a pump-to-flush toilet, a gravity toilet and a bathtub on a lower floor are flushed and drained all at the same time, the variation of pipe pressure and the loss of trap seal water are not likely to exceed the reference values thereof, and therefore, it is considered to be safe to install nursing care pump-to-flush-toilets, which are similar to those used for the experiments, to the drainage stack of an apartment house which is similar to that used for the experiments.

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5. Presentation of Authors

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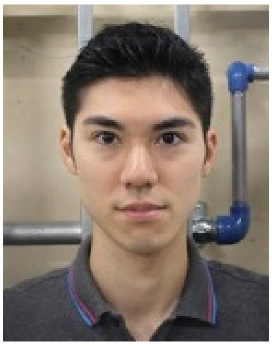

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Affect of Drainage Capacity of the System to Phenomenon of the Funnel–shaped Water Stopper inside the Drainage Stack

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Abstract

"Funnel−shaped water stopper" phenomenon: Refers to buiding stand pipe in normal gravity drainage, due to shape subtle changes of the inner wall of the local structure, so that the original shift to the center of the tube attached to the inner wall circumference circle in the water, forming a funnel shape flow phenomenon. This funnel-shaped water clog the exhaust channel in the pipeline at the riser normal drainage, causing water pressure fluctuations in the value of the inner tube and seal loss increases, lower riser drainage capacity.

On the basis of the reasons a lot of experiments, on the construction of drainage systems "funnel-shaped water stopper phenomenon" of the system conditions and the impact of hazards and preventive measures can be taken and summarized for recommendation to manufacturers, designers and installation of staff caused by the necessary attention.

Keywords

Building Drainage System, Drainage Stack Pipe Funnel-Shaped water stopper, Affect of Riser Pipe Dranige Capacity and System Seal Security

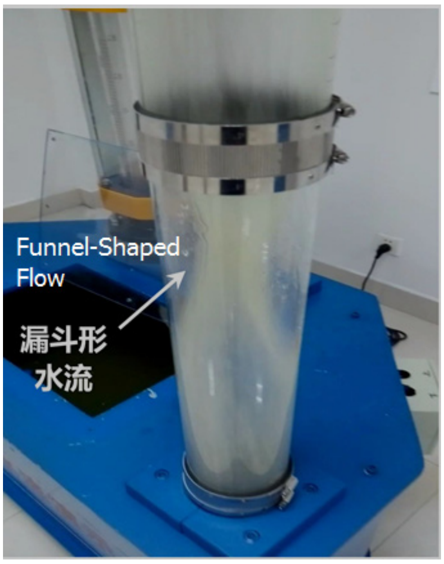


Fig. 1

Since National Building Drainage Piping System Technology Center was established for some time, we conduct building drainage system stack drainage capacity test, often find the same system due to subtle changes in pipe installation, drainage capacity will be a greater difference. When these tests were repeated using the transparent pipe we found that when the inner wall of the pipe protruding annular structure, even a small flow of water attached to the wall, there will be a continuous funnel-shaped water flow (Figure 1) in this area. Because of this continuous flow completely closed funnel-shaped inner riser section hinder the smooth flow of air flow within the tube, we call it "Funnel-Shaped Water Stopper" phenomenon.in this area. Because of this continuous flow completely closed funnel-shaped inner riser section hinder the smooth flow of air flow within the tube, we call it "Funnel-Shaped Water Stopper" phenomenon.

According to the Coanda effect theory, the fluid (water or air) having a flow direction away from the original, replaced with the convex surface tends to flow. Construction of drainage system in the normal drainage, due to Coanda effect gravity flow, water flow within the riser is attached to the wall along the pipe wall falling. When the inner wall of the pipe appears annular protrusion structure, since the curvature of the surface of the water flowing through mutation, force distribution across the Coanda flow to change direction around the inner wall of the riser, to shift the center of the pipe to form a funnel-shaped flow (shown in Figure 3). As long as the riser is attached to the wall of water forms a water film flow, when the pipe wall, annular protruding structure, this funnel-shaped water drainage persists during the entire process. "Funnel-shaped water stopper" hazardous phenomenon is leading to serious drainage stack air passage blocked, airflow resistance surge in volatility in the pipe pressure dropped significantly stack drainage.

1. Reason of "Funnel–Shaped Water Stopper" Phenomenon Formed

According to the current understanding of the situation has been analyzed, the leading cause of drain stack "funnel-shaped water stopper" phenomenon has the following three aspects:

(1) Pipe interface connector in the stack wall to form a cyclic structure protruding. If no bearing cast iron drainage pipe using stainless steel coupling connections when rubber seals, if the seal gasket intermediate ribs too high, or use W1 thin-walled pipe, there will be endless rubber ring protruding structure in the inner

wall of the pipe interfaces (Fig2, Fig3). When the annular protrusion structure height of more than 0.5mm, will form a "funnel-shaped water stopper" phenomenon.

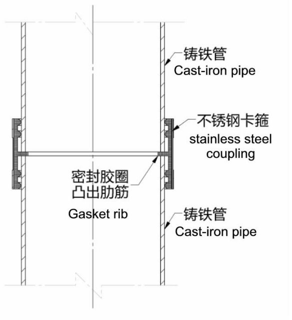


Fig. 2

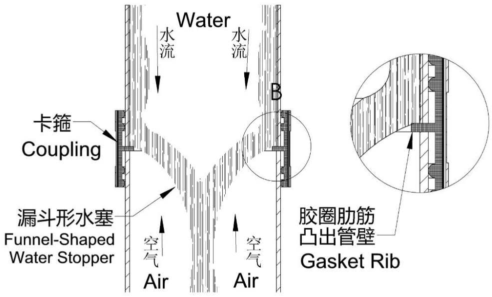


Fig. 3

(2) Stack wall to form an annular projecting structure pipe welding installation. Such as the use of HDPE plastic pipe butt fusion welding connections, the inner wall of the pipe weld interface will melt solidified annular protrusion formed structure (Figure 4), this structure will form a "funnel-shaped water stopper " phenomenon.

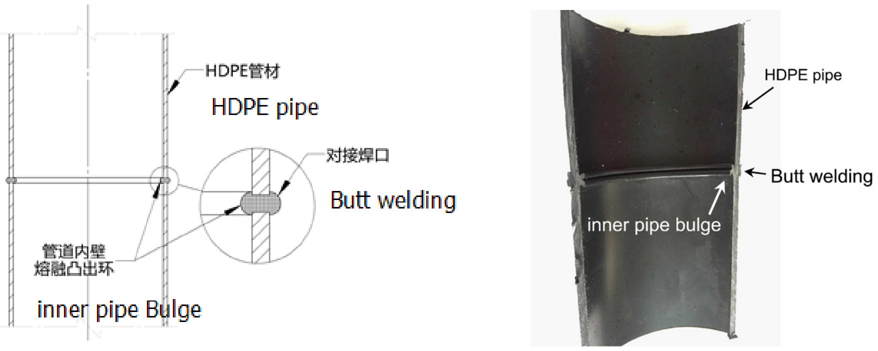


Fig. 4

(3)Pipe and fitting due to the different structure of the inner diameter of the ring projections poor form appears. When the inside diameter of the drain pipe and inconsistent, its interface will form a ladder-shaped ring convex structure (Figure 5), this structure will form a "funnel-shaped water stopper " phenomenon.

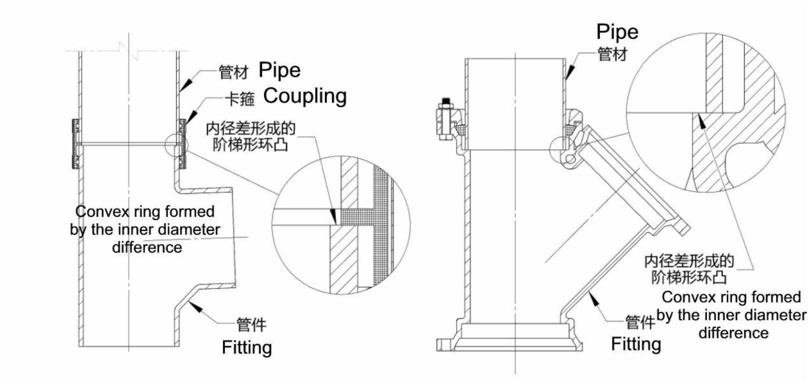


Fig. 5

2. Affect of "Funnel–shaped Water Stopper" to the Construction of Drainage Riser System

To sum up, the drainage standpipe system "funnel-shaped water stopper " phenomenon has four salient features: First, the "funnel-shaped water stopper " generated in the annular drain stack interface protruding structural parts; the second is even in when there will be a small drainage flow; third will continue to appear throughout the drainage process; fourth, drainage stack height is higher, the stack interface ring protruding structural parts, the entire drainage stack "funnel shaped water stopper" the more the number produced.

Below, we compare the research on different wall thicknesses of pipe systems, drainage stack the same height and the same pipe wall thickness test system, the test results of two tests under test height stack different drainage conditions, can prove: as long as memory stack ring convex structure, there may be a "funnel-shaped water stopper " phenomenon, it will form a plurality of closed stack vent channel persistent water stopper, increasing stack airflow resistance, resulting in increased system pressure fluctuations throughout the drainage process, increase in seal loss, decreased drainage capacity. And drainage standpipe, the greater the effect.

(1) Contrast of different wall thickness pipe systems, drainage stack pipe test in the same hight

GB Type strengthen our single stack cyclone special drainage system were compared with experimental tests in SUNS Drainage Experiment Tower (18 floors). Test tube wall thickness at different systems, drainage stack height the same test conditions, the stack pipe W type were used and different wall thicknesses W1 type cast iron pipes, rubber ring interface uses stainless steel coupling connection. Since W1-type cast iron pipe pipe wall thickness is thin, when the pipe interface with high rubber ring intermediate ribs of stainless steel coupling connection, apron rib in the inner wall of the stack to form a cyclic structure projections, will have a "funnel-shaped water stopper "phenomenon. The W-type cast iron pipe thick pipe wall thickness, using the same connection, vertical tube wall without protruding ring structure, does not have a "funnel-shaped water Stopper" phenomenon.

Wall thickness of the pipe system from different test results drainage stack height comparison the same test was found: the W-type pipe-shaped stiffening GY special single stack cyclone maximum drainage capacity of the drainage system for the 11.5 L / s, while the use of W1 thin-walled tube is only 8.5 L / s, drain capacity decreased by 26%. This shows that in the same system, "funnel-shaped water stopper " phenomenon can result in lower system pressure fluctuations and increased drainage capacity.

(2) Contrast of different wall thickness pipe systems, drainage stack pipe test in the same hight

GB same type (formerly GY type) to strengthen the single stack cyclone special drainage system, when in April 2014 at the 33- floors Vanke Experimental Tower test found that the drainage capacity dropped to 4 L / s. After checking the information found at the time on an experimental basis, in Vanke Experimental Tower test stack pipes are used in thin-walled cast iron pipe W1, stand pipe wall portion of each interface are present than 1mm height of the rubber seal ring protruding structure, It will have a "funnel-shaped water stopper" phenomenon. When SUNS Drainage Experiment Tower and Hunan University Drainage Experiment Tower to test the use of W-type thick-walled pipe, pipe wall without rubber seal ring protruding structure, does not have a "funnel-shaped water stopper " phenomenon.

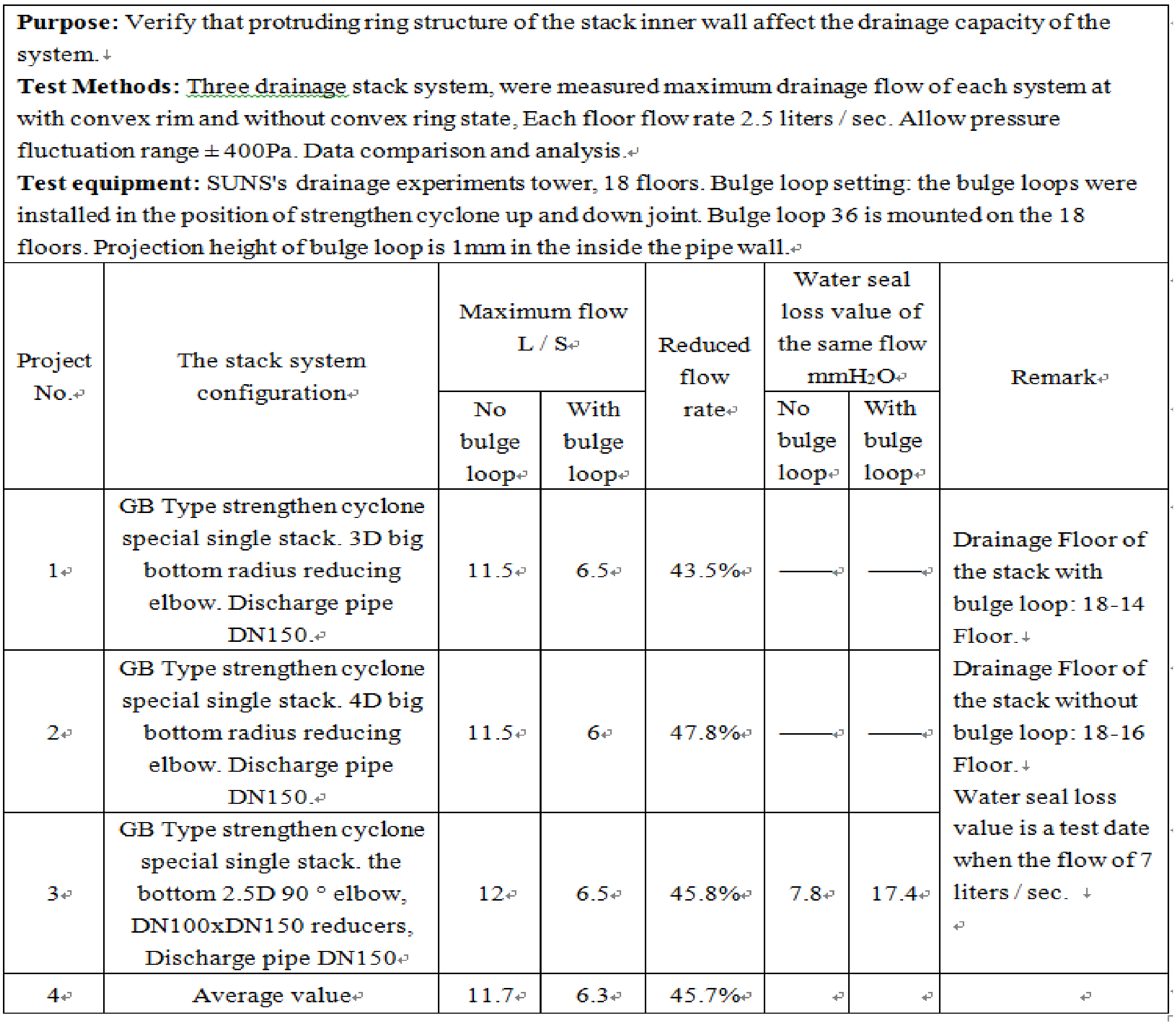
The Vanke Experimental Tower using thin-walled pipes W1 GB type (formerly GY type) to strengthen the single stack cyclone special drainage system test results, and the same system in SUNS Drainage Experiment Tower using thin-walled tubes W1 test results were compared discovery: there are also "funnel-shaped water stopper " phenomenon of the system, the higher the test floor Vanke Experimental Tower, drainage capacity decreased by 53%. SUNS Drainage Experiment Tower and t Hunan University Drainage Experiment Tower system uses the same W-type thick-walled pipe, no "funnel-shaped water stopper " test results compared to the phenomenon, drainage capacity were reduced by 60% and 65%.

Based on previous experimental experience, along with the stack height is increased drainage, ventilation resistance increases because the system, the drainage capacity will be reduced; in accordance with 18 floors and 33 floors height difference, reduced drainage capacity of up to 10% to 15%. Second, the test device of the two towers are not identical experiments, test methods and criteria, there are some differences, which are clearly the cause of the presence of large deviation of the test results. But such a high magnitude lower, to prove "funnel-shaped water stopper " phenomenon affect the drainage capacity of the system is obvious. Thus, a "funnel-shaped water stopper " is one of the main drainage system caused a substantial decline in capacity. And also exists in the "funnel-shaped water stopper " phenomenon 6 system, the higher the floor height, the greater the margin decline drainage capacity.

(3) Comparative test of the same stack system with bulge loop and without bulge loop in the internal pipe wall.

To further confirm the "funnel-shaped water stopper " phenomenon affect to drainage capacity of the stack. In June 2015, we conducted special test in (18 floors) SUNS's drainage experiments tower. Select the three special single stack system for testing, the straight pipes and fittings of all same the wall thickness and inner diameter for testing . Were measured maximum drainage flow of each system at with convex rim and without convex ring state, and compared and analyzed. Bulge loop is a plastic ring, the thickness of 1mm, a height of the inner wall of the tube protrudes 1mm. There bulge loop of the stack system, the bulge loops were installed in the position of fittings up and down joint. The entire stack system were set up 36 bulge loops.

Table 1 The comparative tests results on the “funnel-shaped water stopper ”phenomenon affect on drainage ability of the stack system



Purpose: Verify that protruding ring structure of the stack inner wall affect the drainage capacity of the system.

Test Methods: Three drainage stack system, were measured maximum drainage flow of each system at with convex rim and without convex ring state, Each floor flow rate 2.5 liters / sec. Allow pressure fluctuation range ± 400Pa. Data comparison and analysis.

Test equipment: SUNS's drainage experiments tower, 18 floors. Bulge loop setting: the bulge loops were installed in the position of strengthen cyclone up and down joint. Bulge loop 36 is mounted on the 18 floors. Projection height of bulge loop is 1mm in the inside the pipe wall.

Project No.	The stack system configuration	Maximum flow L / S		Reduced flow rate	Water seal loss value of the same flow mmH$_2$O		Remark
		No bulge loop	With bulge loop		No bulge loop	With bulge loop	
1	GB Type strengthen cyclone special single stack. 3D big bottom radius reducing elbow. Discharge pipe DN150.	11.5	6.5	43.5%	——	——	Drainage Floor of the stack with bulge loop: 18-14 Floor. Drainage Floor of the stack without bulge loop: 18-16 Floor. Water seal loss value is a test date when the flow of 7 liters / sec.
2	GB Type strengthen cyclone special single stack. 4D big bottom radius reducing elbow. Discharge pipe DN150.	11.5	6	47.8%	——	——	
3	GB Type strengthen cyclone special single stack. the bottom 2.5D 90 ° elbow, DN100xDN150 reducers, Discharge pipe DN150	12	6.5	45.8%	7.8	17.4	
4	Average value	11.7	6.3	45.7%			

As can be seen from the comparison and analysis of the test results in Table 1, the same drainage stack system, when there are the convex ring structure inside pipe inner wall, its drainage capacity declined 43.5 ~ 47.8%, average is 45.7%. Under the same flow rate, water seal loss value increased by more than 100%.
It can be seen, "funnel-shaped water stopper " phenomenon opposite effect is much greater than the stack pipe system water Tongue horizontal branch pipe inlet. Despite the formation of closed water stopper tongue thickness smaller than that of water, but it will be part of the entire riser each interface appears in larger quantities. It also differs from the usual sense stack instantly generate a large flow of water inside the plug phenomenon, and will continue to occur at different flow rates. "Funnel-shaped water stopper " a serious obstacle effects of top ventilatory and path of gas flow system downward, causing the system pressure fluctuations increase. Therefore, the phenomenon of "funnel-shaped water stopper " effect to drainage systems of the tall and super tall building, multi- floors building is more than obvious. In particular, special single- stack system for ventilation and drainage share a same stack pipe impact even more. We should give full attention to this issue, in product design, engineering and construction and installation process, and to take the necessary measures to try to avoid the "funnel-shaped water stopper " phenomenon.

3. Precaution of "Funnel–Shaped Water Stopper" Phenomenon

“Influence "funnel-shaped water stopper" on the building riser drainage capacity of the drainage system can not be ignored, but as long as we pay more attention to product design, engineering design, construction, installation and pipe fitting selection, it is possible to reduce and avoid this the occurrence of adverse phenomenon. We also found that by testing, "funnel-shaped water stopper " phenomenon is often in the inner wall of the stack height is greater than the annular projection projecting occur equal 1mm, as long as the protrusion height less than 0.5mm, it is possible to reduce the "funnel-shaped water stopper "Opportunities phenomenon occurred. Provide few specific precautions following:
(1)made of cast iron drainage riser system connecting the stainless steel coupling, coupling the rubber ring seal in the middle of the sealing rib height (see Figure 6 h) should be at least smaller than the pipe wall thickness 0.5mm. To prevent the installation process due to the tightening squeeze cuff, apron sealing rib projecting vertical tube wall (see Figure 2).

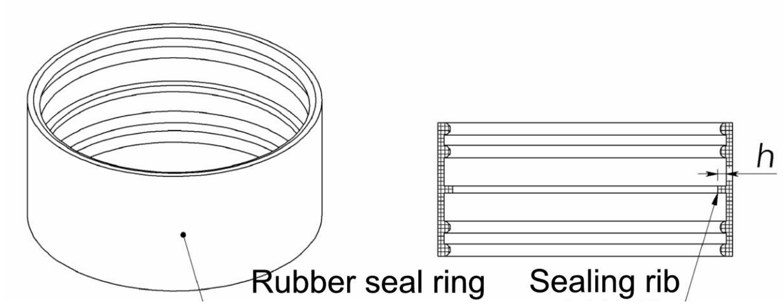


Fig. 6

(2)counterparts in the use of thermal fusion welding plastic pipe drainage installation riser systems, welding is completed, it must remove the stack inner wall of the melting and solidification weld deposits (see Figure 7), to prevent the tube wall, annular bulge structure. The construction requirements are strictly enforced in foreign countries, but the vast majority of domestic construction and installation of the pipe wall without weld clean-up, which would greatly reduce the drainage capacity of the stack. Currently, a number of companies to develop plastic pipe socket fusion welding of plastic pipes, which can effectively avoid the "funnel-shaped water stopper " phenomenon.

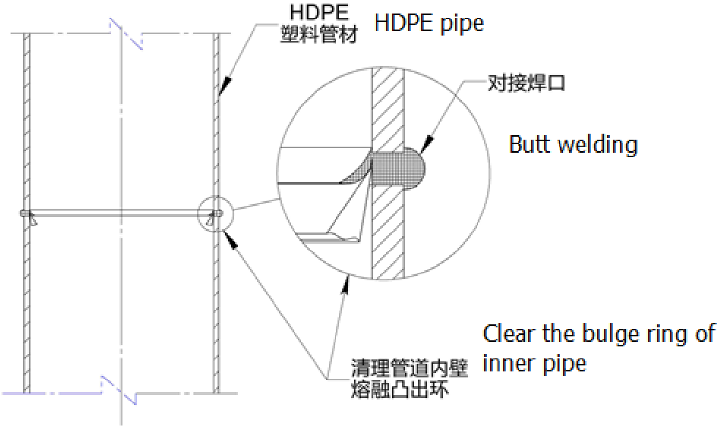


Fig. 7

（3）In the selection of the drainage pipe, make sure the straight pipe and fittings using the same wall thickness range of products. Avoid the use of pipes and fittings series of different thickness, diameter size appears inconsistent, leading "funnel-shaped water stopper " phenomenon in the same stack.

（4）In product design, it should be possible to reduce the wall thickness deviation of pipes and fittings. Some manufacturers in the production process, in order to facilitate manufacture and increase yield, often increasing the wall thickness of the pipe, which is often not conducive to the draining effect of the stack, increasing the chance of "funnel-shaped water stopper " phenomenon occurred.

（5）Drainage pipe products in the standard-setting process should gradually narrow pipe and tube inner diameter and a wall thickness deviation range. Some product standards developed in this area of control more scientific. As the EN877 and ASTM A888 standards, pipes and fittings of diameter and thickness dimensions are the same. This put an end to the drain stack "funnel-shaped water stopper " phenomenon fundamentally.

4. Conclusion

In recent years, the industry's increasing emphasis on experimental studies on the construction of drainage systems, some of our past was not found or could not explain the phenomenon gradually being discovered and clarified. In particular, the establishment of National Building Drainage Piping System Technology Center and put into trial operation for SUNS Drainage Experiment Tower, for further study construction and drainage techniques provide a good test platform. Some experimental studies began a planned, systematic expansion. "Funnel-Shaped Water Stopper" phenomenon is a kind of drain stack flow phenomena we find in the course of the experiment, analysis and comparison of their impact on the drainage system of the building, it seems the phenomenon commonly known as water stopper are similar, but regardless of the size of its drainage flow, flow characteristics persistent, and its impact on the water system is much larger than the usual sense of the plug phenomenon. Let us be known as the construction of drainage riser "funnel-shaped water stopper " phenomenon in this paper, in order to get colleagues to pay more attention.

Experimental Studies on Flow and Pressure Characteristics of Siphonic Drainage System with 100m Piping (Part2) Comparison with Diameters of 25mm and 20mm

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Abstract

In buildings with large floor plans such as plants, the conventional drainage system requires large piping space (height) when water is used at locations far from drainage stacks and pits. The use of siphonic drainage system in such situations can greatly reduce piping space, as the system utilizes long piping with small pipe diameters and no slope. In the previous paper, we examined the characteristics of the siphonic drainage system of 100m long actual-scale horizontal piping models using U-PVC pipes and polybutene pipes (diameter:20mm). In this paper we experimented using pipes with the diameters of 25mm instead of 20mm, examined the flow characteristics and compared the results with those of experiments with 20mm pipes.

We conducted experiments with two types of piping materials, U-PVC pipes and polybutene pipes (diameter:25mm) in 100m long actual-scale horizontal piping models, measured flow rates and pressures in the piping while water was supplied at various flow rates to the inflow part, and examined flow characteristics. We compared U-PVC pipes and polybutene pipes in different diameters and flow rates by making a flow diagram. It became clear that siphonage occurred more readily with U-PVC pipes than with polybutene pipes.

Keywords

Drainage system; siphon; siphonage; long plumbing; plant

1. Introduction

Large piping space is required in the conventional drainage system in buildings with large floor plans such as plants, where water is used some distance away from drainage stacks and pits. Siphonage drainage system can greatly reduce piping space as it makes possible the use of piping with small diameters and no slope. In earlier studies we succeeded to clarify flow characteristics in the 20m long horizontal piping using U-PVC pipes (20mm and 25mm) and polybutene pipes (20mm). And in the previous study we elucidated the flow characteristics of 20mm U-PVC pipes and polybutene pipes in a 100m long real-scale experimental apparatus.

In this study we conducted experiments using the same piping materials and length as in the previous study but with larger diameters of 25mm. We also shed some light on the flow characteristics of siphonage drainage system with long piping based on the results of the previous studies.

2. Experiments on Flow Characteristics

2.1 Outline of Experiments

2.1.1 Experimental Apparatus

The outline of the experimental apparatus is shown in Figures 1 and 2. Two types of pipes, U-PVC (25mm) and polybutene (25mm) were used. Sideway detachable drainage inlets with inflow diameters of 150mm were used. Both riser pipe elbows (50mm in height) and vent valves were constructed in the same way as in the previous study with outflow heads of 1,000mm, 1,500mm, and 2,100mm in a 100m horizontal pipe. Pressures were measured at five locations: the inflow section, 25m, 50m, 75m from the inflow section and the outflow section in U-PVC pipes, and two locations: the flow section and outflow section in polybutene pipes. Discharge flow rate and flow velocity were calculated based on the readings of the flow meter located at the outflow section.

2.1.2 Experimental Conditions

The experimental conditions are shown in Table 1. Supply flow rates to U-PVC pipes were 12L/min., 15L/min., and 18L/min., and to polybutene pipes were 12L/min., 15L/min., and 18L/min., and 22L/min. Measurements were made once for each experimental condition, 23 patterns in total.

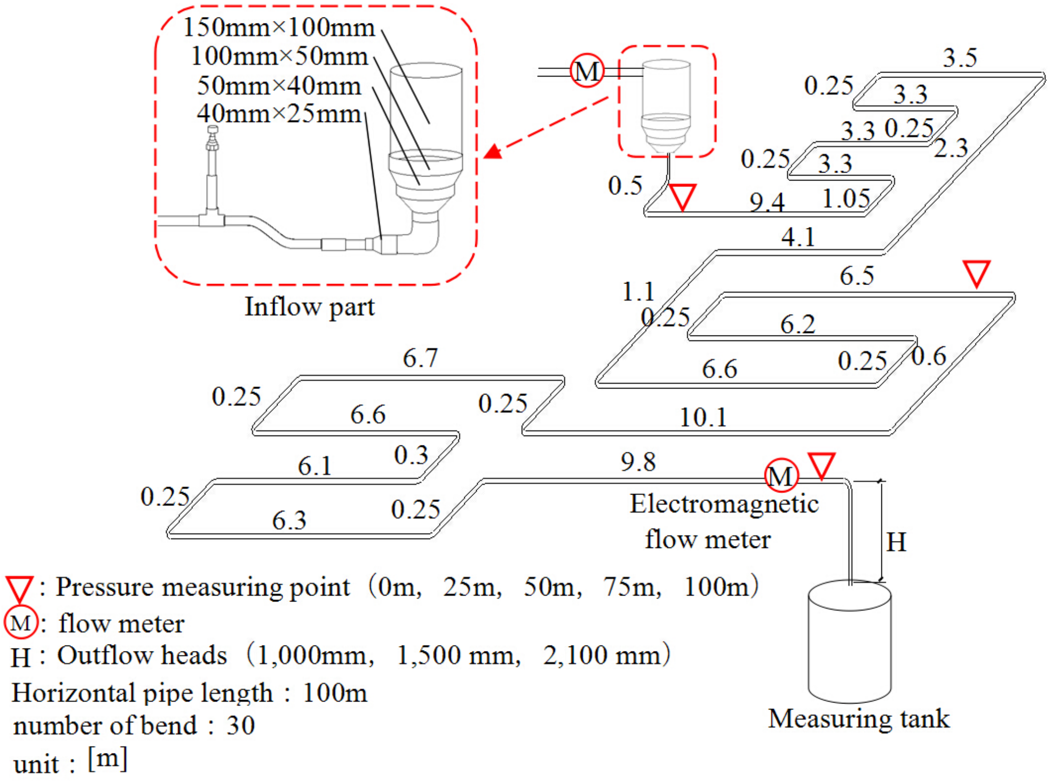


Figure 1 The outline of a piping model using U-PVC pipes

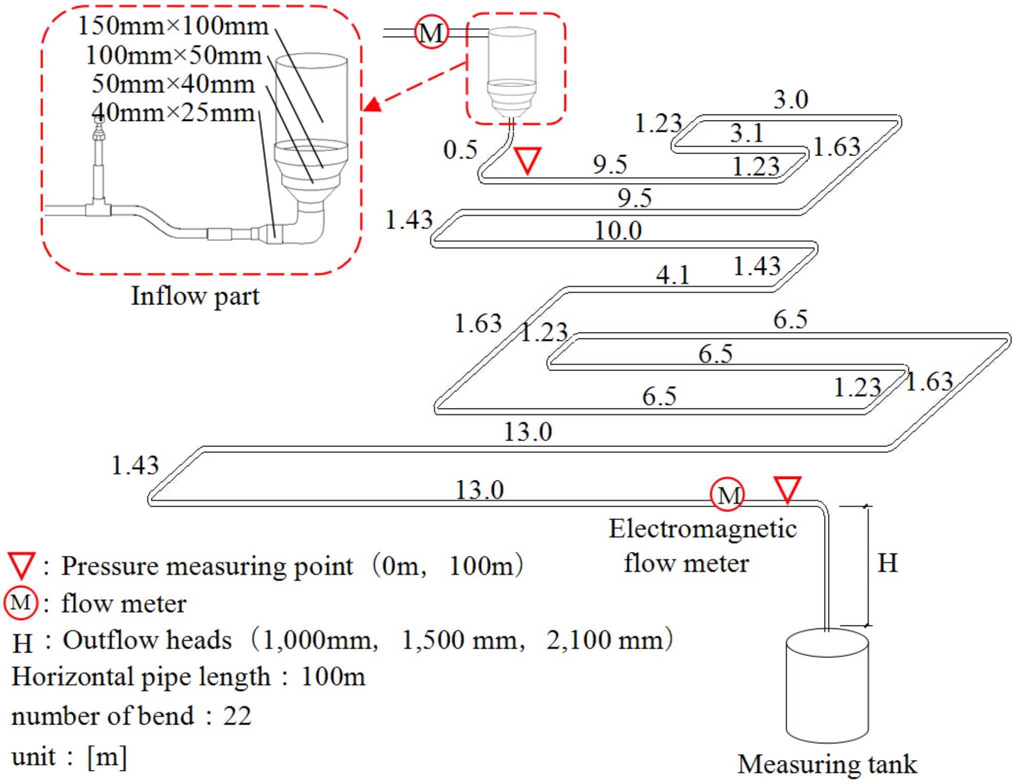


Figure 2 The outline of a piping model using polybutene pipes

Table 1 Experimental conditions

Piping material	Outflow head [mm]	Supply flow rate [L/min]
U-PVC • Polybutene pipes (Diameter of 25mm)	1,000 • 1,500 • 2,100	12 • 15 • 18 • 22

(Measurement made once for each of all 23 patterns)

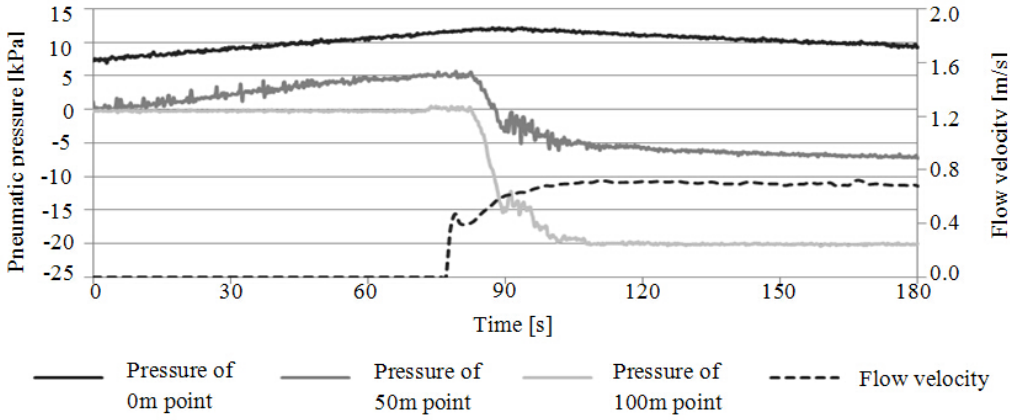
2.2 Results and Discussion

2.2.1 Flow phase

Figure 3 shows the distributions of pneumatic pressure and flow velocity with outflow head of 2,100mm and flow rate of 18L/min. It has been shown that bubble flow was created in U-PVC pipes leading to relatively steady pneumatic pressure and flow velocity after siphonage. On the other hand, intermittent flow was created in polybutene pipes with pneumatic pressure and flow velocity fluctuating after siphonage.

An accurate measurement could not be made in polybutene pipes at flow rates of 12L/min. and 15L/min. as separate flow resulted in small water fullness ratio in pipe.

a) 25mm U-PVC pipes



b) 25mm Polybutene pipes

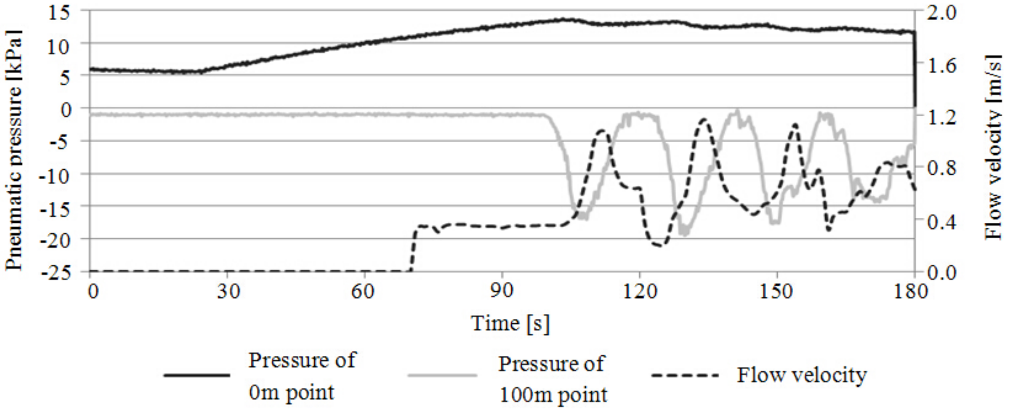


Figure 3 Distributions of pneumatic pressure and flow velocity with outflow head of 2,100mm and flow rate of 18L/min

2.2.2 Siphonic Negative Pressure

The formula for calculating siphonic negative pressure (referred to as P formula below) is shown in Table 2. The results of comparison of actual measured negative pressures with theoretical values derived from P formula for each piping model are shown in Figure 4. There have been no significant differences between actual measurements and theoretical values under any of the experimental condition. Neither have there been any significant differences in siphonic negative pressure between U-PVC pipes and polybutene pipes.

Table 2 P formula

$$P_o = \left\{ (H_a - Z_m) - \frac{(1 + \lambda \frac{L_m}{d} + \sum^{m} \zeta)}{(1 + \lambda \frac{L_a}{d} + \sum^{a} \zeta)} H_s \right\} \rho g$$

P_o : Pressure at outflow section [Pa] H_a : Height from base level to water surface [m]
Z_m : Height from base level to pressure measuring point in outflow section [m]
λ : Pipe coefficient of friction [-] L_m : Pipe length to pressure measuring point in outflow section [m]
L_a : Pipe length [m] d : Pipe diameter [m] ζ : Partial resistance [-]
H_s : Height from end of outflow section to water surface [m]
ρ : Density [kg/m^3] g : Gravity acceleration [m/s^2]

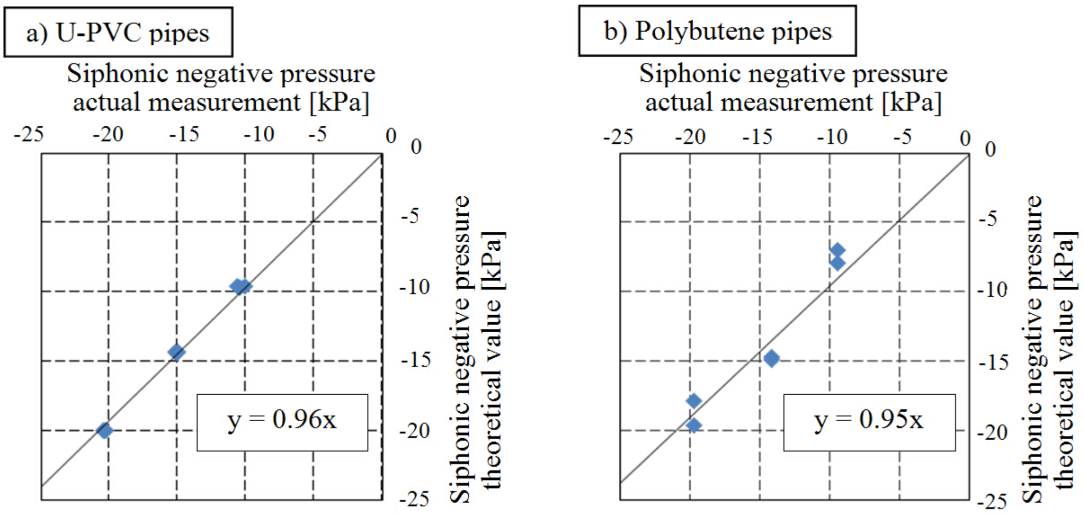


Figure 4 Comparison of siphonic negative pressure measurements and theoretical values

2.2.3 Flow Velocity

Table 3 shows the outline of the formula for calculating flow velocity (referred to as V formula below). Actual measured flow velocities and theoretical values derived from V formula are shown in Figure 5. Flow velocity was calculated from the flow rate when siphonic negative pressure reached maximum at the outflow section. Polybutene pipe tended to contributed to higher flow velocity than U-PVC pipe, which seems to be attributed to the difference in frictional resistance of the two materials. There have been some discrepancies between actual measured values and theoretical values for both types of pipe, but overall, they approximated. The reason for the differences may have been due to water fullness ratio in pipe, and in the case of polybutene pipe, air accumulation due to irregularity of the pipe material that had been rolled.

Table 3 V formula

$$v = \sqrt{\frac{2gH_s}{\underbrace{\lambda \frac{l}{d} + \sum \zeta + 1}_{\text{Equivalent pipe length } L_e}}}$$

By substituting hydraulic gradient $I = H_s/L_e$ and g = 9.8 into the equation, we get

$$v = 4.43\sqrt{I}$$

v : Flow velocity [m/s] g: Gravity acceleration [m/s^2] H_s: Siphon head [m]
λ : Pipe coefficient of friction [-] l: Total pipe length [m] d: Pipe inner diameter [m]
ζ : Partial resistance [-] L_e: Equivalent pipe length [m] I: Hydraulic gradient [-]

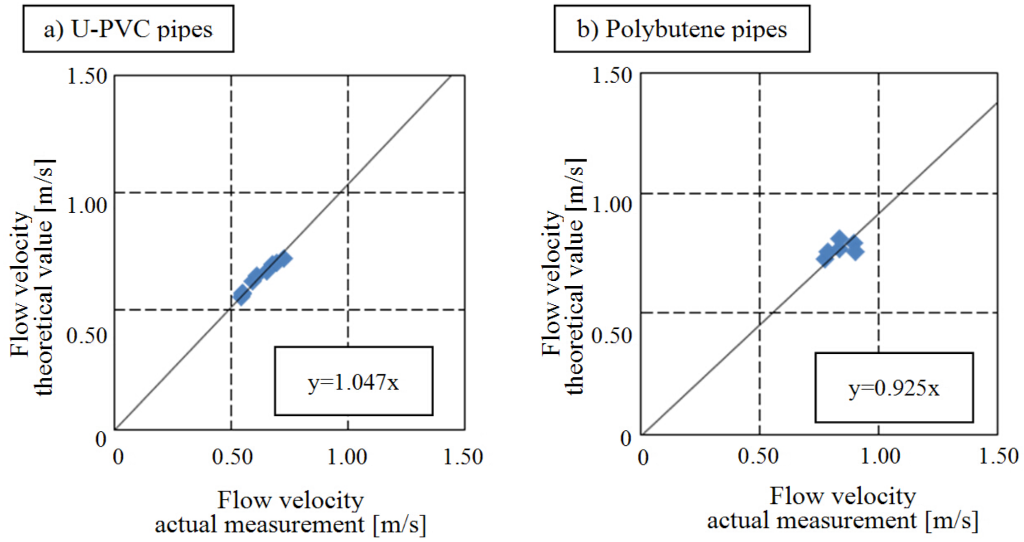


Figure 5 Comparison of flow velocity measurements and theoretical values

2.2.4 Flow Rate Charts

We created flow rate charts based on actual values and flow rates obtained by multiplying velocities in V formula by cross sections, and their relationship with square roots of hydraulic gradient. Flow rate charts of each piping model are shown in Figure 6. The regression line for polybutene pipes showed a higher gradient than that for U-PVC pipes indicating a slightly larger discharge flow rate. Actual measurements and theoretical values for the both approximated confirming the validity of theoretical values.

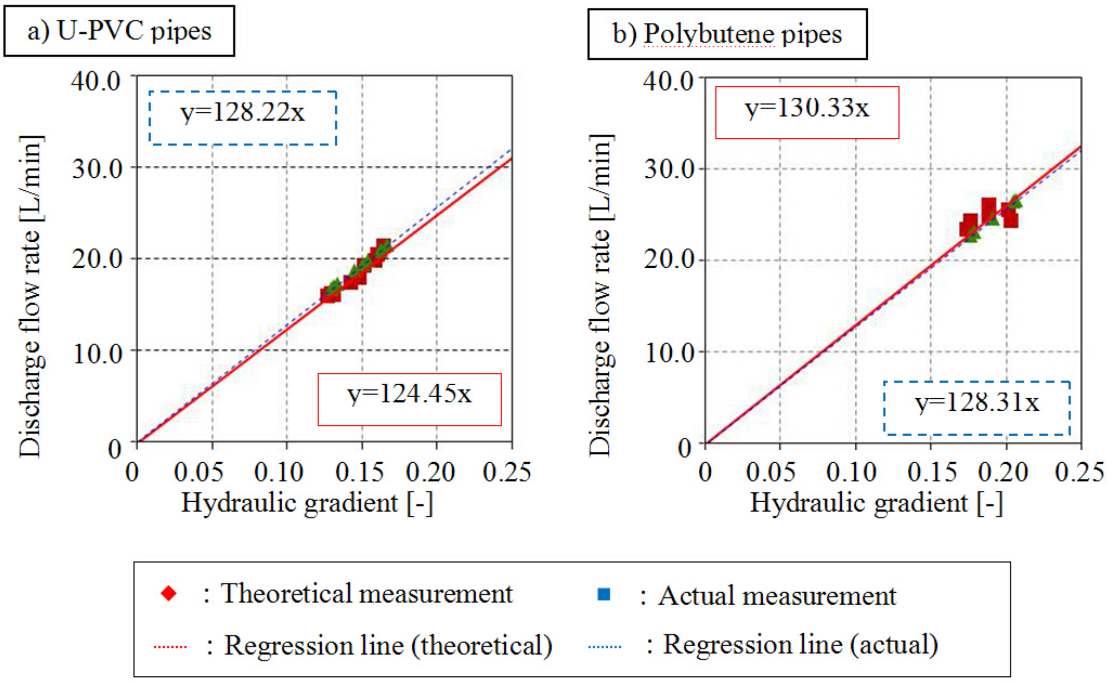


Figure 6 Flow rate chart

3. Discussion on Flow Characteristics

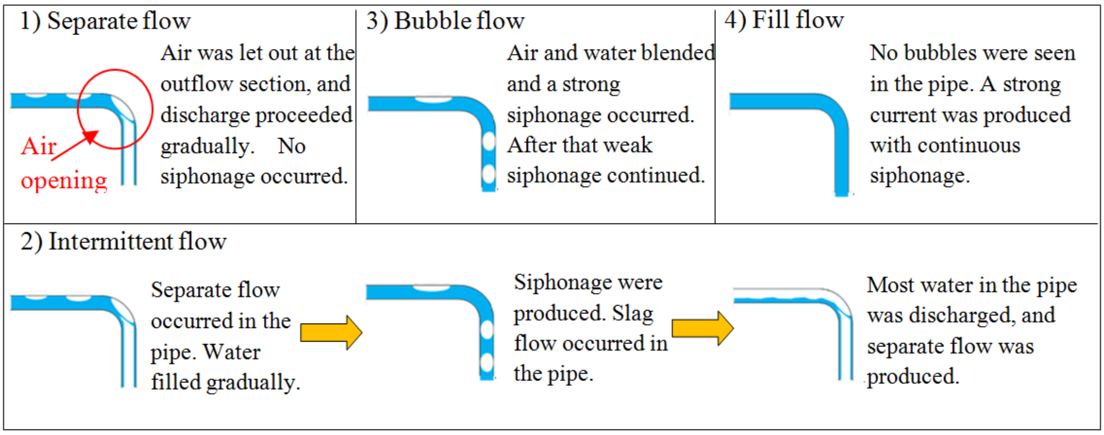
We examined and considered flow characteristics and siphonage negative pressure of the siphonage drainage systems constructed with U-PVC pipes and polybutene pipes based on the previous study with a 100m long 20mm pipe and the current study with a 100m long 25mm pipe.

3.1 Flow phase

It has been known that there are four possible types of flow phases in pipe: 1)separate flow, 2)intermittent flow, 3)bubble flow and 4)fill flow (Figure 7). Flow phases under each piping condition are shown in Table 4. Similar flow phases have been observed in 20mm U-PVC pipes and 20mm polybutene pipes. On the other hand, there have been some differences in flow phases with 25mm pipes; intermittent flow that does not lead to siphonage was dominant at flow rates of 12L/min. and 15L/min. in polybutene pipes,
while bubble flow and fill flow were prominent in U-PVC pipes. Form this it can be safely assumed that permissible discharge flow rate is larger in 25mm polybutene pipes than in 25mm U-PVC pipes. In general, there was a tendency that flow phases with high water fullness ratio in pipe such as fill flow and bubble flow were produced as outflow heads became smaller and water flow rate increased.

3.2 Siphonic Negative Pressure

The relationship between siphonic negative pressure and supply flow rate is summarized by pipe material and pipe diameter in Figure 8, and by outflow head in Figure 9. It has been shown that pipe materials or diameters have little effect on siphonic negative pressure and it fluctuated in response to outflow head.



1) Separate flow

Air was let out at the outflow section, and discharge proceeded gradually. No siphonage occurred.

3) Bubble flow

Air and water blended and a strong siphonage occurred. After that weak siphonage continued.

4) Fill flow

No bubbles were seen in the pipe. A strong current was produced with continuous siphonage.

2) Intermittent flow

Separate flow occurred in the pipe. Water filled gradually.

Siphonage were produced. Slag flow occurred in the pipe.

Most water in the pipe was discharged, and separate flow was produced.

Figure 7 Flow phase diagram

Table 4 Flow phase under each piping condition

Diameter	Diameter of 20mm						Diameter of 25mm					
Material	U-PVC			Polybutene			U-PVC			Polybutene		
Ho[㎜] Flow rate [L/min]	1,000	1,500	2,100	1,000	1,500	2,100	1,000	1,500	2,100	1,000	1,500	2,100
6	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow						
8	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow						
10	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow						
12	Fill flow	Fill flow	Bubble flow	Fill flow	Fill flow	Bubble flow	Bubble flow	Bubble flow	Bubble flow	Separate flow	Separate flow	Separate flow
15							Fill flow	Bubble flow	Bubble flow	Separate flow	Separate flow	Separate flow
18							Fill flow	Bubble flow	Bubble flow	Bubble flow	*Intermittent flow*	*ntermittent flow*
22										Bubble flow	*ntermittent flow*	*ntermittent flow*

3.3 Flow Velocity and Flow Rate

The relationships between flow velocity and supply flow rate, and between discharge flow rate and supply flow rate are shown in Figures 10 and 11 respectively. Also the relationship between discharge flow rate and supply flow rate in connection with flow phases is summarized in Figure 12. Flow velocity was found to be faster in polybutene pipes than in U-PVC pipes. Similarly, discharge flow rate tended to be larger in polybutene pipes than in U-PVC pipes. There was little difference in the relationship between supply flow rate and discharge flow rate in fill flow relative to differences in flow phase. On the other hand, discharge flow rate was 4.5 L/min. ~ 6.0 L/min. larger than supply flow rate in bubble and intermittent .

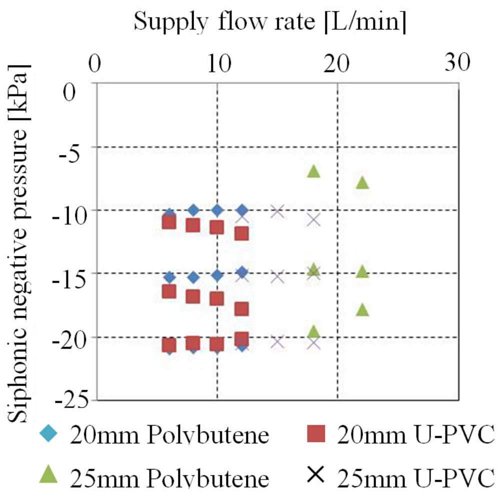


Figure 8 Siphonic negative pressure and supply flow rate summarized by pipe material and diameter

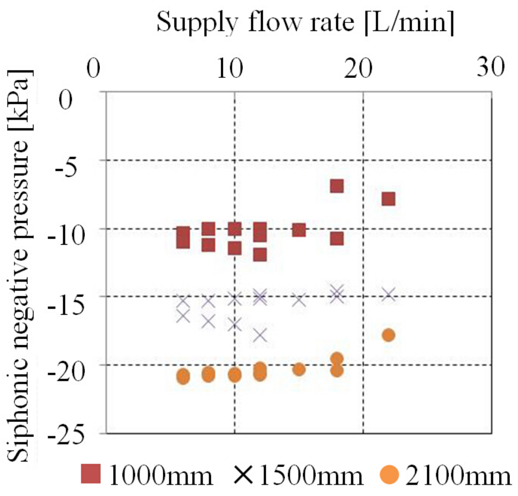


Figure 9 Siphonic negative pressure and supply flow rate summarized by outflow head

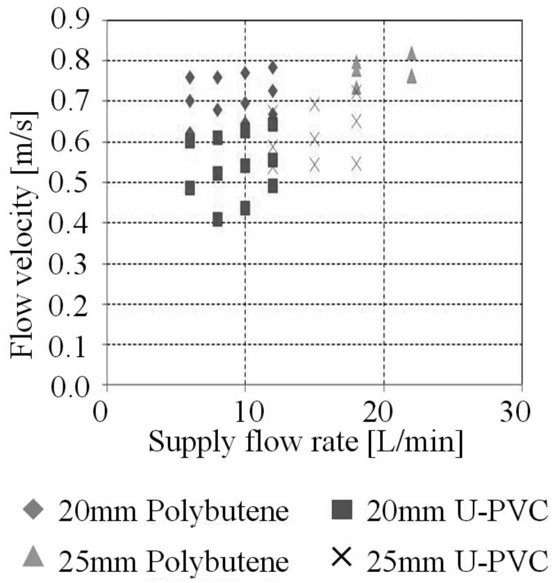


Figure 10 Flow velocity and supply flow rate summarized by pipe material and diameter

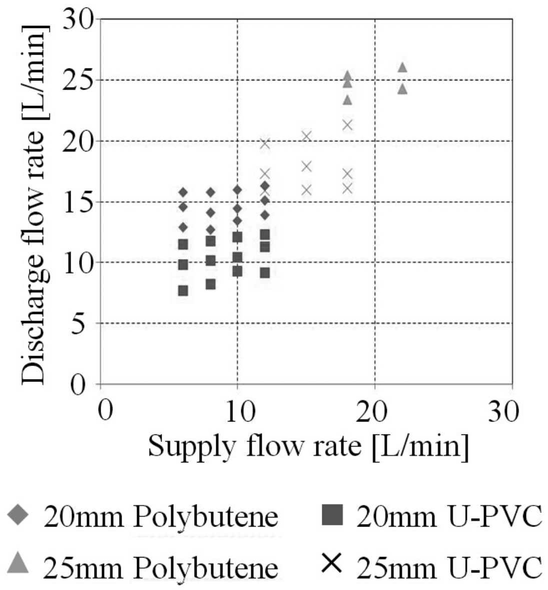


Figure 11 Discharge flow rate and supply flow rate summarized by pipe material and diameter

3.4 Maximum Water Level in Inflow Part

Figure 13 summarizes the relationship of maximum water level in inflow part with discharge flow rate by pipe material and diameter. 20mm and 25mm U-PVC pipes, and 20mm polybutene pipes indicated the maximum water level of 110cm, while the maximum water level of 25mm polybutene pipes indicated between 140cm and 167cm. This may be explained by the fact that it was more difficult to horizontally lay out 25mm polybutene pipes than 20mm pipes, and that air accumulated in irregular sections created resistance to water flow.

3.5 Hydraulic Gradient I′

Based on the assumption that which type of flow phase is to be created in a given condition is determined before water falls down from the top of the outflow pipe, we focused on hydraulic gradient I′, that is obtained by dividing the distance from the water level inside the detachable drainage inlet to the horizontal pipe (Height: Hi) by the equivalent pipe length from the detachable drainage inlet to the top of the outflow pipe (Length: Le′).

The relationship of hydraulic gradient I′ and discharge flow rate is summarized with respect to pipe material and diameter in Figure 14. And Figure 15 summarizes their relationship with respect to flow phase. By and large, hydraulic gradients of 20mm U-PVC pipes and 20mm polybutene pipes fell within the range of 0.006 ~ 0.008 while those of 25mm U-PVC pipes fell in the 0.008 ~ 0.012 range and those of 25mm polybutene pipes in the 0.013 ~ 0.016 range.

From this it has been assumed that a certain amount of pressing force is required to initiate the movement of water for drainage even when permissible discharge flow rate has been increased by the enlargement of pipe diameters. However, as for polybutene pipes, we have yet to collect more data as their performance depends on irregularities created by piping layouts.

3.6 Flow Rate Chart

Figure 16 shows flow rate charts based on the actual measurements with 20mm and 25mm U-PVC pipes and polybutene pipes. The charts clearly indicate that polybutene pipes had larger inclination of the regression line than U-PVC pipes; hence a slightly larger discharge flow rate. As is the case with flow velocity, this can be explained by the differences in friction resistance coefficient and inside diameters.

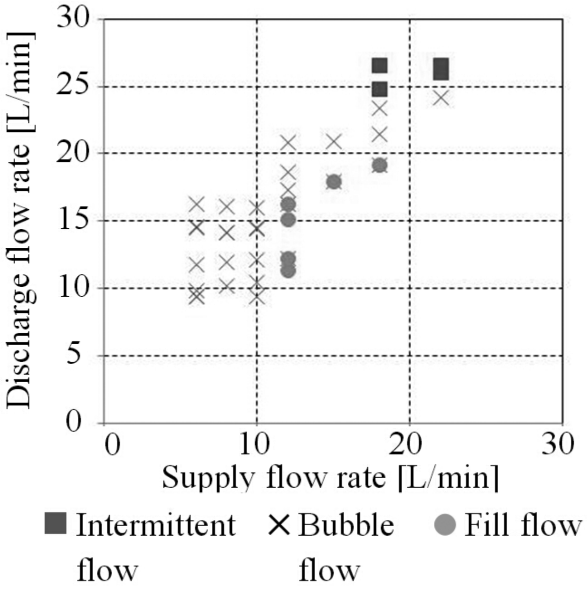


Figure 12 Discharge flow rate and supply flow rate summarized by flow phases

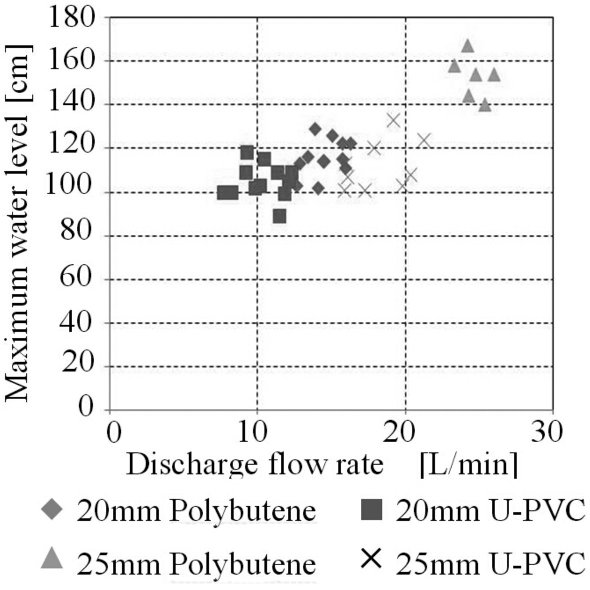


Figure 13 Maximum water level and supply flow rate summarized by pipe material and diameter

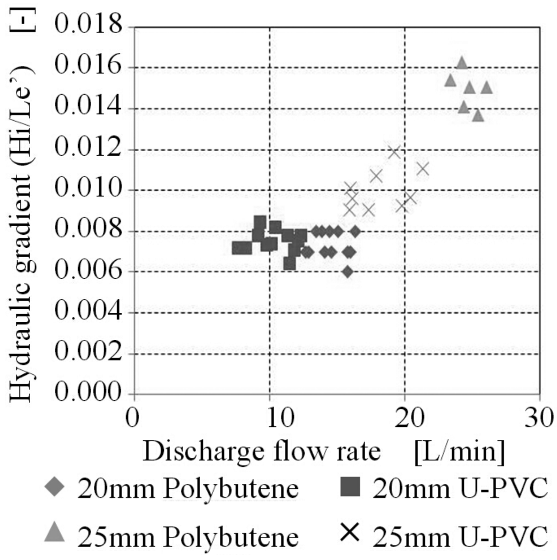


Figure 14 Hydraulic gradient and discharge flow rate summarized by pipe material and diameter

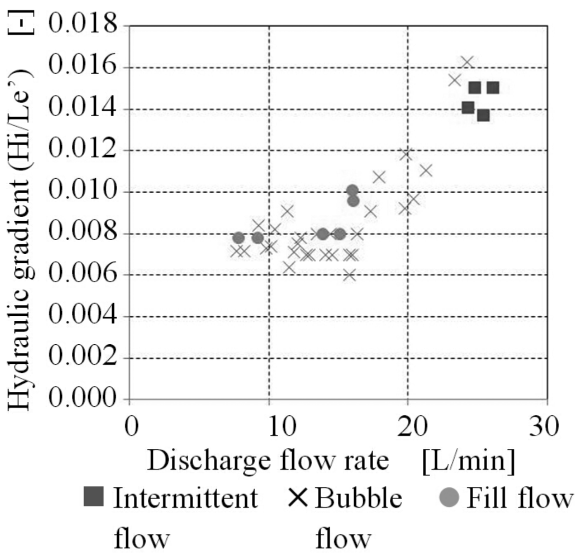


Figure 15 Hydraulic gradient and discharge flow rate summarized by flow phases

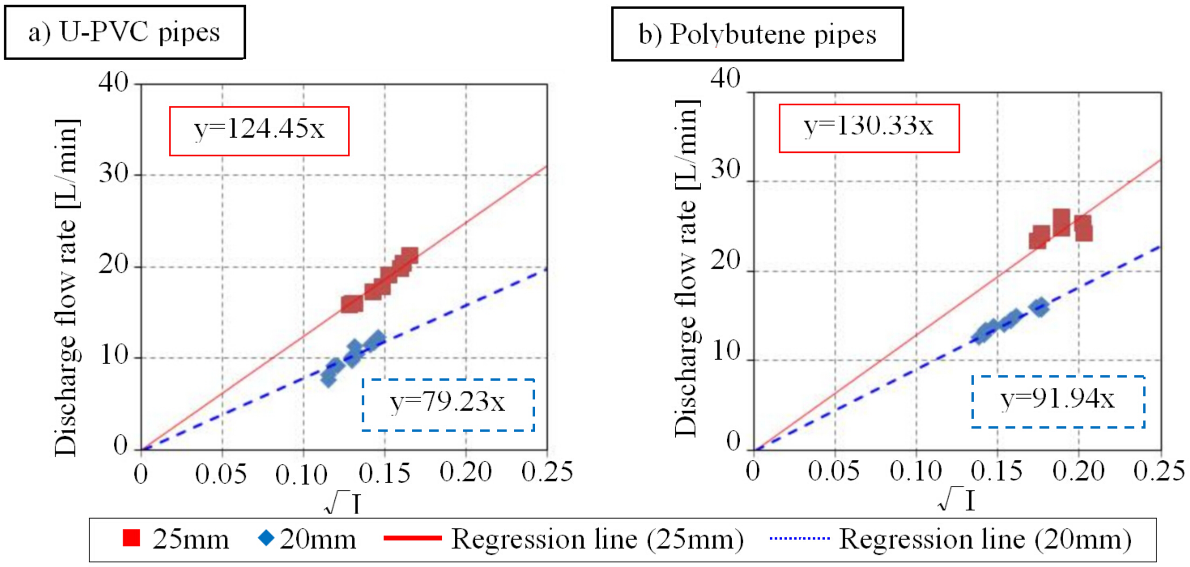


Figure 16 Flow rate charts based on the actual measurements with 20mm and 25mm U-PVC pipes and polybutene pipes

4. Conclusion

The results of the experiments can be summed up as follows:

1. We have shed some light on siphonic negative pressure and flow characteristics of 100 m long 25mm U-PVC pipes and polybutene pipes.

2. We have elucidated the tendencies of various parameters in flow characteristics, and examined how the

differences in pipe material and diameter may affect flow characteristics.

As the present study only allowed a limited number of samples to base our validation on, we need to expand the number of samples for further verification of flow characteristics. Our future research should also include clarification of the effect of irregularities in polybutene pipe on flow characteristics, and appropriate pipe cleaning methods to resolve pipe clogging that is likely to occur in pipes with small diameters.

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Microbial Cross−transmission and Particle Modelling in Building Drainage Systems

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Abstract

In the event of a defect in the building drainage system, a cross-transmission route exists which connects one part of a building to another. Turbulence of discharging wastewater can generate pathogenic bioaerosols which can be transported via airflows within the system and can increase the inhabitant exposure to disease. This paper introduces the work of the new research group (PRoBE) established at Heriot-Watt University to define and characterize the formation and transmission of bioaerosols within building drainage systems and to assess the potential infection risk for building occupants.

Preliminary research has already confirmed significant findings: (i) the building drainage system becomes fully contaminated whenever pathogenic material is introduced into the system; (ii) bioaerosols can be easily formed by the normal flushing mechanism and the turbulent discharge of wastewater within the system; (iii) bioaerosols can be carried in system airstreams and if the water trap seal is lost these bioaerosols can enter the building; (iv) the ingress of bioaerosols from the building drainage system into the building can result in contamination of every surface in a room.

Keywords

Microbial Transport, Cross-transmission, Particle Modelling, Building Drainage Airflows

1. Introduction

The spread of disease via environmental contamination is of great concern to many in Built Environment Research. This cross-contamination can take three main forms: airborne, fomite, or vector. Of these, airborne and fomite cross-contamination routes are the most likely in buildings where people are present. Understandably there is considerable interest in these forms of cross-contamination of disease in buildings, particularly in hospitals where the prevention of disease transmission is most vital.

There is a need for a concerted effort in defining the modes of cross-contamination and transmission of disease in buildings. One area where major gaps in knowledge still exist is the airborne transmission of aerosolised microbial pathogens (commonly known as bioaerosols) which can be carried in airstreams within building systems and throughout the building itself. Often, bioaerosols can originate and be transmitted from building systems themselves and while some of these sources (such as bacteria in ventilation systems, and legionella in water systems) have been well documented, a source which is often overlooked is the building drainage system. As a repository for many potentially contaminated human body fluids (such as vomit, diarrhea, etc.), the building drainage system is a reservoir of pathogenic material. The forcefully emission of these body fluids, together with their flushing into the system, can generate bioaerosols that can then be carried within the natural airstreams that occur within these systems. Water trap seals are still the main defence against the ingress of these airstreams into the building, and so the loss of this seal creates a direct route for the airstream to enter the building, potentially carrying harmful bioaerosols with it [1]. Research has shown that most buildings experience seal loss at some time, and many can experience recurring issues. This form of cross-transmission was identified by the World Health Organisation as being complicit in the 2003 SARS outbreak [2,3].

To address this major knowledge gap, a new research group (known as PRoBE) has been established at Heriot-Watt University with the aim of characterising and defining the aerosolisation, transmission, and infection risk posed by building systems, particularly the building drainage system. This paper introduces some of the preliminary research undertaken by PRoBE which is fundamentally based on the physical experimentation and computational modelling of bioaerosols.

2. PRoBE Identity

PRoBE is a cross-disciplinary research group of engineers, mathematical modellers and microbiologists at Heriot-Watt University. The acronym stands for Pathogen Research in the Built Environment (PRoBE). The PRoBE logo is shown in Figure 1 and more information can be found at the research group website (www.pathogenresearch.org.uk).

Pathogen Research in the
Built Environment

Figure 1: PRoBE Logo

It is intended that this cross-disciplinary group will look at a range of different issues relating to infection spread in buildings. Having been established just over a year ago, the group has already had success in highlighting the complex issues in this area and brings a fresh approach to the discipline.

3. PRoBE Research

3.1 Bioaerosol Transmission

Bioaerosols can pose a significant risk to the spread of infection and disease within buildings. Research activities focus on the characterisation of bioaerosol generation and transmission, coupled closely with the development and application of advanced numerical models for the prediction of bioaerosol transport.

A significant area of research focuses on the transport of bioaerosols within the sanitary plumbing and sewerage system and their cross-transmission into the building. Laboratory tests, using Pseudomonas putida KT2440 as the pathogenic agent within a toilet flush, found that the generated bioaerosols could be spread from one floor of a building to another via the building drainage system. If a defect within the system exists such as, for example, the loss of the seal within a water trap, then the bioaerosols could enter a room on an upper floor and contaminate every surface within that room. Such a cross-transmission route depends on the following confirmed conditions:

1.The sanitary plumbing and sewerage system is a reservoir of pathogenic organisms.
2.Bioaerosols are generated during appliance flush.
3.Airflows within the sanitary plumbing and sewerage system move both in the upward and downward directions and circulate between floors.
4.Biaoerosols can be transported on the airflows that exist within the sanitary plumbing and sewerage system.
5.A defect, such as an empty U-bend, allows air to move from the system into the building.

3.2 Viral transmission in tall buildings

As a common feature of most global cities, tall buildings offer a number of advantages, whether it be to provide offices or homes when urban space is not available or to make an iconic statement on the world stage. However, these “cities in the sky” can also facilitate the rapid spread of infection from one person to another due the high density of people in a single building. Using advanced numerical modelling techniques, researchers at PRoBE were able to confirm the World Health Organisation conjecture that a high cluster of cases of SARS, reported at the Amoy Gardens residences in Hong Kong in 2003, was caused by the vertical transmission of the virus between apartments via both the sanitary plumbing system and the service risers. The 321 confirmed cases of SARS and 42 fatalities suffered by the residents highlight the risk of infection spread within buildings, especially the significance of a vertical transmission route which is particularly unique to tall buildings.

By modelling air flow movement and air pressure wave propagation within the sanitary plumbing system, the PRoBE research was able to demonstrate the likely circumstances within the building that resulted in the rapid spread of the virus. The index patient (the first resident to become infected with the virus) lived on the 16th floor of the 36 storey building. Infected faecal particles were discharged to the building drainage system during the diarrhoeal phase of the infection. The flushing of the WC caused the generation of airborne bioaerosols within the system’s vertical stack. A number of dry floor drains, together with some appliances with no fitted water trap seals, provided a route for the ingress of virus-laden bioaerosols from the building drainage system and into the bathroom, driven by the transient pressures prevailing within the system, natural buoyancy, and the negative pressure created by the bathroom extract fan. After passing through the extract fan, the bioaerosols were then exhausted into the external service riser which acted as a channel to spread the virus to upper and lower apartments via open windows. This mechanism of viral spread was attributed to the infection of residents in some 11 apartments below the index patient and 27 apartments above the index patient – firmly highlighting the significant risk of vertical transmission of infection in tall buildings.

3.3 Infection Spread in Hospitals

With up to 9% of all patients in the UK contracting a Healthcare Acquired Infections and an associated annual cost to tax payers estimated at £1 billion, the control and reduction of the spread of infection in hospitals is a top priority for the NHS in UK. Researchers at PRoBE have identified the building drainage system as a potentially significant, yet often forgotten, source of infection spread within hospital buildings.

The building drainage system is one of only a few engineered systems that interconnect all parts of a building, and it is the only one that acts a collection network for human waste. In a hospital building, this waste has a high potential for pathogenic contamination, making the building drainage system a potentially rich reservoir for pathogenic microorganisms. Failures within the system, such as empty water trap seals at appliances or wastewater backup due to blockages, can contribute to the spread of pathogens from the building drainage system into the hospital building – considerably adding to the risk of infection spread.

Research carried out by PRoBE in hospital buildings using polymerase chain reaction (PCR) tests on waste water samples confirmed that the sanitary plumbing and sewerage system is contaminated by pathogens released directly to the system by infected patients. In one example, the building drainage system tested positive to Norovirus GII over a number of weeks during an outbreak within the hospital building [4].

Furthermore, measurement of the conditions within the hospital sanitary plumbing and sewerage system showed average temperatures of just over 24 ℃ and an average humidity of almost 97%. The warm and humid conditions that exist within the system not only aides pathogen survival, it also facilitates the airborne transmission of aerosolised pathogens around the system, and potentially into the hospital building, through air movement and buoyancy effects [5].

3.4 Laboratory Investigations

At the heart of the work carried out by the PRoBE group is an adherence to excellence in data collection and a rigorous approach to both engineering modelling and microbiology analysis. Molecular techniques such as PCR are used to generate mathematical equations suitable for inclusion in a 1-D method of characteristics model, AIRNET, which is currently being updated to include an algorithm for the simulation of microbial transport on building drainage airstreams. One of the laboratory test rigs used to collect empirical data is shown in Figure 2. Figure 3 shows an example of non-intrusive bioaerosol sampler.

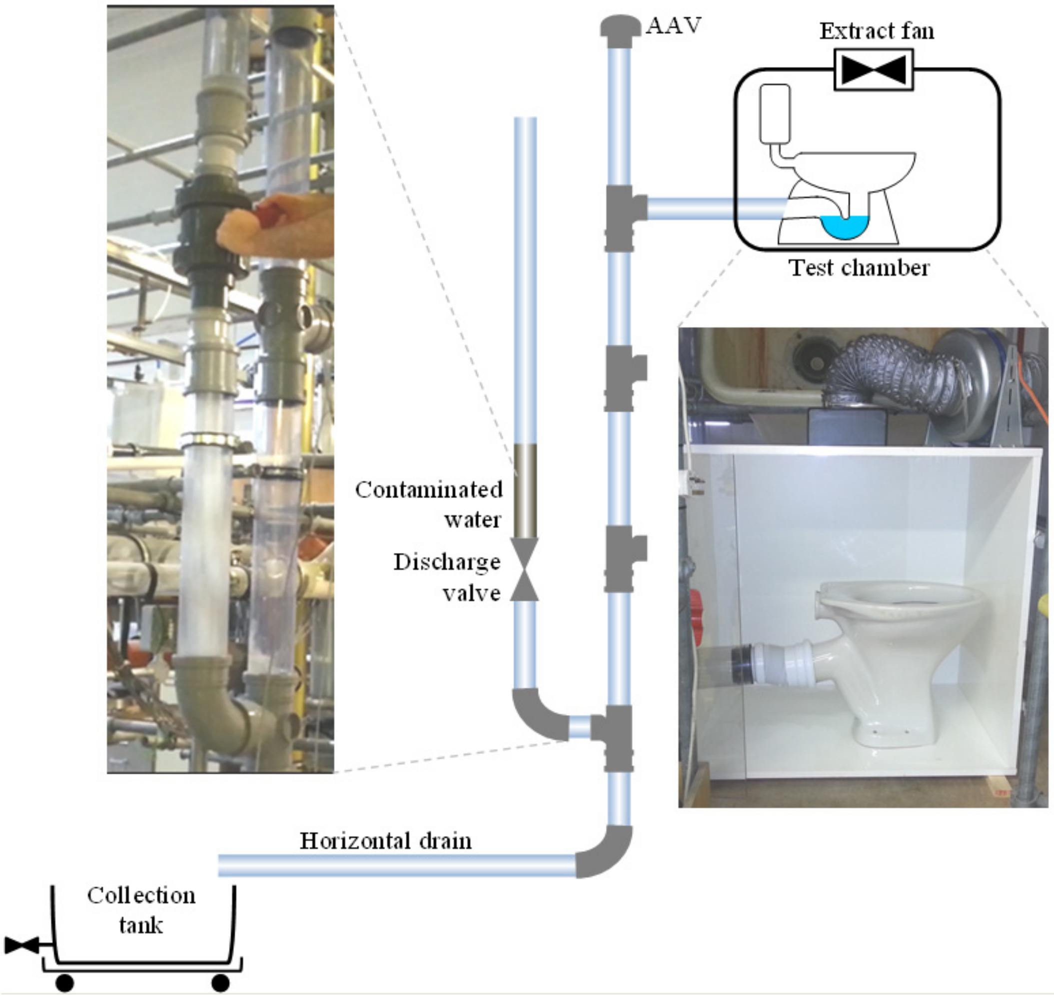


Figure 2: Laboratory test rig for bioaerosol characterisation

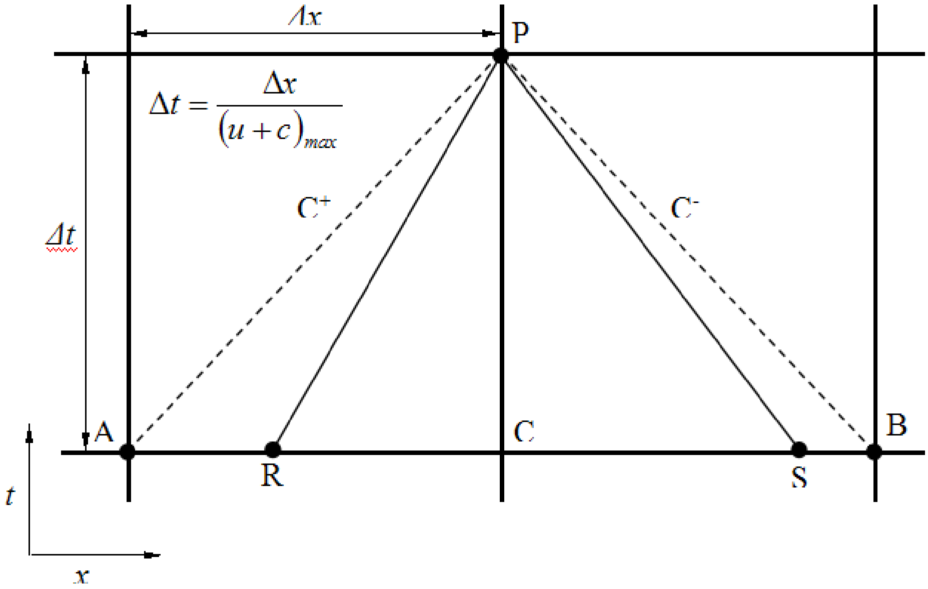
Figure 3: Non-intrusive bioaerosol sampler

3.5 Mathematical Modelling (AIRNET)

Modelling air pressure wave propagation in a building drainage system is suited to numerical techniques applicable to full bore fluid flow. Previous research has developed the simulation techniques to evaluate the risk associated with the propagation of short duration air pressure transients in building drainage systems [6]. The program AIRNET has resulted from the research carried out on this simulation technique over many years.

The program simulates the propagation of low amplitude air pressure transients using the fundamental St. Venant equations of momentum and continuity and by the numerical solution of these equations, via the method of characteristics. The method is used to yield air pressure and velocity within a bounded duct system subjected to air pressure transient propagation.

The diagram in Figure 4 shows the grid representation of the scheme used for the calculation of the propagation of pressure transients along a pipe. The grid is formed in two dimensions, representing time, t and distance, x. The conditions at one point in the grid are based on the conditions upstream and downstream, one time step in the past and require a definition of the characteristic slope as a basis for calculation. The straight lines shown in Figure 1 between A and P and B and P should be curved, however it has been shown that given the very short time steps a first order straight line approximation introduces little error into the calculation. From the grid in Figure 1, R and S represent points where the condition is known by interpolation and P is the condition to be calculated. The characteristic lines between R and P and S and P represent equations used to calculate the condition at point P. The line of communication formed by the characteristic slopes allows information regarding air velocity and wave speed and hence pressure, to be propagated throughout the network.



Note: If $c >> u$, then points R and S tend to A and B

Figure 4: Grid showing characteristic lines as utilised in Method of Characteristics approach to air pressure transient modelling

The discrepancy between A and R and B and S is due to the slopes being given by $1/u+c$. If the velocity of the fluid is much less than the wave speed, then $u<<c$ and the variation in the slope of the characteristic line may be assumed negligible and A/R and B/S are two points.

3.5.1Boundary Conditions

Figure 4 illustrates the technique for the progression of calculations on an x-t grid, where the conditions at a given time step are calculated from conditions upstream and downstream at the previous time step. For calculations to proceed, it is clearly evident that conditions at system boundaries, such as pipe junctions, water trap seals, open terminations Air Admittance Valves (AAVs) and Positive Air Pressure Attenuators (PAPAs) are known. Equations to represent the effect of boundaries on the flow regime can be derived theoretically however in the case of BDS it is more usual to derive suitable boundary equations empirically, through laboratory investigation. In term of the method of characteristics model of airflow in BDS boundaries are represented as either C+ of C-. The predictive technique utilising the method of characteristics described above can be applied to a wide range of fluid situations including; movement of water in a water trap seal, inrush of air at an AAV, or more appropriate for this paper, microbial transport on the naturally occurring airstreams within the drainage system itself.

3.5.2Representing a boundary for particle modelling

Assumptions are made relating to the applicability of different transport models for microbes.A large body of opinion suggests that microbes are so light that they are carried at the air velocity, however such assumptions do not take into account survival of organisms, whether they are viable or not and whether they pose any threat. A boundary condition for microbial transport would take account of these factors and would introduce a decrement factor to relate the transport of viable pathogens in the airstream. The following calculation process is carried out for each timestep.

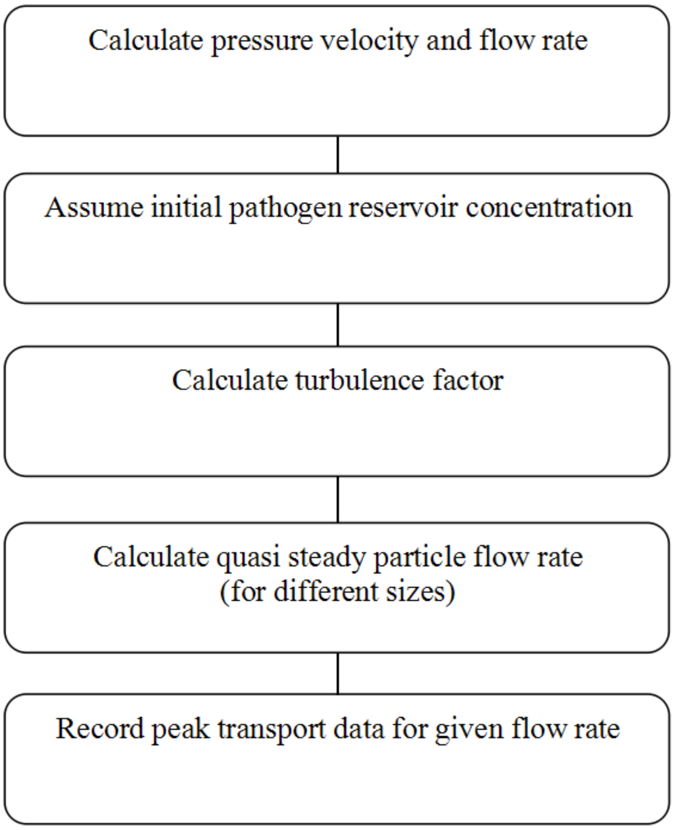


Figure 5: Calculation process for pseudo particle tracking

The concentration of pathogens at any given location can be hypothesised as;

$$P_c = f \{P_{ci}, Q_w, Q_a, Tf, Pd,, Sf, Df\} \text{ Eq. 1}$$

Where

P_{ci} = Initial Pathogen concentration in reservoir/host
P_c = Pathogen concentration at a given point
Q_w, = Water Flow rate
Q_a, = Air flow rate
Tf, = Turbulence factor
Pd,,= pathogen effective diameter
Sf, = Survivability factor for pathogen modelled
Df = Decrement factor (between airflow and pathogen flow)

Taken together these factors contribute to a transmission co-efficient which can be used to determine the risk of viable pathogens contributing to disease spread in a building.

4. Conclusions

The case for transmission of pathogens in building drainage system airstreams has been successfully proven. A cross-disciplinary group of engineers, modellers and microbiologists has been established to further the science associated with this new discipline. The focus of this work, by the PRoBE team at Heriot-Watt University has been on infection spread in hospitals and high rise buildings.

Preliminary research by the PRoBE group has proven that whenever pathogenic material is introduced into the building drainage system, the entire system becomes contaminated. It has also been proven that bioaerosols can be easily formed by the normal flushing mechanism and the turbulent discharge of wastewater within the system. These bioaerosols can be carried in system airstreams and if the water trap seal is lost then these bioaerosols can enter the building and can result in contamination of every surface in a room.

The preliminary research by PRoBE has been characterised by major findings that highlights the potential health risk that bioaerosols from building drainage systems pose and confirms the need for significant further research in this important area.

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Evaluation of the Performance and Impact of the Use of Microorganisms in Maintenance of Drainage Systems

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Abstract

The concern with foul odours in building drainage systems has led specialized companies in biotechnology to invest in products composed of mixtures of living microorganisms that act on the pre-treatment of the wastewater inside traps to fighting against unpleasant odours. The aim of this paper is to assess the performance of using concentrated mixtures of microorganisms to accelerate the degradation of organic compounds in floor drains of building drainage systems and the impact on wastewater treatment plants. The methodology consists of diagnosing of unpleasant odours in restrooms of the Civil and Environmental Engineering building of the University of São Paulo, which is subject to constant complaints on the part of users. Thus, microorganism tablets were introduced in the wastewater of the floor drains of two restrooms and the performance and impacts of their use in restrooms and in sewage treatment plants was investigated. Biochemical Oxygen Demand (BOD) and oxygen uptake rate (OUR) tests were conducted in order to check changes in the sewage. The results show that the microorganisms tablet proved unable to improve these restrooms conditions. On the other hand, the laboratory tests indicate that the microorganisms tablet would also not be able to produce significant changes that could compromise the treatment system in wastewater treatment stations.

Keywords

Drainage System; Microorganisms Tablet; Traps; Floor Drains.

1. Introduction

Considering the maintenance of building drainage systems, one of the critical points is the maintenance of the conditions of cleanliness of sanitary appliances and, in particular, the removal of waste that can be accumulated in traps.

This maintenance is even more important for building drainage systems of high rise or large buildings with high population density, such as hotels, restaurants, schools and office buildings.

The accumulation of substances in grease traps, floor drains and pipes, as well as the seal losses may cause unpleasant odours or blockages, attract insects and promote the proliferation of infectious agents that are harmful to human health.

The need to make the cleaning of building drainage systems more practical and fast has stimulated the development of research on the application of biological agents that facilitate the maintenance of these systems.

This microbial technology has supported the development of products that have the function of biodegrading industrial and domestic effluents, reducing the need for monitoring to identify the right moment of removal of waste such as oil, grease, fats and organic sludge. The consequence is the reduction of the occurrence of blockages and damage to the traps and pipes besides the mitigation of foul odours.

Concentrated mixtures of adapted bacteria, enzymes and minerals are presented in the form of tablets and have the function to accelerate the degradation of organic compounds from domestic use. The use of this technology is quite recent and, therefore, it is necessary to investigate the efficiency of the use of microorganisms in sanitary effluents and if there are risks to the health of users who manipulate this product and the quality of the water pre-treated using these products.

Thus, the aim of this paper is to assess the performance of using concentrated mixtures of microorganisms to accelerate the degradation of organic material in floor drains of building drainage systems and the impact in wastewater treatment plants.

2. The Use of Microorganisms in Drainage Systems

Traps are fittings with water seals in order to prevent foul gases and viruses from sewage pipes entering to the sanitary room. It was well established that the spread of the SARS virus was assisted by poor plumbing maintenance in Amoy Gardens leading to empty water trap seals [1].

This fact shows the importance of avoiding dry traps which, in addition to foul odours, the bad performance of them can facilitate the spread of serious diseases.

2.1 Possible impacts of the use of microorganisms in wastewater treatment

In order to eliminate foul odours in the restrooms, products composed of microorganisms that have the function of pre-treat the wastewater inside the traps and in the floor drains began to be available on the market.

Can the use of these microorganisms in traps mitigate the foul odours in the restrooms? What would be the impact of the use of microorganisms in wastewater treatment plants?

The interference of microorganisms in sewage treatment could be in a variety of ways:

(1) Inhibit the action of microorganisms present in the activated sludge, compromising the quality of the water returned to the watershed;

(2) There is no elimination of microorganisms from the tablets used in the pre-treatment for the disinfection and cause contamination of watersheds by these microorganisms, which in high concentrations could cause imbalances in the aquatic environment reached.

This paper focuses on the general changes in the sewage, for example, in the biochemical oxygen demand (BOD) with the addition of the microorganisms tablet and also the effect these may have on microorganisms that are common to the activated sludge, by employing respirometric test.

3. Methodology

This research was conducted in the following steps: survey of the restrooms, laboratory tests, insertion of the microorganisms tablet in the floor drains, monitoring the performance by the users and analysis of the results.

3.1 Caracterization of the restrooms

The survey was conducted in two restrooms of the Civil and Environmental Engineering Building of the University of São Paulo-USP, one male and one female, which is subject to constant complaints of foul odours on the part of users.

Then, tests are made to check if floor drains were receiving effluents from urinals or if seal water losses was occurring by induced siphonage or self-siphonage.

3.2 Laboratory tests

In order to evaluate the performance and possible impacts of microorganisms in wastewater treatment plants, BOD and respirometric tests were carried out. The BOD test aims to assess indirectly the concentration of biodegradable organic matter, whereas the respirometric test evaluates the metabolic behaviour of microorganisms present in the sample.

Laboratory tests were conducted to determine the BOD of wastewater with and without addition of microorganisms tablet. The results are compared to verify the influence of microorganisms present in the tablet on the BOD.

The method employed for the determination of BOD is the dilution, an incubation for a period of 5 days at a temperature of 20ºC, with the assessment of the initial and final of oxygen rate through the modified Azide method [2].

In order to verify the influence of microorganisms on the BOD values, a dilution in different concentrations of one the tablets was made in a litre of wastewater produced in the University of São Paulo Students Housing.

Afterwards, nine BOD bottles were prepared, with the following compositions:
(1) a bottle with dilution water only, used as a white;
(2) Four bottles with dilution of wastewater and water in different volumes;
(3) Four bottles with different dilutions of wastewater and with different concentrations of microorganisms.

The dilution water is a solution composed of ultrapure water and solutions of micronutrients, necessary to meet the needs of microorganisms during the 5 days of the test. This dilution water is also subject to aeration until the saturation point, in order to provide a sufficient concentration of O_2.

3.3 Insertion of the microorganisms tablet in the floor drain and evaluation of the users

Microorganisms tablet were inserted, in accordance with the instructions of manufacturer, in the floor drains of the restrooms.

Microorganisms tablet performance was accompanied during thirty days, through observations of the restrooms and through interviews of users using a questionnaire.

4. Restrooms Characterization

The restrooms survey was made and the plant is presented in Figure 1. Both of the male and female restroom has only one floor drain. They receive the wastewater from all washbasins and the wastewater used to clean the floor. It is important to mention that the floor drain in the female restroom receive the effluents from the floor drain of the male restroom.

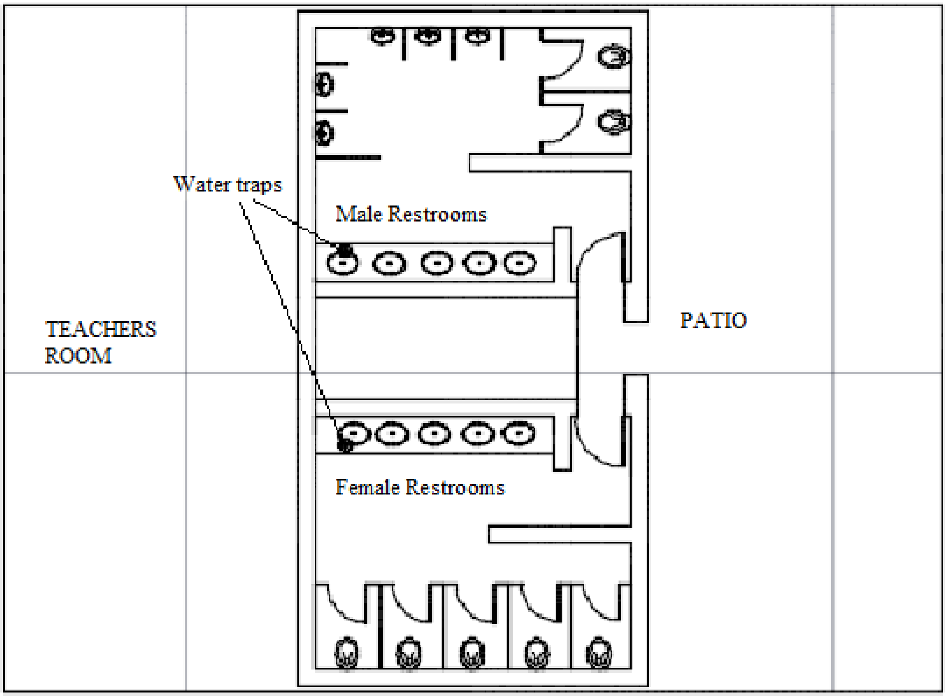

Figure 1 - Plant of the male and female restrooms

There are not windows in the restrooms. There are an exhaust fans in both restrooms, but they are not working.

Tests by using dye were conducted to check if the drain floors were receiving wastewater from urinals or if it was occurring water trap seal losses by induced siphonage or selfsiphonage. It was not observed anyone of this kind of problem.

4.1 Cleaning conditions

The cleaning services of the restrooms are conducted four times a day, using water, soap, disinfectant and chlorine. Apparently the restrooms are in good conditions of cleanness most of the time, but the foul odours are maintained.

4.2 Maintenance

A clearing of the urinals of male restrooms was conducted and Figures 2 and 3 show the large quantities of pasty material, clear colour blocking pipes and the internal walls of the urinals.

Figure 2 - Urinal removed during maintenance

Figure 3 - Detail for the pasty material removed from the urinal during maintenance

5. Results and Discussions

The results of interviews conducted with users of the restrooms after insertion of the microorganisms tablet in the floor drains, as well as the BOD and respirometric tests are presented and discussed in this section.

5.1 Performance evaluation of the use of microorganisms in floor drains to reducing foul odours in restrooms

According to information of the product, the microorganisms tablet is developed for degradation of organic waste and to reducing foul odours in the pre-treatment of wastewater from the personal hygiene, cleaning of utensils and household surfaces.

Microorganisms tablet, based on a solid suspension of bacterial cultures with high enzyme capacity, is recommended for digestion of organic waste and foul odours reduction in domestic floor drains. Figure 4 illustrates the microorganisms tablet being dropped in a floor drain.

Figure 4 - Microorganisms tablet

According to the manufacturer the microorganisms tablet is composed of: Bacillus amyloliquefaciens, Bacillus licheniformis, Bacillus megaterium, Bacillus pasteurii, Bacillus polymyxa, Basillus subtllis, sodium sulfate, methyl silicate, corn flour, polyethylene glycol and dye. It does not contain solvents, acids or caustic elements, so it does not affect any kind of pipe.

Microorganisms tablet were inserted in the floor drains of the male and female restrooms. The cleaning team was oriented not to use antibacterial products in the cleaning of the floor drains.

After insertion of the microorganisms tablet in the floor drains, interviews with the restrooms users were conducted during three weeks in order to verify if the foul odours were reduced and if it was perceived by the users.

Seventy users were asked about how much foul odours was bothering them in three periods. The answers obtained indicate that there has been no significant improvement that could be verified by users under the conditions of the restrooms along the three weeks in which the survey was conducted.

Some hypotheses are considered to the low performance of the microorganisms tablet in reducing the foul odours of restrooms:
(1) The Cleaning Team May Not Have Heeded The Recommendations Of Do Not Use Antibacterial Products During The Cleaning Process;
(2) The Recommendations Given To The Cleaning Team May Have Hindered The Implementation Of Restroom Cleaning, Leading To The Accumulation Of Micro-organisms That Caused The Increase Of Bad Smell During The Period Of Action Of Microorganisms Tablet;
(3) As The Foul Odours Are Appellants In These Restrooms, Some Users May Have Responded To The Survey Taking Into Account The Usual Nuisance Caused By Odours And Not Necessarily The Situation At The Time They Were Asked;
(4) The Restrooms Without Ventilation Systems Makes It Harder On The Removal Of Foul Odours Even If Cleaning Is Appropriate And Make Use Of Biologics Products In The Pre-treatment Of Floor Drains Effluents.

5.2 Evaluation of the impact of the use of microorganisms in the floor drains

In order to assess the possible impacts of the use of microorganisms in the floor drains in wastewater treatment plants, BOD and respirometric tests were carried out.

5.2.1 Biochemical Oxygen Demand - BOD

First of all, it was diluted 7 mg of one of the tablets in a litre of wastewater. This ratio was calculated considering that, in the manufacturer's instructions, is informed that a tablet (70 g of the product) is effective for about 30 days and it is capable of pre-treat the volume of 10 thousand litres of wastewater.

Afterwards, it was conducted a new test, but this time simulating a critical case of contamination, which was diluted 1 g of microorganisms tablet in a litre of wastewater. In this second test relevant differences were obtained between the values of the BOD of the samples with and without microorganisms tablet. These results indicate that, in the case of an excessive use of microorganisms tablet, is possible a significant increase in the value of the BOD of the wastewater.

Finally, two analyses of BOD were conducted, with intermediate concentrations comparing to the previous analysis: 0.1 g and 0.5 g microorganisms tablet per litre of wastewater. It was verified at concentrations analysed in the third test of BOD a significant increase in the BOD in the samples with microorganisms tablet.

In Table 1 are presented the results of four tests conducted and also the BOD increase percentage caused by increased of the microorganisms tablet.

Table 1 - Results of the BOD analysis

Sample	Average BOD wastewater	Average BOD (wastewater + tablet)	Increase (%)
0.007 g BTWT/L	278	276	No change
0.1 g BTWT/L	268	334	24.6
0.5 g BTWT/L	268	532	98.5
1.0 g BTWT/L	162	700	332.1

The results presented in Table 1 show that the microorganisms tablet is able of producing significant changes in the BOD only when in concentrations much higher than specified by the manufacturer of the product.

Figure 5 presents the percentage increase in the values of BOD with the concentration of microorganisms tablet in the sample of wastewater.

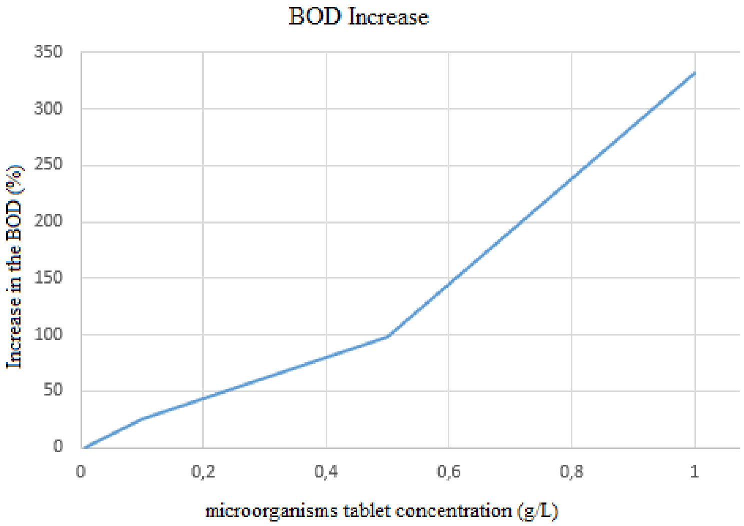

Figure 5 - Relationship between increased percentage of BOD and microorganisms tablet concentration in the sample

5.2.2 Respirometric tests

Respirometrics tests were conducted in order to evaluate the possible effects of the use of the microorganisms tablet present in the biomass employed in the test similar to that used in the main wastewater treatment systems in the metropolitan region of São Paulo.

Respitrometrics test results showed that the OUR was more intense with the addition of wastewater in conjunction with microorganisms tablet compared to adding wastewater only. This indicates that the microorganisms tablet would be unable of producing inhibition in the treatment process, even in extremely high concentration, however causing a greater demand for oxygen.

6. Final Considerations

The microorganisms tablet proved unable to improve these restrooms conditions. On the other hand, the laboratory tests indicate that the microorganisms tablet would also not be able to produce significant changes that could compromise the treatment system in wastewater treatment stations.

The elevation of BOD caused by addition of microorganisms tablet indicates that microorganisms present in the product increase organic load in the sewer that will follow to wastewater treatment plant. In very high concentrations, the product could promote changes in normal conditions of sewage, for which the system could not be prepared. However, the chances of a biological product like microorganisms tablet compromising the efficiency of the wastewater treatment stations is small, since even in a situation of massive use of products like this by the population, the concentration of the product would not be able to produce significant changes.

Another relevant fact shown in the tests of BOD is that organic load was increased due to the introduction of microorganisms tablet and not reduction in function of the tablet composition already contain organic compounds as described in item 5.1. Among other possibilities, such as improper cleaning, the lack of maintenance and ventilation deficiency in the restrooms etc., this is one possible cause for the inefficiency of microorganisms tablet in reducing the unpleasant odours.

Another relevant fact shown in the tests of BOD is that there was increased of the organic load with the introduction of microorganisms tablet and not reduction. It was expected since the product proposes to pre-treat effluents in floor drains, degrading organic matter, with the aim of reducing foul odours in restrooms. Among other possibilities, such as improper cleaning, the lack of maintenance and ventilation deficiency in restrooms etc., this is one possible cause for the inefficiency of the microorganisms tablet in reducing the foul odours.

The results obtained with the addition of microorganisms tablet in the respirometric tests indicates that only in critical conditions, there will be increase in the OCR, which could compromise the tratatmento in a wastewater treatment plant.

Acknowledgments

The authors thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq and the University of São Paulo for financially support this research.

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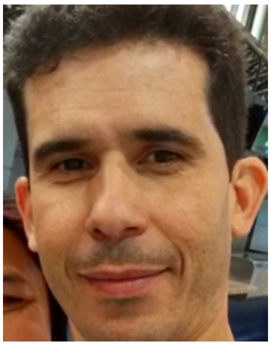

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Controlling Countermeasures of Noise Pollution in Super High−rise Architectural Water Supply and Drainage

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Abstract

The technical background on the development of super high-rise architectural water supply and drainage is explained, the goal of control the noise from water supply and drainage is defined, and how the noise comes from is analyzed in this paper. This paper also put forward the control countermeasures and solutions.

Key words

Super High-rise Building，Drainage Equipment Room，Noise，Vibration Isolation，Floating Floor

1. Introduction

As a highly developed modern city landmarks building type, super high-rise building has its rationality and necessity. China's economic and social development characteristics also provides the conditions for the development of super high-rise building construction. In recent years, super high-rise buildings almost universal to all levels of the city appeared in large numbers in the country, also caused some controversy. People began to pay attention to the negative impact of super high-rise building to people's quality of life. For designers, improve the indoor quality of life is an important issue. Among these, how to reduce noise and create a peaceful living environment is easy to overlook in the super high-rise building design, but is a very important content.

Therefor in the super high-rise buildings on the equipment level pump room noise, vibration and other factors analysis, control measures, to achieve national standards.

2. Technology Background of Super High−rise Building Water Supply and Drainage Noise Control

Super high-rise building refers to building which height greater than 100m. According to the development trend, more than 90% super high-rise building of the world will be located in China.China is the country which has most amount of super high-rise buildings which height higher than 250 m, accounting for more than half the global quantity. The ratio of super high-rise building of central China to the whole China is 23%

According to the different water requirements of super high-rise building， it has different effects on different floors to the sewer system, water pressure equipment, heat exchange equipment, fire water supply equipment. For example: In in the basement it is generally equipped with a set of life pressure pumps, living life transfer pressure pumps, fire pressure pumps, or fire transfer pressure pumps and other firefighting transfusion; usually there is reclaimed water pressure pump or hot water circulation pumps in some building basement; in some mechanical floor there generally has life pressure pump, fire pressure pump, etc. Roof typically has a small set of life pressure pumps, fire pumps. Inevitably it will produce vibration and noise when those equipment is running. This vibration and noise may do great harm for people's living environment. How to reduce and eliminate the effects of vibration and noise in super high-rise building water supply and drainage equipment is a inevitable problem.

3. Target of Super High−rise Building Water Supply and Drainage Noise Control

《Code for design of sound insulation of civil buildings》stipulates detailed for noise control of such buildings as residential building, schools, hospitals, hotels, office buildings and commercial buildings. Super high-rise building has complex functions, common features include: basement has garage, commercial and catering; podium has business, restaurants, movie theaters; tower building has residential building，office and so on. Among them cinema is most sensitive to noise. In《Code for architectural design of cinema》, there is a special section of the vibration and noise control requirements in the chapter of "acoustic design"; Super high-rise building residential, hotel, office and other use of personnel for higher comfort requirements of noise control requirements are also higher, construction noise control indicators should be in line with the requirements of 《Code for design of sound insulation of civil buildings》.

Due to construction noise source and composition is complex, it's difficult to accurately calculate and measure noise level, so that the following mainly focus on the mechanism of super high-rise building noise generated drainage, and qualitative analysis of spread rules and control mode.

4. Analysis of Super High−rise Building Water Supply and Drainage Noise

Noise comes from the Irregular vibration of the object. Vibration is formed noise through solid, liquid, gas and other propagation medium eventually into the ear. It will give analysis of noise source and drain noise transmission route of drainage equipment room.

The drainage system has the following sources of noise in the drainage equipment room :

(1) Pump unit factor. Drainage pump unit is the main noise source in the drainage equipment room, it has the greatest impact on the surrounding room. Pump noise is low frequency noise (frequency below 500Hz). Characteristics of low-frequency noise is attenuation slow, acoustic longer and diffraction wave can easily around obstacles, therefor it is difficult to deal with low-frequency noise. Pump noise is recombination noise of pump working noise and pump motor noise.

The main reasons causing the pump working noise are: vibration of impeller running， pipe resonance caused by impeller， water hammer, friction and hit between water and pipe，and so on. Among these facts，the noise caused by the rotation of the impeller has close relationship to impeller rotate speed. As experience shown, when the power is the same, the faster impeller rotate speed is, the greater the pump noise is, and showing continuous hum. Pipe resonance of the impeller is closely related to the work state of pump. When pump is running in efficiently segment, pipe resonance is relative small. Water hammer phenomenon is systemic, it is caused by both pump factor again pipe factor ,it is happened generally when flow state is sudden changed such as start or stop pump, open or close valve state, showing intermittent pops, accompanied by violently shake of pipe. Vibration by the friction and impact of water and pipe is unavoidable, vibration amplitude is closely related to flow velocity. In general, the greater the flow rate is, the larger the vibration is, the lower the flow rate is, the smaller the vibration is. But when the flow rate of the resonance frequency caused by the natural frequency near the piping system, abnormal vibration will be strengthened. Because of the complexity and diversity of the piping system, its natural frequency is almost impossible to calculate, generally it is estimated by experience and engineering tests.

Pump motor noise mainly is aerodynamic noise, mechanical noise and electromagnetic noise. When the motor is running, the cooling air stream noise and high-speed rotation of the fan blade noise composed of aerodynamic noise. When using water-cooled motor, because there is no cooling fan, so water-cooled motor's noise is smaller than air-cooled motor's noise. Water-cooled motor in general construction is less used， air-cooled motor is important reason to pump room noise. Mechanical noise of the motor includes bearing noise and noise which was caused by rotor imbalance, it is mainly due to the precision of the bearing is not high, bearing wear, lubrication decline, motor disalignment ，and so on. Electromagnetic noise is caused by alternating electromagnetic attraction between stator and rotor ，as well as magnetostriction.

The main spread way of pump room noise is through air or through pipe or through solid such as building components.

(2) Pipe factor. Pipe noise includes water supply noise and drain noise. Water supply noise is mainly composed of water freely flow impact , friction and shock of high-speed flow in the tube, pipe resonance, water hammer, pipe or valve cavitation, air resistance and so on. Free water outflow include faucet flow, shower flow and free overfall of tank. Effect of pipe flow friction and high-speed impact and water hammer to generate noise is mentioned above. Jitter caused by water hammer would cause such indirect consequences as the pipe loosed, fall off, the float valve damaged ， and further exacerbating the effects of noise. In general housing construction, due to the characteristics of normative restrictions and field conditions, self-priming mode were taken by pump launching， it has a small probability and the extent of the phenomenon of cavitation. But due to design or product quality issues, cavitation come into being in fittings and valves, little by little pipe and valve was damaged, cause vibration, make noise. In engineering, it often generate cavitation due to inappropriate pressure reducing ratio of pressure reducing valve， causing sharp whistle. Air ducts at the top of the pipe together to form an airbag, reduce water delivery capacity, resulting in local pressure shocks, can cause noise and vibration.

Drain noise is mainly caused by flow friction and shock, sanitary siphon and water pipe resonance. Drainage water is often mixed with different types of solid and has complex composition. When the solid-liquid mixed fluid horizontal flow or pipe-attached flow, the friction noise will be formed; when drain direction , solid-liquid mixture fluid will hit the pipe occurred generating impact noise, and it is possible to make pipe vibration, shaking and make noise. Sanitary appliance, especially water closet， will Occur siphon flow. When water is flushed to drain-pipe due to siphon, the air is compressed to form noise, it is often said the sound of water closet, in the deep night it would be very harsh. Piping system has own natural frequency, when the action of water or other factors make the vibration frequency of the pipeline near or reach the natural frequency of the pipe ， it will cause abnormal vibration amplification of pipe, ranging from generating disturbing vibration and noise to damage the pipe system.

(3) Valve factor. Opening and closing various types of valves can cause dramatic changes in flow velocity and momentum, resulting in water hammer phenomenon and make noise; mechanical noise of opening and closing check valve ， floating ball valve or solenoid valve ; resonance due to damaged valve or not in place, etc.

(4) Other factors. Including: steel tanks noise due to pipe vibration ， heat exchanger coil noise due to excessive flow velocity, vibration or shaking caused by unstable fixed equipment or pipeline ， etc.

The drainage system noise spread ways of mechanical floor are mainly in terms of following aspects:

(1) Pipe. Noise vibration can be transmitted to other place through building space by vibration, passing distance is much more than in the air. The noise sources through pipes are the noises caused by pumps， valves and heat exchanger which connected with pipes, as well as noise by pipe water flow.

(2) Building component. On the one hand， noise vibration of pumps and heat exchanger is transmitted to building component though device base， on the other hand， noise vibration of devices and pipe is transmitted to building component though pipe supports and hangers.

(3) Airborne. After all, the vast majority noise is transmitted to ear of human through air.

5.Control Measures of Super High–rise Building Water Supply and Drainage Noise

By analyzing of previous section, we can take pointed measures to respectively solve the problems to noise sources and transmission routes. Specific measures are as below:

(1) Equipment such as pumps, tanks, heat exchangers should be placed in dedicated room, and should not near quiet room such as concert halls, wards, classrooms, hotel rooms, residential.

(2) When it is inevitable that transfer pressure pump room of super high-rise building should be settled up or below quiet room, we can take the following measures according to the situation: when pumping room is right located directly in upper floor of quiet room, as isolation measures floating floor or double floor can be adopted; when pumping room is right located directly in lower floor of quiet room, as isolation measures double floor or sound-absorbing ceiling can be adopted; pump room should use sound absorption walls, double doors and windows to reduct noise. Floating floor settle place is shown in Figure 1; Typical floating floor is shown in Figure 2.

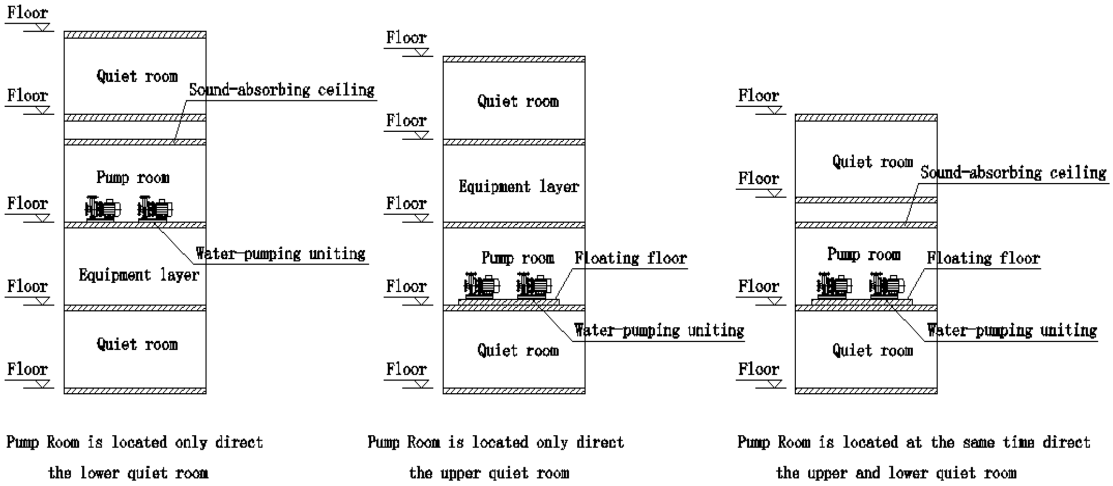


Figure 1:Floating floor settle place

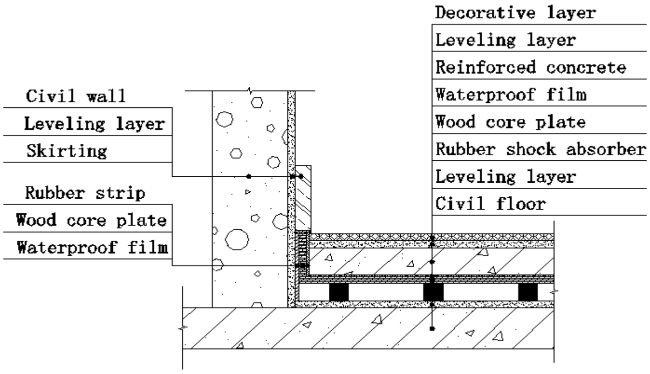


Figure 2:Typical floating floor

(3) The drainage pipe should be located in the vertical tube wells, horizontal tube should be located in the ceiling. Sound-absorbing ceiling should be adopted.

(4) Pump should be the preferred low-speed pump, the preferred quality and reliable pumps, preferred a shorter coupling pumps, use water-cooling pumps when pemitted.

(5) Use of check valve that has the function of silencing and preventing water hammer in pump outlet such as slow closing silencer check valve. The pump outlet pressure is greater than 0.5MPa, the pressure relief valve should be set.

(6) Flexible connection Should be used between all pipes and isolation equipment (such as pumps, heat exchangers, etc.), such as flexible joints, bellows. Flexible connection fittings shall be in the natural stress state.

(7) The pump foundation should set inertia block to reduce resonance effects. Pumps should use isolation base. Vibration isolation methods are rubber mats, rubber isolator, damping spring vibration and so on. Pump motor power exceeding 22kW should not share basis. Rubber isolation pads should be established between the finished water tank and foundation. It should have sufficient working height below the vibration isolation device basis. Isolation pumping station installation diagram is shown in Figure 3.

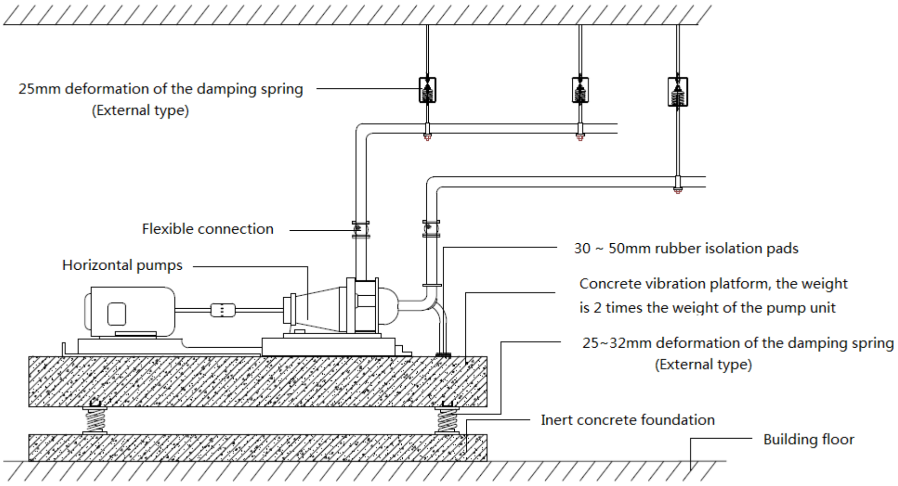


Figure 3: Isolation pumping station installation diagram

(8) When the vibration equipment such as pumps is located in acoustic sensitive locations or close to acoustic sensitive rooms, acoustic enclosures can be used to strengthen insulation, sound insulation should not be less than 20Hz.

(9) The principles of isolators usage:

Table 1

Device natural frequency	Isolator Selection
＞ 20~30Hz	Rubber isolation pads, compression-type rubber vibration isolator
=20~30Hz	Steel coil spring isolators, cut style rubber isolator, composite isolator
=0.5~2Hz	Steel coil spring isolators, air spring isolators

(10) It should be careful to determine the location of vibration pumps and other equipment, optional on the ground floor, near the top of the structure of the main support columns and beams, to avoid too much equipment supporting point span.

(11) Adopt the pipes of better soundproof effects: ① Plastic coated metal tube noise reduction effect is better than metal pipe. ② Due to the thicker wall, cast iron drainage pipe generally do not need the noise reduction processing; Ordinary UPVC drainage pipe can be coated insulation layer manner, generally available 8 ~ 10dB of sound effects; Spiral receive about noise quiet pipes 4dB of sound effects. UPVC drainage pipe insulation practices is shown in Figure 4.

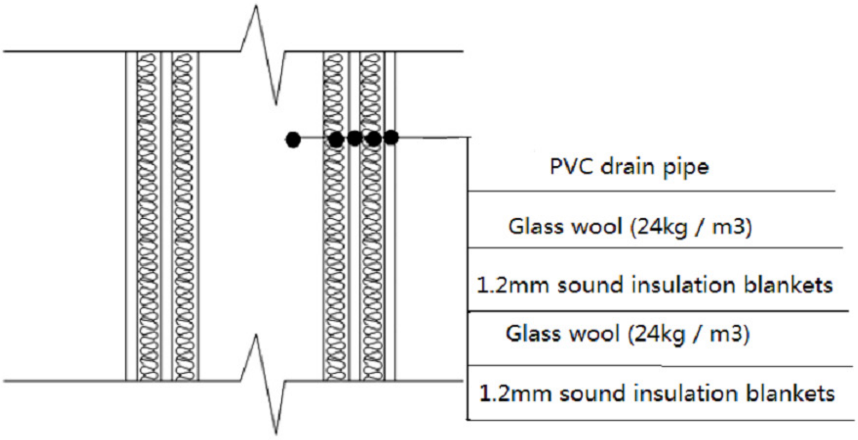
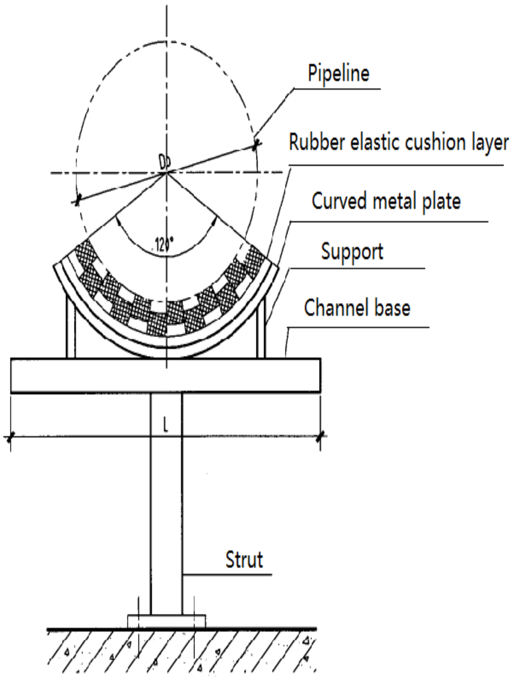


Figure 4:UPVC drainage pipe insulation practices

(12) Pipe design take lower flow rates, flow rate should be carried out according to《Code for design of building water supply and drainage》 and《Technical code for fire protection water supply and hydrant systems》. Pipes shall not pass through noise-sensitive rooms, such as movie theaters, concert halls and so on.

(13) The pipes should be firmly fixed to the structural unit or embedded parts. It should be based on elastic material gasket between the pipe and fittings. Flexible pipe hangers, brackets and vibration isolation bracket should be adopted . Between the pipe and the hanger bracket it should be filled elastomeric gasket material. Isolation stand should be considered at least 50% overload margin. Bolted pipes and equipment should be regularly checked and re-tightened, so as not to fall off. Flexible bracket schematic is shown in Figure 5; Elastic hanger detail schematic is shown in Figure 6.



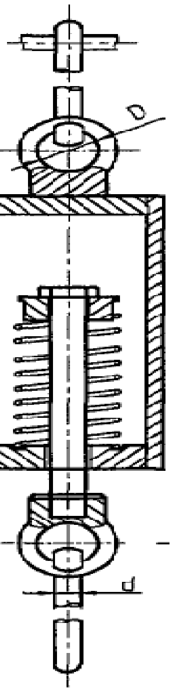


Figure 5: Flexible bracket schematic Figure 6: Flexible hanger schematic

(14) Pipe and equipment insulation has silencing isolation function.

(15)When pipe through floor or wall, the blank of pipe and hole should be filled with elastic material . It should use waterproof casing when waterproof required, rigid waterproof wing ring should not be used. ① For pipe crossing non-firewall, isolation pads can be used to block the casing and the gap between pipe and wall, and then plugging sealant or cement mortar; Pipe crossing non-firewall insulation practices is shown in Figure 7; ② For the pipe through the firewall or floor, use rock wool block, then use cement mortar seal. Pipeline crossing the firewall insulation practices is shown in Figure 8.

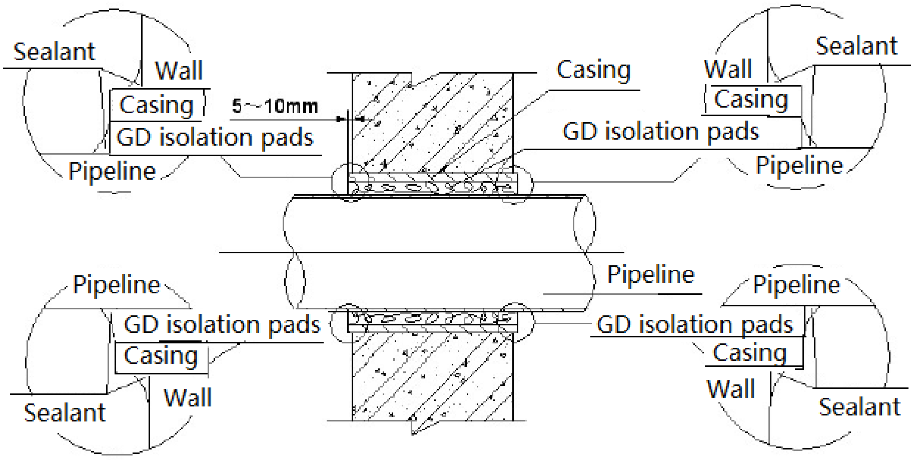


Figure 7: Pipe crossing non-firewall insulation practices

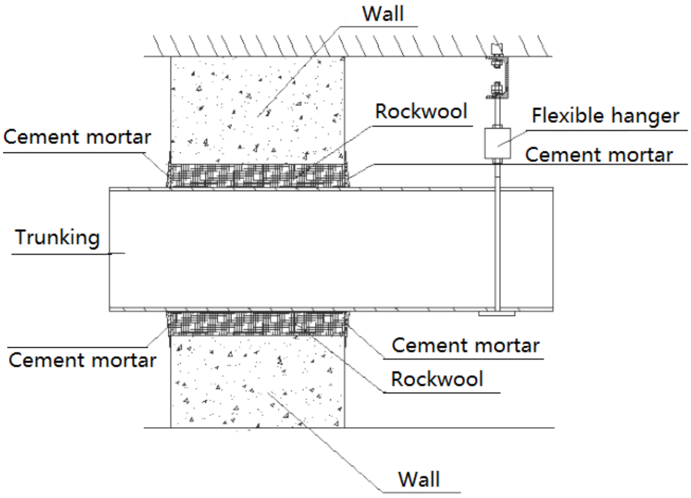


Figure 8: Pipe crossing the firewall insulation practices

(16) Using inflatable faucet, inflatable shower, water closet uses mute water closet, such as jet siphon water closet. Inflatable faucet is shown in Figure 9; Siphon water closet is shown in Figure 10.

Figure 9: Inflatable faucet

Figure 10: Siphon water closet

(17) Into the water tank to avoid free falling water outflow. For example, 《Code for design of building water supply and drainage》 GB50015-2003 (2009 edition) in 3.2.4A requires the tank inlet should be above the water, so as to prevent the free fall of water into the water, the water should be taken measures to guide flow, such as setting up diversion ducts.

(18) The pressure ratio of valve should not be too large, proportional pressure should not exceed 3: 1, before the adjustable pressure reducing valve and the valve differential pressure should not exceed 0.4MPa.

(19) Auto exhaust valve should be set on the top of pipe where gas gathered, such as the top of the water supply system, hot water pipe network and so on.

6. Conclusion

(1) The noise sources of super high-rise building mainly are pumps factors , piping factors, valves and other factors. To take targeted measures to control these adverse factors can effectively reduce drainage noise.

(2) The position of equipment room determines the scope and extent of noise sources influence to the surrounding environment. The appropriate position of equipment room can decrease adverse affect of equipment noise to a minimum. To take passive measures can not entirely solve the adverse effects of equipment room noise.

(3) Floating floor technology applied to the water supply and drainage equipment room provides an effective noise solution. It is a systematic solution to solve the adverse affect of pump room noise on adjacent floors in super high-rise building, it is benefit to flexible design room for architecture, and beneficial to create favorable conditions to maximize revenue for the owners.

(4) Noise of water supply and drainage need to be controlled by selection of equipment, calculation parameters, optimization of construction practice and strengthening post-comprehensive control maintenance management, so as to create a peaceful and harmonious environment.

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Research on the Measurement of the Draining Noise from the Soil Stack

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Abstract

The same floor drainage system and the conventional under floor drainage system are both being applied and installed in buildings in China. PVC-U, HDPE, PP and cast iron are the most popularly used the piping materials. Very small amount of AGR and galvanized steel are applied in very few cases. There is more and more discussion about draining noise with different piping materials in China in recent years. We believe our research on the draining noise and measurement will be helpful to improvement of the standard revision as well as the application of the various draining systems.

Keywords

Draining noise, Draining noise measurement, Conventional drainage system and the same floor drainage system.

We have tested the four kinds of most commonly used materials and take the HDPE as the example that has more types of branch fittings. We make the analysis on the testing measurement in the standard, fittings impact on the draining noise, and the relationship with the building structure and the draining system in order to provide the information and reference for the standard revision.

1. Testing Standard

In China, the current effective national standard for noise measurement is CJ/T 312-2009 Measurement of Noise from Building Water Drainage Piping System. The testing diagram is as the following where the fitting will be conventional branch fittings or special branch fittings.

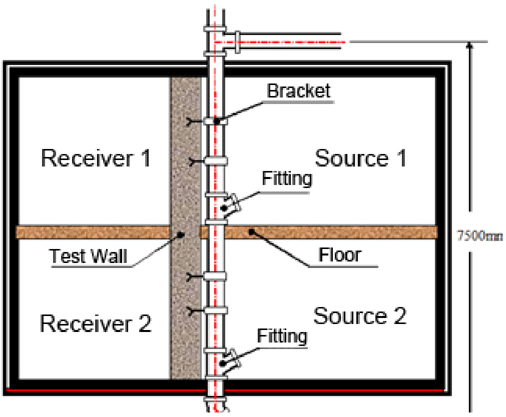

Figure 1 Noise Test Diagram

It is obvious that the branch fittings are set in open that is quite similar to the under floor drainage system.

2. Test Result

With constant flow, the noise is measure in both the source room and the receiver room and the result is in the following table.

Table 1 Test result

Item		SPL（dB）			
Flow rate		0.5 L/s	1 L/s	2 L/s	4 L/s
Sovent	Source	57	61	64	67
	Receiver	22	27	32	38
Cyclone	Source	52	56	59	62
	Receiver	21	25	29	32
Tee with swept-entry	Source	53	55	58	59
	Receiver	24	25	27	31

3. Result Analysis

（1）Water in the special branch fittings flows in changing direction resulting in more impact on the wall of the fittings. As the flow increases, the impact becomes larger resulting in larger noise.

（2）Water in the conventional branch fittings flows in less changing direction so there is less impact on the wall of the fittings that generates less noise.

（3）HDPE has a density of 0.95g/cm^3 that is much smaller than other pipe materials resulting in more vibrations and more noise when the wall thickness is close.

4. Application Condition

When we have a close look at the test result and the test diagram, we can find that the fittings generate more noise than the pipe because of the changing flow inside. In the meanwhile, the fittings are set in open reflecting the conventional under floor drainage system instead of the same floor drainage system.

In China, the branch fittings in the same floor drainage system are often fixed in filled structure as there is a need for floor drains in the bathroom as shown in Figure 1. When the branch fittings are firmly fixed in the filled structure even in concrete, there will be less vibration when there is flowing water inside. When this is less vibration, there is less noise.

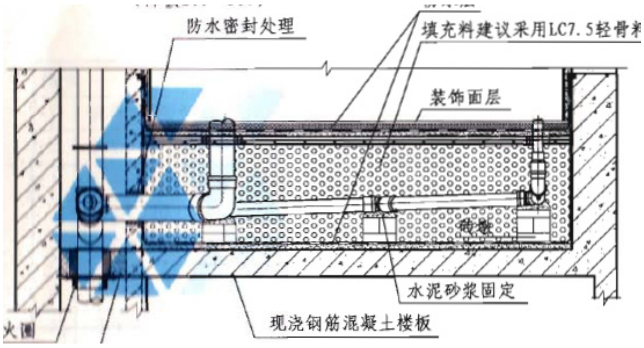

Figure 1 - Structure of the same floor drainage system in China

The test results show that the noise level in the receiver room is much lower than that in the source room. The source room is more likely reflecting the conventional under floor drainage system while the receiver room is more likely reflecting the same floor drainage system.

5. Conclusion

（1）Measures can be taken to lower the noise level by reducing the vibration of the branch fittings

（2）Testing method in the standard should be developed for reflecting the same floor drainage system.

6. Presentation of Authors

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Experiment Study on the Drainage Capacity of Special Single Stack Drainage System By Using Instantaneous Flow

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Abstract

This experiment used instantaneous flow generator drain away water on 34-layer tower. Investigate the different drainage pressure in eachspecial single stack drainage system, explore the relationship between the pressure and flow rate, confirm the corresponding drainage capacity and analyze from multiple perspectivesto. The results show that: the drainage capacity of Sovent system is better than that of DN110mm spiral + strengthening type cyclone system and DN110mm spiral ordinary + ordinary type cyclone system, and the pressure fluctuation of the pipeline system is significantly less than the other two systems;the drainage capacity of the two spiral system is significantly less than the maximum design flow capacity value of building water supply and drainage design specifications (GB50015-2009).

Keywords

Special Single Stack Drainage System; Instantaneous Flow; Drainage Capacity

Because of the advantages of saving material and space,the big drainage and other advantages, special single stack drainage system make up for the shortcomings of ordinary single stack drainage system and specific vent stack system. Based on the research of confluence flow by using instantaneous flow[1], the research group made a series of systematic research on three kinds of special single stack drainage system which commonly used in engineering(DN110mm spiral + ordinary type cyclone system ,DN110mm spiral + strengthening type cyclone system, Sovent system). Use ±300Pa as the criteria, confirm the corresponding drainage capacity and compare the advantages and disadvantages of each systems to provide references for further engineering application.

1. Test Method

1.1 Test stack system

This experiment carried out in the research and development base of high rise building device system in equal proportion, China National Engineering Research Center for Human Settlements –Vanke building Research Centre. DN110mm spiral + ordinary type cyclone system and DN110mm spiral + strengthening type cyclone system use inner screw tube(PVC-U),the tube of strengthening type cyclone system has 12 rotating ribs, the average height of the rib is about 2.50mm. Sovent system use DN110mm ordinary tube(PE). The horizontal pipe of each layer is DN110mm PVC–U pipe,using special members to connect the drain pipe.Using plug to block the horizontal pipe except the drainage layer.

1.2 Test installation and instrument

U.S. GE DruckPTX610 (±10 KPa, PTX) Bi-type pressure sensor is installed on the horizontal pipe of each layer in addition to the drainage layer. It's set at a distance of 500 mm to the center of the drainage vertical pipe. Its measurement range is ±10000 Pa, its measurement accuracy is ±0.08% and the acquisition cycle is 20 ms. Collect data and transfer to the server to detect pressure fluctuation. The one or two instantaneous flow generators installed on every drainage layer from top to bottom discharge water in the test. Figure 1 shows the test system of instantaneous flow drainage system.

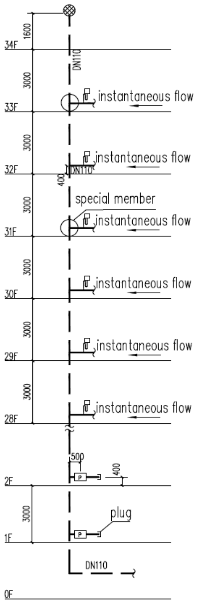


Fig.1 Test system of special single stack drainage system by using instantaneous flow

The instantaneous flow generator simulate the common siphon toilet to discharge water. Each time of displacement is 6 L, the peak of drainage flow is 1.8L/s. Discharge water by electronically controlled pressing. GE Druck RTX1930 input type level gauge is set in the instantaneous flow generator, the measurement range is 0~50kPa（0~5 mH_2O）, the measurement accuracy is ±0.06%. Using measuring cylinder to measure the instantaneous flow convergence displacement. The diameter of measuring cylinder is 0.72m. The test equipment is composed of rectifier disc, pressure sensors, input type level gauge, etc[2].

1.3 Test procedures and decision condition

Figure 2 shows the test procedures.

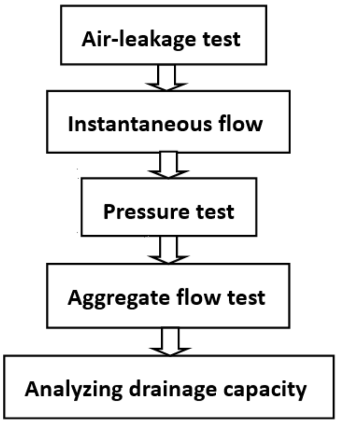


Fig.2 Experimental procedure

The maximum positive and negative pressure automatically measured by pressure sensor is the largest positive and negative pressure of this floor. As show in figure 3 (DN110mm spiral + ordinary type cyclone system; 6 instantaneous flow generators drain water).

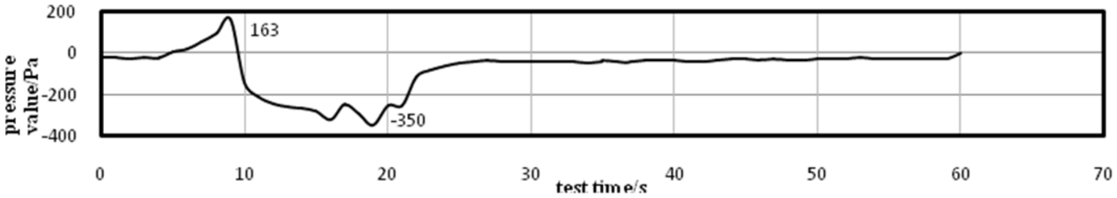
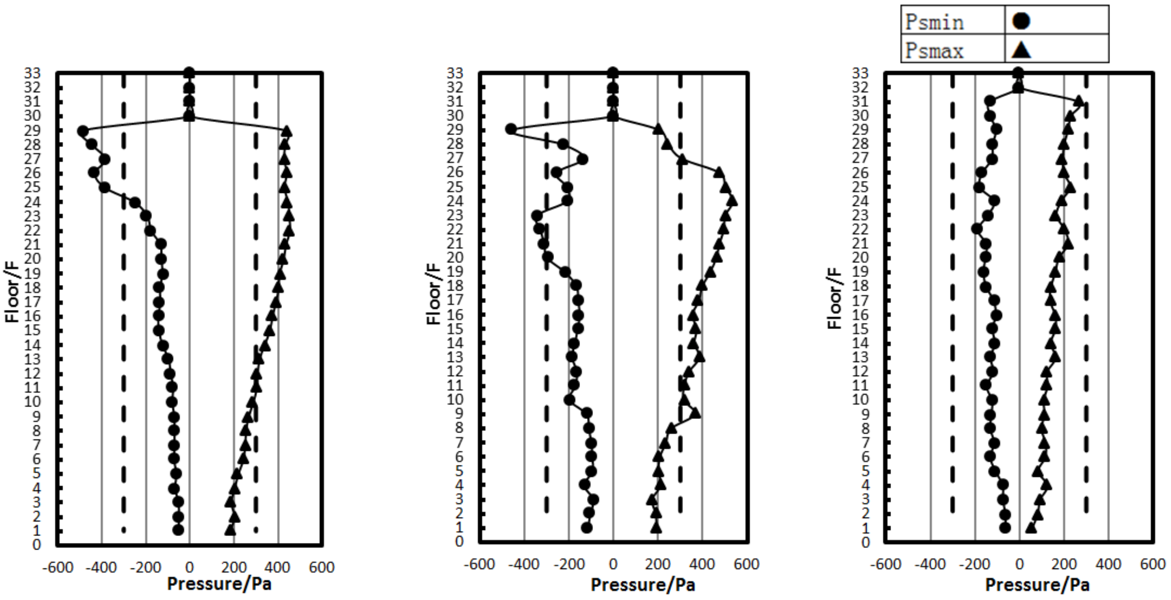


Fig.3 Pressure distribution of horizontal branch pipe of 28th floors

2. Test Result

2.1 Pressure test of special single stack drainage system

The pressure test of three kinds of special single stack drainage systems was done in the way of using instantaneous flow ,combined with the system pressure value corresponding to different number of instantaneous flow generator, choose the system pressure value of four instantaneous flow generator, as shown in Figure 4.When using instantaneous flow, the maximum positive and negative pressure of the drainage system taken place in the high layer of the system. When the number of instantaneous flow generator is same,the positive pressure produced in the high layer of the system from large to small in turn is: DN110mm spiral + ordinary type cyclone system ＞ DN110mm spiral + strengthening type cyclone system ＞ Sovent system; the negative pressure from large to small in turn is: DN110mm spiral + strengthening type cyclone system ＞ DN110mm spiral + ordinary type cyclone system ＞ Sovent system.



a. DN110mm spiral + ordinary b. DN110mm spiral + strengthening c. Sovent system

Fig.4 Positive and negative pressure distribution of each special single stack drainage system when instantly stream generators drain

The maximum positive and negative pressure distribution of the drainage system of different number instantaneous flow generator is shown in figure 5. The maximum positive and negative pressure of each system increased with the increasing of the number of the instantaneous flow generator.When the number of the instantaneous flow generator was same,the difference of the maximum positive and negative pressure between DN110mm spiral + ordinary type cyclone system and DN110mm spiral + strengthening type cyclone system were not very big. Su Vito system was significantly smaller than another two sets of system. The maximum positive pressure or the maximum negative pressure of the system that first to reach the maximum pressure at the moment of the system was shown in Tab 1.

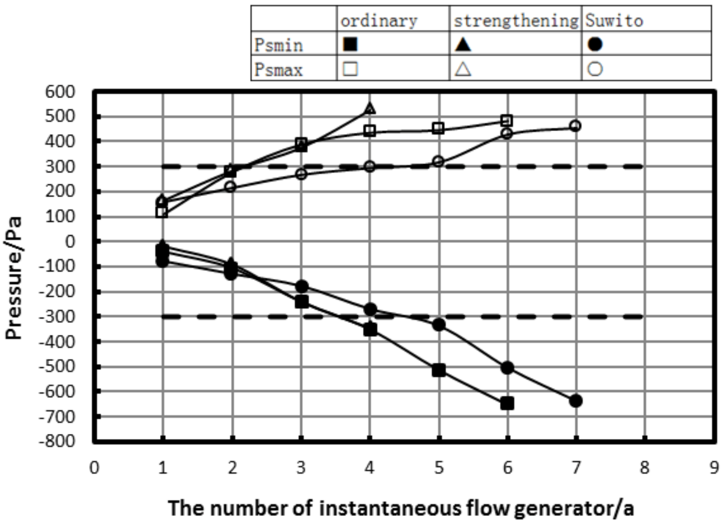


Fig.5 Positive and negative pressure distribution of each special single stack drainage system when instantly stream generators drain with different numbers

Tab.1 The situation of first to achieve maximum determining pressure value for each system

system	Positive pressure	Negative pressure
DN110mm spiral + ordinary	√	
DN110mm spiral + strengthening	√	
Sovent system	√	√
Notes：√Indicates that the system pressure reached the maximum pressure value.		

2.2 Analysis of drainage capacity of special single stack drainage system

When the maximum pressure of the system was between±50 Pa, the measured flow rate is the drainage capacity of the special single stack drainage system. If there aren't the test value that meet the conditions, draw the system drainage pressure - flow curve according to the test value(as shown in Figure 6),and make the curve fitting of the trend line, the flow value on the curve that first meet the judging pressure is the value of the drainage capacity of the special single stack drainage system when the determination coefficient R^2 > 0.8 that represent it has a good correlation. The drainage capacity of the special single stack drainage system is shown in table 2.

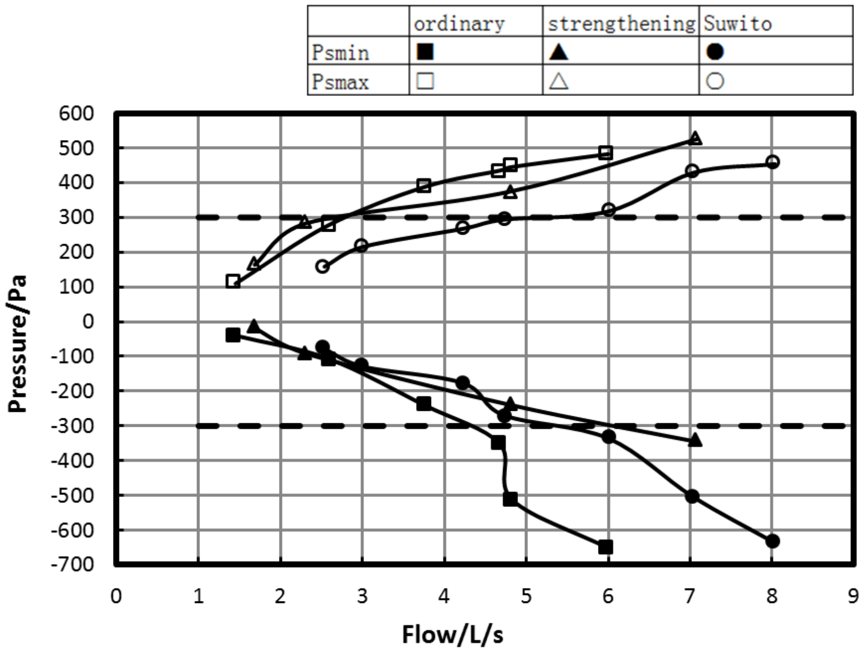


Fig.6 Maximum positive and negative pressure of each special single stack drainage system under different drainage flow rates

Tab.2 Capacity of instantaneous flow drainage of special single stack drainage system

System	Instantaneous flow generator /a	drainage capacity /(L/s)	P_{max}/ Pa	P_{min}/ Pa	Fitting curve	R^2
DN110mm spiral + ordinary	2	2.58	277	-106	$P_{max} = -16.629x^2 + 203.79x - 146.65$	0.9978
DN110mm spiral + strengthening	2	3.3	283	-92	$P_{max}=-1.5193x^2 + 73.364x + 76.203$	0.9506
Sovent system	4	6.0	267	-177	$P_{max}=0.1446x^2 + 49.906x + 46.986$	0.9656

Compared the test value of the test of instantaneous flow of each special single stack drainage system with the corresponding maximum design drainage capacity in the tab. 4.4.11 of building water supply and drainage design specifications（GB50015-2009）, as shown in Figure 6. The drainage capacity of the system in the instant flow test is different from that of the current standard value of building drainage in China, the drainage capacity from high to low in turn is: Sovent system ＞ DN110mm spiral + ordinary type cyclone system ＞ DN110mm spiral + strengthening type cyclone system.

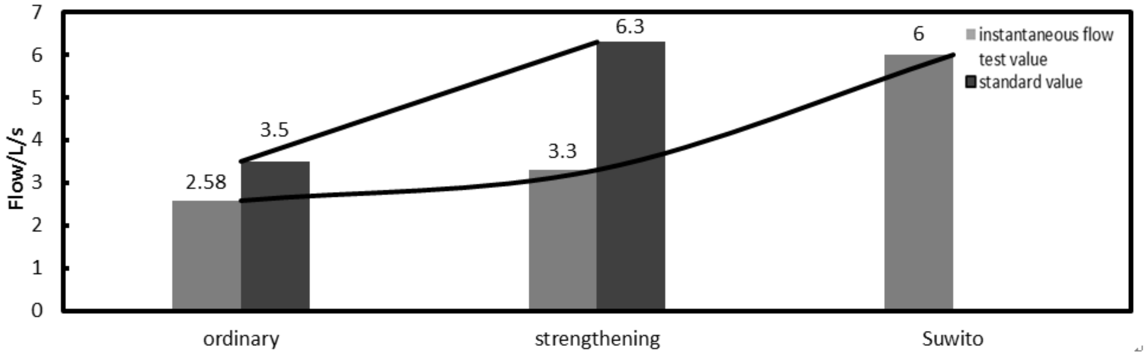


Fig.7 Tendency of drainage capacity for special single stack drainage system

3. Conclusion

① The drainage capacity of Sovent system is obviously better than that of DN110mm spiral + ordinary type cyclone system and DN110mm spiral + strengthening type cyclone system, and the pressure fluctuation in the whole piping system is obviously less than the other two systems. The drainage capacity of DN110mm spiral + strengthening type cyclone system is slightly higher than that of DN110mm spiral + ordinary type cyclone system when use instantaneous flow.

② The drainage capacities of DN110mm spiral + ordinary type cyclone system and DN110mm spiral + strengthening type cyclone system that tested in the experiment are obviously less than the corresponding maximum design drainage capacity in the tab. 4.4.11 of building water supply and drainage design specifications（GB50015-2009）. The drainage capacity of Sovent system is obviously better than the other two systems, so it is necessary for Sovent system to do some further systematic study.

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5. Presentation of Authors

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Study on the Influence of Air Pressure Fluctuation to Trap–seal

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Abstract

As a barrier of building drainage pipeline, trap-seal plays a very important role in the indoor water environmental safety and people's health. In order to study the influence of drainage pipe air pressure fluctuation to trap-seal, an experimental and theoretical analysis study of the pressure fluctuation in the drainage pipeline, trap-seal loss, trap-seal failure and trap-seal structure was done by the test of drainage pipe air pressure fluctuation and trap-seal in the drainage test tower.

Keywords

Air Pressure Fluctuation, Trap-seal Loss, Trap-seal Failure, Trap-seal Ratio, Trap-seal Depth.

Due to a large number of bacteria and pathogens existing in sludge wastewater and pipeline space, it may poses a serious threat to residents' health. So polluted waste water and harmful gas should be enclosed within the piping system and interior space should be completely isolated from the pipe space. Trap-seal plays an important role in the measures of isolating drainage system and indoor environment, because it can prevent the gas in the drainage pipe system spilling into the indoor environment. The pressure fluctuations of the unreasonable designed building drainage system will be unusually strong. Pressure fluctuation can lead to trap-seal loss and harmful gas spillage by the positive pressure spurt and negative pressure suction. But trap-seal's ability to withstand pressure fluctuation is limited, so the pressure fluctuation is likely to lead to trap-seal failure. Then the harmful gas and microbes of drainage pipe enter the room and pose a serious threat to health of the residents living in the buildings.

1 Status of Water Environment in Chinese Bathroom

Study found that the smelly problems in China's bathroom is relatively common. One of the most easily lead to smelly problem fixtures is the floor drain. In the Chinese market at present, compared with the mechanical seal floor drain, the type of water seal floor drain is more single. Li Xuewei [1] has done related research of 25 kinds of floor drains in Beijing building materials market. The research involved 15 water seal floor drains, 8 mechanical seal floor drains and 2 blend seal floor drains. But the result showed that the pass percent of water seal floor drain is only 16.7%, mechanical seal floor drain prone to failure and untight seal, mechanical parts of blend seal floor drain also appeared problems. The main problems of these floor drains are as follows:

(1) The depth of trap-seal cannot meet the norms;
(2) The mechanical seal floor drain’s seal is lax;
(3) Some functions of the floor drains are impractical and cannot be achieved;
(4) The installation of some floor drains is not standard.

The type of the mechanical seal floor drain is more but the quality level is uneven. Problems often occur in practical use is the leak flap and T type magnetic sealed floor drain. The turning plate in the floor drain is used as a lever counterweight parts easy to fall off or be eroded, and it is easy to be blocked by some hair or other contaminants. The problem of T type magnetic seal floor drain is similar, also due to some hair, fibers and oil dirt, etc. locked in the intermediate shaft or sandwiched plate. In view of the current situation, there are various problems in mechanical seal floor drain[2]. So the water seal floor drain is generally recommended, and “Code for design of building water supply and drainage” claim that the trap-seal depth cannot be less than 50mm[3].

2 Study on the Influence of Air Pressure Fluctuation to Trap–seal

2.1 Relationship between trap–seal ratio and trap–seal loss

Trap-seal ratio equals to the cross section area ratio of water outlet-end and inlet-end. At present, in China's current specification there is no normative content related to trap-seal ratio. But it has been already widely discussed in the industry. Many scholars and researchers has published articles and putted forward their own views about trap-seal ratio.

Trap-seal with different ratio, under the same pressure conditions, will produce different trap-seal loss. Generally under the same negative pressure condition, the bigger the trap-seal ratio is, the smaller the trap-seal loss becomes, also the greater the capacity of anti-pressure it has. Under the same positive pressure conditions, the higher the water column is on the water inlet, the stronger the ability to resist pressure becomes.

In order to verify the influence of trap-seal ratio to trap-seal loss, a test of pressure fluctuation and trap-seal loss was done for two floor drains with different trap-seal ratio in high-rise drainage test tower where a de 160 PVC-U single vertical pipes system with 33 layers was built. This test use the constant flow rate drainage method to produce pressure fluctuation. And the two floor drains were arranged in the same horizontal branch pipe. Test results are shown in figure 1.

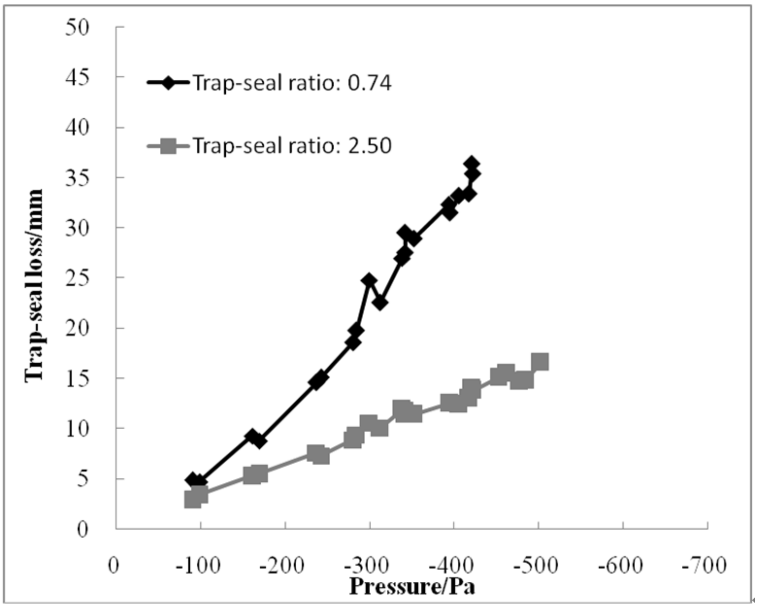

Fig 1 The relationship between pressure and trap-seal loss of two floor drains with different trap-seal ratio

Seen from Figure 1, at -400Pa, the trap-seal losses of the floor drains with 0.74 and 2.50 trap-seal ratio are 32.7mm and 12mm. Under the same negative pressure conditions, the trap-seal losses of the floor drain with 0.74 trap-seal ratio are far greater than the 2.5 trap-seal ratio. Even under -502Pa, the trap-seal losses of 2.50 trap-seal ratio floor drain are only 16.6mm. Its pressure resistance is particularly strong. So we conclude that the bigger the trap-seal ratio is, the stronger the trap's ability to against negative pressure becomes.

Because of their different functions, different sanitary wares' trap-seal structure and trap-seal ratio are not the same. Also in the 33 layers de160 PVC-U single vertical pipes system, we did the pressure fluctuation and trap seal loss test for four different sanitary wares (trap-seal ratio of the four sanitary wares can be seen in table 1) by using the constant flow rate drainage method. Figure 2 shows the relationship between pressure and trap-seal loss of different sanitary wares.

Table 1 The parameter of different sanitary ware

Sanitary ware	Size	Trap-seal depth/mm	Trap-seal ratio
S-trap	DN50	72	1.00
Siphon toilet	DN110	56	——
Floor drain A	DN50	50	0.74
Floor drain B	DN50	50	2.50
P-trap	DN50	55	1.00

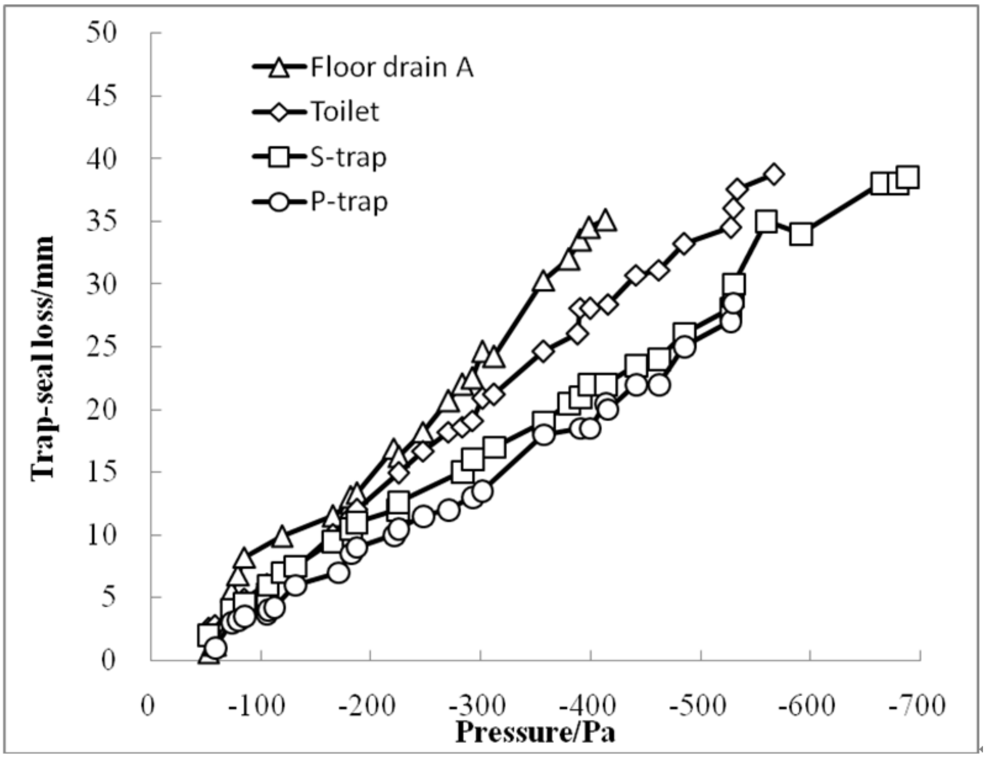

Fig 2 The relationship between pressure and trap-seal loss of different sanitary wares

From the figure 2 we can see, the relationship between trap-seal loss and pressure of the four wares were substantially linear relationship. The trap-seal loss of the floor drain A is the largest of the four sanitary wares under the same pressure, the decrease in turn are: toilet, S-trap and P-trap. Reason for such a result is trap-seal structure, the most significant impact are trap-seal ratio and the angle between the outlet-end and the horizontal (angle α as shown in Figure 3). Because water inlet section of the toilet is gradual, so there is no trap-seal ratio data, but it can be sure that the trap-seal ratio is less than 1. By comparing the trap-seal ratio, we can summarize that the bigger the trap-seal ratio is, the more the trap-seal loss becomes, and then the stronger the ability of resisting negative pressure becomes. And by comparing the structure of the S-trap and P-trap, we can see that reducing the angle α can also improve the seal negative pressure resistant ability.

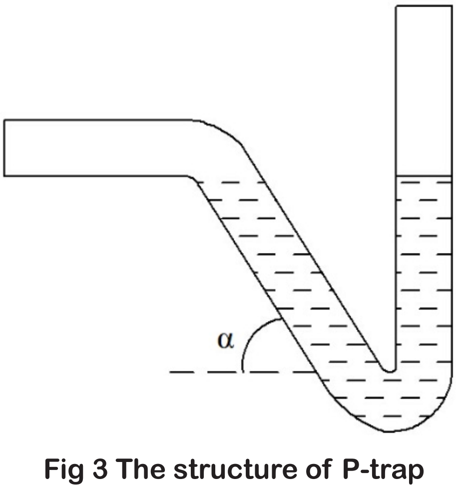

Fig 3 The structure of P-trap

2.2 Importance of trap–seal depth

Drainage behavior will produce certain negative pressure in the pipeline system. Negative pressure will lead the trap-seal to loss some water, the remaining water seal depth after the loss, we call for residual trap-seal depth. The residual trap-seal depth directly determines the trap-seal’s resistance ability to positive pressure and the retention time under the evaporation. Therefore, the trap-seal depth is particularly important.

“Code for design of building water supply and drainage” claim that the trap-seal depth cannot be less than 50mm. It means that the trap-seal depth may be 50mm, 60mm or more. In Europe, the depth of trap-seal can even reach 160mm.

Commonly, trap-seal depth has two important significance:
(1)On the circumstances of same trap-seal ratio and same trap-seal loss, trap-seal depth always in proportion to the residual trap-seal depth. Take S-trap (trap-seal ratio: 1) for example, under the same negative pressure condition and the same trap-seal loss, the deeper the trap-seal depth is, the deeper the residual trap-seal depth becomes. As is shown in figure 4, the test took three S-traps that share same trap-seal ratio of 1, and the trap-seal depth is 50mm, 72mm, 152mm respectively, connected to one same horizontal branch pipe. Under the same negative pressure, due to the difference of trap-seal depth, the residual trap-seal depth are different naturally despite of the same trap-seal loss, that is to say, they show different ability of enduring the following destruction of trap-seal.

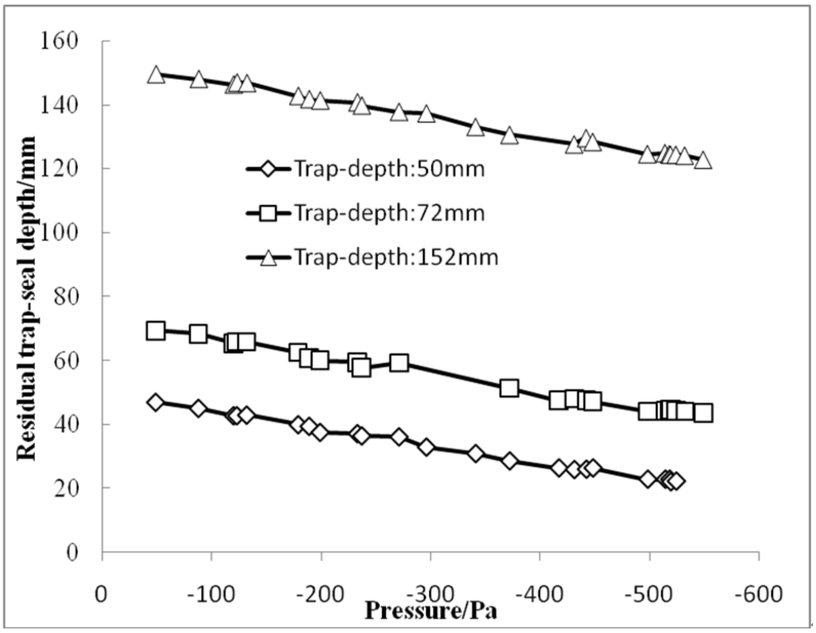

Fig 4 The relationship between pressure and the residual trap-seal depth of S-traps with different trap-seal depth

(2)The deeper the trap-seal depth is， the better the ability to resist positive and negative pressure becomes. The so-called trap-seal depth i.e. the water height on two sides of the trap. As “h” shown in figure 5 and figure 6. Commonly, given the circumstances that positive pressure take effect on outlet-end, lower down the outlet-end liquid level, inlet-end liquid level raise up. When outlet-end liquid level reach the nadir, inlet-end liquid level reach zenith at the same time, this head of water (approximately twice the trap-seal depth) determine its ability to endure seal breaking by positive pressure. Thus, the deeper the trap-seal depth is, the higher the head of water becomes, and the better the ability to resist positive pressure becomes. When negative pressure take effect on outlet-end liquid level, keep outlet-end liquid level invariant, the inlet-end liquid level keep lowering down. At the point that the inlet-end liquid level reaches nadir, the head of water determine its ability to endure seal breaking by negative pressure. Hence, the deeper the trap-seal depth is, the better the ability to resist negative pressure becomes.

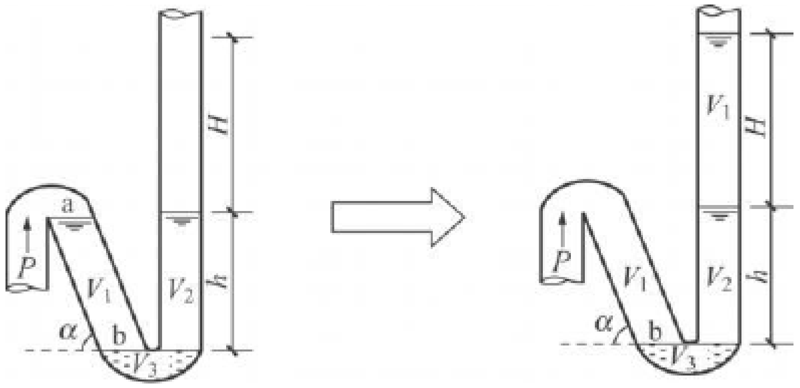

Fig 5 The positive pressure take effect on outlet-end[7]

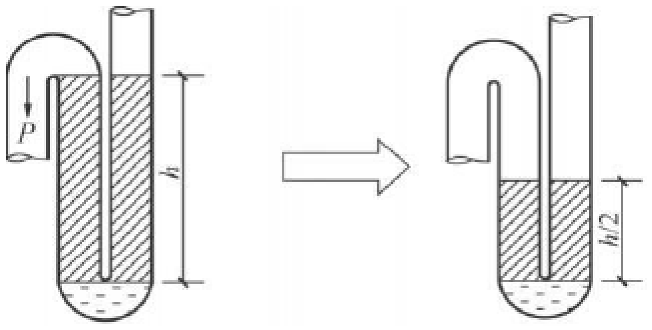

Fig 6 The negative pressure take effect on outlet-end[7]

Table 2 The pressure when the trap-seal is sucked dry

Sanitary ware	Pressure/Pa
Floor drain A	-485~-500
P-trap	-530~-575
Toilet	-691~-733
S-trap	-691~-726

The results show that, the trap-seal loss is increasing as the increase of negative pressure. When the negative pressure is big enough, it can suck the water dry in the trap-seal. Table 2 reflects the pressure range when the trap-seal is sucked dry. Due to the pressure value can' t be measured accurately, what we can do is to narrow the scope to determine the pressure value interval. By comparing with the trap-seal depth in table 1, it can be seen that the pressure when trap-seal is sucked dry may be associated with the depth of trap-seal. So the deeper the depth is, the harder the trap-seal would be sucked dry.

It can be seen from the above analysis, the trap-seal depth plays an important role in resisting pressure to break the seal. Some scholars have pointed out that due to the trap-seal still have certain residual seal depth after the negative pressure suction, we could design the floor drain whose trap-seal ratio is larger but the depth of the trap-seal is very small. So that it can be the trap-seal protection device for other sanitary wares. When the negative pressure in the horizontal branch pipe increases, the floor drain' s trap-seal is firstly broken. At the same time the air is sucked into the pipe to ease the negative pressure, just like that it was an air admittance valve. But according to the results of this test and observation, it is considered that the idea is reasonable, but the condition with too big negative pressure is not considered. When negative pressure did not exceed a certain range, the floor drain' s continuous air suction can indeed be maintained and play a role in negative pressure relief. But in some high-rise system or some unreasonable design drainage system, it will produce too big negative pressure. The excessive pressure will lead trap-seal to be sucked completely dry. This phenomenon in this test can be observed. Therefore, to maintain high trap-seal depth is very necessary for the ability of resisting pressure break.

2.3 Trap–seal failure caused by alternating positive and negative pressure

The role of the trap-seal is to prevent the gas in drainage pipe into the room. Although that negative pressure suction can have a very obvious influence on trap-seal loss, only the negative pressure did not reach to the pressure that trap-seal can be completely sucked dry, the remaining trap-seal can still cut the stink off. And if the positive pressure reached the pressure that can spurt, only a bubble can pass through the trap-seal into the room, it may have caused pollution on the room air. Therefore, the influence of the positive pressure to trap-seal failure is more direct.

In the rational design of the drainage system, if the depth of trap-seal maintains larger than 50mm, the positive pressure of low floors generally cannot break the trap-seal. As Table 3 shows, if the 55mm P-trap would be broken by the positive pressure, 910Pa~930Pa pressure is needed; if the 56mm toilet would be broken by the positive pressure, 563Pa~594Pa pressure is needed; if 72mm S-trap would be broken by the positive pressure, 863Pa~906Pa pressure is needed.

Table 3 The positive pressure range that can break the trap–seal of different sanitary wares

	P-trap	toilet	S-trap
Pressure/Pa	910~930	563~594	863~906

We analyze both the data of table 3 and table 1 and can get the conclusion that trap-seal breaking pressure almost has positive correlation with trap-seal depth, the reason why P-trap' s breaking pressure is larger than S-trap' s is that the outlet-end of P-trap has certain angle, so it can resist the larger positive pressure. From this we can conclude if the positive pressure of system is controlled within 400Pa, positive pressure breaking will never occur. However, if negative pressure suction occurs at certain floor in the system at first, the trap-seal has already lost some water and then there occurs positive pressure, at this time the ability of residual trap-seal resisting positive pressure breaking will drop a large scale.

Take a high-rise residential building as an example, we assume a sanitary ware is located in lower floor A of the residential building, there occurs drainage in the upstairs of floor A, so the tubes in floor A gets a negative pressure, negative pressure has a suction role on the trap-seal of the sanitary ware and lose a part of trap-seal and in the conditions that the trap-seal of sanitary ware hasn’ t get immediate supply, in the higher floors of the residential building there are a few floors having the simultaneous drainage, at this time there will produce positive pressure in floor A tube. Because at this time the trap has already lost certain depth of residual trap-seal, under positive pressure, the height of water jacked in ware inlet is less than double depth of trap-seal. So the ability of resisting positive breaking pressure will drop a large scale, the phenomenon of bubbling will easily occur and the stink in the tube enters indoor and pollutes the indoor environment.

In order to simulate the situation above, we have done the positive pressure test of different wares with different residual trap-seal depth. In the 33 layers de160 PVC-U single pipe system, we tested by using the constant flow rate drainage method, and the test floor is the 2nd floor. Firstly this test adjusted residual trap-seal depth to the target depth, and then drainage, by increasing the drainage flow to get greater positive pressure, from 200Pa to 700Pa. Looking at the trap-seal surface, when we found bubble phenomenon, we wrote down the pressure as the positive breaking pressure. The residual trap-seal depth diminishing by 5mm from 50mm to 5mm. Table 4 is the final result of this test.

Table 4 The positive breaking pressure of different sanitary wares with different residual trap–seal depth

Sanitary ware Breaking pressure/Pa Residual trap-seal depth /mm	Toilet	Floor drain B	S-trap	P-trap
50	465~483	>700	>700	>700
45	418~442	>700	>700	>700
40	399~405	>700	658~687	>700
35	370~385	>700	653~719	>700
30	346~352	>700	498~535	>700
25	312~335	627~675	455~475	650~705
20	237~260	638~697	335~373	500~536
15	<200	591~628	304~313	374~421
10	<200	428~465	205~239	273~290
5	<200	359~398	<200	213~269

Through the data above we can see that, with the decrease of residual trap-seal depth, the ability to resist positive breaking pressure of wares is gradually reducing. When the residual trap-seal depth of toilet is 15mm, it can only carry the positive pressure under 200Pa; Due to the trap-seal ratio of floor drain B is a little big, even if there is only 5mm left, it can still bear the positive pressure of 359Pa~398Pa; when the residual trap-seal depth of S-trap is 5mm,it can only carry the positive pressure under 200Pa; when the residual trap-seal depth of P-trap is 5mm, it can only carry the positive pressure under 213Pa~269Pa. It can also be seen that the bigger the trap-seal ratio is, the greater the ability to resist positive breaking pressure it has.

From the results above, it can be seen that the situation that positive pressure and negative pressure break trap-seal alternately cannot be neglected. Therefore, when designing the trap-seal of wares such as floor drain we should do our best to enlarge trap-seal ratio to reduce the trap-seal loss caused by negative pressure and improve the ability to resist positive breaking pressure, at the same time, ensure the trap-seal depth that can ensure enough residual trap-seal depth to resist positive breaking pressure later after some trap-seal loss.

3 Conclusions

An experimental and theoretical analysis study on trap-seal ratio, trap-seal depth and trap-seal failure was introduced in this paper. The conclusions are as follows:

(1) Under the same negative pressure condition, the bigger the trap-seal ratio is, the smaller the trap-seal loss becomes. When under -400Pa, the trap-seal losses of the floor drains with 0.74 and 2.50 trap-seal ratio are 32.7mm and 12mm. Even under -502Pa, the trap-seal losses of 2.50 trap-seal ratio floor drain are only 16.6mm. Its pressure resistance is particularly strong. So under the same situation, the bigger the trap-seal ratio is, the stronger the trap’ s ability to against negative pressure becomes.

(2) From the results we can see, the relationship between trap-seal loss and pressure of the four appliance were substantially linear relationship. The trap-seal loss of floor drain is the largest of the four sanitary wares under the same pressure, the decrease in turn are: toilet, S-trap and P-trap. By comparing the trap-seal ratio, we can summarize that the bigger the trap-seal ratio is, the more the trap-seal loss becomes, and then the stronger the ability of resisting negative pressure becomes. And by comparing the structure of the S-trap and P-trap, we can see that reducing the angle between the outlet end and the horizontal can also improve the seal negative pressure resistant ability.

(3) On the circumstances of same trap-seal ratio and same trap-seal loss, trap-seal depth always in proportion to the residual trap-seal depth, and the deeper the trap-seal depth is, the stronger the ability to resist positive and negative breaking pressure becomes. The floor drain with 50mm trap-seal depth was sucked dry at -485Pa~-500Pa, but the S-trap with 72mm trap-seal depth can be sucked dry at -691Pa~-726Pa. The positive breaking pressure of toilet with 50mm depth is at 465Pa~483Pa, but while the residual trap-seal depth is only 25mm, the positive breaking pressure is at 312Pa~335Pa. So the bigger the trap-seal depth is, the stronger the ability to sesist pressure fluctuation is.

(4) With the decrease of residual trap-seal depth, the ability to resist positive breaking pressure of wares is gradually reducing. So attention should be paid to the situation that negative pressure suction occurs at first and then the positive pressure spurt out to break the trap-seal. When the residual trap-seal depth of toilet is 15mm, it can only carry the positive pressure under 200Pa; when the residual trap-seal depth of S-trap is 5mm,it can only carry the positive pressure under 200Pa; when the residual trap-seal depth of P-trap is

5mm, it can only carry the positive pressure under 213Pa~269Pa. Therefore, when designing the trap-seal of wares such as floor drain we should do our best to enlarge trap-seal ratio to reduce the trap-seal loss caused by negative pressure and improve the ability to resist positive breaking pressure, at the same time, ensure the trap-seal depth that can ensure enough residual trap-seal depth to resist positive breaking pressure later after some trap-seal loss.

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5 Presentation of Authors

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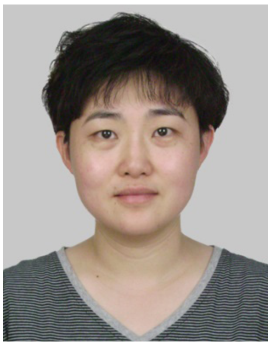

Zhao Zhenyi is a member of CNERC for Human Settlements. She has designed 4 construction designs for water supply and drainage system. She has been a member in the full scale experiments in the full scale experimental tower of housing performance for a long time in doing building drainage experiments.

Connection Technology of Plastic Pipe & Development of Special Pipe Fitting

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Abstract

Shanghai Hope Look New Pipes Co., Ltd is an enterprise converged product development, mold design and manufacture and application of technology research and development as an integrated new plastic pipe system manufacturers; it is also an manufacturing enterprises for HDPE and HTPP plastic drainage pipe, plastic drainage sewage wastewater collection and discharge pipe; it is the earliest research and development manufacture of PP mute drains products. Since its inception, we have been adhering to the "Quality win, Refinement Business, Honest Treatment" development concept , adhere to the science and technology as the first productivity and quality, and has applied for and has a number of invention patents and utility model patents. Companies strictly enforce the standardization of production, in line with national and international standards-related series.

In recent years, Shanghai Hope Look New Pipes Co., Ltd. Cooperate with demostic famous experts, develops new connections way of plastic pipe fittings and special single riser drainage system in special pipe fitting. The detail introduction as below.

Keywords

Plastic Pipe，HDPE Drainage Pipe，HTPP Drainage Pipe，Speical Single Riser Drains System，Special Pipe，Special Fittings

1. Connection Technology of Plastic Pipe

Plastic pipe have certain length, pipe and fitting needs to be connected. In order to collect and discharge of sewage and wastewater, needs elbow, tee, corss and other fittings,so pipe and pipe fittings have connectivity problems. Therefore, in the design of pipe specifications, dimensions, while taking into account the need for pipeline connectivity issues, which is a pipe production and application inherent problem is the design and construction of the pipeline to avoid the technical problems can not be countered. A pipeline connection to two pipes or pipes and fittings fused, so that has a certain anti-pull force, the second is good joints sealing performance, the third is to the construction and installation simple and convenient. new connections HTPP HDPE drainage and sewer construction of two drainage pipes, thus connecting pipe is HDPE drainage and sewer connection problems HTPP two building drain.

1.1 HDPE Drainage Connection

HDPE drainage pipe drainage system is mainly used for construction of life and roof drainage systems, including siphonic roof drainage system. HDPE sewer connection charge of hot melt connection and fused connection. Hot melt connection, also known as hot-melt welded connections or welded connections, the connection will be welded HDPE pipe end face pressed against the vertical weld plate, keeping full access; when the thickness is greater than the wall thickness of the weld surface and meet certain requirements, quickly and firmly welded together face pressure; pressure to achieve welding time requirements, to butt at the natural cooling, welding is completed. Completion of the welding surface will be higher than the thickness of the annular projection, these cyclic projections supposed to be be removed, but the corresponding standards in our country is no such requirement, it will form a "Funnel-Shaped Water Plug" phenomenon on the inside of the pipe (Figure 1), the impact of obstructions to the airflow, the impact of water flow, affect the drainage capacity. For siphon roof drainage system, because it is full pipe flow pressure, impact is not very significant, and for gravity flow roof drainage system and domestic wastewater Systems of large drainage capacity of drainage riser may be reduced by about 1/3.

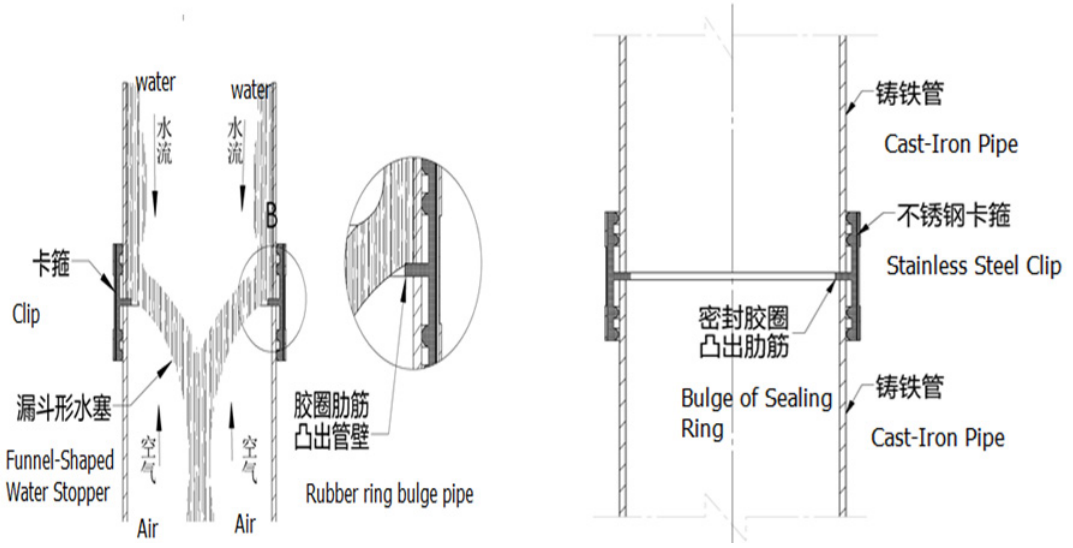


Fig. 1 "Funnel-Shaped Water Plug" phenomenon

The solution is to change the connection, the Shanghai Hope Look New Pipes Co., Ltd adpot hot melt socket connection and flexible gasket socket connection, eliminating the "funnel-shaped water plug" phenomenon radically.

Melt socket connection, follow these steps:
1) hot-melt equipment connet with power, after reaching the operating temperature indicator light in order to take over;
2) cut to the desired length of pipe, pipe end surface after cutting should be perpendicular to the tube axis;
3) Remove the end face of the flash and burrs;
4) pipe and tube connections face should be clean, dry and free of oil. If necessary, use a dry cloth or acetone to clean;
5) the pipe end with a caliper measurement and appropriate pen and plot socket depth;
6) without rotation of the tube end into a heating jacket, is inserted into the depth of the mark, while the tubular member without rotation onto the heating head, reaches the predetermined depth;
7) After reaching the heating time, immediately remove the pipes and fittings from the heating jacket and heated head straight without rotation quickly inserted into the standard uniform depth.
Melt socket connection, see (Fig. 2, Fig. 3); a flexible connection socket see (Figure 4);

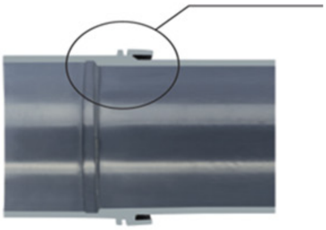


Fig. 2 hot melt socket connection

Fig. 3 After hot melt socket connection

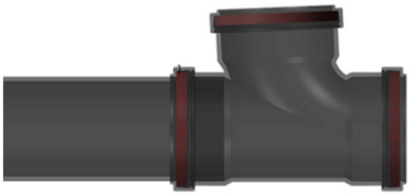


Fig. 4 flexible connection socket see

1.2 HTPP Sound Proof Pipes Connected

Shanghai Hope Look New Pipes Co., Ltd manufacture PP drainage pipe and call it HTPP soundproof pipes. "HT" it meeans high temperature.

PP pipe is generally three-layer structure (Figure 5), inside and outside of polypropylene material, the middle layer of filler material.

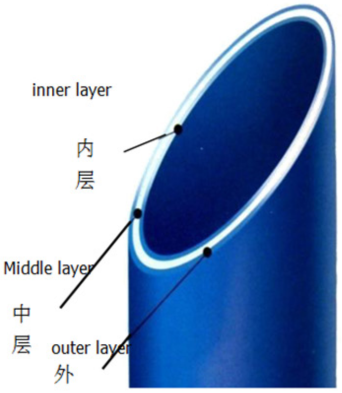
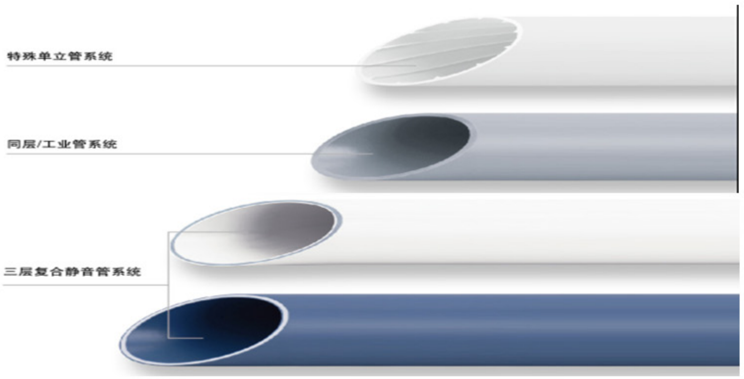


Fig. 5 three-layer structure



PP Soundproof Pipe Series

Connection using a rubber ring connection. This connection can not be used in the same layer drainage board laying down, in part because the current national standard "building water supply and drainage design specifications" GB 50015-2003 (2009 edition) does not allow provisions; second reason is the same drainage layer laying down plate, drain in a falling lamina, and embedded in the cushion, the lower plate approach has advantages and disadvantages, one of the drawbacks is down lamellar water. Lamellar water fall from the sky there are a number of reasons, including the expansion coefficient of cushion filling plastic pipe expansion coefficient is different, after a long time, thermal expansion and contraction will pull the pipe bedding material interfaces, resulting in lower plate layer of water one of the reasons.

For the down lamellar water, there are many domestic countermeasures.
1) Modular - the drainage layer of water-saving modular integrated system, using the same drainage layer module, there will backfill material.

Cushion with plastic drainage pipe with module separated the two affect each other. Survey and Design Institute of China Sinopec Zhongyuan Petroleum Exploration Bureau, the development of technology.

2) Multi-channel adapter - standpipe and drainage layer laying plumbing fixture drain connection with a multi-channel connector, multi-channel connector channel number determined by the number of sanitary ware. Each drain plumbing fixture directly connected to the drain riser in the middle there is no interface, reducing the interface leak opportunities.

3) Double socket fittings - Wrigley building drainage with a hard PVC double leak pipe fittings, joint venture of Shanghai New Building Materials Co. products imported from Singapore-based technology. Fittings for the two-tier structure, when pipes and fittings connected to the pipe ends of the double-sided adhesive applicator, doubling the length of the flow channel to increase the flow resistance of extravasation.

4) Water eliminator - the water drop eliminator plate layer is provided in order to exclude lower lamellar water. This means more production enterprises, but also have some effect.

5) Hot melt connection - Change drop lamellar horizontal drainage branch pipe connections, pipe connection using hot melt connection, including connection Butt, hot melt socket connections. But the general PP pipe production enterprises, PP pipes are three-tier structure, PP pipe connection layer structure can only be rubber ring connection, not connected with the melt, and connection rubber seals is prohibited use drop in the drainage layer board layer. Shanghai Building Materials Co., Ltd. Tim Wang deep sea HTPP mute possession of two structural types: one is the three-tier structure, with flexible ring socket connection. The other is a single-layer structure, using hot melt socket connection, hot melt connection make pipes and tubes, pipe and tube fused into a whole, from the fundamental solution to the problem of leakage pipe interface is considered to be resolved down the plate laminate water, the best way pipe joint leakage.

2. Reserch and Development of Special Pipe Fittings

Ordinary single riser pipe system drainage system has three weaknesses:

1.Horizontal branch drain pipes and drainage riser pipe connected to the upper portion of the (three-way or four-way), horizontal branch pipe drainage water formed tongue will block the flow riser gas flow passages. The solution is to split or swirl, shunt means taking steps to make the riser flow and cross-flow manifold separately as Su Weituo. Swirl is when you set the guide vanes in the pipe, so that water flows down forming a vortex flow along the inner wall, forming an intermediate air passage so that water and air flow separately.

2.Drainage bend at the bottom of the riser, due to changes in the flow direction of the change, the flow rate, the conversion of kinetic energy, potential energy and other reasons, there will be water jump and backwater phenomenon, resulting in poor air flow channel, affect the smooth flow of water. The solution is to increase the radius of curvature and adjustable elbow.

3.Water plug according to the theory, when the water riser share 1/3 ~ 1/4 (7/24), the drain standpipe water plug phenomenon occurs riser cross-sectional area. Below the water plug positive pressure, negative pressure above the water plug. When the water is less than the vertical riser pipe cross section of 1/3 ~ 1/4 (7/24), it does not appear water plug phenomenon. Solution to the water plug phenomenon are: expansion, expansion in the pipe at.

Implementation of these three measures will have a
Special Pipe - strengthening the internal type spiral.
Special Fittings - Reinforced cyclone;
Large diameter bend radius of curvature.

Special pipes and special fittings consisting of a single riser system is a special drainage system. Special single stack drainage system has two advantages: First, to improve the drainage capacity of the drainage standpipe, standpipe drain DN110 drainage capacity of up to 8.5L / s ~ 10L / s, far more than ordinary single-risers 3.5L / s, but also more than double riser drainage system 8.8L / s. Second is to reduce the flow noise, improve the environment, according to the current national construction materials testing center inspection reports, when the riser drain flow 5L / s, drain noise is less than 45dB (A) only special single riser drainage system.

Su Weituo system earlier in the 1970s, introduced to China from Switzerland; and the introduction of reform and opening HDPE material Su Weituo system. This product deep-Hong Tian Shanghai Building Materials Co., productive. Within enhanced spiral system introduced from Japan in 2003, to strengthen the number of type spiral within a spiral rib is 12, spiral rib height of 3mm. Shanghai Building Materials Co., deep sea Wang Tim On this basis, we created a single spiral reinforced inner spiral, spiral rib number of a spiral rib height of 6mm ~ 7mm, its drainage capacity greater than 12 spiral ribs reinforced inner spiral.

Special fittings reinforced cyclone, Shanghai Building Materials Co., deep-Hong Tian summary of different materials in domestic and foreign, different types of enhanced cyclone, based on a small number of research and development to guide vanes, drainage ability of enhanced cyclone . To swirl tee (see Figure 6) as an example: modular structure, forming convenient. Horizontal branch pipe access tangentially tube, and there is significant decreasing gradient in the access side with baffles to reduce the horizontal branch pipe flow riser flow interference. Fittings overall expansion, eliminating the water plug. There are guide vanes, a horizontal branch pipe above the access point, in order to solve the interference of the riser flow cross-flow manifold. A horizontal branch pipe flow in the opposite direction, it can make the water flow and the riser pipe flow horizontal branch are forming a vortex.

Fig. 6 Swirl Tee

Fig. 7 Swirl Right Angle Cross

It is clear to see Shanghai Hope Look New Pipes Co., Ltd is is the first domestic production of PP material special single riser drainage system; is the only domestic production of both companies PP material, and the production of HDPE material special single riser drainage system; also the within the enhanced spiral made bold reforms, but received only the effectiveness of the enterprise; also the only production of special fittings, and the production of special pipe business.

Currently, special single riser drainage system is used only for residential buildings, including hotels, hospitals ward building, inpatient nursing homes and other buildings. Next planned special single riser drain of the Technical Committee, special fittings to have outstanding advantages, special pipe to extend them to a special double riser drainage system, to extend them to public buildings. Special double vertical riser pipe drainage system a drain, a standpipe ventilation, drainage and aeration vertical riser pipe connecting pipes H, unlike ordinary double riser drainage system, special dual riser pipe drainage system for the cyclone H H tube (Figure 8), there are guide vanes, and the expansion, drainage capacity from ordinary dual riser of 8.8L / s to 18L / s, creating a peak drain riser ever DN110's drainage capacity.

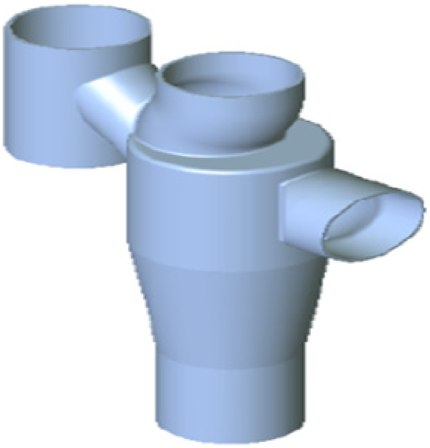


Fig. 8 Swirl H pipe

An essay written no less than too much content, special fittings Shanghai Building Materials Co., Ltd. Tim Wang deep sea, as well as special pipes DN125 series, as well as horizontal branch pipe diameter is DN160 special pipe fittings, and PP materials DN90 pipe series, because the horizontal drainage pipe for drainage capacity tested DN90 series of horizontal drainage branch pipe its transport capacity better than DN110 series.

These are the deep-Hong Shanghai Building Materials Co., Ltd. Tim plastic pipe (HDPE pipe, PP pipe) is connected with special fittings, special.

Research and development work done by special tubing, please peer criticism!

Experiment Study on Drainage Capacity of Self–circulation and Double Stack System by Using Instantaneous Flow

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Abstract

This experiment used instantaneous flow generator drain away water on 34-layer tower. Investigate the different drainage pressure in each stack drainage system, explore the relationship between the pressure and flow rate, and confirm the corresponding drainage capacity. Analyze from multiple perspectives to provide reference for engineering application. The results show that: the drainage capacity (when the arranging diameter of the vent is the same) is main and secondary loop vent stack system > self-circulating loop vent stack system > self-circulating specific vent stack system, and DN110mm × DN110mm > DN125mm × DN110mm in each system; And the drainage capacity of the three drainage systems is significantly less than the maximum design flow capacity value of building water supply and drainage design specifications (GB50015-2009).

Keywords

Self-circulation vent stack system; Double stack drainage system; Instantaneous flow; Drainage capacity

Recently, with the increasing demand of the drainage capability on account of the rapid development of high-rise buildings, We study on the self-circulation(including specific venting and loop venting) and double stack drainage system(main and secondary loop venting) which significantly improves the drainage performance compared to single stack drainage system for the sake of practical engineering design In order to further study the drainage capacity of each vent stack system, the research group made a series of systematic research on three kinds of vent stack systems which commonly used in engineering.

1. Test Method

1.1 Test stack system

This experiment carries out in the research and development base of high rise building device system in equal proportion, China National Engineering Research Center for Human Settlements –Vanke building Research Centre. The drainage system all use PVC-U specific vent stack system，the horizontal pipe of each floor is DN110mm PVC–U pipe. The drainage stack connects the horizontal pipe with 90° three link. Chart 1 shows the settings of pipes for specific vent stack system.

Tab.1 Settings of pipes for vent stack system

System number	vent stack system category /mm	Conjugation piping layout	Drainage stack/mm	Vent stack/mm	Discharge pipe /mm
1#	DN110×DN110	self-circulation specific venting	DN110	DN110	DN110
2#	DN110×DN110	self-circulation loop venting	DN110	DN110	DN110
3#	DN110×DN110	main and secondary loop venting	DN110	DN110	DN110
4#	DN125×DN110	self-circulation specific venting	DN125	DN110	DN125
5#	DN125×DN110	self-circulation loop venting	DN125	DN110	DN125
6#	DN125×DN110	main and secondary loop venting	DN125	DN110	DN125

1.2 Test installation and instrument

U.S. GE DruckPTX610 (±10 KPa, PTX) Bi-type pressure sensor is installed on the horizontal pipe of each floor in addition to the drainage floor. It's set at a distance of 500 mm to the center of the drainage vertical pipe. Its measurement range is ±10000 Pa, its measurement accuracy is ±0.08% and the acquisition cycle is 20 ms. Collecting data and transferring to the server to detect pressure fluctuation. The one or two instantaneous flow generators installed on every drainage floor from top to bottom discharge water in the test. Figure 1 shows the test system of instantaneous flow drainage system.

The instantaneous flow generator simulates the common siphon toilet to discharge water. Each time of discharge is 6 L, the peak of drainage flow is 1.8L/s. Discharging water by electronically controlled pressing. GE Druck RTX1930 input type level gauge is set in the instantaneous flow generator, the measurement range is 0~50kPa（0~5 mH_2O）, the measurement accuracy is ±0.06%. Using measuring cylinder to measure the instantaneous flow convergence displacement. The diameter of measuring cylinder is 0.72m. The test equipment is composed of rectifier disc, pressure sensors, input type level gauge, etc [2].

1.3 Test procedures and decision condition

Figure 2 shows the test procedures.

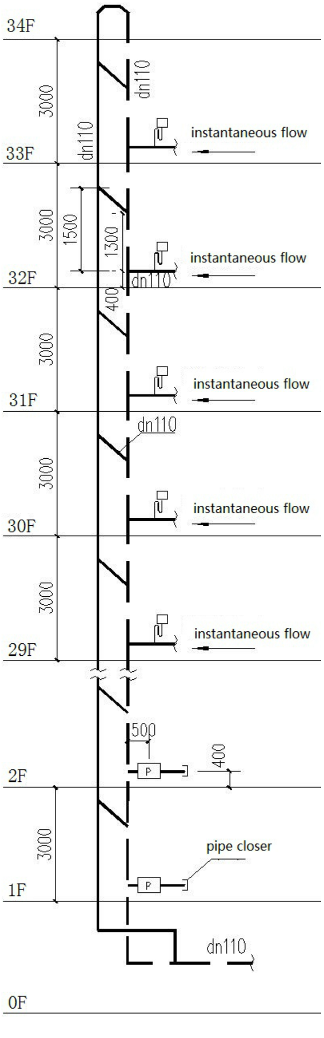


Fig.1 Test system of instantaneous flow drainage system（DN110mm × DN110mm，self-circulation specific vent stack drainage system）

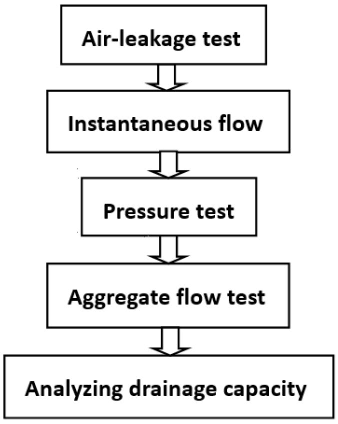


Fig.2 Experimental procedure

The maximum positive and negative pressure automatically measured by pressure sensor is the maximum positive and negative pressure of this floor. As show in figure 3 (DN110mm × DN110mm, self-circulation loop venting; 2 instantaneous flow generators drain water). According to the national industry standard "Test standard for capacity of vertical pipe of the domestic residential drainage system" (the examination and approval of draft). The determination conditions for this test is: the maximum pressure of drainage system should not be larger than +300Pa when using instantaneous flow, the maximum negative pressure should not be less than -300Pa. The drainage flow is the drainage capacity of the system when the maximum pressure achieving the maximum decision value.

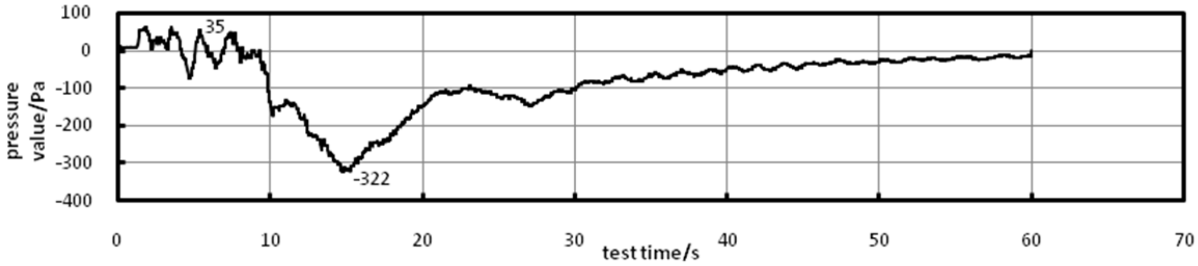


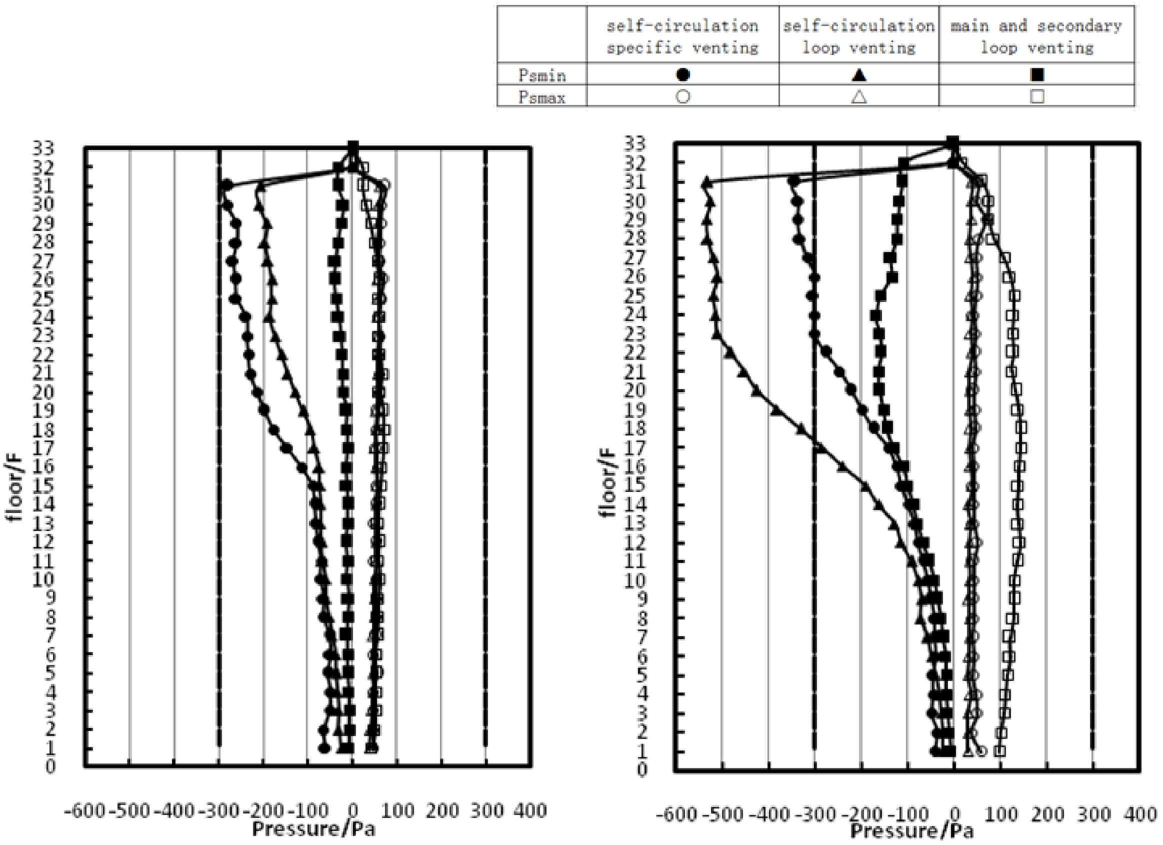
Fig.3 Pressure distribution of horizontal branch pipe of 22th floors

2. Test Result

2.1 Pressure test for each vent stack drainage system

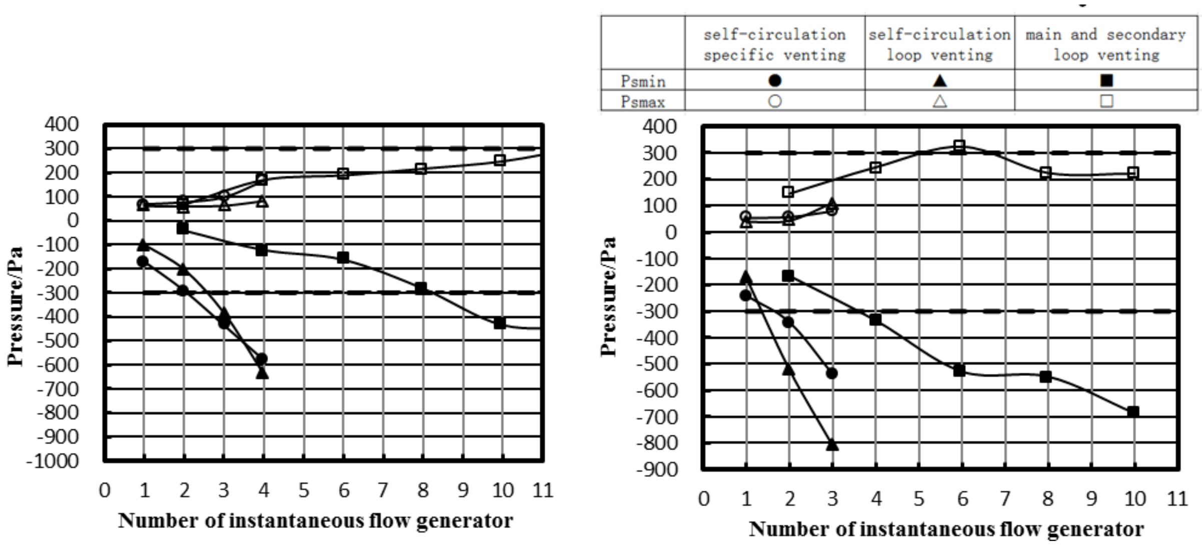
Measured pressure of each vent stack drainage system by using instantaneous flow. The pressure value of each system by using 2 instantaneous flow generators is shown in figure 4. It can be seen that the maximum positive and negative pressure occurs in the top floor（not the drainage floor) of vent stack system. When the same number of instantaneous flow generator discharge, the maximum negative pressure of each system is self-circulating specific vent stack system> self-circulating loop vent stack system > main and secondary loop vent stack system , and DN110mm × DN110mm < DN125mm × DN110mm. The maximum positive pressure is connected with the pipe diameter. In DN110mm × DN110mm the value is similar, while in DN125mm × DN110mm the maximum positive pressure of main and secondary loop vent stack system is obviously larger than of self-circulating ones.

The maximum positive and negative pressure values of each vent stack system when instantaneous flow generators drain with different numbers are shown in figure 5. It can be seen that the pressure value within each drainage system increase with the increase of the number of instantaneous flow generators. The positive and negative pressure distribution of each When the same number of instantaneous flow generator discharge, the maximum positive pressure of main and secondary loop vent stack system is the largest while the values of self-circulating specific and self-circulating loop vent stack system are similar , the maximum negative pressure of main and secondary loop vent stack system is always the lowest while the values of self-circulating specific and self-circulating loop vent stack system have obvious difference connected with the diameters. Overall, negative pressure of each system achieves -300Pa firstly, main and secondary loop vent stack performance is superior to the self-circulating system, and the performance of self-circulating specific and self-circulating loop vent stack drainage system is comparably similar. The situation of the maximum pressure achieving the maximum decision value first for each drainage system is shown in table 2.



(1) DN110×DN75 (2) DN125×DN110

Fig.4 Positive and negative pressure distribution of each vent stack system when two instantly stream generators drain



(1) DN110×DN75 (2) DN125×DN110

Fig.5 Positive and negative pressure distribution of each vent stack system when instantaneous flow generators drain with different numbers

The situation of the maximum pressure achieving the maximum decision value first for each drainage system is shown in table 2.

Tab.2 The situation of first to achieve maximum determining pressure value for each system

Drainage system	Positive pressure	Negative pressure
DN110×DN110 self-circulation specific venting		√
DN110×DN110 self-circulation loop venting		√
DN110×DN110 main and secondary loop venting		√
DN125×DN110 self-circulation specific venting		√
DN125×DN110 self-circulation loop venting		√
DN125×DN110 main and secondary loop venting		√
Note： √ means the pressure of the system to achieve the maximum pressure decision value.		

2.2 Drainage capacity analysis of each vent stack drainage system

When the maximum pressure value is within ± 50Pa of decision value, the measured flow value is the drainage capacity of the system. All the drainage capacity of each specific vent stack system in this test are measured values.

Compared with the maximum design flow capacity value of building water supply and drainage design specifications (GB50015-2009) table 4.4.11, it is found from figure 6 that the drainage capacity of specific vent stack system by using instantaneous flow is similar to the standard value. The drainage capacity (when the arranging diameter of the vent is the same) is main and secondary loop vent stack system > self-circulating loop vent stack system > self-circulating specific vent stack system, and DN110mm×DN110mm > DN125mm×DN110mm in each system. The drainage capacity of each vent stack system is less than the corresponding standard value.

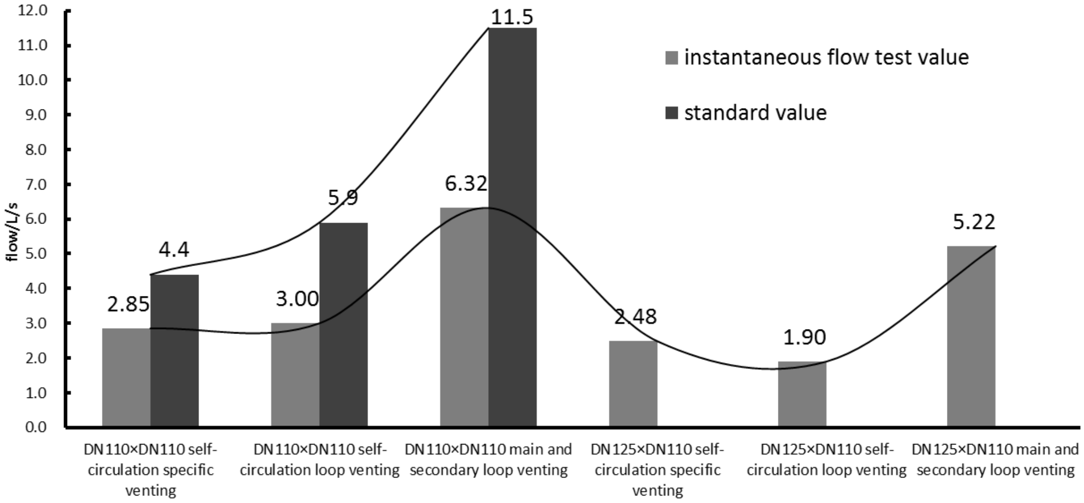


Fig.6 Tendency of drainage capacity for each vent stack system

3. Conclusion

When using instantaneous flow, the maximum negative pressure occurs in the top floor, and the maximum positive pressure occurs in the intermediate floor in self-circulating and double vent stack system. Compared with the maximum design flow capacity value of building water supply and drainage design specifications, it is found that when the pipe setting with the same diameter, the drainage capacity of instantaneous flow testing is main and secondary loop vent stack system > self-circulating loop vent stack system > self-circulating specific vent stack system, but is less than the corresponding standard value. When using different diameters in the same system, the drainage capacity is DN110mm×DN110mm >DN125mm× DN110mm.

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Researches on Reclaimed Water Quality Changes and Biofilm Characteristic

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Abstract

Under the certain circumstances of global shortage of freshwater resources, reclaimed water, as a potential water resource, has gained extensive concerned for its sustainability. When there are excessive organic matters in treated water, bacterial regeneration and pipeline corrosion occur, which will severely damage water quality. So the biological stability of water is significant to water quality and safety. As biofilm is commonly found on the wall of reclaimed water pipe due to the limit of water nutrient environment, they have a great impact on the quality and security of water supplement.

Effluent of water recycling plant are treated as water source, 4 CDC biofilm reactors in each of 2 groups in series operation are applied to simulate the recycling network system, scanning and detections of ductile iron and PE plate are completed by electron microscopy and XRD. The variation of water quality, formation of biofilm process and the interaction between microorganisms and residual chlorine in reclaim water are studied.

Significant differences are observed in biofilm morphology when different tube conditions are applied. Corrosion made the pipe wall become loose and uneven on nodular cast-iron pipe while biofilms on polyethylene pipe were relatively smooth and with certain viscosity. And the structure of the rough biofilm changing with water flow can increase the specific surface area of the biofilm which will promote the growth and the development of bio-film as well as the removal rate of pollutant.

Water recycling is a key element of water resource management. By proper water protection and recycle, we can maintain and conserve freshwater resources, meet people’s demands on the environment, achieve the sustainable development of human and nature, and then provide an important guide and practical signifi cance to the improving of reclaimed water reliability.

Keywords

Reclaimed Water; Biofilm; Microbial Community Structure; SEM

1. Introduction

With the increase of global population, the demand of water resource is also rising day by day; the shortage of water resources becomes the lifeblood to restrict the whole world economic development. Reclaimed water is one of the most effectively ways to relieve water resource. Although, the technology has been adept in sewage treatment in China, however, the regenerated water after processing will be generated corrosion scale in the process of different pipeline transportation and distribution system that will change the water quality of the pipe network. In particular, when nodular cast iron pipes are used in reused water distribution system, scale of internal corrosion can be accumulated and mound-like features referred to as tubercles.[1] These block the velocity and flow of reused water, shelter microorganisms, and act as sinks for toxic metals [2-3].The tubercle will deliver toxic and harmful substances, also bring "red water" including "yellow"; this affects the chromaticity and turbidity of reclaimed water. Carbon or phosphorus, which can act as nutrients for microbial, can leach from plastic pipe materials e.g. i n the form of microbial available phosphorus (MAP) [4] or assimilable organic carbon (AOC) [5]. In carbon rich, phosphorus limited waters typical in Finland, microbial growth in waters [6] and biofilms [7] is limited by the availability of phosphorus rather than carbon.

A lot of researches have illustrated in detail the research progress of the biological stability of main water in water supply network. Escobar put forward, AOC and BDOC described the biological stability of water pipeline network together. When the regrowth of microbes in the water supply network is the key research, AOC should be used as the evaluation index. When the microorganisms need amount of chlorine and disinfection by-products formation potential is a research focus, should be BDOC as evaluation indictor. [8] Bio was used to study the research on dynamics of microbial growth in water supply network and its influence factors by Using experimental and computer simulation method. The results show that the network in different parts of the microorganisms presents different characteristics, and network does exist biofilm and biological membrane has a strong ability of resistance to chlorine, and the microorganisms in bulk water for residual chlorine is sensitive. [9] Kaye N. by using analog device to study the influence factors of the microorganism in the water supply network. The results showed that the water supply pipe network in microbial was regrowth, and microbial biomass had obvious linear relationship with turbidity; and the amount of microbial in water supply network is increasing with the extension of the pipe network. [10] Hamme studied the effect of water purification process and water supply network on the biological stability, compared representation of biological stability with the AOC and flow cytometry (TCC). The results show that the AOC and TCC can effectively characterize biological stability. The density of bacteria in the main water is rising with the increase of organic concentration. When the water quality of TCC was 8.97x104cells/ml, and the concentration of DOC was 0.78mg/L, AOC concentration is 32 g/L; its value is little change in the water supply network, which can say the effluent of biological stability is extremely high. [11]

This is prevailing to research the progress of biofilm growth of pipe wall in water supply network. This is prevailing to research the progress of biofilm growth of pipe wall in water supply network. Simões[12] shows that about 95% of bacteria are attached to the tube wall by biofilm. Because of corrosion and deposition, the corrosion layer of water supply network has a certain thickness, which has a huge surface area suitable for microbial attachment that can provide the conditions for its growth.

Patrick Niquette[13] studies the effect of the biofilm of pvc, pe, gray cast iron, cast iron with cement mortar, uses surface water and groundwater as experimental water. The results showed that the density of the biofilm in the gray cast iron pipe was the highest, followed by a line of cast iron pipe, PVC and PE pipe bio density was the smallest. The results show that the biofilm can be formed in 7 days, and the biofilm can exceed 105cfu/cm^2 within six weeks. There are dynamic changes in the bacterial population, but it is common to see the genus bacillus, bacillus and Pseudomonas in the biofilm. Both concentration and the detection rate of the microspheres were high. In addition, the Escherichia coli group, and other bacteria can get secondary growth in the biofilm. [14]

In the present research, a laboratory-scale reactor was used to simulate reclaimed water distribution systems. The primary purpose of the work were to survey: the study the quality and the characteristics of the biofilm on the pipe wall, study the water quality of the pipe network from the aspects of microbiology that can reveal the fundamental cause of the effect of the water quality.

2. Materials and Methods

2.1 Experimental installation and pipeline

Effluent of water recycling plant are treated as water source, 4 CDC biofilm reactors in each of 2 groups in series operation are applied to simulate the recycling network system. The CDC biofilm reactor consists of Plexiglas, every reactor include 8 coupon-carriers (each carrying 3 coupons). Particular situation is shown in figure 1. The coupons were made of nodular cast iron and PE, the diameter was 12.7mm and the thickness was 3mm. The chemical composition of the coupons was as follow (0.075), C (2.98), Si (2.45), Mn (0.68), and S (0.075), with the remainder consisting of Fe.

In the middle of the reactor has an H baffle. It was connected with the magnetic stirrer, mixing the device to simulate the shear force of water, 5 seconds into the water and stop with 30 seconds. The experiment was using continuous flow operation mode, reclaimed water was respectively through the peristaltic pump up to simulate pipe R1, R2, R3, R4 and then the water was discharged at a rate of 0.26m/s to exclude pipeline R4. Pipeline system R2, carrying disinfected reclaimed water treated with5mg/L sodium hypochlorite and 15mg/L bromogeramine (a non-oxidative bactericide containing 98% polyquaternary ammonium—for more detailed information see the Supplementary materials), was intended to provide comparative results in the absence of biofilms.[15]

2.2 Sample preparation

The reactor was running a week for test; every week would take water sample and coupon after officially running for three months. The typical water quality parameter of the raw is presented in Table 1. The following water quality indicators are in line with the water quality of the Landscape Environment of Urban Wastewater Reclamation and Utilization.

Table 1—Average feed water quality parameters of raw reclaimed water used for pipeline systems.

Water quality parameter	Unit	Reclaimed water
Temperature	℃	23
Ph		7.39
Turbidity	NTU	1.8
Alkalinity	mg/L	202
Residual chlorine	mg/L	1.35
SO_4^{2-}	mg/L	87.2
Hardness	mg/L	189.1
total iron	mg/L	0.1707
TOC	mg/L	5.212
ATP	CFU/L	21915

After operating for a period of two mouths, the corrosion scales were removed from the PE, nodular cast iron coupons and then allowed to vacuum dry for up to 24h. Each sample was utilized for mineralogical testing and chemical analysis using X-ray diffraction. The surface morphology characteristic of the corroded coupons was observed by SEM.

3. Results

This experiment is to establish a set of simulation reuse water pipe network system, and study the water quality and microbial changes in the network system. The experiment is mainly divided into two aspects: on the one hand, the water quality and the change of the reactor along the course of water consumption are studied; on the other hand, the change is mainly on the biofilm: the main research reactor along the biofilm on the number of bacteria, extracellular polymers, adsorption amount of metal and biofilm microbial morphology changes.

3.1 Water quality changes of simulation system

3.1.1 The change of organic carbon along the course

TOC as organic carbon index in pipe network system, the change of TOC along the way is shown in Figure 2.

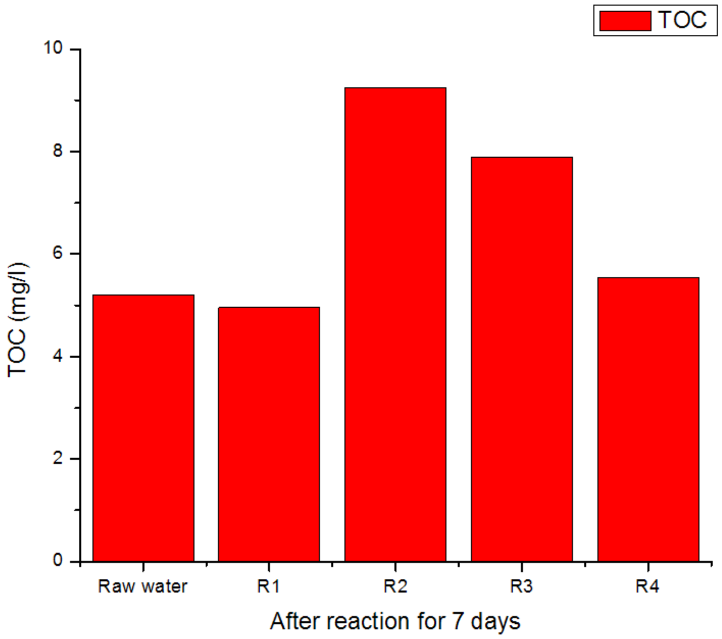

Fig2. The change of TOC in the pipe network reactor

Compared with raw water, the disinfected reclaimed water in R2 had higher TOC. This results that the addition of bromogeramine increase the carbon but can negligible. [16] By the R2 in the process of the pipeline through the R4, TOC is constantly declining, respectively, 14.61%、28.67%. TOC decrease is mainly due to the bacteria growth and reproduction process TOC as nutrients utilization. However, the change of TOC in the pipe network system is small, because of the microbial is mainly use of BDOC, it can not use of the part of TOC in the water. The main factors influencing the concentration of BDOC are: 1. Bacterial utilization the organic matter in water, BDOC concentration was reduced in the pipeline, 2. residual chlorine oxidation certain difficult degradation organic matter, the BDOC concentration was increased. In the diagram, TOC has a downward trend in the network, mainly due to the small amount of residual chlorine, although have raw water constantly inject but chlorine consumption is fast along with the network extension that unable to oxidize organic matter. Therefore, the TOC decreases along the path and the decreasing amplitude is smaller.

3.1.2 The variation of ATP in water

ATP is a metabolic energy substance commonly found in microbial cells such as bacteria. There are biofilms in water, including microorganisms, EPS and inorganic substances. Under the condition of the existence of organic carbon, heterotrophic bacteria were the main pathogenic bacteria, especially lack of residual chlorine in the pipeline. After simulating pipeline operation for 7 days, obtained the change of ATP along the water after 4 sampling. Figure 3

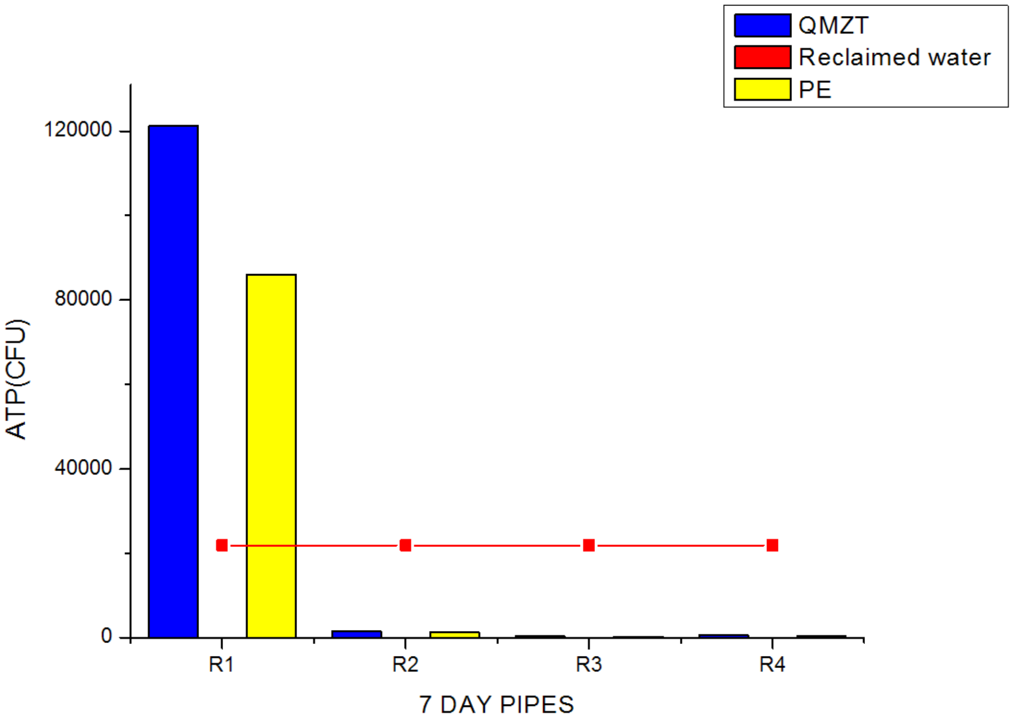

Fig.3 Raw water and ATP in different reactors

First of all, we can see the ATP in the raw water is within the allowable range. Secondly, compared with raw water, the ATP in reactor 1(no matter in the PE pipeline or nodular cast iron) was growth rapidly. The experimental part mentioned that R2 reactor joined 5mg/L sodium hypochlorite and 15m/L bromogeramine. Finally, from the fig.3, we can clearly see the number of ATP in R2 reactor decreased sharply. There is no much left in R2, R3 and R4 reactors.

As shown above, it can draw the following conclusions: (1)In the water supply pipe network, high ATP generally indicates failure or residual chlorine disinfection was exhausted, [17] and the residual chlorine has decay completely generally in the end. As a result, the ATP in the end of the pipe network is larger. In this study, the maximum values of ATP occurred in the beginning of the pipeline, the main reason is that the water of the nutrient concentration is high and there have raw water injection to ensure the residual chlorine; it provides the regeneration of microbes in R1 with adequate nutrients. (2) Pipe casting an amount of disinfectants such as: sodium hypochlorite and bromogeramine against substrates of growth so as to curb the growth of heterotrophic bacteria reproduction. It is advantageous to the reclaimed water reuse, save the economic costs of application of reclaimed water treatment in the process.

3.1.3 Iron ion release in the reclaimed water

The total iron release fluctuation scenarios relative to their values in different experimental phases are illustrated in fig.4 [18]

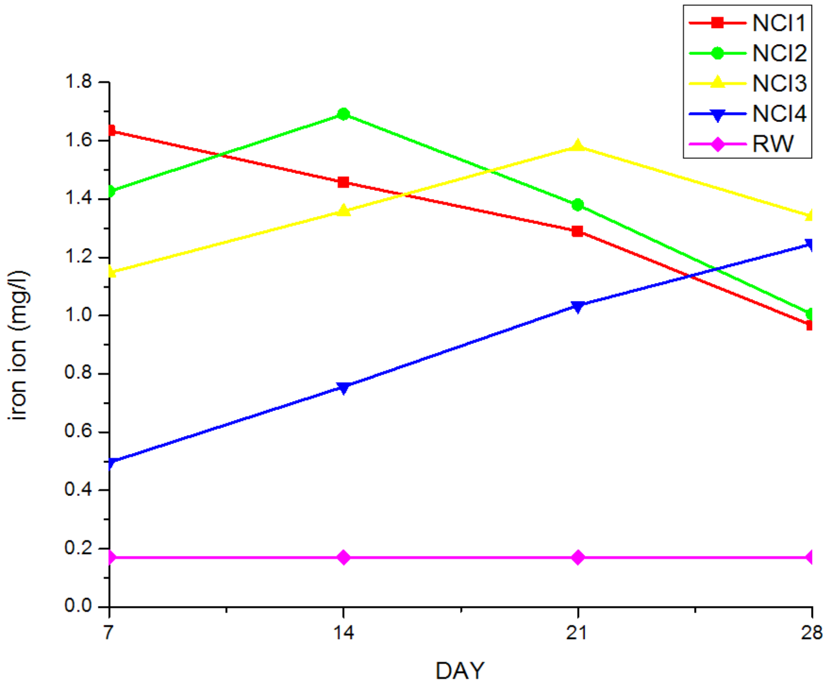

Fig. 4—Iron ion release fluctuation scenarios for nodular cast iron pipeline 1, 2, 3, and 4

The release value of Fe in the raw water was 0.1707. Overall the trend of the release of iron ions in the picture is the first increase and then decrease. With the simulation of pipe reactor for continuous operation, the ductile cast iron pipeline corrosion was caused by iron ion release in water that increase the content of iron ion in water, when the reactor was operating 28 days, the pipeline corrosion tends to be stable meanwhile four water pipes of the iron ions content are almost in the same.

3.2 Biological membrane characteristics of the pipeline system

3.2.1 Study on the influence of surface roughness on the biofilm

Figure 5 is analyzed the formation of the biofilm by the case of nodular cast iron. It can vivid to see the coupon without experiment is smooth.

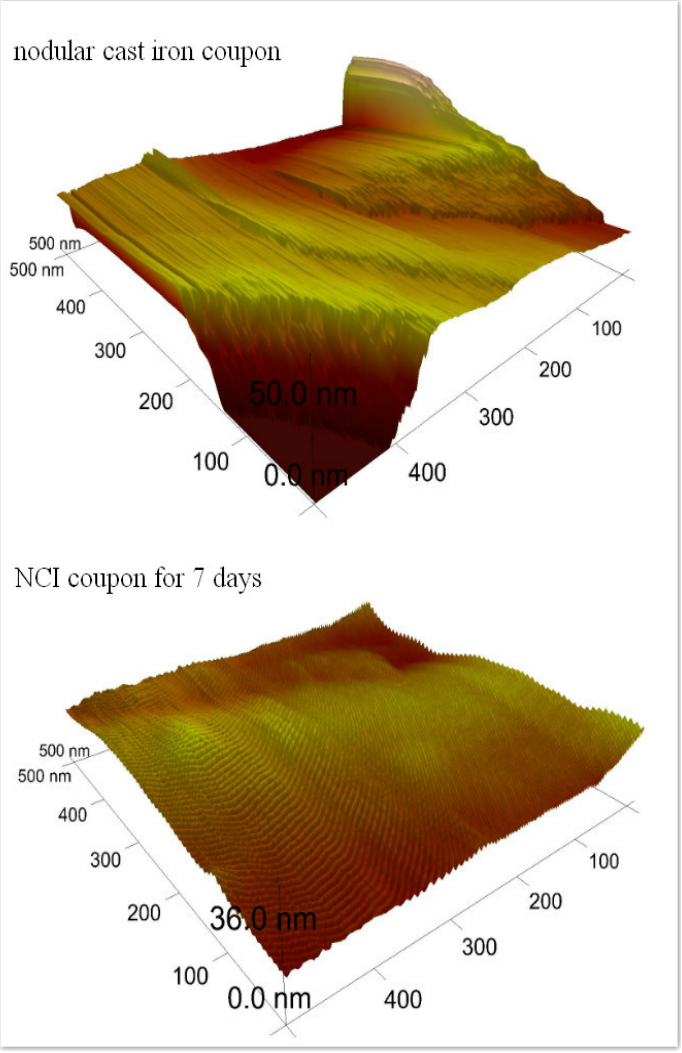

Fig. 5—Surface morphology of nodular cast iron

After 7 days for reaction，the surface of the hanging plate has been corroded obviously, the surface roughness of the coupon is increased, and the texture of the surface can be clearly seen, but the grain distribution is uniform and relatively smooth. The surface roughness increases the surface area of the coupon, which is advantageous to aggrandize the adhesion force of the surface of the coupon, which lays the foundation for the generation of the biofilm.

Compared with pe coupons after 7 days reaction, the nodular cast iron had easier to corrosion.（Fig. 6）The conclusion is shown like figure 4; pe tube has a smooth surface, poor adhesion, and reclaimed water on the corrosion is also poor. Although simulation pipe reactor operation is only 7 days, but nodular cast iron pipes have obvious corrosion phenomenon that in agreement with the conclusions reached with the above: Specific surface area determines the speed of corrosion rate.

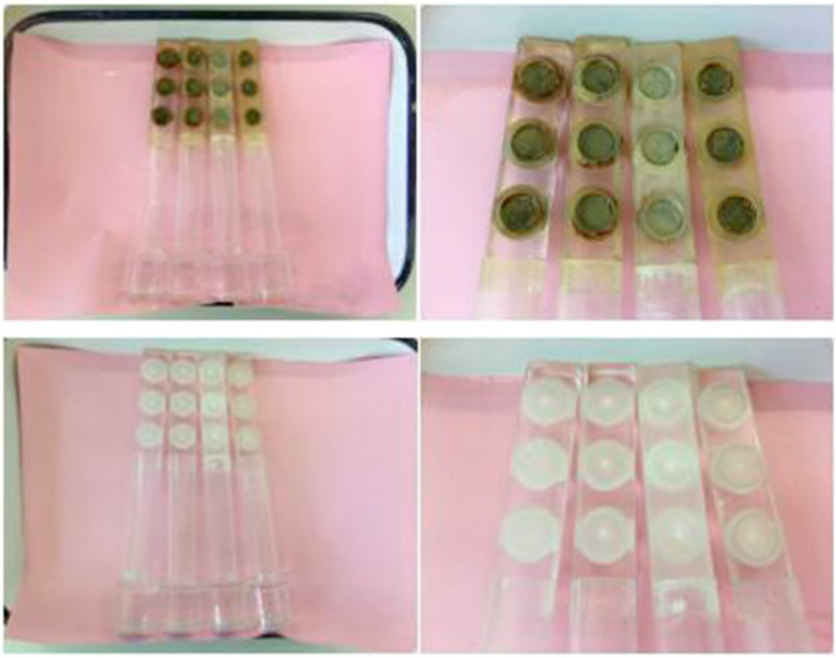

Fig. 6—Rotary coupon corrosion morphology figure for 7 days

3.2.2 Electron microscope scanning analysis of biofilms

Because nutrients along the pipeline network system is different, lead to the microstructure of biofilm quantity, types and the morphological is not the same, specific circumstance is shown in figure 7.

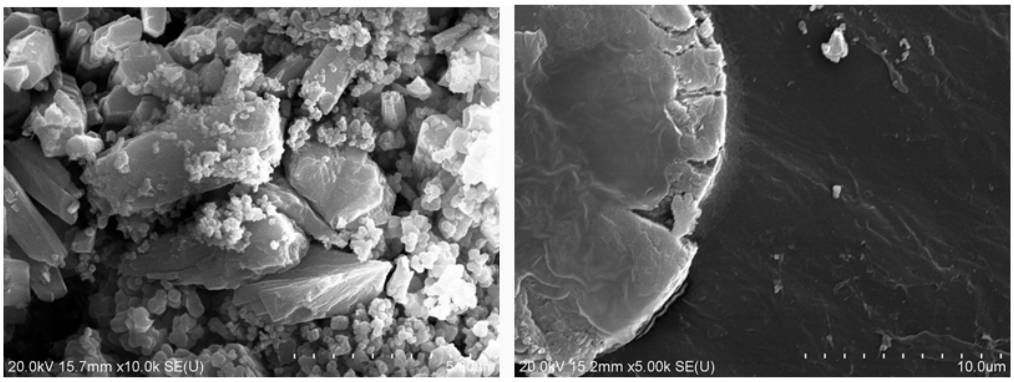

Fig. 7—Nodular cast iron & pe coupons in R1 for 7 days (a)

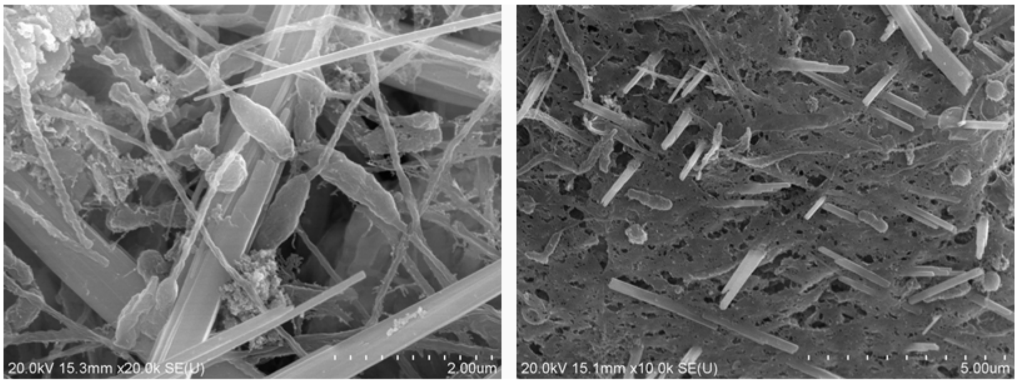

Fig. 8—Nodular cast iron & pe coupons in R1 for 35 days (b)

The bacteria on the coupon were observed by electron microscope, can be found coccus and bacillus. Such as the coccus accounted for 40%, bacillus accounted for 60%. Among them, the typical strain under the scanning electron microscope (5000 x - 20000 - x) the observation results are shown in figure 7.

The bacteria in the water supply are mostly bacillus that is separated from the pipe biofilm. With smaller individual, which bacillus length mostly less than 1 μm, coccus volume is relatively small and the diameter is less than 0.5 μm; but there are also a small number of bacilli the length over 1 μm. We know that the microbial volume is smaller, the greater the specific surface area, the more easily to absorb the nutrients. In the water supply network the oligotrophic environment, C, N, P and other nutrients is an important factor to limit microbial growth, in the long process of evolution volume small, more easily absorbed nutrients microbial populations retained. Studies have shown that existed in the nature of a class of bacteria whose diameter is less than 0.3 μm, slow growing on the surface of agar nutrient rich, this type of bacteria called ultra bacteria.[19] Therefore, most of the microorganisms in the water supply pipe wall biofilms are the bacteria.

4. Conclusion

The experiment is self-made water supply network simulation device as the research object, which select disinfectants and pipes are the main influence factors. It has research the influence on water quality, pipe wall biofilm biomass and draws the following conclusion:

(1)The water quality indicators in the reclaimed water are meeting the requirement, but due to calcium and magnesium ions in the water are little higher, a white suspension scale has appear in the water.

(2)There are two kinds of pipes: PE, cast iron pipe wall biofilm biomass in 7 days did not achieve stability, and compared two kinds of pipes, cast iron pipe wall biofilm biomass are most, followed by PE pipes. The influence of residual chlorine concentration on biofilm biomass varied depends on pipe, PE pipe biofilm biomass decreased with the increase of residual chlorine concentration, but present in cast iron pipe instead of law. The biomass of the biofilm was positively related to temperature, turbidity and the number of bacteria in the body water.

Acknowledgments

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A Study on Maintaining the Function of Water Piping, which Are Life Lines for Buildings

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Abstract

If an earthquake occurs, damage to water piping, which serve as the “life lines” for buildings and thus need to be kept in working order, can lead to secondary damage such as water leaks, making it difficult for the building to be used. In earthquake disasters in the past, collapsing water piping and damaged pipe joints have resulted in water leaks, which lead to temporarily shutting off these life lines, thus making using the building impossible. Given this background, existing sprinkler systems are different from ordinary building services and utilities in that it must be possible to easily maintain them and restore function immediately after an earthquake occurs. This is in order to preserve the life lines of the building in the event of a disaster, thus, if the building is in a sound condition, preventing the spread of fire in the immediate aftermath of the earthquake. There are concerns that a large-scale earthquake could occur in the near future, and it will be necessary to preserve the functions of automatic fire extinguishing equipment such as sprinkler systems in the event of such a disaster. To achieve this objective, we created a model of the type of sprinkler system installed in existing buildings and conducted shaking table tests and numerical analysis in order to explore effective earthquake-proof countermeasures.

Keywords

Life line; Water piping; Sprinkler system; Shaking table test; Numerical analysis.

1. Introduction

Although improved construction structure have bolstered safety measures, recent earthquake disasters have led to significant building equipment damages. Therefore, damage of building equipment was becoming apparent. In the Great East Japan earthquake, damage to building equipment led to a temporary shutdown of building function. Damage to water pipes can lead to secondary structural damage through water leaks. Because of this possibility, existing fire sprinkler systems must differ from ordinary building services and utilities as they must be able to be easily maintained for immediate service following an earthquake.

The purpose of this study is to explore effective seismic measures of building equipment by conducting seismic performance evaluations of sprinkler piping systems in high-rise buildings that need to maintain uninterrupted service. Hence, a fire sprinkler system model was created at Kogakuin University, Shinjuku campus.

Numerical analysis was conducted by evaluating both vertical and horizontal sprinkler piping models. To understand the importance of sprinklers during disasters, a sprinkler piping model was employed using dynamic loading on the basis of an anticipated Tokyo inland earthquake. In addition, further measures are verified for evaluating seismic building equipment.

2. Damages of Sprinkler Piping by The Great East Japan Earthquake

According to the fire extinguishing equipment damage report 1) for the Great East Japan earthquake, most fire sprinkler systems were compromised due to thin piping at distal ends and sprinkler heads. Moreover, the earthquake damaged the joints of water supply piping and branch piping, in addition to arm-over drop piping. Generally, differences in vibration characteristics can cause damages to mutual piping and other materials, and water pipe damage caused by seismic damage can lead to secondary damage through water leaks.

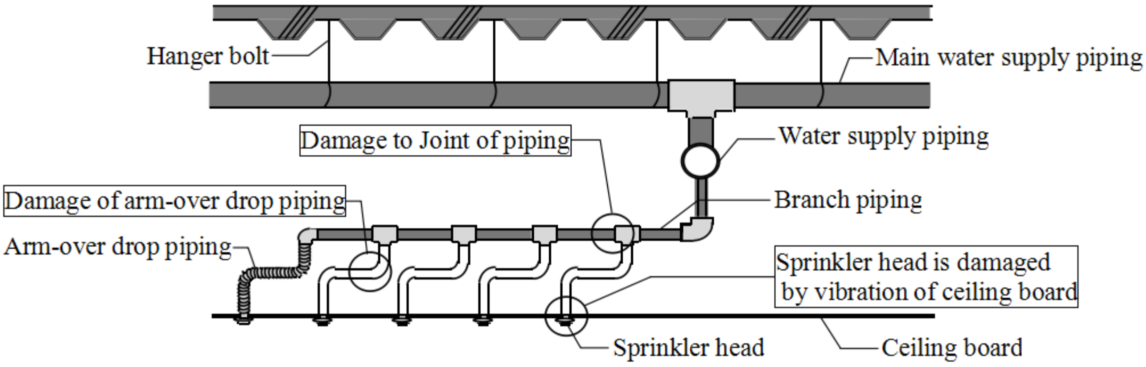


Figure1 Damage case of fire sprinkler system 1)

3. Outline of Numerical Analysis

3.1 Vertical piping on Numerical Analysis

Seismic performance was examined using pipe stress analysis software (AutoPIPE, Bentley Systems, Incorporated). Timoshenko’s beam theory, in which the pipe is a shearing deformation beam element, was used as the calculation model. In addition, the following rigid matrix method was used in the calculation.

Table 1 shows the contact conditions of each element in the vertical sprinkler piping. Figure 2 shows a model outline of the vertical sprinkler piping in the evaluated building. The contact conditions for each element was set as follows: the rigid joint parts are the slabs of the upper, lower floors and hanger bolts; the tank, pump, and piping; and the fireproof compartment of the main water supply piping. Moreover, the pin-joint parts are the under-floor piping connected to the auxiliary elevated tanks in the roof floor, fixed points of the vertical sprinkler piping, and hanger rings.

The input conditions used were the maximum relative-story displacement of each floor determined by employing dynamic loading2) from an anticipated Tokyo inland earthquake. The vertical sprinkler piping follows the construction structure. Therefore, the relative-story displacement were entered at the following: the penetration parts of floor slabs, fireproof compartments and fixed point of vertical sprinkler piping.

Table1 Contact conditions of each elements in vertical sprinkler piping

Symbol	Each elements	Contact conditions
Ⅰ	Tank • pump - piping	Rigid joint
Ⅱ	Fixed point of vertical sprinkler piping（U band）	Pin joint
Ⅲ	Slab of upper and lower floor - piping	Rigid joint
Ⅳ	Fireproof compartment of main water supply piping	Rigid joint
Ⅴ	Fixed point of vertical sprinkler piping（U band）	Pin joint
Ⅵ	Slab of upper floor - hanger bolts	Rigid joint
Ⅶ	Hanger ring	Pin joint

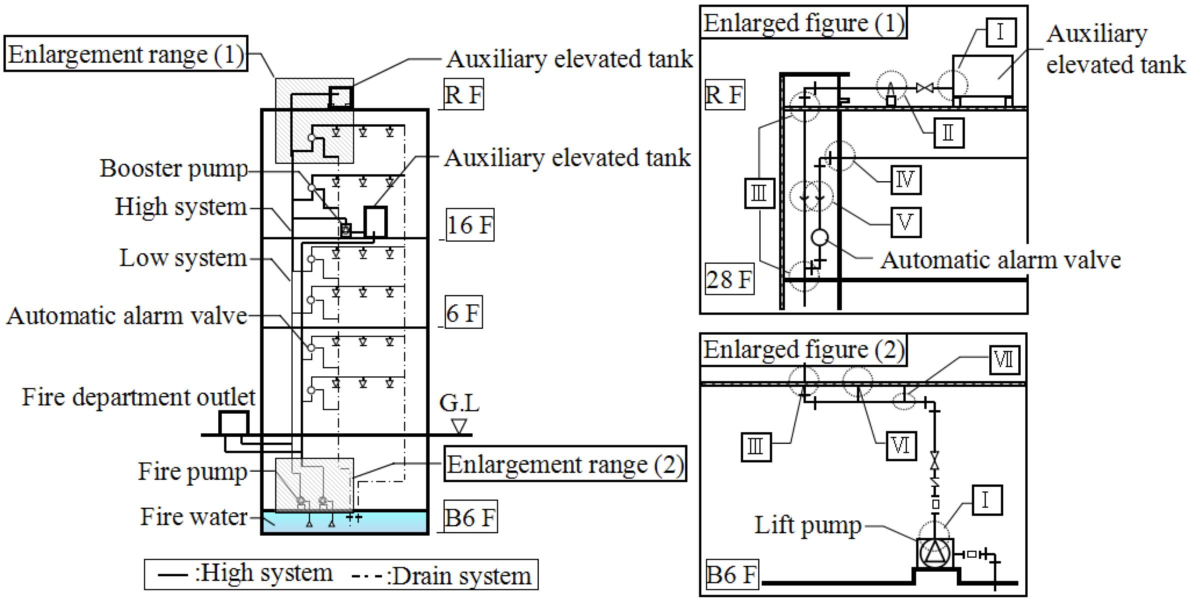


Figure2 Model outline of vertical sprinkler piping in evaluation building

3.2 Horizontal piping on Numerical Analysis

Figure 3 shows the model outline of the horizontal sprinkler piping, and Table 2 shows the contact conditions of each element in the horizontal sprinkler piping. In previous studies2) were maximum relative floor acceleration was assumed on the 29th floor of the building for Tokyo inland earthquakes. Hence, the sprinkler piping installed on the 28th floor of the Building was evaluated. The sprinkler piping was installed in horizontal expansion in the ceiling system, and the branch piping from the main water supply piping were connected and was also connected to the sprinkler head in the ceiling; the pipe diameter was 150–25 A.

Contact conditions were set based on investigation into actual construction situation. In common conditions of the calculation model, the fireproof compartments penetration and smoke control zone compartment penetration comprise rigid joint because it is a mortar filled joint. The hanger bolts comprises rigid joint parts in the upper floor slab, and the hanger ring comprises pin joint parts. Moreover, the vibration characteristics of the arm-over drop piping attached to the ceiling material containing sprinkler head are complicated. Therefore, the interpolation of two conditions of the joint of the sprinkler heads and ceilings with the pin-joint parts and without the connection (Free), and will be predicted under the impact of the external load.

For input load, the maximum response acceleration of 1911 gal was used as input from the south direction of the evaluated building. In the event of a Tokyo inland earthquake, maximum vibration is assumed for the entire piping system. Moreover, results of contact conditions 1 shows Fig.8 and contact conditions 2 shows Fig.9.

Table2 Contact conditions of each elements in horizontal sprinkler piping

Symbol	Each elements	Contact conditions	
		1	2
$\boxed{A}$	Joint with a ceiling	Pin	Free
$\boxed{B}$	Main water supply piping - fireproof compartments penetration • water supply piping - smoke control zone compartments penetration	Rigid joint	
$\boxed{C}$	Slab of upper floor and hanger bolts	Rigid joint	
$\boxed{D}$	Hanger ring	Pin joint	

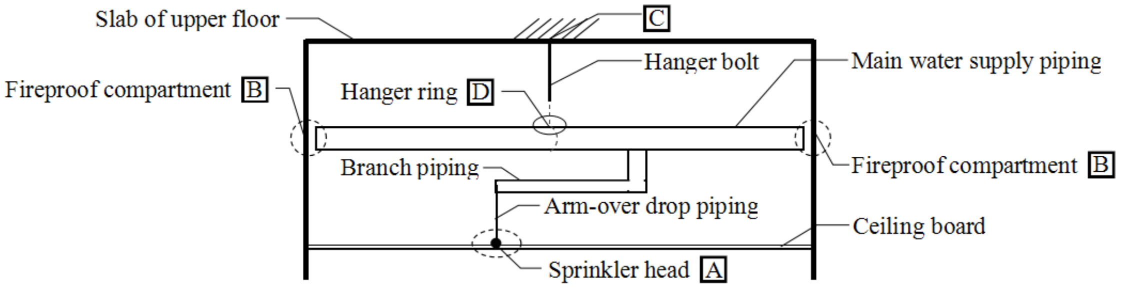
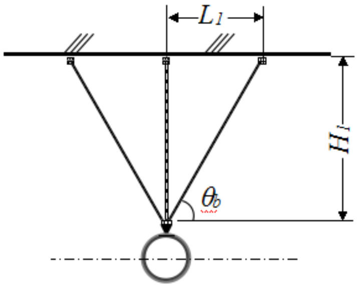


Figure3 Model outline of horizontal sprinkler piping in numerical analysis

3.3 Seismic measures to verify

To verify the seismic parameters of the fire sprinkler system, the braces described in Fig. 4 were installed on the calculation model. The effectiveness of these measures was evaluated by comparing the contact conditions of the braces under conditions 1 and 2. The braces were placed at the upper hanger rings following the measures1) used in the actual construction. Contact of a brace and slab of upper floor are rigid joint. In the calculation model, five braces were installed on the main water supply piping and six places on the water supply piping following the locations of the existing hanger bolts.



Number brace[-]	2
Length of brace[mm]	H_1=800
Span of brace[mm]	L_1=400
Angle of brace [°]	θ_b=65

Figure4 Conditions of modeling brace with numerical analysis

4. Result of Numerical Analysis

4.1 Numerical analysis result of vertical piping

Figure 5 shows the stress distribution of the vertical sprinkler piping from the calculation results of the evaluated building for a Tokyo inland earthquake. Figure 6 shows the calculation results of the stress intensity occurring in the vertical sprinkler piping and branching main water supply piping on each floor.

In Figure 5, the stress concentration is shown to occur at the compartments penetrate of each floor which are the perforated fireproof compartment and the floor slab perforated compartment. Nevertheless, the generation of large stress was not confirmed in all vertical sprinkler piping. The pipe must be rigidly secured to the building frame while maintaining a resistance to the ground motion.

Therefore, the intensity of stress that occurs when the floor slab penetrates the compartment is relatively high (Fig. 6.) However, the intensity of stress in the vertical sprinkler piping with short-term loading in the evaluated building at both sites was approximately 20 N/mm^2 or less, which is lower than the allowable stress of 111.8 N/mm^2. Therefore, the possibility of damage to the vertical sprinkler piping is low.

$$f_c = 290 \times \frac{1}{3.5} \times 1.5 \times 0.9 \cdots (1)$$

f_c : Allowable unit stress for temporary loading of vertical piping [N/mm^2]
290 : Bending stress of SGP piping [N/mm^2]
1/3.5 : Allowable unit stress for sustained loading-a Safety Factor [-]
1.5 : Allowable unit stress for temporary loading-a Safety Factor [-]
0.9 : Joint efficiency[-]

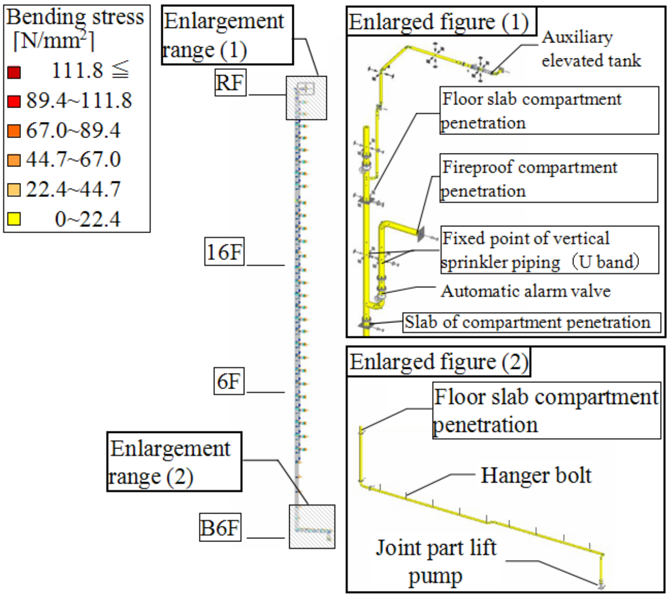


Figure5 Stress distribution of vertical sprinkler piping

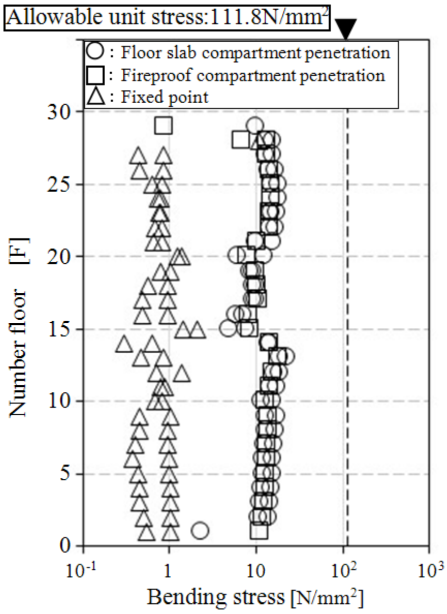


Figure6 Calculation results of the intensity of stress with occurs vertical sprinkler piping and branching main water supply piping

4.2 Numerical analysis result of horizontal piping

Figure 7 shows the numerical analysis results of contact condition 1, and Fig. 8 shows the analysis results of contact condition 2. Figure 7 shows the prediction of displacement and stress applied to the sprinkler piping under existing conditions, in which the stress concentration occurs around the main water supply piping. The maximum moment is calculated at the main water supply piping that rises from the center of the floor. The maximum response displacement was 24 mm at the branch piping of the distal end.

In contact condition 2, the stress concentration was observed in main water supply piping in a similar position as that for contact condition 1, and the maximum response displacement was 241 mm at the branch piping of the distal end.

$$f_c = 290 \times \frac{1}{3.5} \times 1.5 \times 0.8 \quad (2)$$

f_c : Allowable unit stress for temporary loading of vertical piping [N/mm²]
290 : Bending stress of SGP piping [N/mm²]
1/3.5 : Allowable unit stress for sustained loading-a Safety Factor [-]
1.5 : Allowable unit stress for temporary loading-a Safety Factor [-]
0.8 : Joint efficiency[-]

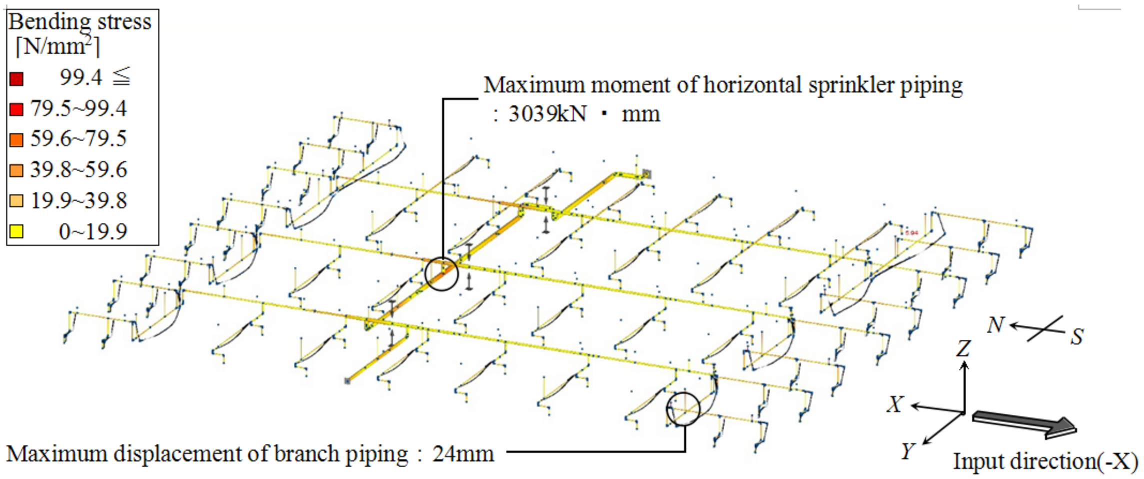


Figure7 Numerical analysis results of contact condition 1

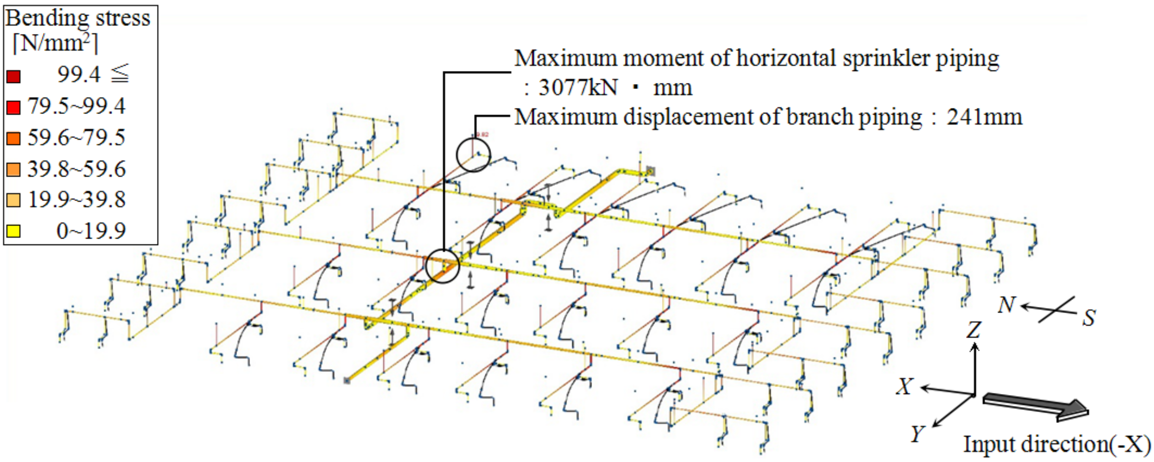


Figure8 Numerical analysis results of contact condition 2

4.3 Numerical analysis results by seismic measures

Figure 9 shows the numerical analysis results of the brace installation for contact conditions 2. Moreover this results shows contact condition 2′. For contact conditions 1 and 2, the stress on the main water supply piping was reduced, as confirmed by the installed brace. Therefore, the stress was concentrated at the joint of the water supply piping and the branch piping. Moreover, as in contact condition 2, the response displacement was in the branch piping of the distal end, at 241 mm.

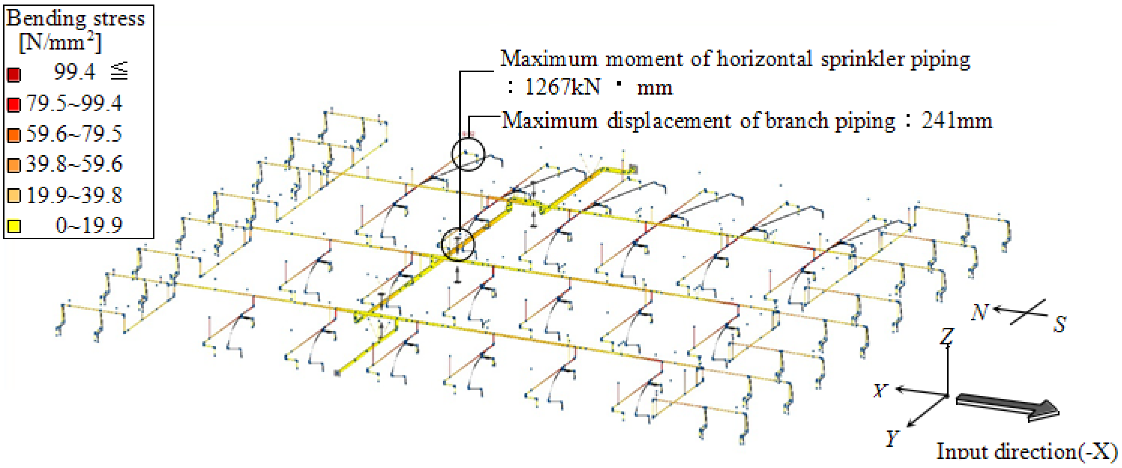


Figure9 Numerical analysis results of installing the brace to contact condition 2

4.4 Comparison of numerical analysis in each system

Figure 10 compares the calculation results of contact conditions 2 and 2′. Figure 12 compares the calculation branch piping and arm-over drop piping in contact conditions 1 and 2. For main water supply piping, water supply piping and branch piping were extracted the joints with the hanging bolts; and for, arm-over drop piping was extracted the joints with the branch pipes were shown.

In Fig. 10, a moment occurs when the main water supply piping begins a decreasing trend, compared with the calculation results of contact conditions 2 and 2′, because of the installation of the brace.

Figure 11 shows the calculation results for the moment and response displacement of the branch piping and arm-over drop piping in contact conditions 1 and 2. In both contact conditions, the moment has not reached the measurement rupture moment of 1,054 kN/mm obtained in the static loading test reported in a previous study [3)]. However, the response displacement was calculated to be approximately 200 mm at the branch piping and arm-over drop piping in contact condition 2.

These results indicate that the installation of the braces on the water supply piping can contribute to the prevention of stress propagation and concentration. In addition, seismic measures of the distal end of the sprinkler piping system and the changes made to the flexible piping can respond favorably to excessive response displacement.

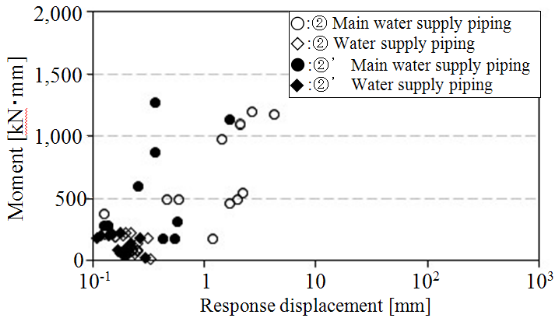


Figure10 Compares calculation results of moment and response displacement(2-2')

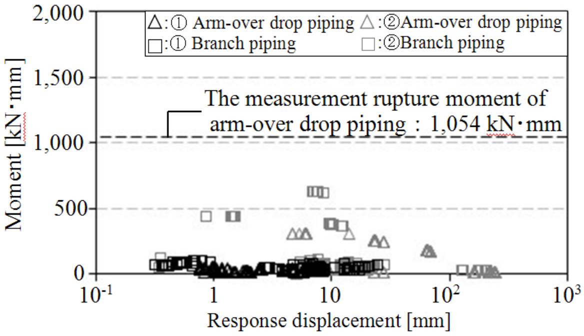


Figure11 Compares calculation branch piping and arm-over drop piping (1-2)

5. Conclusions

This study was conducted to explore effective seismic measures by evaluating the seismic performance of sprinkler piping systems in high-rise buildings by preserving the integrity of the life lines of building during disasters.

Vertical sprinkler piping in the evaluated building followed the relative story displacement of the construction structure and did not exceed the allowable stress. In addition, the installation of braces on water supply piping was shown to contribute to the prevention of stress propagation and concentration according to the numerical analysis of the horizontal sprinkler piping in evaluation of Building 28F. Moreover, the arm-over drop piping used flexible piping in the sprinkler piping system end piece, and it was shown that it was able to correspond to the displacement of the branch pipe.

Acknowledgments

The present study was supported by the Research Center for Urban Disaster Mitigation of Kogakuin University and JSPS KAKENHI Grant Number 24360231. The authors would like to thank Profs., Yoshiaki Hisada and Profs., Tetsuo Yamashita of Kogakuin University. Also in preparing this paper, the authors would like to thank Mr. Masamune Shimakura and Mr. Keisuke Yagasaki who worked with us.

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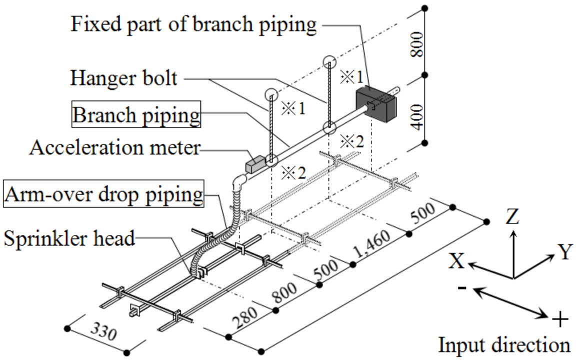
NOTES

Outline of sprinkler piping on shaking table test

Subjects of the shaking table test were the sprinkler system included the arm-over drop piping and the arm-over drop piping using flexible piping. The vibration of the sprinkler piping was produced by shaking table test assuming that the branch piping and arm-over drop piping were connected to the water supply piping. An accelerometer was placed at the distal end of the branch piping to measure the acceleration generated in the pipe. The input wave was a random wave expected in the evaluation of Building 28F for Tokyo inland earthquakes.



	Branch piping	Arm-over drop piping	Hanger bolt
Material, standard	SGP、25A	SUS316	w3/8
Length	2,460 mm	1,100 mm	800 mm
Mass	7.1kg(2.9kg/m)	1.0kg(0.91kg/m)	-
Total mass	8.1kg		
note	・ Upper parts is Rigid joint part with double nut (※1) ・ Fixed piping and hanger ring(※2)		

Figure12 Outline of test material and experimental condition (Unit : mm)

Modeling of sprinkler piping on shaking table test

Figure 13 shows the calculation model of the test materials, and Table 3 shows the materials of the calculation model. To conduct the shaking table test under the same conditions, the hanger bolt side had rigid joint parts and the hanger ring side had pin parts. In addition, the weights of the hanger ring (i.e., 0.1 kg × 2), the flexible piping (i.e., 1.0 kg) and the accelerometer (i.e., 0.2 kg × 2) were used as input in the calculation model. The conditions of the fixed points were rigid at 82 N/mm^2 for similarity in the experiment.

Table3 Material condition of calculation model

Material	Diameter outside [mm]	Thick [mm]	Vertical elastic modulus E[N/mm^2]	Elastic modulus (circumferential direction) E[N/mm^2]	Shear elastic modulus E[N/mm^2]	Density [kg/m^3]	Poisson's ratio
Branch pipe	34	3.2	0.2032×10^6	0.2032×10^6	0.0782×10^6	7850	0.3
Hanger bolt	7.9	3.95	0.203	0.2032	0.09	7135	0.3

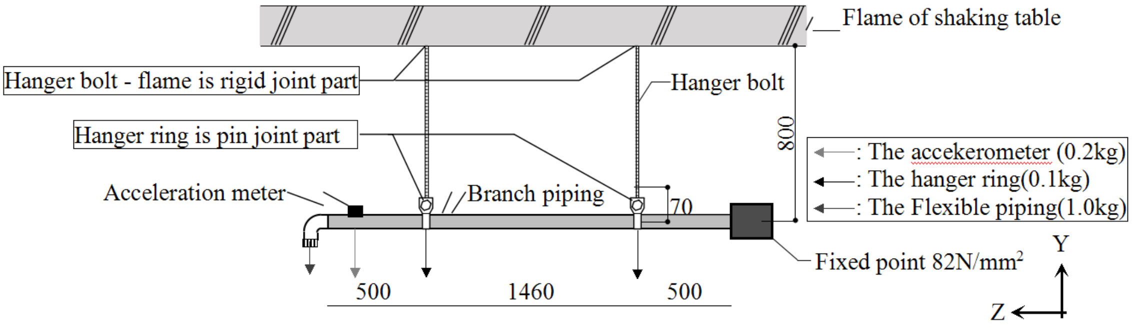


Figure13 Model of test materials (unit mm)

Comparison of numerical analysis and test results

Figure 14 shows the comparison of the response displacement in the experimental results and that in the numerical analysis for a random wave of a Tokyo inland earthquake. The figure confirms the validity of the shaking table test and numerical analysis in random wave. Displacement of the numerical analysis is based on response displacement of 56.9 mm with the addition of 1 G in the calculation model that was calculated by the linear analysis of the response acceleration in shaking table test. The maximum displacement of the numerical analysis was approximately 111 mm that is roughly equivalent to the calculation result and maximum relative displacement of approximately 109 mm, which was measured by the shaking table test. The time difference between the maximum values was calculated; however, only a roughly similar waveform was observed in the behavior of the sprinkler piping.

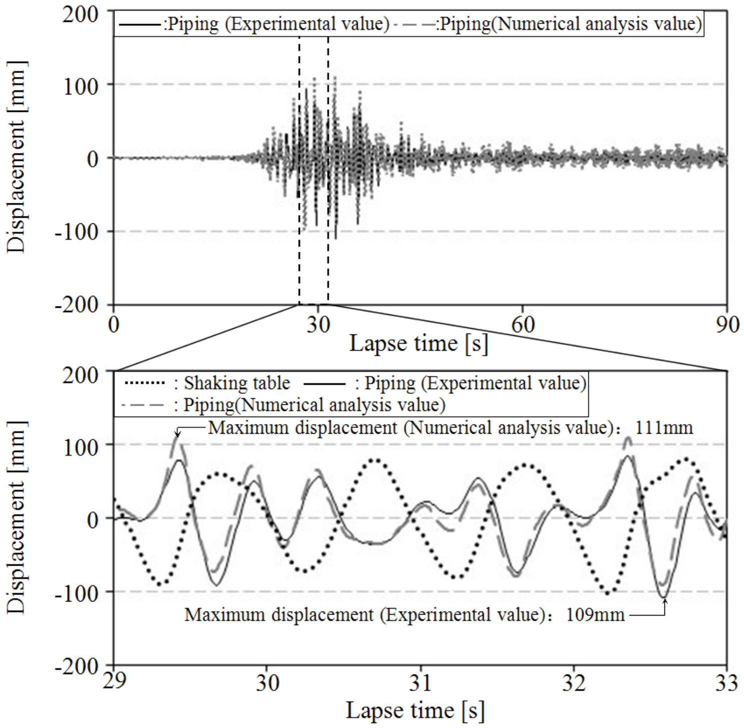


Figure14 Comparison of respose displacement caused by the experimental results and the numerical analysis in random wave(Tokyo Inland Earthquake)

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Comparison of Design Methods for Water Supply Pipework: a Case Study Analysis

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Abstract

Recent years have seen an emergence, internationally, of different methods for the assessment of simultaneous flows for the design of domestic hot and cold water systems for buildings. However, in the UK, the Loading Unit methodology continues to underpin design standards and guidelines. The evolution of these UK-based codes has meant that transparency has eroded, and correspondingly, so too the degree to which discretion and judgement may be exercised by the design engineer. At the same time, it is clear that the types of appliances integrated within buildings and the user-behaviours that determine demand patterns and ‘level of serviceability’ expectations have also changed significantly. As a result, there is growing, and compelling, evidence that the current methodology results in oversizing of networks and ancillary equipment.

Using a case study building, this paper presents a comparison of two standards used within a UK setting. It confirms previous research that illustrates the perceived over-prediction of design flow rate by BS6700 relative to BSEN806.

Keywords

Water supply, sizing methods, Loading Units, water conservation

1. Introduction

The need to accurately represent the use of water within a building is a topic that has been much discussed at CIBW062 symposia. Establishing a model that is both sufficiently adaptable and readily workable has presented a challenge for researchers and design engineers over many years. Recently within the UK, there has been a particular focus on this topic, as there is a growing body of evidence that suggests that current methods of sizing domestic hot and cold water pipework and ancillary equipment are resulting in increasingly problematic examples of over-sizing.

In the UK, the sizing of domestic hot and cold water systems is based on a traditional Loading Units methodology. This approach allows for an assessment of the simultaneous flows that form the basis for the design of all hot and cold water pipework and for specifying the design duty of pumps and pump motors, as well as for related ancillary equipment. This approach has been in place, and has been commonly adopted, for a number of decades. The methodology is underpinned by a statistical approach based on predicted usage patterns that is aligned with a corresponding level of serviceability (ie where the actual load will exceed the design load) commonly accepted as 1%.

In the UK, the designer is referred to the harmonised EU standard BSEN806 Part 3[1], a document that essentially supersedes the previously used BS6700[2]. Section 2 of this paper outlines the methods adopted by these two standards and also makes reference to other design guidelines commonly recognised across the sector. As noted above however, there is a growing awareness that these codified documents yield differing and often diverging results, specifically when applied to larger buildings.

The following text outlines the comparisons enabled by use of both BSEN806 and BS6700 using a case study building.

2. Design Standards

BSEN 806: 3: 2000 presents what is referred to as a ‘simplified method’ for pipe sizing, but also notes that ‘the designer is free to use BS6700:1997’ (both apply to both hot and cold water distribution pipes). BSEN 806:3 clearly ‘defines’ one Loading Unit as being equivalent to a draw-off flow rate of 0.1l/sec, and uses a design flow-rate for which ‘probable simultaneous demand has been taken into consideration’. It also presents a table of loading units for the most commonly-used domestic appliances. This ‘simplified method’ of pipe sizing is often observed as one for which there has been a loss in transparency, in that the underpinning theory has become subsumed, making adaptability in response to new appliances and approaches somewhat challenging. BS8558:2011[3] (a replacement for BS 6700), described as complementary guidance to BSEN 806 does little to enhance this transparency. The general consensus from designers and engineers appears to be that the approach yields generally accurate pipe sizing results other than when the Loading Unit value is less than 15. In addition, this standard is limited in its conversion to an upper threshold of only 9 litres per second.

BS 6700:2006 is a British Standard that is no longer current but that is still used by engineers and is cited by both BSEN 806 and the Building Regulations. It similarly allocates Loading Units to appliances but instead maps the total for the pipe to simultaneous demand in litres per second. This approach is clearly more transparent than that presented in BSEN 806 however it is believed that the calculation of flow-rate frequently results in over-sized distribution pipes.

There are a further two documents that may be referred to by the design engineer. These are CIPHE's Design Guide4 and CIBSE's Guide G5; two documents that are similar in that they both explain the basics of probability theory and present a graph for the probability factor for multiple appliances being used at any given time. They also present a table of simultaneous demand figures that link appliances with Loading Units based on capacity, flow-rate and demand (cast as 'low', 'medium' and 'high'). Although more detailed in terms of presentation, it seems that there is still some concern about using CIPHE's Design Guide where modified Loading Units values are relevant.

3. Statistical Basis

Each of the methods of pipe sizing presented in the documents outlined above relies upon a statistical approach. Underpinning this is the fact that the probability of a single appliance being in use at any given time is given by :

$$p = \frac{t}{T} \tag{1}$$

where t is the 'fill time' and T the interval between uses. The probability of two appliances of a given type being in use simultaneously is given by p^2 (and for three, p^3 and so on).

To allow for combinations of appliances, the binomial theorem is applied:

$$P = c_r^n p^r (1-p)^{n-r} \tag{2}$$

where P is the probability of any number of appliances, 'r', from a total of 'n' of the same appliance type, being in use. $c_r^n = \frac{n!}{r!}(n-r)!$ denotes the number of combinations of 'n' appliances taken 'r' at a time.

It can be seen that applying a 1% exceedance 'level of service' (where the actual load will exceed the design load) to this equation means that the design point may hence be represented as:

$$\sum_{r=r}^{r=n} c_r^n p^r (1-p)^{n-r} = 0.01 \tag{3}$$

The limitations in application of the equations above are evident in that they refer only to appliances of the same type. It was for this reason that Loading Units were first introduced and persist today. By introducing a factor that is representative of the propensity of an appliance to introduce load, pipework design may encompass a far wider range of appliances typically found as part of the distribution network. For the time being, this loading unit approach has negated the need for the introduction of a more robust statistical representation that is based on a generalised binomial or multinomial distribution.

What is clear from this brief overview is that although the methods outlined in relevant literature and guidance documents yield a 'broadly suitable' range of pipe-sizing techniques, none provide a definitive approach.

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[1] CIPHE Chartered Institute of Plumbing and Heating Engineering

[2] CIBSE Chartered Institution of Building Services Engineers

4. Case Study Application

The building used in this case study example is a central London office block, with 16 above-ground storeys and 3 below-ground. The footprint of the building is broadly as shown in Figure 1, with unshaded areas representing open-plan office space, and shaded areas indicating those where most of the sanitary amenities are provided. Water services are provided mainly for toilet blocks and for janitors' closets, as well as for individual disabled toilet facilities.

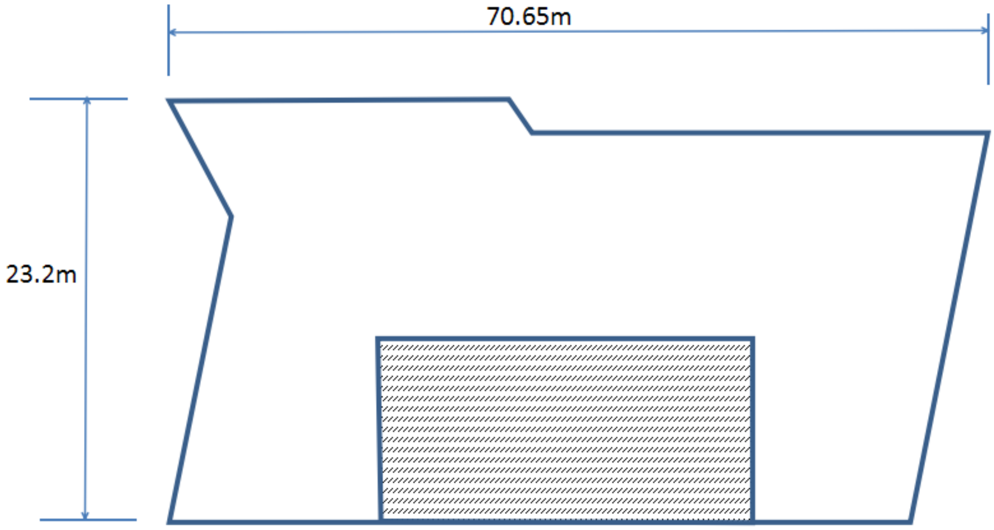

Figure 1: Approximate footprint for the case study building (shaded areas show central sanitary amenities)

Table 1 Summary of above-ground sanitary appliances

	Toilet Block (M)	Toilet Block (F)	Ind. Toilet	Disabled Toilet	Janitor's Closet	Points for future expansion
Floor 16	0	0	2	1	1	1
Floor 15	1	1	0	2	1	3
Floor 14	1	1	0	1	1	3
Floor 13	1	1	0	1	1	3
Floor 12	1	1	0	1	1	3
Floor 11	1	1	0	1	1	3
Floor 10	1	1	0	2	1	2
Floor 9	1	1	0	2	2	2
Floor 8	1	1	0	2	1	2
Floor 7	1	1	0	2	2	2
Floor 6	1	1	0	2	2	2
Floor 5	1	1	0	2	2	2
Floor 4	1	1	0	2	2	2
Floor 3	1	1	0	2	2	2
Floor 2	1	1	0	2	2	2
Floor 1	1	1	0	2	2	2
Ground	0	0	1	0	0	2

Table 2 Summary of above-ground sanitary appliances

Level	Description of sanitary appliances
-1	Small miscellaneous
-2	Miscellaneous: reception room, storeroom, workshop, disabled shower, 24 showers, two single toilets,
-3	No water services

Additionally, one of the below-ground levels introduces a 'welfare' provision for office workers (allowing for, for example, bicycle storage and locker space) and hence includes a number of showers (in addition to two toilets). Broadly speaking, the provision on each of the upper levels is similar (although there are some minor differences in layout where necessary).

Table 1 presents a summary of the sanitary appliances connected on each of the above-ground floors, and Table 2, those for all below-ground levels. Importantly, it should be noted that a greywater system is provided and that this serves the w.c.'s and urinals throughout the building. Additionally, the provision of cold mains and grey water is accommodated through the integration of six main risers (three for each). All pipework, both mains and greywater, is copper.

Other than the services already specified, the building includes capacity for expansion through the provision of take-off points for future tenants. All of these were noted as having a Loading Unit attribution of 8 based on the assumption that they serve of a small kitchenette area (encompassing a wash-hand basin, a sink and a dishwasher, as well as a drinks machine and coffee machine (defined through a special fittings allowance).

Table 3 illustrates the differences in attribution of Loading Units when using both BSEN806 and BS6700.

Table 3 Attribution of loading Units for BSEN806 and BS6700

	6700		806	
Outlet	LU	Max flow rate	LU	Max flow rate
Basin	1.5	0.15	1	0.1
Basin (Public)	3	0.15	2	0.2
Basin (Peak)	-	0.15	-	0.15
Spray tap	-	0.04	-	0.04
Bath	10	0.3	4	0.4
Bath 28mm	22	0.6	8	0.8
Bath (Peak)	-	0.6	-	0.6
Sink 15mm	3	0.2	2	0.2
Sink 22mm	5	0.3	2	0.2
Sink 28mm	5	0.6	8	0.8
Sink (Peak)	-	0.6	-	0.6
shower nozzle	3	0.1	2	0.2
shower (peak)	-	0.1	-	0.1
shower rose	-	0.4	-	0.4
Bidet	1.5	0.15	1	0.1
Dishwasher	3	0.2	2	0.2
Washing machine	3	0.2	2	0.2
urinal stall	-	0	3	0.3
wc	2	0.1	1	0.1
wc (peak)	-	0.1	-	0.1
special	user inputs information		user inputs information	

The differences in attribution are evident from this table, particularly for basins, baths and, to an extent, for w.c.'s. It can also been seen that, in general, BS6700 attributes a higher loading than BSEN806. It will be appreciated that for small buildings, including single individual dwellings, these differences are not particularly significant. Indeed, they may be deemed to be insignificant in terms of mains pipe sizing. However, when designing for a larger building of the scale noted herein, in can be seen that the cumulative difference could be substantial.

For the office block under consideration, it was calculated that the total loading units for each system, and using both BSEN806 and BS6700, are as shown in Table 4.

Table 4Total Loading Units

Supply (Total LUs)	BS6700	Design Flow (l/s)	BSEN806	Design Flow (l/s)
Mains	1058	7	772	3
Greywater	633	4.8	272	1.7

Figure 2 and 3 represent the differences broken down by riser for the mains cold water and the greywater supply respectively.

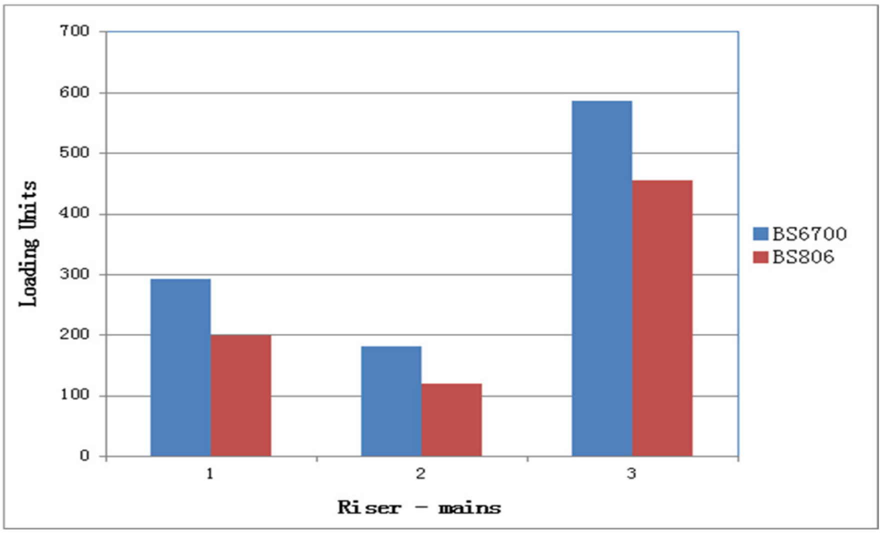

Figure 2: Comparison of Cumulative Loading Unit attribution by riser (mains cold water)

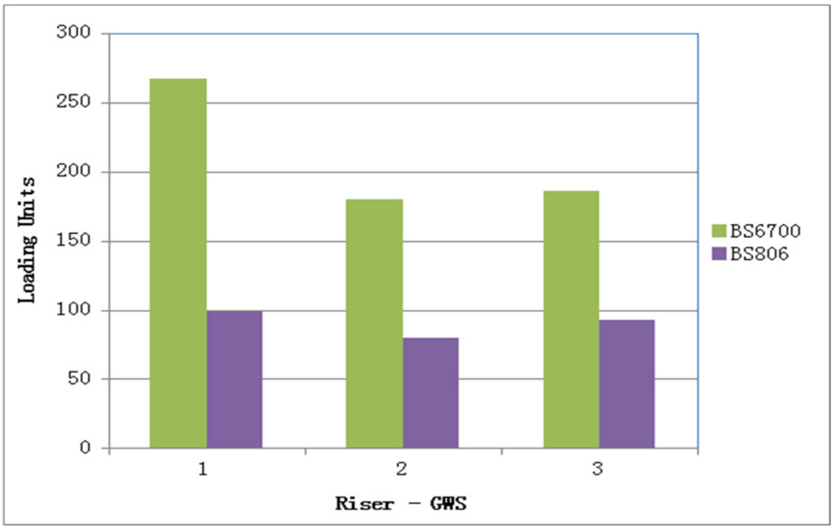

Figure 3: Comparison of Cumulative Loading Unit attribution by riser (greywater)

5. Discussion

These two figures show the cumulative effect of the difference in Loading Unit allocation across an office building of this size. It is worth noting from Figure 2 that that, although riser 3 appears to bear much of the cold water load for the building, this is due principally to the attribution of the welfare area shower block. As anticipated, the cumulative attribution of Loading Units is notably lower when BSEN806 is used. However, Figure 3 shows a more pronounced difference due to the relative imbalance of loading unit allocation for the w.c. fittings. The corresponding difference in design flow rate has a knock-on and potentially significant impact upon pipe sizing, particularly for the incoming mains and any booster pump sets. It can be seen that pipe sizing also influences cost, space-take, energy loads and heat loss associated with the design of hot and cold water distribution pipework. Additionally, it has been highlighted by Agudelo-Vera et al[6] that oversizing in this way introduces risk in terms of water quality, health and hygiene.

Although the case study discussed herein represents an existing building, it has been necessary at various points in the process to make assumptions about provisions where specific details have not been available. For this reason, it is important that the data and results presented herein are not interpreted as a wholly accurate representation of this building; rather they provide an indication of the typical loading requirements for the purposes of comparing each of the two codified documents discussed.

It should also be stressed that these finding are not necessarily 'new' in that there has been a growing awareness amongst engineers within the UK that both BS6700 and BSEN806 yield design flow rates that exceed the actual, or any measured, rate. Indeed a useful comparison was established between these two standards and the CIPHE Design Guide[4] by Tindall and Pendle[7] who compared these three codified documents with measured results from two blocks of flats in the North-East of England and found that measured flow rates were, on average, only 20% of those calculated.

Although this CIBW062 paper has reinforced the 'over-sizing' message and has done so using an up-to-date office building, the main purpose is to highlight the pressing need for action and for a new approach. The issue of aligning design methods for pipe and pump sizing with the correct loading attributes for a building has been a long-standing concern of CIBW062. In particular, research groups from Hong Kong, Brazil and the Netherlands have tackled the issue, with research spanning connected load models[8], the application of fuzzy logic[9], and use of the Monte-Carlo method of simulation[10,11]. Reflecting on this research and the growing awareness in the UK of the projected oversizing introduced by current codified documents, the LUNA (Loading Units Normalisation Assessment) group has been established. This joint CIPHE & CIBSE project group, established initially as a group of like-minded engineers who recognised the shortcomings of the Loading Units methodology and who sought solutions to address the problem, are now working with Heriot-Watt University to produce recommendations for a new UK methodology.

6. References

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7. Presentation of Authors

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The Experiment on Earthquake−proof Performance of Stainless Steel Piping with Pipe Fitting of the Mechanical Type for Water Supply

Part 3 Relative−story Displacement Oscillation Experiments with Various Piping Diameters and Supports

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Abstract

This report shows the results of a relative-story displacement oscillation test conducted on vertical piping using thin-walled stainless steel pipes. The main purpose of this experiment is to investigate the influence of relative-story displacement oscillation on the vertical pipes with various diameters and supporting methods.

In the previous research, the relative-story displacement oscillation test conducted on a vertical piping using thin-walled stainless steel pipes was reported, whereas no report on the piping that have various diameters and supporting methods.

The shaking table test was conducted for pipes combined 14 kinds of vertical pipings and 2 kinds of piping support methods.

In the case of simply supported, displacement of a small-sized piping with branch increased. The displacement of the vertical pipe without fitting is almost the same as the piping without branch piping. In addition, displacements of the fitting of the pipe was amplified , and large response displacement of the branch pipe connecting to the vertical pipe also occurred.

It is apt to occure vibration when a small-sized piping is simply supported, which is close to actual constructional supporting. For this case, it needs consideration taking such measure as narraw supporting distance.In actual buildings, a vertical pipes without branch are used in many cases, where the simply support is commonly used. In addition, because response displacement of the branch pipe also occurs, it is nesesarry to choose the fitting that withstand the large repeated displacement between the vertical pipe and the branch.

Keywords

Water supply equipment; Stainless steel piping; Pipe fitting of mechanical type; Relative-story displacement;Support method.

1. Introduction

In Japan, there is a custom to directly drink tap water. Therefore, special attention is paid to ensure the safety, hygiene, and earthquake-proof performance of building equipment plumbing for water supply piping and interior piping. There are many buildings with piping system using stainless steel, in particular, in hospitals, hotels, and public buildings.

The stainless steel piping system, comprising thin-walled stainless steel pipes with a thickness of 1–2 mm, as prescribed in JIS G3448, have been widely used because of their workability. Mechanical-type pipe fittings designed particularly using thin-walled stainless steel pipes are used in many construction sites.

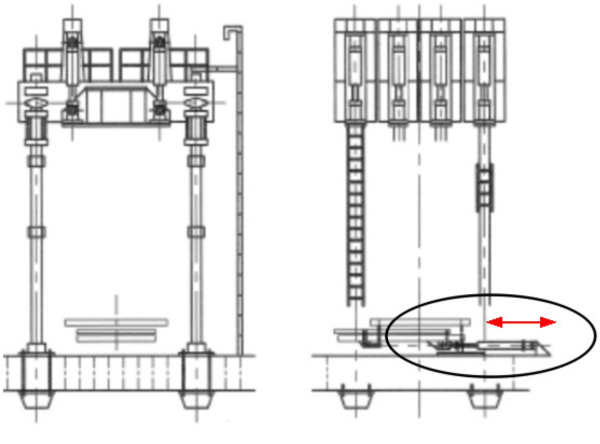
As reported in the previous study [1], the relative-story displacement shaking experiment of vertical piping using thin-walled stainless steel pipe demonstrated the good earthquake-proof performance. However, findings regarding the different diameter and the support were not evaluated. The earthquake-proof design and construction guideline for building equipment [2] states that the story drift angle shall be 1/100 or smaller, and thus, it is required to investigate the effect of seismic shaking on full-scale piping.

In this study, a relative-story displacement shaking test of piping systems was performed, where two types of piping supporting methods were combined with 14 vertical pipes. The piping systems were subjected to shaking at 1/50, which was two times that of the reference story drift angle. We describe the measurements obtained from the relative-story displacement oscillation test such as the displacement response magnification factor and the effect of piping.

2. Seismic Device, Test Piping and Details of Experiments

2.1 Seismic device and test piping

The experiment was performed using a shaking equipment placed on a seismic isolation table, as reported in a previous study [1]. As shown in Figure 1, the shaking equipment comprised a shaking table and the shaking machine, which is a 250 kN hydraulic device with 800 mm stroke (Model/Type 244.31 SLVDT) made by MTS Systems Corporation in the United States (Figure 1). The length between the upper and lower support of the stainless steel vertical piping was 2,800 mm, as shown in Figures 2 and 3.

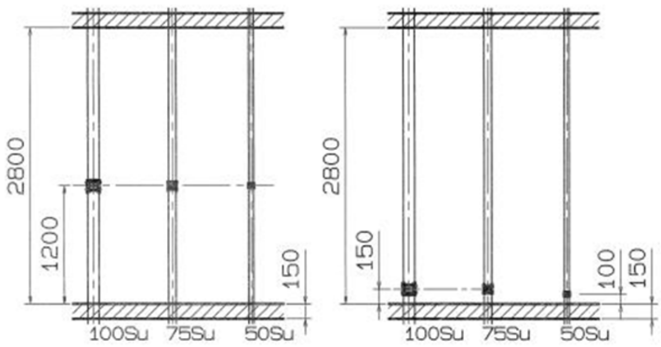


(a)Front view (b) Side view

Figure 1- Shaking equipment (shaking table and shaking machine)

Four configurations of test piping were prepared as follows: 1) Vertical piping with a pipe fitting at 1,200 mm from the shaking table (Figure 2 (a)); 2) Vertical piping with pipe fittings at 150 mm (100 and 75 Su) and 100 mm (50 Su) from the shaking table (Figure 2 (b)); 3) Vertical piping with branch pipes; and 4) Vertical piping with no fitting.

The sockets of the mechanical stainless steel pipe fittings and reducing tees (three sizes of 50, 75, and 100 Su) were used to connect the vertical piping, and 90° elbows and ball valves (two sizes of 20 and 50 Su) were used in the branch pipes. The shape and dimensions of each configuration are shown in Figures 2 and 3, and the setup is shown in Figure 4. Water with a pressure of 2.0 MPa was sealed in the test piping and pressure fluctuations were checked. Furthermore, water leakage was visually inspected during test.
The mechanical stainless steel pipe fittings used in the experiments are shown in Figure 5.



(a) (b)
Figure 2- Vertical piping

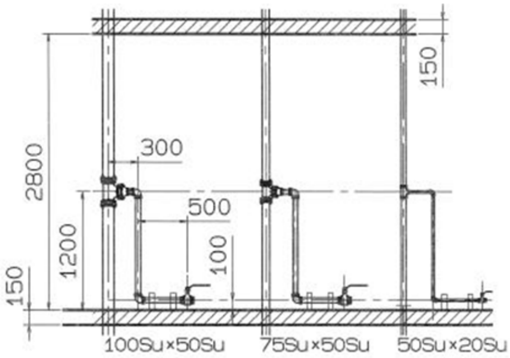


Figure 3- Vertical piping with branch piping

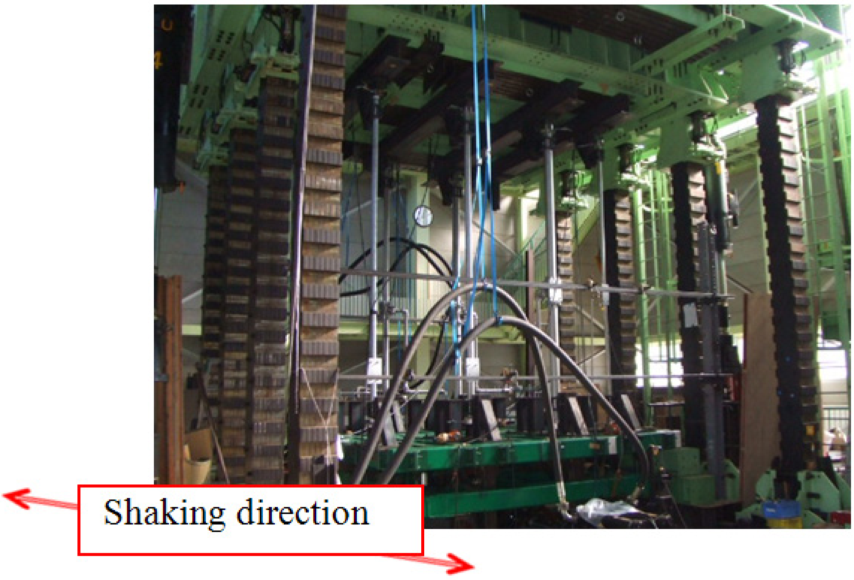


Figure 4- Photograph of shaking equipment and installation

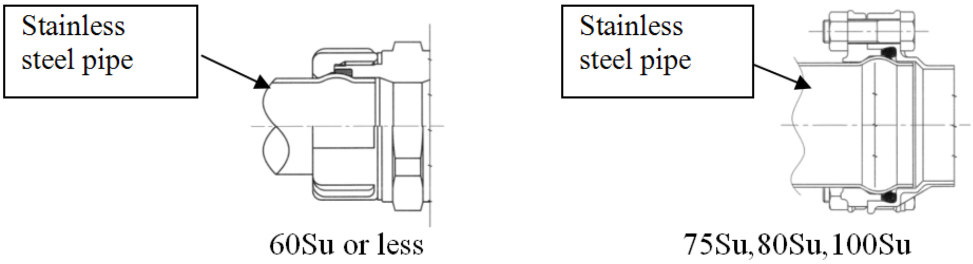


Figure 5- Structure of mechanical-type pipe fitting

In the experiment, the upper end of the test piping was secured to the fixed frame and the lower end was anchored to the shaking table. Two support methods were adopted.

In the first method, the upper and lower ends of the piping were securely fixed. In the second method, a simple support was used, which is close to the actual piping support used in most buildings. The two support methods are shown in Figure 6. In the fixed support, the support width was 150 mm to simulate the actual thickness of the building floor and the piping was fixed to the shaking table. In the simple support, the piping was fastened with a U-bolt at the upper and lower ends, and a roller was placed between the lower end of the test piping and the shaking table; thus, the entire structure could move flexibly in the direction of shaking.

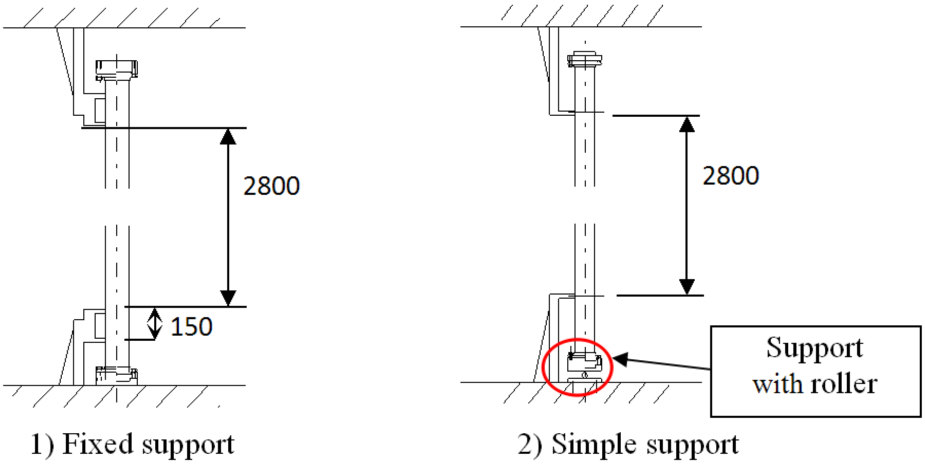


Figure 6- Support method

The outline and specimen numbers of test piping are shown in Figure 7. Test numbers were assigned on the basis of the combinations of piping and support method (Table 1).

Figure 7 (a) shows specimen 1, which is vertical piping without branch pipes, and the pipe fitting placed at 1,200 mm from the shaking table. Figure 7 (b) shows specimen 2, which is vertical piping without branch pipes, and the pipe fitting placed at 150 mm (100 and 75 Su) or 100 mm (50 Su) from the shaking table. Figure 7 (c) shows specimen 3, which is vertical piping with branch pipes, and seismic waves applied perpendicular to the branch pipes. Figure 7 (d) shows specimen 4, which is a vertical piping with branch pipes, and seismic waves applied parallel to the branch pipes.

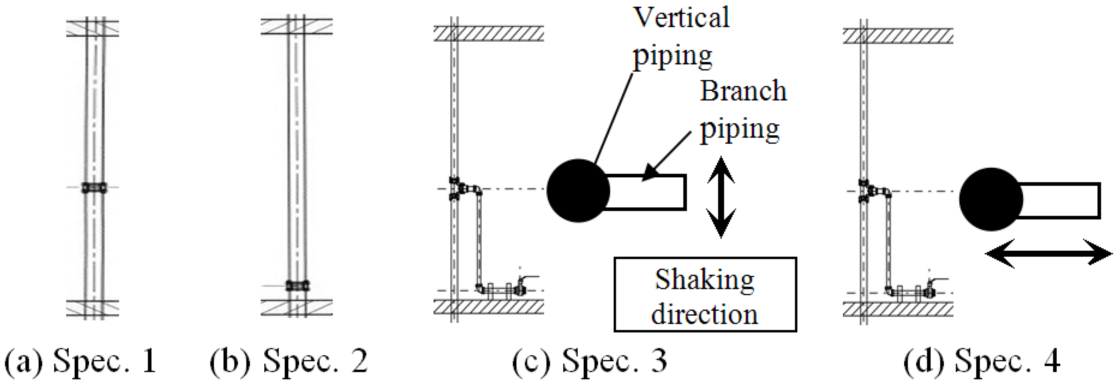


Figure 7- Outline and specimen number of test piping

Specimens 1–4 in Figure 7 show test piping, where the vertical pipes are connected with the pipe fitting. In addition to these specimens, specimen 5 was prepared which does not have any pipe fittings as one straight pipe. This was used as reference for specimen 1. As already reported in a previous study [1], the support of specimen 5 is not fixed because fixed support may subject the specimen to plastic deformation.

The reflecting plates of the laser displacement meter described in a previous study [1] were attached to the sockets and reducing tees of the vertical piping. Moreover, reflecting plates and an accelerometer were attached to the shaking table to measure acceleration and displacement. Similar to specimen 1, the displacement of specimen 5 was measured at 1,200 mm from the shaking table.

Table 1 Test number

Specimen number	Vert. piping dia. [Su]	Supporting method and test number	
		Fixed support	Simple support
Spec. 1	100	1-F-100	1-S-100
	75	1 -F -75	1 -S -75
	50	1 -F -50	1 -S -50
Spec. 2	100	2-F-100	2-S-100
	75	2 -F -75	2 -S -75
	50	2 -F -50	2 -S -50
Spec. 3	100	3-F-100	3-S-100
	75	3 -F -75	3 -S -75
	50	3 -F -50	3 -S -50
Spec. 4	100	4-F-100	4-S-100
	75	4 -F -75	4 -S -75
	50	4 -F -50	4 -S -50
Spec. 5	100	-------	5 -S-100
	50	--------	5 -S -50

The measuring instruments were a small, low-capacity, tri-axial accelerometer (Tokyo Sokki Kenkyujo Co., Ltd., ARF-100A-T) and a diffuse-reflection type laser displacement meter (OPTEX FA CO., Ltd., CD5 series). Figure 8 shows the positions of the shaking table and specimens, as observed from above, and the direction of the applied seismic waves. Figure 8 (a) shows the position and layout of the vertical piping and shaking table, and Figure 8 (b) shows the position and layout of the shaking table and vertical piping with branch pipes.

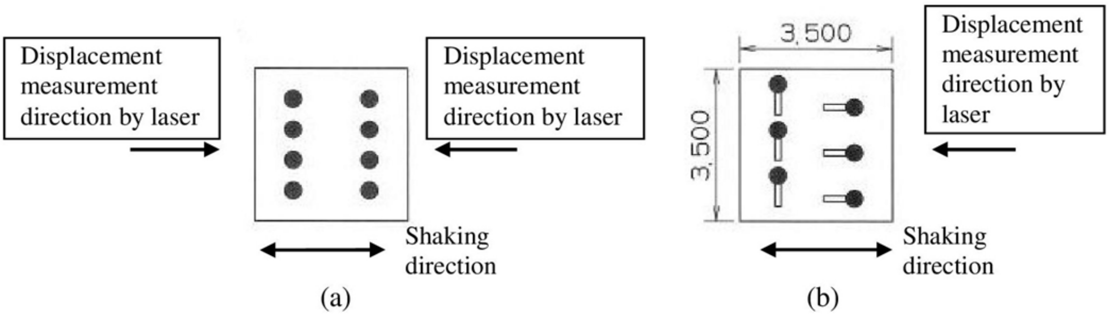


Figure 8- Positional relationship of shaking table and specimen, and the direction of shaking

2.2 Details of experiments

The details of the shaking experiment and the shaking model are shown in Figure 9.

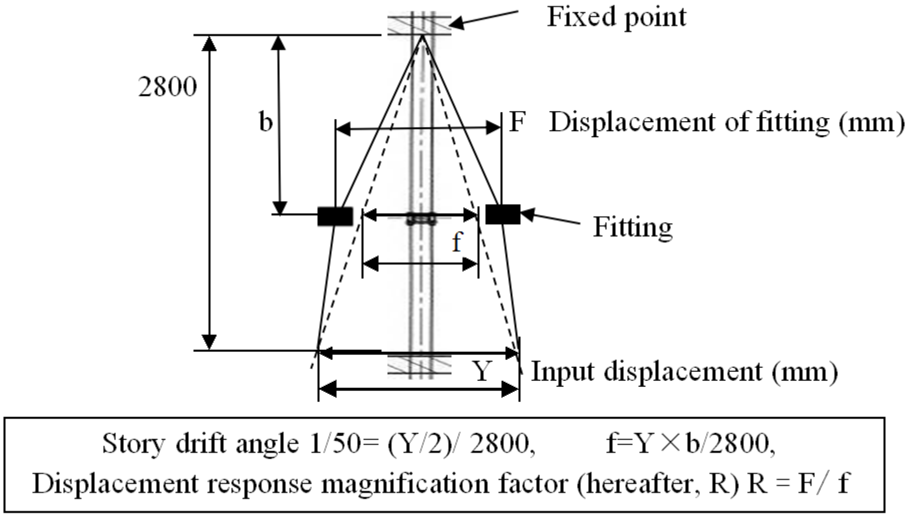
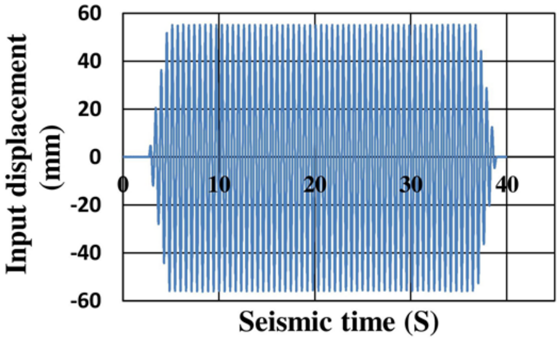


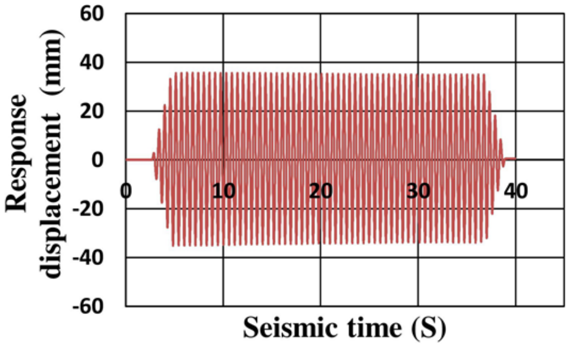
Figure 9- Seismic model of piping and relationship of displacement

Input acceleration of 900 and 1,000 gal was applied for 30 s to the shaking table. The piping was displaced by 56 mm (single-side displacement = Y/2) to attain the story drift angle of 1/50 (0.02 rad). The pipe fitting (section) displacement of the vertical piping was measured and checked for irregularities, and water leakage from the piping.

As shown in Figure 9, the lower end of the stainless steel vertical piping was shaken with input displacement of Y (i.e., +/− Y/2 from the vertical line) and the displacement (F) of the pipe fitting section was measured. The displacement response magnification factor at the vertical piping fitting section was obtained by dividing the displacement (F) of the pipe fitting measured during the experiment with the pipe fitting displacement (f), which calculated from the triangle whose base was the input displacement (Y) and height was the length of vertical piping.

The measured input displacement and pipe fitting displacement are shown in Figures 10 and 11, respectively. The test number of these measurements was 1-F-100.





Test number 1-F-100

Figure 10-Input displacement Y **Figure 11-Displacement of fitting F**

As it can be seen from these two figures, the measured displacements are stable; thus, we use the average of the peak displacements as the displacement.

3 Results and Considerations

The results of the shaking experiments and relative-story displacement data for each test specimen are shown in Table 2, Table 3 and Figures 12–16.

3.1 Fixed support method

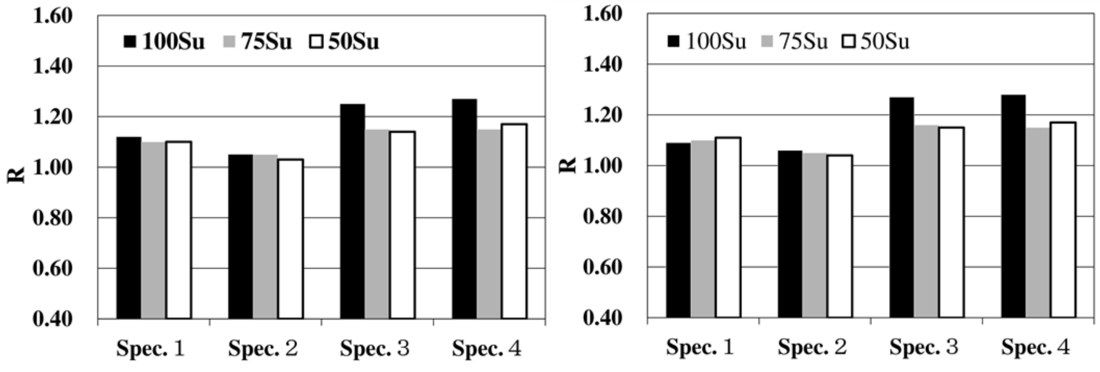
The data in Table 2 show the case of the fixed support of the piping. The story drift angle is 0.019–0.021 rad. As it can be seen from Figures 12, the difference in the displacement response magnification factor for acceleration between 900 gal and 1,000 gal is insignificant. The displacement response of specimen 2 which connected to the pipe fitting near the lower support on the shaking table is lower than that of the other specimens.

The comparison of the factors of specimens 1, 3, and 4, connected at 1,200 mm from the lower support, suggests that in the case of specimen 1 without branch pipes, the displacement response is only slightly different among these different diameters. In the case of specimens 3 and 4 with branch pipes, the displacement response changes only slightly with shaking direction but the displacement response of large diameter piping (100 Su) is larger than that of the other diameter pipings (75 and 50 Su). This implies that the larger the diameter is, the more susceptible to the relative-story displacement the displacement response is.

Table 2 Displacement response magnification factor(R) of fixed support

	Vert. piping dia. (Su)	Test number	Acceleration							
			900gal				1000gal			
			Y (mm)	f (mm)	F (mm)	R	Y (mm)	f (mm)	F (mm)	R
Spec. 1	100	1-F-100	111.2	63.5	71.0	1.12	108.8	62.2	67.8	1.09
	75	1- F -75	111.2	63.5	69.6	1.10	108.8	62.2	68.6	1.10
	50	1- F -50	111.2	63.5	70.0	1.10	108.8	62.2	68.8	1.11
Spec. 2	100	2-F-100	111.2	105.2	110.0	1.05	108.8	103	108.8	1.06
	75	2- F -75	115.6	109.4	114.4	1.05	112.6	106.6	112.2	1.05
	50	2- F -50	111.2	107.2	110.8	1.03	108.8	104.9	109.0	1.04
Spec. 3	100	3-F-100	115.6	66.1	82.4	1.25	112.6	64.3	81.4	1.27
	75	3- F -75	115.6	66.1	75.8	1.15	112.6	64.3	74.6	1.16
	50	3- F -50	115.6	66.1	75.0	1.14	112.6	64.3	74.2	1.15
Spec. 4	100	4-F-100	115.6	66.1	83.6	1.27	112.6	64.3	82.4	1.28
	75	4- F -75	111.2	63.5	72.8	1.15	108.8	62.2	71.6	1.15
	50	4- F -50	115.6	66.1	77.0	1.17	112.6	64.3	75.0	1.17

The displacement response magnification factor (R) for each specimen is graphically shown in Figures 12.



(a) 900gal (b) 1000gal

Figure 12- Fixed support displacement response magnification factor

3.2 Simple support method

The data in Table 3 suggest that for simple-support piping, the story drift angle ranges from 0.018 to 0.020 rad. As it can be seen from Figures 13, the difference in the displacement response magnification factor between the two large accelerations (900 gal vs. 1,000 gal) is also insignificant, as in the case for piping with fixed support. Similar to the case of the displacement response for fixed-support piping, specimen 2 with two pipes connected with the pipe fitting near the lower support on the shaking table has a smaller displacement response than that of the other specimens.

In the case of simple support, which simulates the actual piping support and is more realistic than the fixed support, the displacement response magnification factor of the small diameter piping tends to increase more than that of the large diameter piping. This trend in the displacement response differs from that of the fixed support. Furthermore, the increase in the displacement response is more pronounced in the piping with branch pipes. It is considered that the displacement response of the small diameter piping (specimen 4) is greatly affected by the shaking when it is applied parallel to the branch pipes because shaking on the branch pipes also applies force on the vertical piping. This is similar to the results of the resonance test reported in in the previous study [3].

Because the displacement response of specimen 5, with vertical piping that does not have pipe fittings, is similar to that of specimen 1. It is possible to construct vertical piping without fittings (i.e., specimen 5) using conventional and actual pipe support methods, which are similar to the simple support method discussed in this study.

Table 3 Displacement response magnification factor(R) of simple support

	Vert. piping dia. (Su)	Test number	Acceleration							
			900gal				1000gal			
			Y (mm)	f (mm)	F (mm)	R	Y (mm)	f (mm)	F (mm)	R
Spec. 1	100	1-S-100	111.4	63.7	66.4	1.04	109.4	62.5	65.2	1.04
	75	1 -S -75	111.4	63.7	67.8	1.07	109.4	62.5	67.6	1.08
	50	1 -S -50	111.4	63.7	68.2	1.07	109.4	62.5	68.2	1.09
Spec. 2	100	2-S-100	111.4	105.4	104.8	0.99	109.4	103.5	103.2	1.00
	75	2 -S -75	111.4	105.4	105.6	1.00	109.4	103.5	104.4	1.01
	50	2 -S -50	111.4	107.4	110.8	1.03	109.4	105.5	107.4	1.02
Spec. 3	100	3-S-100	104.4	59.7	63.2	1.06	102.6	58.6	64.8	1.11
	75	3 -S -75	104.4	59.7	70.4	1.18	102.6	58.6	68.4	1.17
	50	3 -S -50	104.4	59.7	70.6	1.18	102.6	58.6	72.8	1.24
Spec. 4	100	4-S-100	104.4	59.7	65.8	1.10	102.6	58.6	64.8	1.11
	75	4 -S -75	104.4	59.7	77.4	1.3	102.6	58.6	75.0	1.28
	50	4 -S -50	104.4	59.7	75.2	1.26	102.6	58.6	74.4	1.27
Spec. 5	100	5 -S-100	111.4	63.7	67.0	1.05	109.4	62.5	66.0	1.06
	50	5 -S -50	111.4	63.7	68.6	1.08	109.4	62.5	67.8	1.08

The displacement response magnification factor (R) for each specimen is graphically shown in Figures 13.

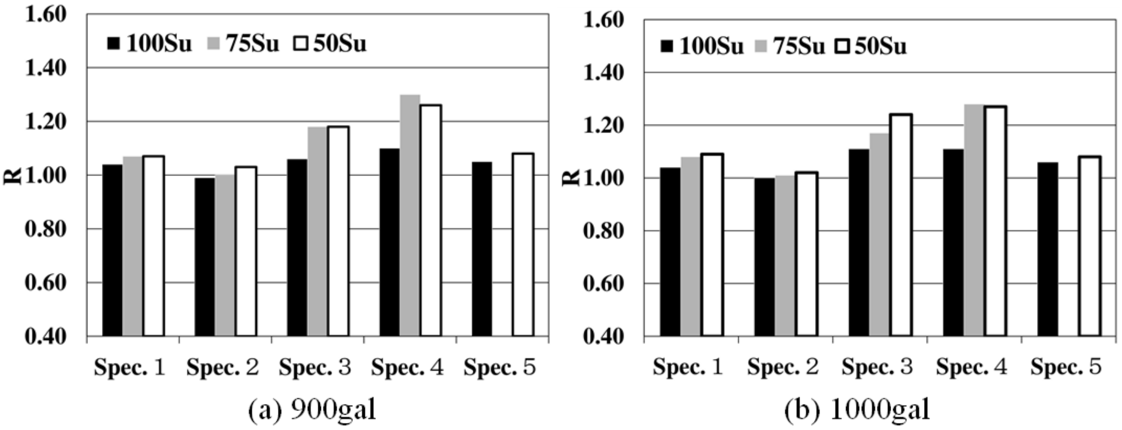


Figure 13- Simple support displacement response magnification factor

3.3 Response displacement of branch pipes

The input displacement (Y) is different from the displacement (F) at the branch pipe fitting section, as shown in the piping shaking model (Figure 9). The dotted lines in Figure 14 show the response displacement of branch pipes. To deal with this response displacement, mechanical-type pipe fittings is desirable.

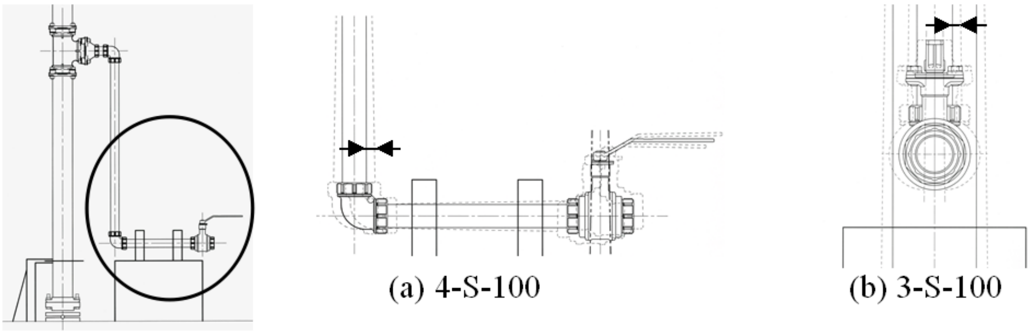


Figure 14- Response displacement on branch piping

3.4 Effect of shaking on pipe fitting and pipe

No water leakage was observed in the pipe fittings, pipes, and interfaces between the pipe fittings and pipes during and after the experiment, and the water pressure applied to the piping before the experiment was maintained to be constant after the experiment.

Examples of the specimen conditions after the experiment are shown in Figures 15 and 16.

Figure 15- 2-F-100

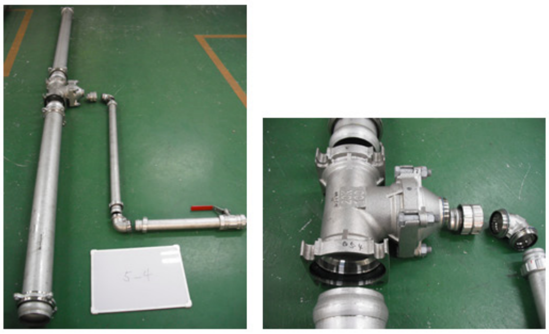


Figure 16- 4-S-100

After the experiment, there was no damage on the pipe fittings and piping that would degrade functions of the piping and all were in good condition.

4 Conclusions

1. The story drift angle of the test piping ranged from 0.018 to 0.021 rad.
2. The difference in the displacement response magnification factor for accelerations between 900 gal and 1,000 gal was insignificant because the accelerations were no so large.
3. The response displacement was observed on branch pipes connecting the pipe fitting on the vertical piping to the pipe fitting of the shaking table. Thus, it is necessary to use mechanical-type pipe fittings that can withstand the displacement on the interface between the pipe fittings and piping when the vertical piping is connected to the pipe fitting near the floor or the ceiling.
4. Fixed support method
4.1 In the case of vertical piping without branch pipes, the displacement response magnification factor changes only slightly among pipes with different diameter.
4.2 For vertical piping with branch pipes, the displacement response magnification factor changes slightly in shaking direction but that of the large diameter piping (100 Su) is larger than that of piping with different diameter piping (75 and 50 Su). This implies that the larger the diameter is, the more susceptible to the relative-story displacement the displacement response is.
5. Simple support method
5.1 In all specimens, the displacement response magnification factor of the small diameter piping tends to increase more than that of the large diameter piping. This increase in the displacement response magnification factor is more pronounced in the piping with branch pipes.
5.2 It is considered that the displacement response of the small diameter vertical piping is greatly affected by shaking when the shaking is applied parallel to the branch pipes. The shaking on the branch pipes applies forces on the vertical piping and increases the displacement. This resembles the resonance test results. To minimize the displacement, it is required to consider supporting the small diameter vertical piping with clamps placed at small intervals.
5.3 It may be said that it is appropriate to construct vertical piping without pipe fittings in the case of simple support.

Based on the observations for the simple support of vertical piping, it is possible to construct piping systems with support used commonly similar to simple support. The earthquake-proof performance of vertical piping systems can be secured by supporting the small-diameter vertical piping with clamps placed at small intervals and by adopting mechanical-type pipe fittings on the interface between vertical piping and pipe fittings near the floor and the ceiling.

6. No water leakage was observed on the test piping and the mechanical pipe fittings; furthermore, the deformation of the pipe at its supported section was negligibly small. By inspecting the piping after the completion of the test, no damage was seen that might affect the functions of the piping system.

5. References

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6. Presentation of Author

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Verification of Calculating Method using the Monte Carlo Method for Water Supply Demands: the Water Consumption of Mixed–use Building for Rent

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Abstract

In Japan, there are four methods of calculating water supply demands for office buildings based on SHASE-S 206 and two methods based on the design standard of MLIT. However, these methods were found to produce overestimated values when applied to recent sanitary fixtures with advanced water saving features. In order to cope with this problem, MSWC (Murakawa's Simulation for Water Consumption), which utilizes the Monte Carlo method to calculate water usage dynamically has been developed. In this study we evaluated the validity of MSWC on water consumption of an office building. Actual water consumption data were collected from an 11-story mixed-use building (mainly for office use). Water consumption estimates calculated by the six conventional methods and MSWC were compared with the actual measurement values. Though the calculations based on the conventional methods significantly deviated from the actual measurement values, those made by MSWC closely resembled them.

Keywords

Water supply load; calculating method; mixed-use building; Monte Carlo method

1 Introduction

In Japan, the design standard of MLIT [1)](referred to as the design standard below) and The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan Standard 206 [2)] (referred to as SHASE-S 206 below) have been used since the 1970s as water load calculation methods. However, there is a risk of overestimation if they are applied to modern sanitary fixtures with advanced water-saving features.

On the other hand, Murakawa et al. developed MSWC (Murakawa's Simulation for Water Consumption), a tool that enabled to dynamically calculate various water usages in buildings by applying them to probability models.

In this study we measured changes in daily water consumption and investigated the number of occupants in a mixed-use building. Then we compared actual daily water consumption (referred to as Q_{day} below) and peak flow rate of water supply (referred to as Q_{max} below) with values calculated by the existing methods and design standard to evaluate the validity of MSWC.

2 Outline of Measurement

2.1 Measurement of Water Consumption

2.1.1 Purpose

This part of the study was intended to measure water consumption in drainage system over time and obtain basic data for evaluating load calculation methods such as MSWC.

2.1.2 Outline of Drainage System

A 11-story building with a basement floor was used in this study. The outline of the building and its tenants are shown in Table 1 and Table 2.

Table 1 Outline of the building

Major use	tenant
Floor	11 floors aboveground 1 floor underground
Total floor space	15239.0m^2
Water supply system	gravity tank system
	increase-pressure water supply system

Table 2 Tenants of the building

Floor	Tenants
7~11	Company F
6	Bank E
5	Clinic D
4	Company C
3	University B
1~2	Bank A
B1	Restaurant

The water supply system diagram is shown in Figure 1. The floors from 1 to 9 were equipped with gravity tank systems, and 10th and 11th floors with increase-pressure water supply systems.

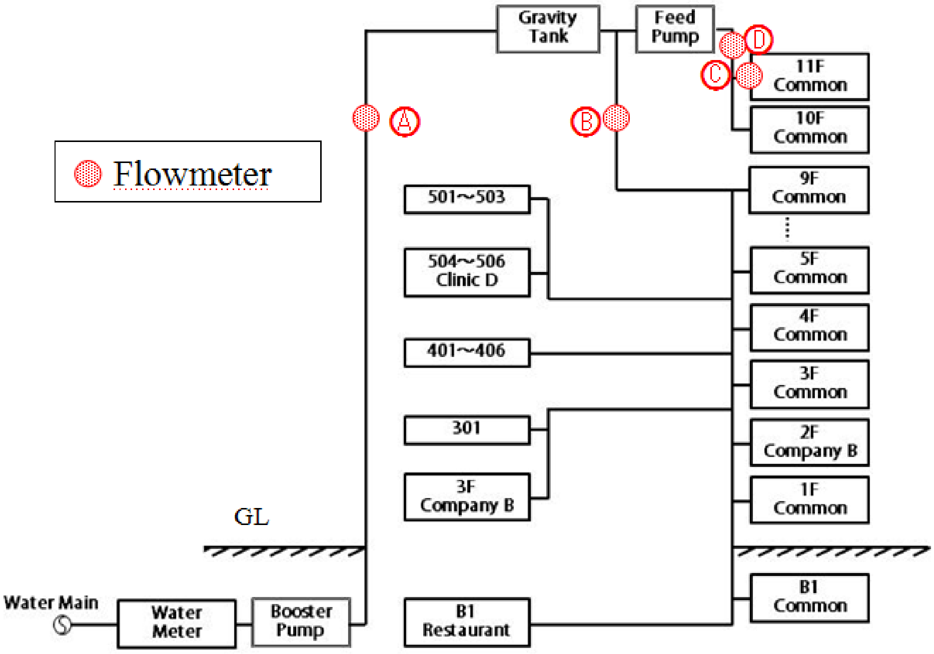


Figure 1 water supply system diagram

2.1.3 Method of measurement

Flowmeters were installed as shown in Figure 1. Four flowmeters were installed at the following locations: the lift pipe leading to the gravity tank systems (A), the supply pipes of B1 to the 9th floor (B), the supply pipes of the 11th and 10th (C) floors, and the horizontal branch on the 11th floor (D). Measurements were made at one-second interval from Sunday, September 27, 2014 to Sunday, October 5, 2014.

2.1.4 Results and Discussion

Daily water consumption data measured at the gravity tank, on the floors 1 to 9, on the floors 10 and 11, and on the floor 11 on weekdays are shown in Tables 3,4,5, and 6.

Table 3 Daily water consumption at the gravity tank

Classification	Period					Avg.
	9/29 (Mon.)	9/30 (Tue.)	10/1 (Wed.)	10/2 (Thu.)	10/3 (Fri.)	
Qday [L/day]	26,324	27,284	27,059	29,087	32,563	28,463

Table 4 Daily water consumption on the floors 1 to 9

Classification	Period					Avg.
	9/29 (Mon.)	9/30 (Tue.)	10/1 (Wed.)	10/2 (Thu.)	10/3 (Fri.)	
Qday[L/day]	19,155	20,040	19,598	18,568	20,940	19,660
Qmax[L/min]	74	104	76	94	79	85

Table 5 Daily water consumption on the floors 10 and 11

Classification	Period					Avg.
	9/29 (Mon.)	9/30 (Tue.)	10/1 (Wed.)	10/2 (Thu.)	10/3 (Fri.)	
Qday[L/day]	3,581	4,108	4,782	4,639	4,588	4,340
Qmax[L/min]	29	30	34	29	48	34

Table 6 Daily water consumption on the floors 11

Classification	Period					Avg.
	9/29 (Mon.)	9/30 (Tue.)	10/1 (Wed.)	10/2 (Thu.)	10/3 (Fri.)	
Qday[L/day]	2,504	2,700	2,385	2,691	2,229	2,502
Qmax[L/min]	21	19	16	20	19	21

Average daily water consumption (referred to as Q_{day} below) was 28,463 L/day at the gravity tank, 19,660 L/day on the floors 1 to 9, 4,340 L/day on the floors 10 and 11, and 2,502 L/day on the floor 11. Average peak water supply flow rate (referred to as Q_{max} below) was 85 L/min. on the floors 1 to 9, 34 L/min. on the floors 10 and 11, and 21 L/min. on the floor 11.

2.2 Number of Occupants

2.2.1 Purpose

The number of occupants on the 10th and 11th floor were counted to grasp the exact number of occupants.

2.2.2 Method of Counting

1. Occupants on the 10th and 11th floors

Burglar alarms were installed at the entrance doors to men's WCs for 9 days starting from Saturday, September 27 to Sunday, October 5 to count the number of times the doors were opened and closed.

2. Occupants in the whole building (OWB)

The number of people entering and leaving the building was counted at thirty-minute intervals by gender with a counter installed at the entrance to the building between 7:00 on Monday, September 29 and 18:00 on Tuesday, September 30. The number of people entering the building during 0:00 ~ 7:00 and 18:00 ~ 0:00 was regarded as 0.

2.2.3 Results and Discussion

1. Occupants on the 10th and 11th floors

One opening and closing of the door was counted as one "large flush" of the WC. The number of flushes and the frequency of use are shown in Table 7. The number of flushes H indicates the cumulated number of flushes for the five days. The number of flushes in men's WC can be active hours per person per day is 10 hours, it was changed

Table 7 The number of flushes and the frequency of use

Classification	The No. of flushes H		the frequency of use f [Times/Person・10h]
	10F	11F	
Male	582	592	1.11

Table 8 The number of male occupants

$$H_i = n \cdot N_i \cdot f_i \cdot x / 10$$

H: The number of flushes [Times]

n: Number of days

x: Active hours per time

i: Fixture type

N: Number of occupants

to 12 hours later. So $f^{3)}$ in Table 7 was corrected accordingly. The number of male occupants was obtained based on the formula in Table 8. The number of female occupants was calculated based on the male-to-female ratio of 7:3[1)4)]. As a result the number of male occupants on the 10th floor was calculated to be 88, on the 11th floor 89, and that of female was 38 on the both floors.

2. Occupants in the whole building

The changes in the number of occupants in the whole building every half an hour on September 30 are shown in Figure 2. As shown in Table 9, the maximum number of occupants on week days was 491 on Monday, September 29 and 603 on Tuesday, September 30. The male-to-female ratio of the maximum number was 5.6:4.4 on Monday, September 29 and 5.4:4.6 on Tuesday, September 30.

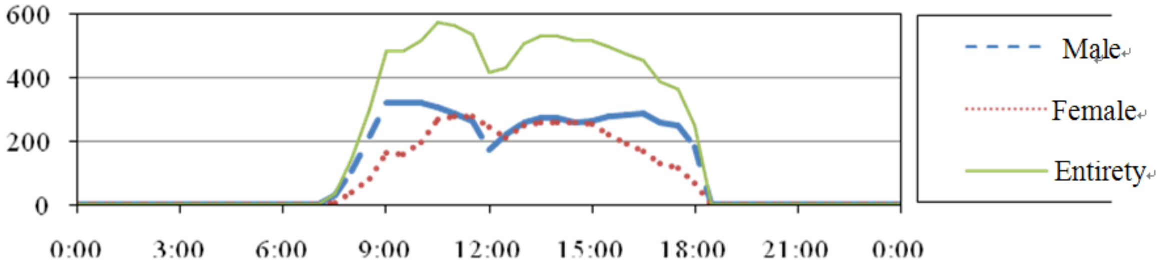


Figure 2 The changes in the number of occupants on Sep.30th.

Table 9 The number of occupants

Date	Male	Female	Entirety
9/29(Mon.)	277	214	491
9/30 (Tue.)	323	280	603

3. Calculation of Water Supply Demand Based on Conventional Method

3.1 Outline of Calculation Method

Type of conventional water supply demand calculation methods based on the design standard and SHASE-S 206 and their common names are shown in Table 10.

3.2 Results of Calculation

Q_{day} and Q_{max} for the whole building , BF 1 to F9 and F10/11 obtained by each calculation method are shown in Table 11. As SHASE-S 206 does not specify the calculation method for Q_{day}, Q_{max} only was calculated by this method.

Table 10 Conventional water load calculation methods

Calculation method		Abbr.	Possible calculated water supply demand
Facilities design criteria of MLIT[1)]	Calculation method based on personnel	PM	Q_{day} Q_{max}
	Calculation method based on sanitary fixture	FM	
SHASE-S 206[2)]	Calculation method based on Water use time rate and Fixture unit for water supply	WFM	Q_{max}
	Method based on newer water supply demand unit	NWM	
	prediction of fixture usage	PFM	
	Method based on water supply load unit of fixture	SLM	

Table 11 Results on the conventional methods

Water consumption		MLIT		SHASE-S 206			
		PM	FM	WFM	NWM	PFM	SLM
Whole building	Q_{day}[L/day]	150,000	73,680	-	-	-	-
	Q_{max}[L/min]	121200	60720	-	-	-	-
B1~9F	Q_{day}[L/day]	758	633	974	550	989	800
	Q_{max}[L/min]	14400	6480	-	-	-	-
10F&11F	Q_{day}[L/day]	90	68	179	250	223	104
	Q_{max}[L/min]	39.7	45.0	88.0	75.0	110.0	95.0

4 Calculation of Water Supply Demand Based on MSWC

4.1 Conditions

The characteristics of water release of WC were established before measuring their actual amount of water use and maximum flow rates, which constituted calculation conditions. The results are shown in Figure 3. The average amount of water release and average release time per WC were found to be about 60 L/min. and 6 seconds respectively based on the average flow rate of about 60 L when one WC was used, about 120 L when two WCs were used at the same time, and the average time for supply water was 6 seconds.

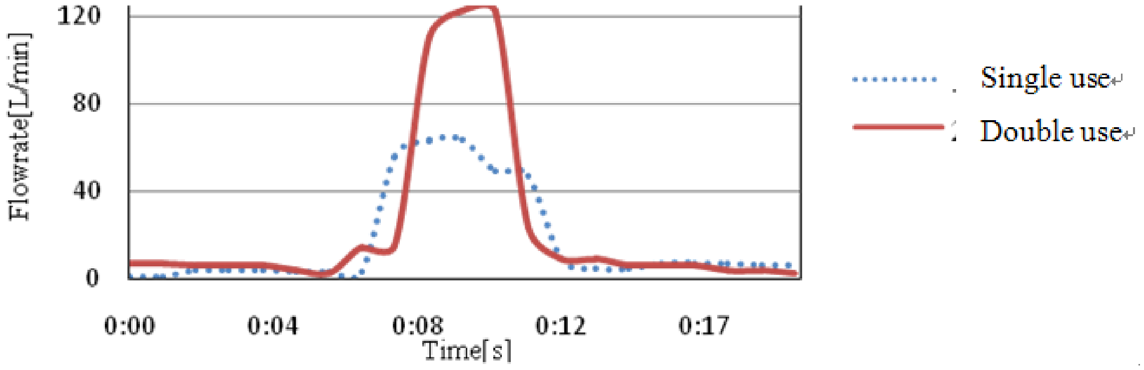


Figure 3 The water release of WC

The calculation conditions based on MSWC simulation are shown in Table 12. With simulation conditions such as average water release time and average water release amount taken into account, water supply demand was calculated by simulating water use in the building and by changing the number of occupants[4) based on the male-to-female ratio.

Table 12 Conditions of Simulation

Fixture	Men's WC	Men's urinal	Men's wash basin	Women's WC	Women's wash basin
No. of fixture					
Distribution diagram phase of average water supply discharge time	-1	0	0	-1	0
Average water supply discharge time (second/use)	1	10	3	1	3
Distribution form phase of average water supply discharge volume	6	5	3	6	3
Average water supply discharge volume[L/min]	0	0	0	0	0
Distribution form phase of occupancy time	6	10	10	6	10
Average occupancy time (second/person)	60	12	3	60	3
Increase of usage with multiple use taken into account	0	0	1	0	1
No. of people, house, room					
Fixture usage rate (Ratio of water to hot water)	260	37	12	110	17

4.2 Water Supply Demand on 10th and 11th Floors

A simulation was made based on the number of occupants calculated by the personnel method of the design standard (referred to as WPM below) and those calculated based on the number of times toilet doors were opened and closed (referred to as WTD below). As a result, the number of occupants calculated by the personnel method was 179, and simulated Q_{day}, Q_{max} based on the male-to-female ratio of 7:3 were 4,425 L/day and 80 L/min. respectively. Q_{day}, Q_{max} on the 10th floor based on the number of times the door was opened and closed were 2,910 L/day and 31 L/min. and those on the 11th floor were 2,611 L/day and 30 L/min.

The measurement result and the simulation result of the water supply demand (Q_{max}) on the 10th floor on September 30 are shown in Figure 4.

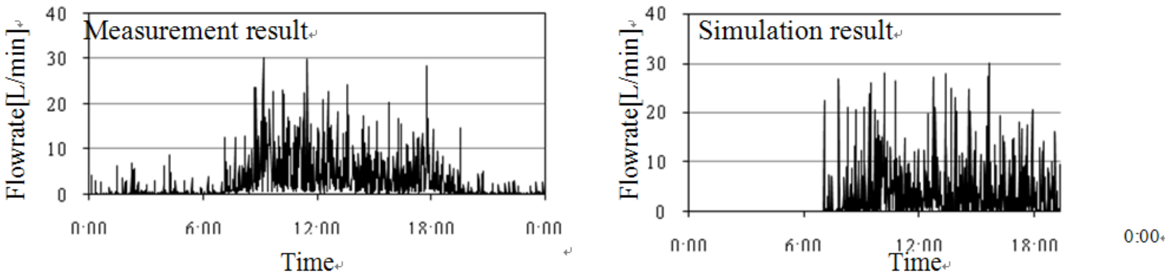


Figure 4 Comparison between the measurement result and the simulation result

4.3 Water Supply Demand for BF1 to 9F

The number of occupants on the floors BF1 to F9 obtained by multiplying personnel density of 0.2 person/m2 and effective area was found to be 1,510. Qday and Qmax based on the male-to-female ratio of 7:3 were 35,942 L/day and 191 L/min.

Water supply demand (Q_{day} only) for the whole floors was 44,264 L/day. Q_{day} and Q_{max} obtained by MSWC are shown in Table 13.

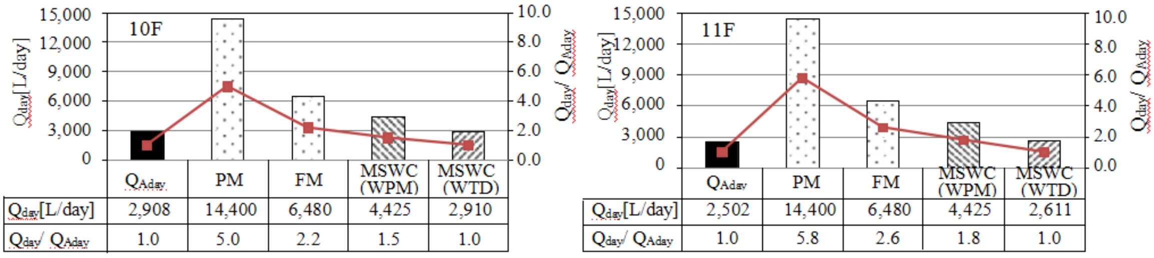
Table 13 Q_{day} and Q_{max} obtained by MSWC

Classification		WPM	OWB	WTD
Whole building	Q_{day}[L/day]	44,264	16,193	-
B1~9F	Q_{max}[L/min]	35,739	-	-
	Q_{day}[L/day]	220	-	-
10F&11F	Q_{max}[L/min]	4,425	-	2,910
	Q_{day}[L/day]	80	-	31
Whole building	Q_{max}[L/min]	4,425	-	2611
	Q_{day}[L/day]	80	-	30

5 Comparison of Water Supply Demand Calculation Methods

5.1 Water Supply Demand Calculation for 10/11 Floors

The comparison of Q_{day} obtained by each method is shown in Figure 5 and that of Q_{max} in Figure 6.



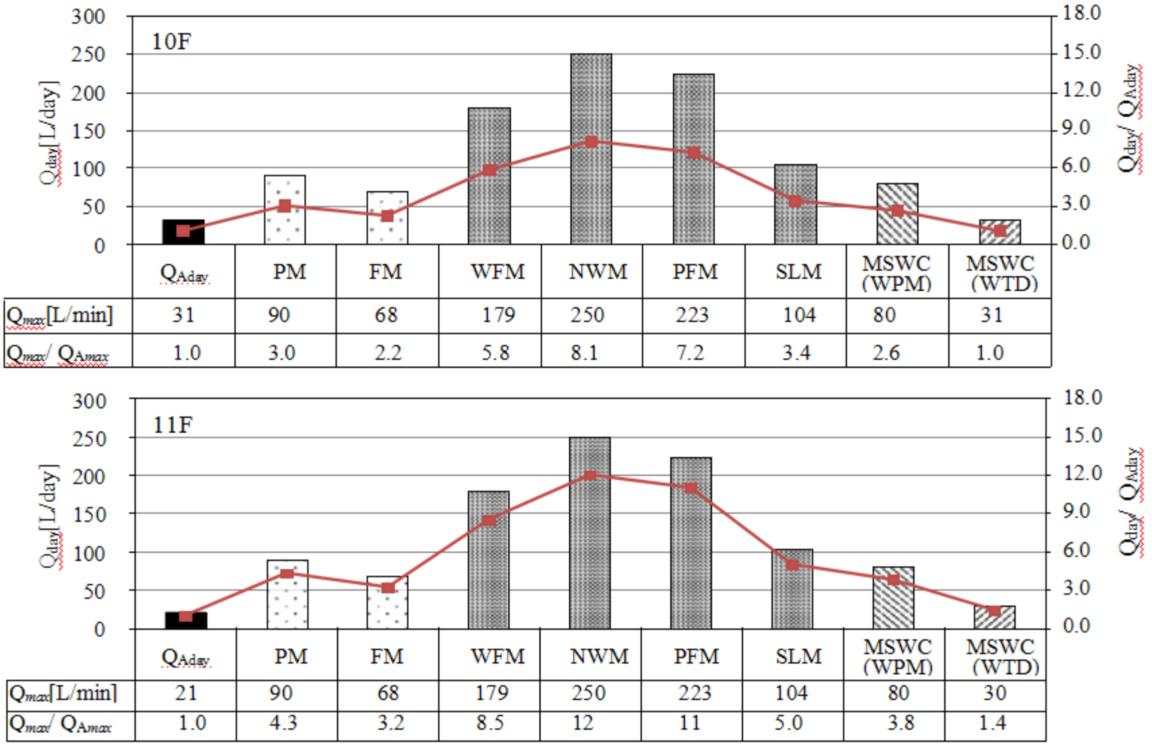
10F

	Q_{Aday}	PM	FM	MSWC (WPM)	MSWC (WTD)
Q_{day}[L/day]	2,908	14,400	6,480	4,425	2,910
Q_{day}/ Q_{Aday}	1.0	5.0	2.2	1.5	1.0

11F

	Q_{Aday}	PM	FM	MSWC (WPM)	MSWC (WTD)
Q_{day}[L/day]	2,502	14,400	6,480	4,425	2,611
Q_{day}/ Q_{Aday}	1.0	5.8	2.6	1.8	1.0

Figure 5 comparison of Q_{day} obtained by each method



10F

	Q_{Aday}	PM	FM	WFM	NWM	PFM	SLM	MSWC (WPM)	MSWC (WTD)
Q_{max}[L/min]	31	90	68	179	250	223	104	80	31
Q_{max}/ Q_{Amax}	1.0	3.0	2.2	5.8	8.1	7.2	3.4	2.6	1.0

11F

	Q_{Aday}	PM	FM	WFM	NWM	PFM	SLM	MSWC (WPM)	MSWC (WTD)
Q_{max}[L/min]	21	90	68	179	250	223	104	80	30
Q_{max}/ Q_{Amax}	1.0	4.3	3.2	8.5	12	11	5.0	3.8	1.4

Figure 6 comparison of Q_{max} obtained by each method

The results of calculation by all methods including both the design standard and SHASE-S 206 were found to overestimate water supply demand. On the other hand, as far as he number of occupants based on effective area and personnel density is concerned, the ratio of Q_{day} and Q_{Aday} to actual values (referred to as Q_A below; actual values corresponding to Q_{day} and Qmax are called Q_{Aday} and Q_{Amax}) obtained by MSWC were 1.5 on the 10th floor and 1.8 on the 11th floor approximating to Q_A.

Also in terms of the number of occupants based on the number of times the door was opened and closed in MSWC, the ratio of Q_{day}/ Q_{Aday} on the 10th and 11th floors was 1.0, hat of Q_{max}/ Q_{Amax} on the 10th floor 1.0、and on the11th floor 1.4.

In MSWC utilizing the Monte Carlo Method, 100 trials per hour were made to calculate peak flow rate, and it is considered appropriate to determine Q_{max} in the exceedance probability range of 0.2% ~ 5% based on the samples per hour 5) .Simulated values with the exceedance probability of 0.2% and 5%, and actual values（Q_A）for 10th and 11th floors are shown in Figure 7.

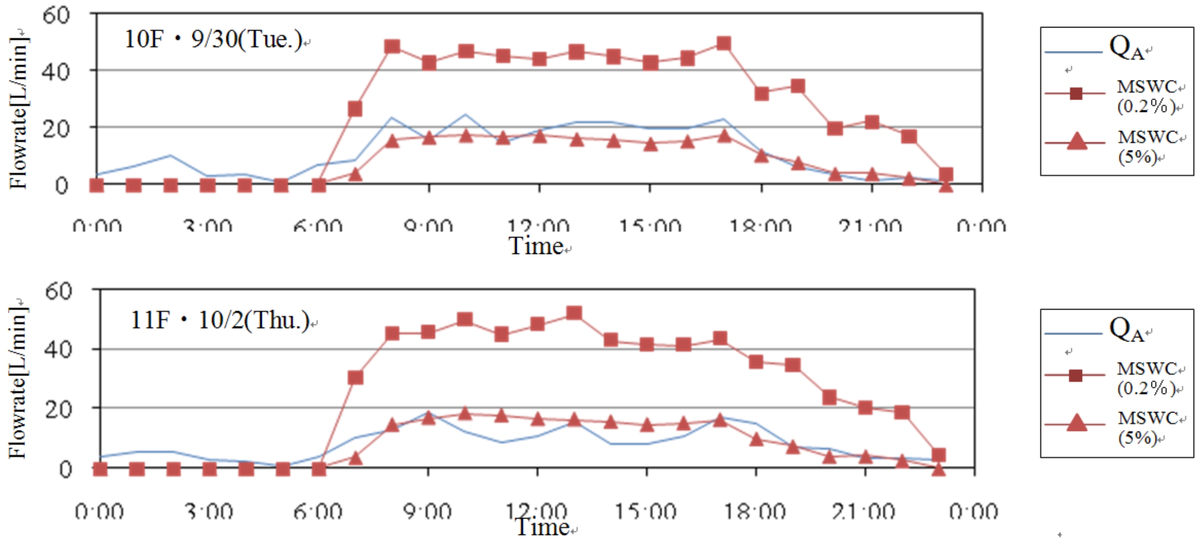


Figure 7 Simulated values with the exceedance probability and actual values

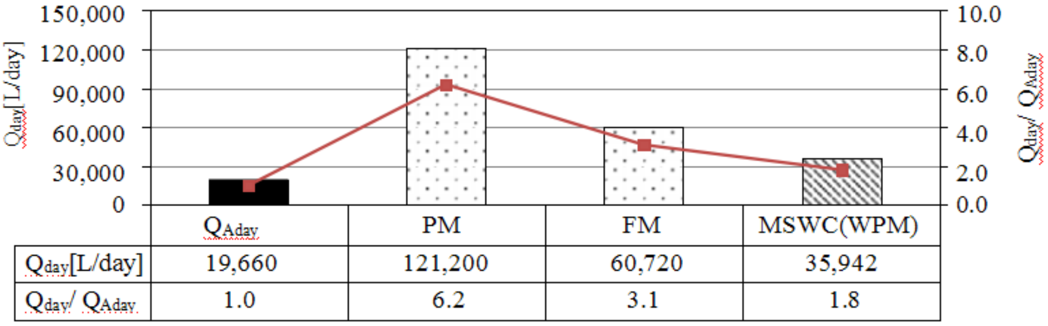
Q_A for the 10th floor remained higher than the exceedance probability of 5%, and Q_a for the 11th floor remained a little lower than 5%. From this, it was shown that calculation of water supply demand on the 10th and 11th floors by MSWC was extremely accurate.

5.2 Water Supply Demand Calculation for BF1 ~ F9

Q_{day} obtained by each calculation method are shown in Figure 8, and Q_{max} in Figure 9. It was confirmed that all the calculation methods tested in this study overestimated water supply demand.R_d and R_m against Q_a obtained by MSWC were 18 and 22, which approximated to Q_a.

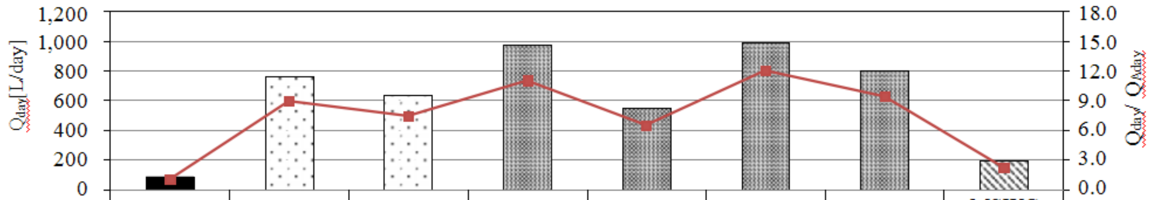
5.3 Water Supply Demand Calculation for the Entire Building

Q_{day} obtained by each calculation method are shown in Figure 10. R_d against Q_a in the number of occupants per area obtained by MSWC was 1.6, and that of R_d in the number of occupants was 0.6 The reason for the smaller R_d in the number of occupants is that the number of people entering and leaving a restaurant on BF1 was not included in the number of occupants and that the simulation by MSWC was made on the premise that the entire building was being used exclusively for business purposes.



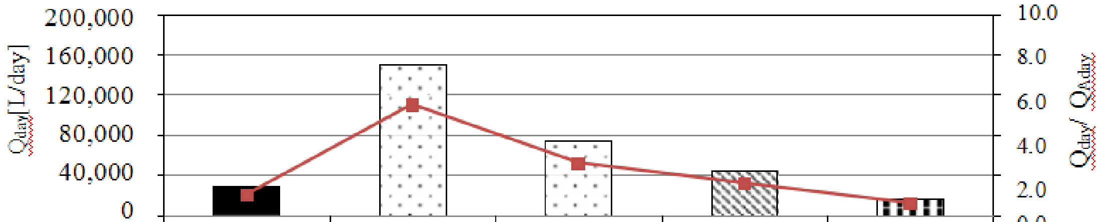
	Q_{Aday}	PM	FM	MSWC(WPM)
Q_{day}[L/day]	19,660	121,200	60,720	35,942
Q_{day}/ Q_{Aday}	1.0	6.2	3.1	1.8

Figure 8 Q_{day} obtained by each calculation method



	QAmax	PM	FM	WFM	NWM	PFM	SLM	MSWC (WPM)
Qmax[L/min]	85	758	633	974	550	989	800	191
Qmax/ QAmax	1.0	8.9	7.4	11	6.5	12	9.4	2.2

Figure 9 Q_{max} obtained by each calculation method



	QAday	PM	FM	MSWC (WPM)	MSWC (OWB)
Qday[L/day]	28,463	150,000	73,680	44,264	16,193
Qday/ QAday	1.0	5.5	2.6	1.6	0.6

Figure 10 Q_{day} obtained by each calculation method

The amount of water used in restaurant taken from literature is shown in Table 14[6)] and table 15. Water supply demand can be calculated from the amount of water use (L) per m^2 per day. In this study it was calculated based on the seat turnover rate of 1.5~3.0. The amount of water used totalled 6,775 L ~ 12,553 L.

Table 14 Calculation formula of Q_{day}

$$Q_{day} = Y \cdot S$$

$$Y = -10.14 + 55.6 X_2 + 8.56 X_1$$

$$X_1 = n/seat$$

$$X_2 = N_s/S$$

Y: The daily water consumption of the restaurant [L/day]

S: The area of the restaurant [m^2]

X_1: Seat turnover rate X_2: Seats per unit area

n: Number of guests N_S: Number of seats

Table 15 Q_{day} of the restaurant

S[m^2]	N_S[seats]	X_1[n/seat]	X_2[seats/m^2]	Y[L/day • person]	Q_{day}[L/day]
450	100	1.5~3.0	0.22	15.05~27.90	6,775~12,553

Adding this amount to the values calculated by MSWC, a grand total of 22,968 L ~ 28,746 L was obtained, and Q_{day}/ Q_{Aday} ratio was 0.8 ~ 1.0, which approximated to Q_A.

From the results above, it was confirmed that all of the conventional water load calculation methods overestimated water supply demand and that calculation by MSWC yielded values closest to Q_A.

6. Conclusions

In this study we examined various water load calculation methods and compared the conventional methods with the simulation based on MSWC for their accuracy. The results can be summarized as follows:

1. It was confirmed that the conventional methods tended to overestimate water supply demand.
2. MSWC produced values closer to Q_A than other conventional methods did.
3. Calculation by MSWC for 10th and 11th floors based on number of occupants calculated based on the number of times toilet doors were opened and closed produced results that were extremely accurate. MSWC based on the number of occupants also yielded the results closer to the actual values if the amount of water used in a restaurant was included.

As the accuracy of calculation of water supply demand by MSWC largely depends on whether or not the exact number of personnel is grasped, it is necessary to draw up a realistic personnel load model in the future by collecting water supply demand data from buildings for multiple uses and verifying the data based on detailed personnel measurement.

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Water Conservation: the Implications of User Awareness, Attitude, and Behaviour

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Abstract

Much of the water conservation effort has focused on the technological advancement of water-using appliances in order to make them more water efficient. However, since user interaction with water-using appliances is a major influence on the amount of water used by the appliance, which is itself influenced by the habits, rituals, and expectations of water use, more research is needed that focuses on the user.

This study uses a water use survey to assess user awareness of water issues and their attitudes to water conservation, in order to determine their influence on water saving behaviour of the user. The findings of the study show an overall mixed and limited awareness of the severity of water scarcity issues in the UK. While most users have a favourable attitude to water conservation, many give no thought to the amount of water they consume each day. While a number of users declare that they try to save water throughout the day, evidence shows that they tend to adopt simple water saving actions and the effect on water consumption is relatively small. Few take account of water consumption figures when purchasing new appliances and less than half of the users taking part in the survey had any type of water efficient appliance installed at home. However, the majority of users suggested that they would like to increase their knowledge of water stress issues and would welcome additional information about the environmental and financial consequences of wasting water, ways on how they can save water in the home, and more details information on water efficient appliances. This research shows that while there is a disparity between the positive attitude that users have towards water conservation and actual water saving action, there is a great opportunity to reduce household water consumption through improved user knowledge.

Keywords

Water conservation, water stress, water efficiency, awareness, behaviour, attitude.

1. Introduction

The combined effects of global population increase, climate change impacts, and lifestyle changes are exerting growing pressures our vital water resources leading to widespread water stress in many countries. In the UK, many areas have already reached maximum abstraction levels [1]. Furthermore, the treatment, supply and heating of water carries a high energy and emissions burden [2]. As a result, there is growing realisation of the urgent need to conserve water. While technological advances of water-using appliances offer increased efficiency, the way in which users interact with these appliances ultimately has a major effect on the water performance of the appliance. However, user interaction with water-using appliances is inextricably linked to the habitual (and sometimes ritual) use of water and their expectations of cleanliness, comfort, and relaxation [3]. As such, the consumption of water has become a routine and inconspicuous part of everyday life with most people giving little consideration to the conservation of water.

In the UK, there are currently very little incentives to save water. Just 40% of households in England and Wales have a water meter [4], with household water meters in Scotland being almost unheard of. Those without water meters are charged indirectly based on the Council Tax band which relates to the rateable value of the property.

To develop effective water conservation policies and intervention strategies aimed at encouraging water saving behavioural change (including both the adoption of water efficient appliances and the implementation of water saving practices) an understanding of users' perceptions, attitudes, and values is needed. This study aims to provide new evidence of users' awareness of water issues and their attitudes to water conservation, and how these relate to water saving behaviours. A water use survey was used to gather attitudinal and behavioural information to fully assess their influence on user water consumption. The findings from this study allow socio-demographic and psycho-social profiles of water users to be developed which can help inform future demand management policy.

2. Methodology

Data for this current study was gathered using a water use survey aimed at collecting new empirical evidence of user water behaviour as well as assessing user attitude and awareness towards household water conservation. The survey consisted of 18 multi-item questions designed to elicit information about various aspects of household water consumption and conservation, as well as standard demographic information. The majority of questions used categorical multi-choice questions, with some open-ended questions also included.

Participants were first asked about their individual water consumption to determine if they were conscious of the amount of water they use each day. Participants were then asked to calculate their average daily water consumption using the online Water Calculator provided by Scottish Water[http://www.scottishwater.co.uk/you-and-your-home/your-home/water-efficiency/water-calculator]. They were also asked about their attitude towards water conservation (their perception of the need to save water), curtailment behaviours (the extent to which they engage in everyday water saving practices), and efficiency behaviours (whether they currently had any water efficient appliances installed). Finally, participants were asked about behavioural change mechanisms (what would encourage them to change their behaviour in order to save more water).

The survey was released on social media and emailed to all staff and students within the School of Energy, Geoscience, Infrastructure and Society at Heriot-Watt University. A total of 124 valid responses were received and analysed.

3. Results and Discussion

3. 1Socio−demographic characteristics

The socio-demographic characteristics of the survey participants are summarised in Table 1. Since no sampling protocols were used while conducting the survey, participant characteristics are not demographically representative of the UK population. A large proportion of the participants are aged between 18-24 (59%) and 25-34 (22%), with those over 35 years representing just 19% of all participants. A large proportion of participants are male (59%), which differs slightly from the national average (51% male : 49% female) [5]. Of those aged over 35 years, all are British and whilst those in the younger age ranges are predominantly British, over a third of those in the 18-24 age range are non-British. This is characteristic of the fact that over half (53%) of all participants, and the majority (81%) of those between 18-24, are students. The small sizes of participants in the age ranges over 35 years, particularly the 55-64 and 65+ ranges, reduces the likelihood of statistically significant data in these groups, however, some general trends were observed.

Table 1: Characteristics of survey participants

Descriptor	All	Age range					
		18-24	25-34	35-44	45-55	55-64	65+
Quantity *number (%)*	124	73(59)	27(22)	8(6)	11(9)	4(3)	1(<1)
Gender ratio *(%male:%female)*	59:41	62:38	67:33	38:62	27:73	75:25	100:0
Nationality *(%British:%non-British)*	77:23	68:32	78:22	100:0	100:0	100:0	100:0
Employment *(%student:%employed)*	53:47	81:19	19:81	25:75	0:100	0:100	0:100
Household income[a] *(£)*	34,000	27,000	39,000	50,000	53,000	48,000	45,000

[a] Estimated by taking average of selected household income category of each participant

3.2 Individual water consumption

From the daily water consumption values calculated by each participant using the Water Calculator from Scottish Water, the overall average water consumption was found to be 182 litres per person per day (l/p/d). This is higher than the UK average (150 l/p/d) and EU average (160 l/p/d) but is within the UK regional average range (110 l/p/d to 185 l/p/d) [6]. The relative high average found in this study could be a symptom of the relatively small sample size or be due to a number of socio-demographic and psycho-social factors concerning water conservation attitudes of the specific survey sample.

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http://www.scottishwater.co.uk/you-and-your-home/your-home/water-efficiency/water-calculator

In terms of household composition, individual water consumption was found to decrease as the total number of people in each household increased, see Figure 1. While the differences between 1 to 4 person households is less pronounced than those with larger person households, this trend is similar to those found in other studies which report that smaller households tend to be less efficient, require more resources, and so use more water per person than larger households [7,8].

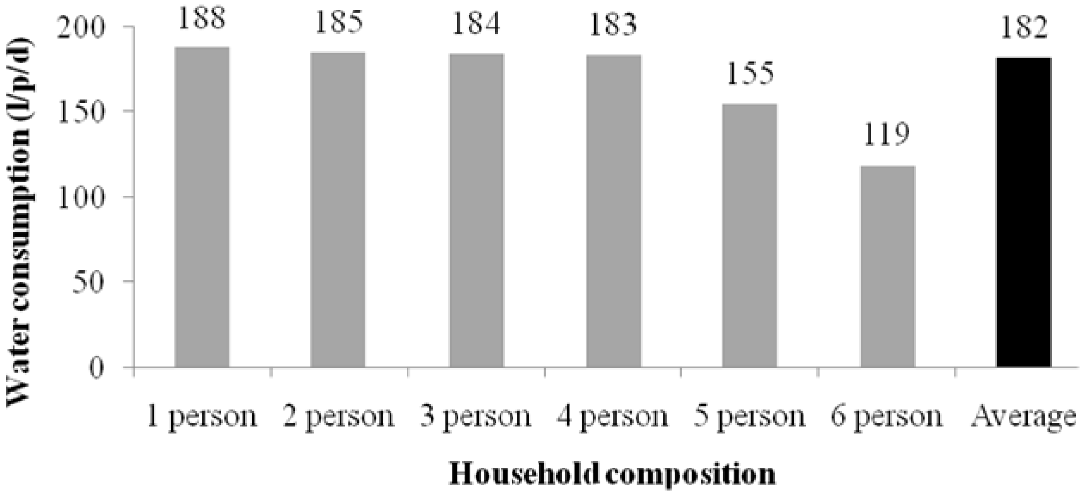

Figure 1: Average individual water consumption values calculated using the Water Calculator for different sizes of household composition

No significant trend in water consumption was found between male and female participants, which agrees with studies by others [9]. However, no trend was observed regarding household income, despite other studies reporting that higher income households tend to consume more water [10,11,12,13].

3.3 Levels of conscious water use

Overall, just 51% of participants claimed to be conscious of the amount of water they used each day. This increased to 62% for bill payers and dropped to 33% for non-bill payers; showing clearly that while water in Scotland is not metered, those participants who had responsibility for household bills were actually more conscious of their water consumption. Participants who identified themselves as being water-conscious were found to use less water than those who were not water-conscious; having average water consumption values of 171 l/p/d and 193 l/p/d, respectively, a significant difference of 22 l/p/d.

Interestingly, household income was found to relate to how conscious the participants are of the amount of water they use each day. Findings show a general increase in the proportion of participants who identify as being water-conscious with increasing household income. The number of participants who identified as being water-conscious was also found to increase with age group, see Figure 2. Generally, the study shows that those who identify as being water-conscious tend to be the bill payer, have a higher household income, and tend to be older in age.

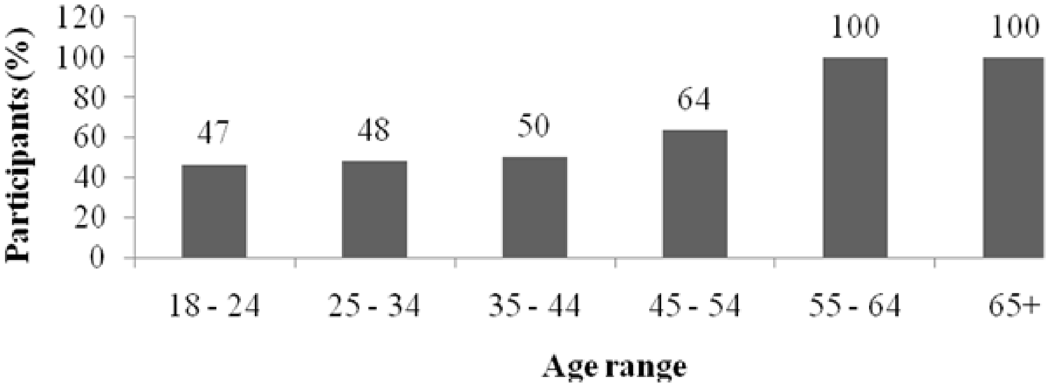

Figure 2: Comparison of the number of participants who identify as being water-conscious across each age range

3.4 Awareness of water scarcity risk

Analysis of participant's awareness of water stress issues shows a mixed perception of water scarcity risk in the UK, see Figure 3. Just over a fifth of participants perceive the UK to have a Low water scarcity risk, with just under a half perceiving the risk to be Low to Medium. A further quarter of participants consider there to be a Medium to High risk, and just 8% consider the risk to be High.

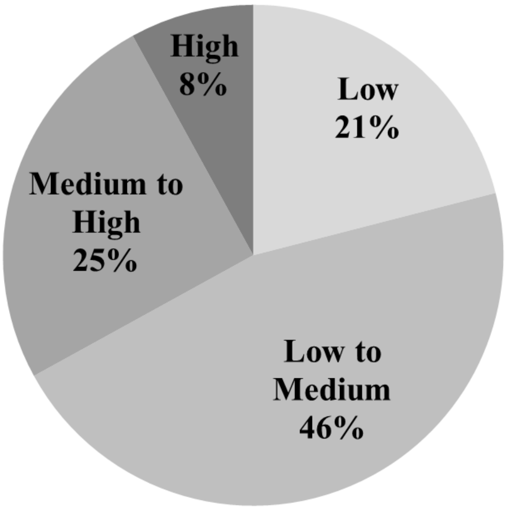

Figure 3: Comparison of participant awareness of UK water scarcity risk

The mixed views of water scarcity risk may reflect the fact that, in reality, the level of water scarcity risk varies widely across the UK and is dependent upon the balance of water demand with the available water supply capacity. While large areas of Scotland are considered to have a Low water scarcity risk, in some areas of Central Scotland the risk is Medium to High, particularly around areas with large populations such as cities like Edinburgh and Dundee. The risk of water scarcity is greater in England, where many parts of the South East, in particular, are at High risk of water scarcity. The participant's perception of water scarcity risk could be related to their own experience of water scarcity. Studies have found strong correlation between past experience of water shortages with water awareness and water conservation behaviour [13,14]. For those who perceived there to be a Low water scarcity risk in this study, the majority

(69%) also identify as being not water-conscious. Additionally, all participants that perceived a Low risk were in the youngest two age categories: 18-24 (77%) and 25-34 (23%).

3.5 Attitudes to water conservation

Overall, participants indicate a positive attitude towards water conservation with 83% stating that they consider there to be a need for households in the UK to save water. However, this is a lower proportion than similar studies in Australia which found that between 94-98% of participants regarded water conservation as important [15,16]. This difference may be due to the heightened awareness that Australians have of water scarcity issues as many regions have experienced severe droughts in recent years due to the combined effect of lower than average rainfall and high population growth [12]. As a result, many Australians have experienced water restrictions and water saving measures imposed by government authorities to manage demand and to ensure the conscious use of water. This will have undoubtedly affected the positive attitude that Australians show towards the need for water conservation over those in Scotland and the UK.

Analysis of the water consumption values provided by participants indicates that a positive attitude towards water conservation translates to a relative reduction in water consumption. Results show that those who consider water conservation to be necessary, typically consumed less water (176 l/p/d) than those who deem it to be unnecessary (209 l/p/d); an increase of almost 19%. These findings are in agreement with other studies which show that environmental attitudes can be a strong predictor to water efficient behaviour [13, 17]. No socio-demographic trends were found to influence water conservation attitudes amongst the participants.

3.6 Evidence of curtailment behaviour (water saving practices)

Participants were asked if they try to save water. 85% of all participants stated that they did make an effort to try to save water throughout the day. Of the 15% who admitted to making no effort to save water, most (94%) also stated that they were not water-conscious, the majority (61%) were students, and just 44% were bill payers.

The water saving practices followed by participants are summarised in Table 2, which compares the results from this study with those from a previous UK-wide study [8] and a similar Australian study [15]. The main water saving practice is ensuring that taps do not drip (86%), followed by turning off the tap while brushing teeth (67%). These responses compare well with the previous UK-wide study, however, more Australians appear to actively ensure taps do not drip (98%). A total of 58% state that they take showers rather than baths and 54% indicated that they fill the kettle with only the amount of water needed, which is over double that found in the previous UK-wide study (25%). When using dishwashers and washing machines, just 49% of participants stated that they only use them when fully loaded, compared to 78% and 81% fully loading dishwashers and 80% and 89% fully loading washing machines in the UK-wide and Australian studies, respectively. Just 44% of participants in this study indicated that they use a basin rather than running a tap, which is half of the number in the UK-wide study. With regards to outdoor water use, only 19% stated that they use a bucket to wash their car and just 16% use a watering can in the garden. These are significantly lower than the number of participants that engage in these activities in the UK-wide study, however, the numbers in this study to not account for participants without a car or garden. There is also a clear difference in the number of participants who use alternative sources of water, with just 1% of participants in this study indicating that they reuse bathwater for watering garden plants, while the Australian study found that between 44-47% of participants recycled grey-water for garden or outdoor use.

Table 2: Water saving practices of participants

	This study (%)	UK-wide study [8] (%)	Australian study [15] (%)
Ensure taps do not drip	86	87	98
Turn off tap while teeth brushing	67	70	-
Take showers rather than baths	58	-	-
Fill the kettle with only the water needed	54	25	-
Fully load dishwashers/washing machines	49	78/80	81/89
Use a basin rather than running tap	44	88	-
Wash car with bucket rather than hose	19	48	-
Water garden plants with watering can rather than hose	16	58	-
Reuse bathwater for garden plants	1	-	44-47

[a] Adding participants with A+ (22%) and A (35%) rated washing machines.

[b] Participants who state using a dishwasher eco-setting.

Interestingly, the difference in water consumption between those who try (180 l/p/d) and those who do not (192 l/p/d) was just 12 l/p/d, perhaps supporting findings from previous studieswhichindicate that positive environmental intention does not always translate into actual reductions [13] and that householder perceptions of their water consumption is often not well matched with their actual consumption [12,15]. Some of the participants in this study who stated that they try to save water consumed as much as 401 l/p/d. These participants may be displaying possible bias towards self-reported attitudes and behaviour; reporting a more socially desirable answer.

3.7 Evidence of efficiency behaviour (water efficient appliances)

Despite a large number of participants stating that there is a need for water conservation (83%) and that they practice water saving activities (85%), just 42% take water consumption into account when purchasing new appliances. In terms of gender, female participants (47%) were slightly more inclined than male participants (38%) to consider water consumption when making a purchase decision. A clear trend was also found regarding age such that older participants were far more likely to consider water consumption when making a purchase than younger participants.

The current ownership of water efficient appliances is shown in Table 3.The most adopted water efficient appliance is the dual flush toilet with 33% of participants having one installed which is comparable with the 39% of participants who stated owning one in the previous UK-wide study [8]. It can be seen, however, that a significantly larger number of Australians (87%) own a dual flush toilet which is mainly due to legislation being introduced in Australia making dual flush toilets mandatory[15].

The second most adopted water efficient appliance is the water efficient washing machine (32%), followed by the water efficient dishwasher (25%) and then, finally, the water efficient showerhead (13%). All of which, apart from the water efficient dishwasher, are lower ownership numbers than those reported by the previous UK-wide study. Again, however, the numbers in the Australian study are far higher, with many more participants having these water efficient appliances installed at home. This difference is likely to be due to incentive schemes introduced in Australia to encourage uptake such as rebates offered for water efficient washing machines and water efficient showerheadsbeing provided to households at no cost [15].

Table 3: Participant ownership of water efficient appliances

	This study(%)	UK-wide study [8](%)	Australian study [15] (%)
None	45	-	-
Dual flush toilet	33	39	87
Water efficient washing machine	32	57[a]	75
Water efficient dishwasher	25	23[b]	58
Water efficient showerhead	13	21	82

[a] Adding participants with A+ (22%) and A (35%) rated washing machines.

[b] Participants who state using a dishwasher eco-setting.

Of particular concern is the large number of participants (45%) who report having no water efficient appliance at home. Although participants were not asked about why they did not own any water efficient appliances in this study, other studies have found the biggest barriers to include perceived impracticality and poor quality of water efficient appliances, participants having no need for new appliances, and the cost and inconvenience of installing new water efficient appliances [15]. Other factors which strongly affect the adoption of water efficient appliances are property ownership status and whether the water is paid for volumetrically with a water meter [17]. Since a large proportion of the participants in this study are students and so are unlikely to own their own home, and domestic water in Scotland is generally unmetered, these may be significant factors in explaining the lack of incentive for these groups to adopt water efficient appliances. A strong correlation between the ownership of water efficient appliances and household income was found. Lower income households were less likely to own water efficient appliances, see Figure 4, which is consistent with research that shows that higher income households are more likely to install water efficient appliances [11,17].

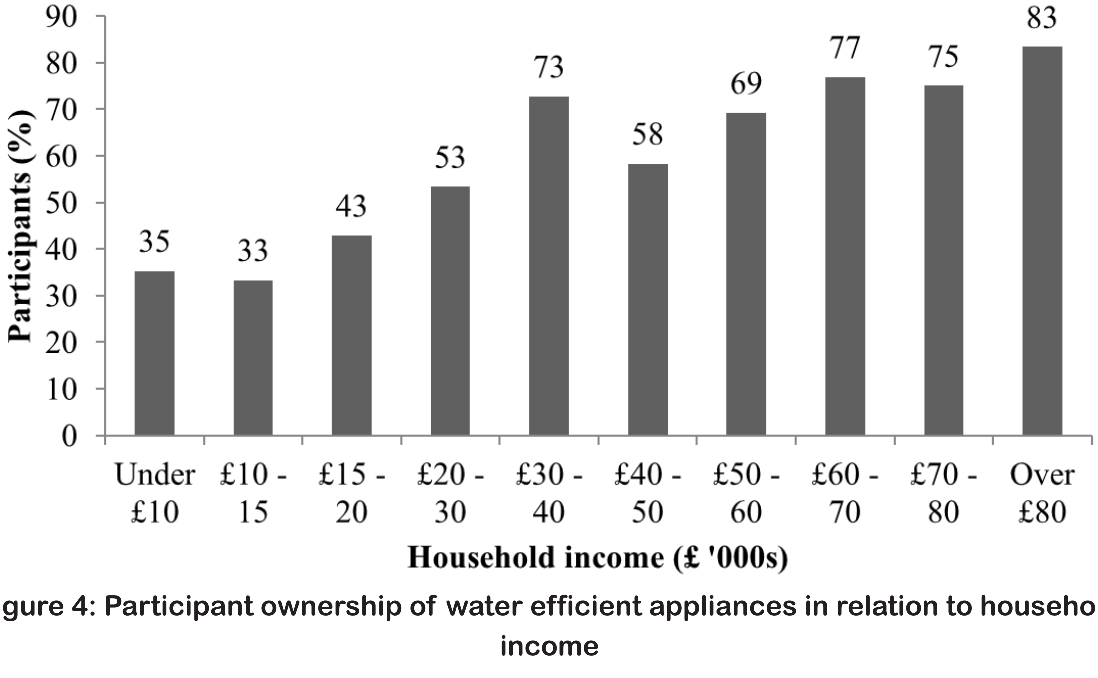

Figure 4: Participant ownership of water efficient appliances in relation to household income

3.8 Behaviour change mechanisms

Factors identified that would encourage participants to change their behaviour in order to save water include: installing a water meter (71%); having more information about the environmental and financial consequences of wasting water (56%); and increased water prices (30%). The installation of water meters and the charging of households based on their direct consumption have been found to be an effective way of encouraging water saving behaviour [17]. In England, studies have shown that households with water meters use an average of 10% less water [4].

While there is general support for water conservation, it seems that many feel that they lack the knowledge or awareness of both the environmental and financial implications of using too much water. Improving knowledge and awareness of water saving issues, therefore, presents a major opportunity for altering water consumption behaviour. 61% of participants expressed that they would welcome information on ways to save water, 60% would like more details about water efficient appliances, and 53% would like more information on water consumption figures.

When asked what format they would like to receive this information, this most popular was the internet (57%), followed by TV (52%), and then by leaflet (43%), see Figure 5. Next on the list were newspaper (27%), email (24%), and then radio (22%). Perhaps surprising is that 17% of participants indicated that they would like to have a home visit from a water expert to inform them on how they could save water in their home. The least preferred options to receive water saving information were by text message and phone call, reflecting people's dislike for unsolicited "cold-calling" from companies and organisations. Nevertheless, participants are open to a great number of formats for receiving information to improve their knowledge and understanding of water issues.

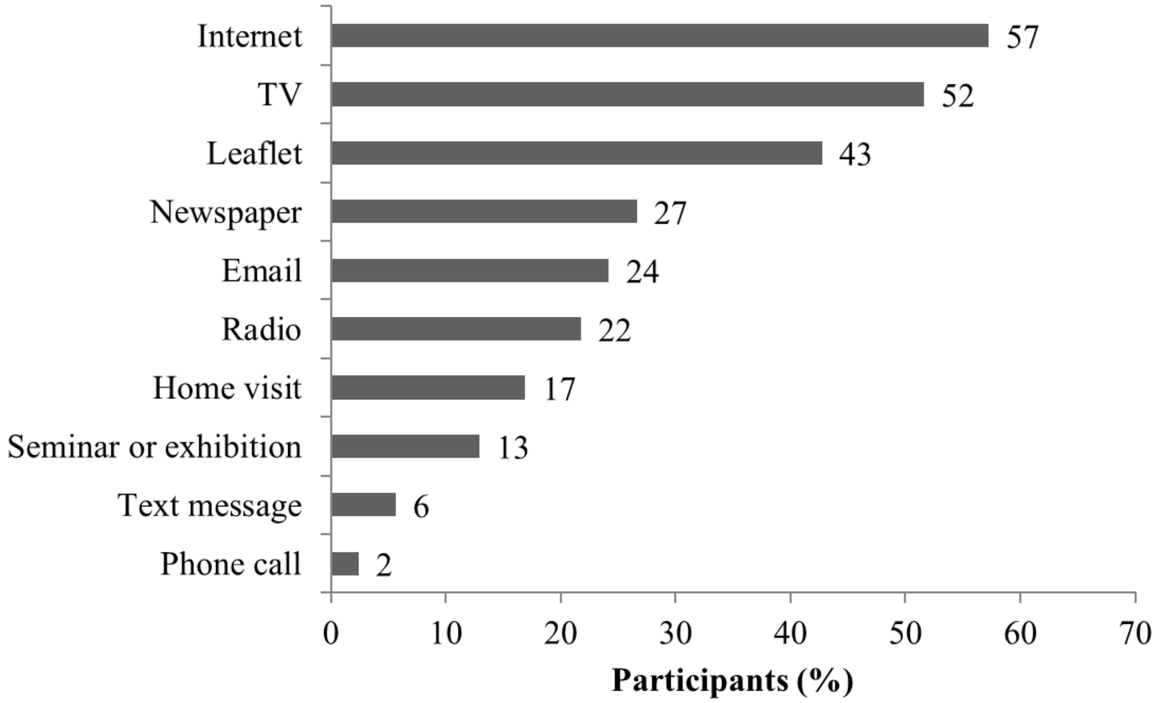

Figure 5: Preferred formats for receiving information about water saving issues

4. Conclusions

Using data derived from a comprehensive water use survey, this study presents new evidence of user awareness and attitudes towards household water conservation in Scotland, and how these relate to water saving behaviours.

Awareness of user water consumption was found to be limited, with just over half of participants identifying as being conscious of the amount of water they consume. Many were found to have favourable attitudes to household water conservation, yet this attitudinal enthusiasm translated only to a modest reduction in water consumption. Many also declared to using water saving practices, however, participants were more likely to engage with simple actions such as stopping dripping taps than more involved actions of, for example, reusing bathwater. Furthermore, the favourable attitude and water saving intentions did not reflect the adoption of water efficient appliances, with less than half of all participants stating that they do not own any such appliance.

While a favourable attitude to water conservation does not always translate to water saving behaviours, the fact that so many are in favour of water conservation provides much opportunity for future household water management strategies. In addition to the installation of water meters and increased water prices, participants highlight that increasing user knowledge of water issues (e.g. the consequences of wasting water, water consumption figures) as well as social marketing campaigns (e.g. providing information on how water can be saved in the home, communicating information about the quality and performance of water efficient appliances) would help encourage water saving behavioural change.

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Development of the Calculating Method for the Loads of Cold and Hot Water Consumption in a Business Hotel

(Part 1) Cold and Hot Water Demands through the Attributes of Guests and Plumbing Fixtures

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Abstract

The water-saving techniques of plumbing fixtures have greatly improved in recent years. Among the various types of building, the hotel requires in large amounts of hot water demands compared with the office buildings, etc. Therefore, it is effective to introduce the water-saving fixtures to the guest rooms in hotel from the perspective of water and energy-saving. As for the plumbing design of building, it is required an accurate estimation of cold and hot water supply demands. The authors have developed a dynamic calculation method for cold and hot water supply demands (MSWC) which was shown in the CIB-W062 symposium (2014). Also, the authors reported the measurement results in the guest rooms of a city hotel, and showed the models of cold and hot water usage in the guest rooms of a city hotel for the dynamic calculation method at the CIB-W062 symposium (2005, 2007).

In this paper, the authors show the measurement results for the loads of cold and hot water consumption at the five guest rooms in a business hotel which is mainly targeted at business travelers. The measurement was conducted throughout the year from March, 2013 to March, 2014. The five guest rooms were introduced different types of plumbing fixtures. The daily loads of cold and hot water consumption are analyzed by the characteristics of guests and plumbing fixtures. As the results, daily loads of cold and hot water consumption per people in a business hotel show less volume than that in a city hotel. As for the different types of plumbing fixtures, the effects of saving cold and hot water consumption are discussed in each usage.

Keywords

Hotel; Cold and hot water supply demand; Water-saving fixture; Cold and hot water usage

1. Introduction

The conservation of energy and water resources in commercial building has been a great matter of concern to the building service designers. Therefore, on the field of plumbing for cold and hot water supply systems, it is required to set up effectively the energy and water-saving facilities. When we compare the annual energy consumption per square meter as to the total floor area in commercial building in Japan, the building for hotel has the biggest value of energy consumption. Especially, the energy consumption of hot water supply usage occupies a large percentage to the whole building consumption. However, the energy consumption in hotel has different values by the management styles such as city hotel, business hotel, resort hotel, etc. For an example, the energy consumption in business hotel occupies a large percentage in the guest rooms when we compare with the city hotel of having the large public spaces such as reception halls, conference rooms, aerobics gyms, etc. Therefore, the management of energy saving in the guest rooms is required intensely for business hotel. In the case of city hotel, the authors showed the investigation results of hot and cold water usage in the guest rooms, and suggested the dynamic calculation method for the loads of hot and cold water demands at the CIB-W062 symposium (2005, 2007) [1] [2].

In this paper, the authors show the cold and hot water consumption in the guest rooms which were set up the energy and water saving plumbing fixtures based on the measurements throughout the year. And, we discuss the effects to introduce the water- saving plumbing fixtures in comparison with the conventional facilities.

2. Outline of the Investigation

2.1 Outline of the subject hotel

A business hotel located in Kawasaki City of Kanagawa Prefecture in Japan was selected for the subject of investigation. The building is composed of eight floors made by SRC structure. The first floor has a small lobby and a restaurant for a light meal. The guest rooms; 151 rooms, locate from second floor to eight floor. Table 1 shows the outline of the architecture and equipment in the subject building. The check in and check out time of the hotel are 15:00 p.m. and 11:00 p.m. respectively.

Table 1 - Outline of the architecture and equipment

Building name	M hotel
Location	Kawasaki City, Kanagawa Prefecture, Japan
Building use	Hotel, Restaurant, etc.
Site area	723.54 m^2
Total floor area	4403.34 m^2
Structure	SRC / 8 stories above, 1 penthouse
Scale	Number of guest room : 151, Guest room floor : from 2 to 8 story
Water supply system	Booster pump system
Gravity tank	No tank
Hot water supply system	Hot water boiler : 4 boilers, Hot water storage tank : 2 tanks

2.2 Outline of the guest rooms

As for the subject investigation guest rooms, the authors selected one twin room and four single rooms located in the same floor. The unit bath room is same type both of twin and single room. However, the specifications of plumbing fixtures were changed in each room because of comparison with the effects of water saving facilities. The authors divided into three groups, which were standard, down-grade and up-grade according to the specifications of plumbing fixtures. In this paper, these guest rooms are described as TS; twin room and standard type, SSd; single room and standard type, SS; single room and standard type, SD; single room and down-grade type and SU; single room and up-grade type.

Table 2 shows the figures of plumbing fixture which were installed in each guest room. As for the faucet at bathtub, three types of fixture were selected among five guest rooms; mixing faucet with thermostat for TS, SSd and SS, type of two valves for SD and mixing faucet with thermostat and constant flow valve for SU. As for the shower head, spray type was set up for SSd and air-in type was set up for the other rooms. As for the faucet at wash basin, three types of fixture were selected among the five guest rooms; single-lever for TS, SSd and SS, two handle type for SD and Eco-single lever* for SU. As for the water closet, super water-saving type; flushing volume of 4.8L (L) and 3.8L (S), was set up for SU, and conventional type; flushing volume of 13L, was set up for other guest rooms. All the water closets were installed with the devices of warm seat and a bidet function.

Table 2 - Plumbing fixtures in each guest room

Fixture	Guest room TS	Guest room SSd	Guest room SS	Guest room SD	Guest room SU
Bathtub faucet	Mixing faucet with thermostat	Mixing faucet with thermostat	Mixing faucet with thermostat	Type of two valves	Mixing faucet with constant flow valve
					
	Setting up temp. automatically	Setting up temp. automatically	Setting up temp. automatically		Setting up temp. automatically Setting up flow rate by dial
Shower	Air-in shower	Spray shower	Air-in shower	Air-in shower	Air-in shower
					
	Average flow rate : 7L/min	Optimum flow rate : 8.5L/min	Average flow rate : 7L/min	Average flow rate : 7L/min	Average flow rate : 7L/min
Wash basin faucet	Single-lever	Single-lever	Single-lever	Two handle type	Eco-single lever mixing faucet
					
					A click feeling divides between hot and cold water
Toilet	Water closet conventional type	Water closet conventional type	Water closet conventional type	Water closet conventional type	Water closet super water-saving type
					
	Flushing volume : 13L/frequency	Flushing volume : 13L/frequency	Flushing volume : 13L/frequency	Flushing volume : 13L/frequency	Flushing volume : L4.8L/frequency S 3.8L/frequency

Note: *Eco-single lever; A click feeling divides between cold and hot water.

2.3 Outline of the measurements

In each the subject guest room, the authors had measurements of the consumption and temperature for cold and hot supply water from the first of March, 2013 to the end of March, 2014. The data on the number of guests, the gender of guests, etc. were made an offer by the cooperation of hotel.

Table 3 and Figure 1 show the outline of measurements and the pipe lines for cold and hot water supply systems into the guest rooms of TS, SSd, SS and SD. In the case of SU, there are some differences for the pipe lines of cold and hot water supply systems. However, the measurements of each item were carried out with the same method for the other guest rooms. The volumes of cold and hot water consumption were recorded by the data loggers with the interval of two seconds. The measurement flow meter had the accuracy of 0.012L as to one pulse. The temperature of cold and hot supply water was measured on the surface of branch pipes to enter the guest rooms by the thermocouples.

Table 3 - Outline of measurements (Guest room TS, SSd, SS and SD)

Measurement points		Symbol	Instrument	Measurement contents
Cold water consumption	Total	M_1	Flow meter	Pulse signal [0.0124L/pulse]
	Wash basin	M_2	Flow meter	Pulse signal [0.0124L/pulse]
	Toilet	M_3	Flow meter	Pulse signal [0.0124L/pulse]
Temperature of clod supply water		T_1	Thermocouple	Temperature [°C]
Hot water consumption	Total	M_4	Flow meter	Pulse signal [0.0124L/pulse]
	Wash basin	M_5	Flow meter	Pulse signal [0.0124L/pulse]
Temperature of hot supply water		T_2	Thermocouple	Temperature [°C]

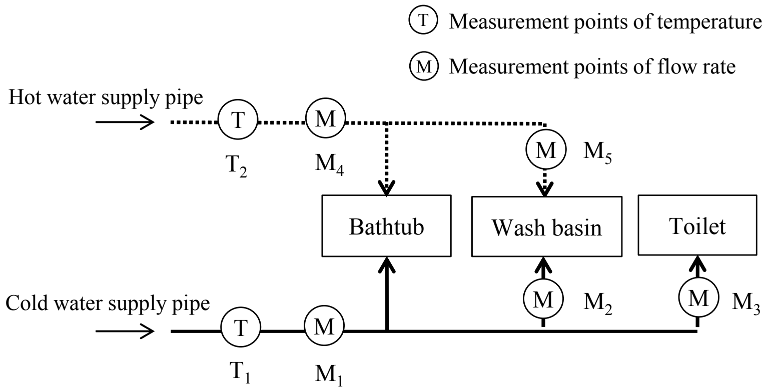


Figure 1 - Pipe lines for cold and hot water supply systems (Guest room TS, SSd, SS and SD)

3. Characteristics of the Guests

The composition percentage for the number of guests and the gender of guests in each guest room per night throughout the year are shown in Figure 2. Also, Figure 3 shows the composition percentage for the number of guests in each generation group.

From the composition percentage for the number and gender of guests shown in Figure 2, the group of one people and male accounts for about eighty percent in the four single rooms excluded the twin room TS. The similar tendency in business hotel can be grasped in the past investigation [3]. On the other hand, the high percentage of two people accommodation is shown in the twin room TS. The group of two people occupied by male and female accounts for about forty percent to the total number of used days.

From the composition percentage for the number of guests in each generation shown in Figure 3, the group of thirty generation shows the highest percentage among the four guest rooms excluded the room SU, and accounts for about thirty percent to the total number of guests. The number of people for thirty, forty and fifty generation accounts for about 63-88 percent to the total number of guests. The up-grade room SU is occupied with the aged generation because the room SU is charged with some higher amount than that of the other rooms.

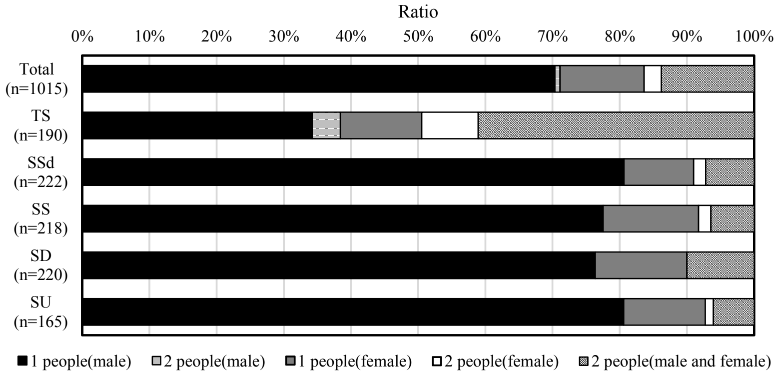


Figure 2 - Composition percentage for the number and gender of guests

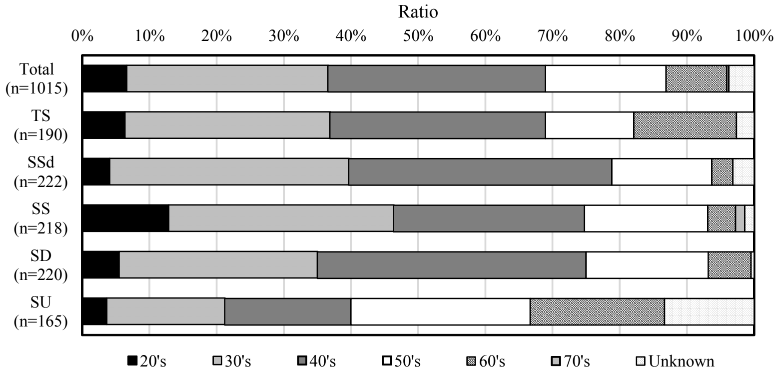


Figure 3 - Composition percentage for the number of guests in each generation

4. Analysis of Cold and Hot Water Consumption

4.1 Fluctuation of cold and hot water consumption throughout the year

The authors analyzed the measurement data throughout the year on the basis of excluding the unusual days which were recorded for the long discharge time from the plumbing fixtures. As an example of the room TS, Figure 4 shows the average values of cold and hot water consumption per day in each month throughout the year from March, 2013 to the end of March, 2014. These values were analyzed based on the data which were recorded by the guest usage of cold and hot water from check in time to check out time. Also, the average temperatures of cold and hot water supplied in each month are shown in Figure 4.

There are some differences for the number of data that were analyzed in each month. As the values of cold and hot water consumption are influenced by the behaviour of water usage and characteristics of the guests, it is difficult to find out clearly the tendencies of major difference among the monthly values. However, the percentage of hot water consumption as to the total values of cold and hot water consumption per day have a little higher values in winter season than those in summer season because the temperature of cold water in winter season is lower than that in summer season. The supplied temperature of hot water is controlled with the constant value of sixty degrees Celsius. However, as shown in Figure 4, the measured temperature shows a little lower than that of supplied hot water. It is supposed that the differences of these temperature are caused by the measurement methods. On this investigation, the temperatures of cold and hot water were measured on the surface of supply branch pipes by thermocouples. When the authors checked the differences, it appeared just slightly lower temperature than that at the outlet of faucet in the guest room. Therefore, the authors deal with the values of hot water consumption in this paper as the temperature of hot water is supplied approximately with sixty degrees Celsius.

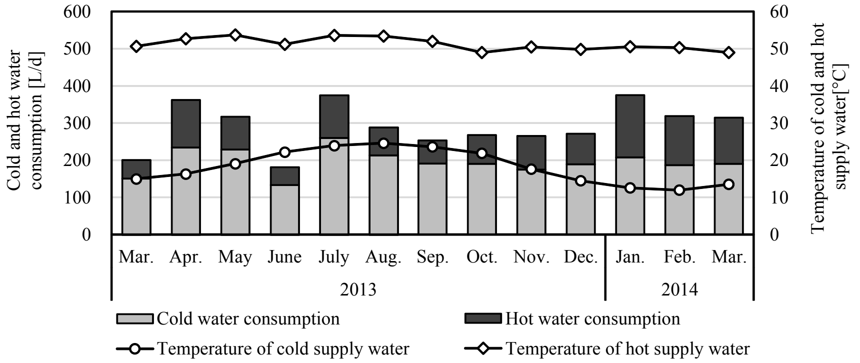


Figure 4 - Cold and hot water consumption per day in each month (Guest room TS)

Figure 5 shows the average values of cold and hot water consumption per day in each guest room throughout the year. These average values show about 200-300L per day and per guest room. The twin room TS has larger value than these of other single guest rooms. The past investigation shows the average value of 281L per day for the single room in business hotel [3]. The value of room SD is closely to that in the past investigation. However, in the case of our past investigation, the value of twin room in a city hotel shows about twice as 700L per day and per guest room [1]. The authors discussed in the past paper that the large consumption in the city hotel depended on two people usage per guest room and actions of taking shower and body washing at the outside space of bathtub. The differences of the consumption among the four single rooms are influenced by the specifications of water-saving plumbing fixtures that are set up in each guest room. The detail of differences will be discussed at the next chapter.

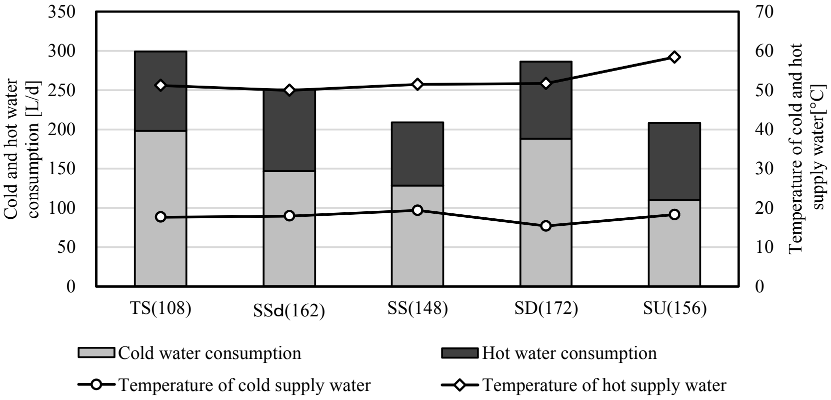


Figure 5 - Average values of cold and hot water consumption per day in each guest room

4.2 Analysis of cold and hot water consumption based on the characteristics of guests

When the authors analyzed the data of hot and cold water consumption based on the characteristics of guests, not only the days of recording unusual usage of water but also the water consumption for cleaning of equipment in the guest room and for the continuous staying were excluded. The distinction of cold and hot water consumption between the operation of faucet at bathtub and the usage of shower device was estimated by the time of flowing and flow rates.

Figure 6 shows the average values of cold and hot water consumption by the characteristics of guests as the examples of guest room TS and SS. The consumption by two people staying in a guest room was analyzed with male and female together because of the small number of samples. On the past investigation in a city hotel, the value of cold and hot water consumption by female was larger than that of male. However, as shown in Figure 6, the results of this investigation don't have distinct difference for the consumption between female and male.

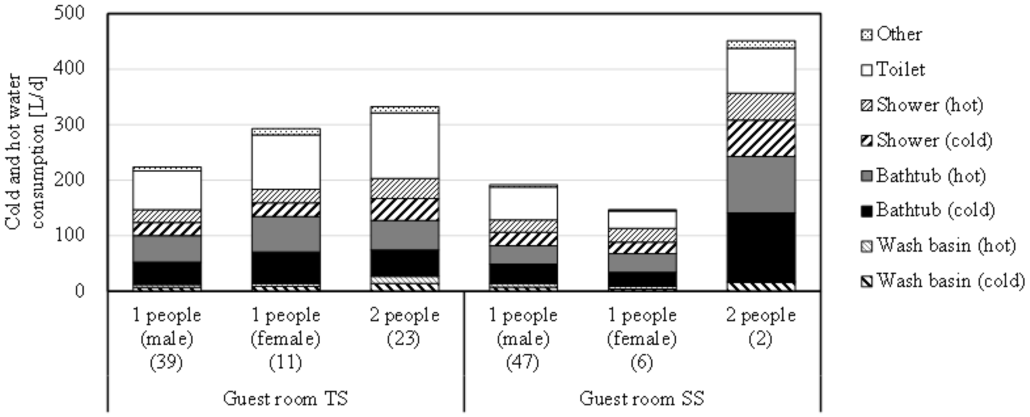
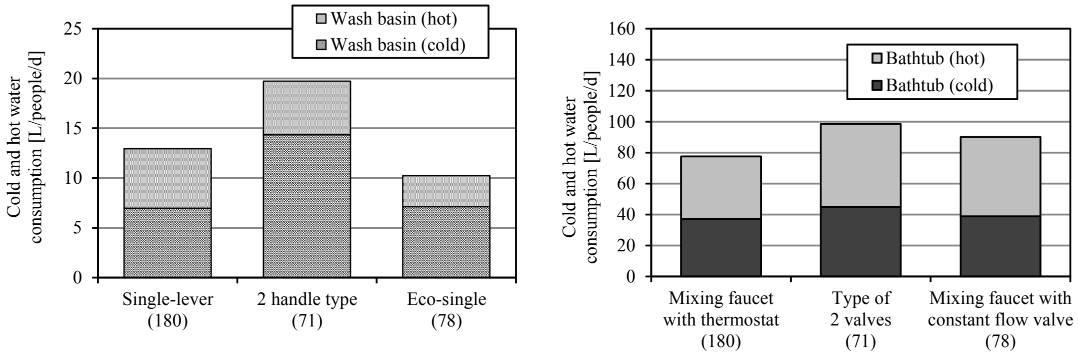


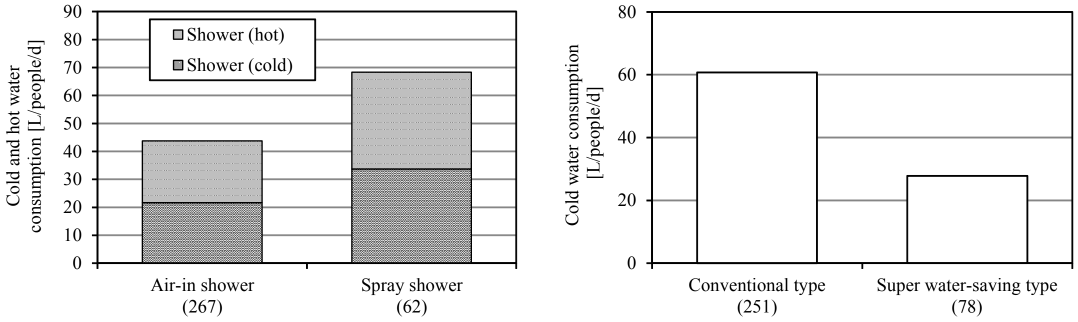
Figure 6 - Average values of cold and hot water consumption by the characteristics of guests (Guest room TS and SS)

5. Discussion on the Values of Cold and Hot Water Consumption Based on the Specifications of Plumbing Fixture

In this chapter, the authors make the evaluation of water-saving effects on cold and hot water consumption in the guest rooms which are set up with the plumbing fixtures produced by several specifications. As for the unit values of cold and hot water consumption per people and per day, Figure 7 and Figure 8 show the average values by the distinction based on the specifications of plumbing fixture and by each guest room respectively. In the case of Figure 7, the values of consumption in each fixture usage are calculated by the classified guest rooms set up with the same plumbing fixture.



a) Wash Basin b) Bathtub



c) Shower d) Toilet

Figure 7 - Average values of cold and hot water consumption with distinction of the specifications of plumbing fixture

In comparison with the consumption of each usage shown in Figure 7, the clarified contents are as follows;

As for the usage of faucet at wash basin, the consumption by two handle type shows the largest value, and Eco-single lever shows the smallest value. When we compare the values of cold water between Eco-single lever and Single-lever, there is no difference between these faucets. However, the values of hot water consumption show the remarkable difference. From these results, it will be grasped that the Eco-single lever is useful to save the energy for hot water supply systems.

As for the usage of bathtub, the consumption by the mixing faucet with thermostat shows the smallest value, and type of two valves shows the largest value. It is difficult to find out a high effect of saving energy by setting up the constant flow valve because we suppose that the guests don't have sufficient knowledge to use the function. The shower head with Air-in device has a very high effect of saving for cold and hot water in comparison with the conventional spray type.

As for the usage of toilet, the super water-saving type shows remarkable reduction of water consumption for flushing. The average values of water consumption per people and per day are 60.7L by conventional type, and 27.8L by super water-saving type.

From the results of cold and hot water consumption shown in Figure 8, the differences among the guest rooms can be discussed as follows.

On the total values of cold and hot water consumption per people and per day in the distinction of guest rooms, the single and up-grade room SU shows the smallest value of cold and hot water consumption. The single standard room SS is next saving type of cold and hot water consumption. The single down-grade room SD has large values by usage of toilet and bathtub faucet. Also, the single standard room SSd with spray type of shower head shows large values by usage of taking shower and toilet. Therefore, the both guest rooms; SD and SSd, show larger total values of cold and hot water consumption in comparison with the other guest rooms.

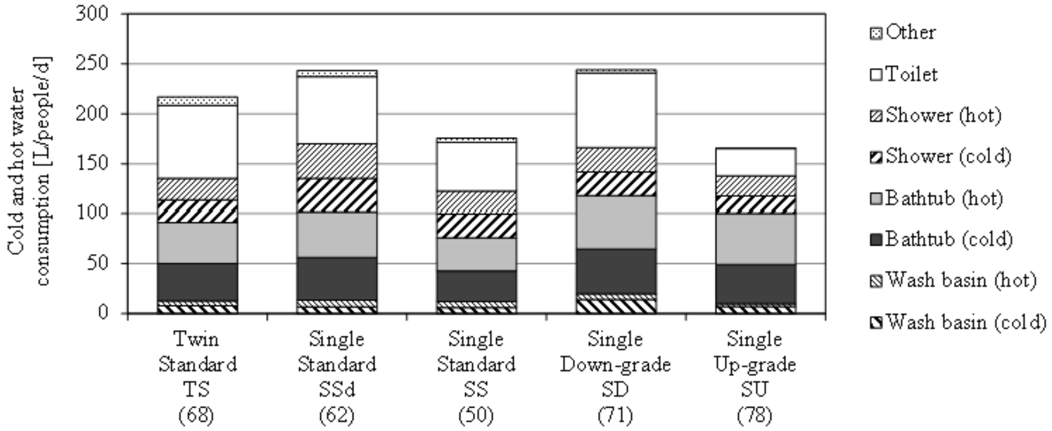


Figure 8 - Average values of cold and hot water consumption in each guest room

6. Conclusion

In order to clarify the cold and hot water consumption and the effects of water-saving plumbing fixtures in business hotel, the authors carried out the investigation for five guest rooms in a business hotel throughout the year. In this paper, the authors analyzed the fluctuations of cold and hot water consumption, and the behaviour of cold and hot water usage in each guest room which was set up with the conventional or water-saving plumbing fixtures. As for the analyzd results, remarkable differences of cold and hot water consumption between the conventional types and the water-saving types of plumbing fixture were confirmed distinctly.

Based on the results, the authors will analyze more detail for behaviour of cold and hot water usage in each guest room, and will have plan to construct the calculation models for dynamic simulation method to estimate accurately cold and hot water consumption in business hotel.

Acknowledgment

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8. Presentation of Author

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Development of the Calculating Method for the Loads of Cold and Hot Water Consumption in a Business Hotel (Part 2) Dynamic Estimation for the Loads of Cold and Hot Water Demands

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Abstract

As previously reported, the authors carried out the measurement for the loads of cold and hot water consumption of the five guest rooms in a business hotel from March, 2013 to March, 2014. In the previous paper, the daily loads of cold and hot water consumption were analyzed by the characteristics of guests and plumbing fixtures.

In this paper, the cold and hot water usage in the guest rooms are discussed. The authors analyze the frequency of fixture usage, duration time of water discharge, flow rates and temperature of water usage in each fixture. Based on these analyzed results, the authors intend to develop the cold and hot water usage models in the guest room of business hotel for the dynamic calculation method.

As the results, the peak hour of the frequency of each fixture usage appears in the morning in the case of business hotel. On the other hand, the peak hour of the frequency of taking shower and bathtub usage appears in the night in the case of city hotel. The patterns of fixture usage are different between business hotel and city hotel. In addition, the authors propose the cold and hot water usage models for calculation of cold and hot water consumption. The loads of cold and hot water demands in time series for business hotel are calculated by using the method applied the Monte Carlo Simulation technique that is referred to as the MSWC program. The effects of saving cold and hot water are verified by the dynamic simulation methods.

Keywords

Hotel; Cold and hot water consumption; Water-saving fixture; Dynamic estimation

1 Introduction

We have two kinds of methods for estimation of cold and hot water demands in building. One is presented as the daily standard unit values per people or per square meter to the floor area in building, which are used for the design of the capacity of break tank, storage tank, etc. Another is presented as the instantaneous maximum flow rates, which are used for the design of cold and hot water supply networks of piping systems. Recently, the direct water supply pumping up systems are increasing in the high-rise commercial and residential building. And the high accuracy for estimation of instantaneous flow rates is required for energy saving in the design of plumbing. However, there is no correlation between the two estimation methods that are mentioned above. Also, the estimation values have been point out the over-specification to design of plumbing systems because of being on the increase of setting up water saving equipment in building.

Therefore, S.Murakawa and H.Takata et al. have developed the estimation methods for the loads of cold and hot water consumption, which are presented in the international symposium of CIB-W062 from [1] to [11]. The method is applied for the design of cold and hot water supply systems based on the estimation of instantaneous flow rates, hourly and daily loads in each usage through a day by applying the Monte Carlo simulation technique. Now, they are working to promote the calculation methods that has been developed as the MSWC (Murakawa's Simulation for Water Consumption) program.

In this paper, the authors set up the calculation models for business hotel based on the investigation results which were analysed in a business hotel mentioned previous paper as part 1. And, the loads of cold and hot water consumption are estimated by using the MSWC program. On the basis of the calculation results, the authors discuss the effects of saving cold and hot water when we set up the water-saving fixtures instead of the conventional types, and show the characteristics of cold and hot water consumption in the guest rooms of business hotel.

2. Outline of the Dynamic Simulation Methods

It is very useful for design of plumbing systems to grasp the fluctuations of water supply loads with one minute interval through a day. The dynamic estimation methods are only possible by applying the technique which is simulated with the people's behavior of water usage in building. The significance and procedure to apply the dynamic estimation methods were explained in the 40th CIB-W062 international symposium by S.Murakawa, et al. [11]. However, to make easy understand of this paper, the authors describe the outline of the dynamic simulation methods.

As for setting up the simulation models at first, we have to grasp the occurrences of fixture usage through a day, which are processed with the hourly frequency of fixture usage. The intervals of water usage are taken account of random operations for setting time zone such as one hour. In this case, the arrival ratios for using fixture or water [number of people/minute] are closely to the Poisson distribution, namely, the intervals of occurring time show the exponential distribution. Next, it is required to grasp the phenomena for operating fixtures in details such as duration time of water discharge, flow rates, using temperature of cold and hot water, etc. These results are analyzed statistically, and summarized with the average values and distributions. The simulation models are modified easily based on the measurement basic data in each country having the unique culture of water uses. Figure 1 shows the schematic occurrence of water demands and examples of flow rates in a guest room of city hotel. Based on the calculation models in each fixture usage, the simulation of water demands is carried out by generating random numbers in a computer according to the distribution of fixture usage. The outlines are shown in Figure 2.

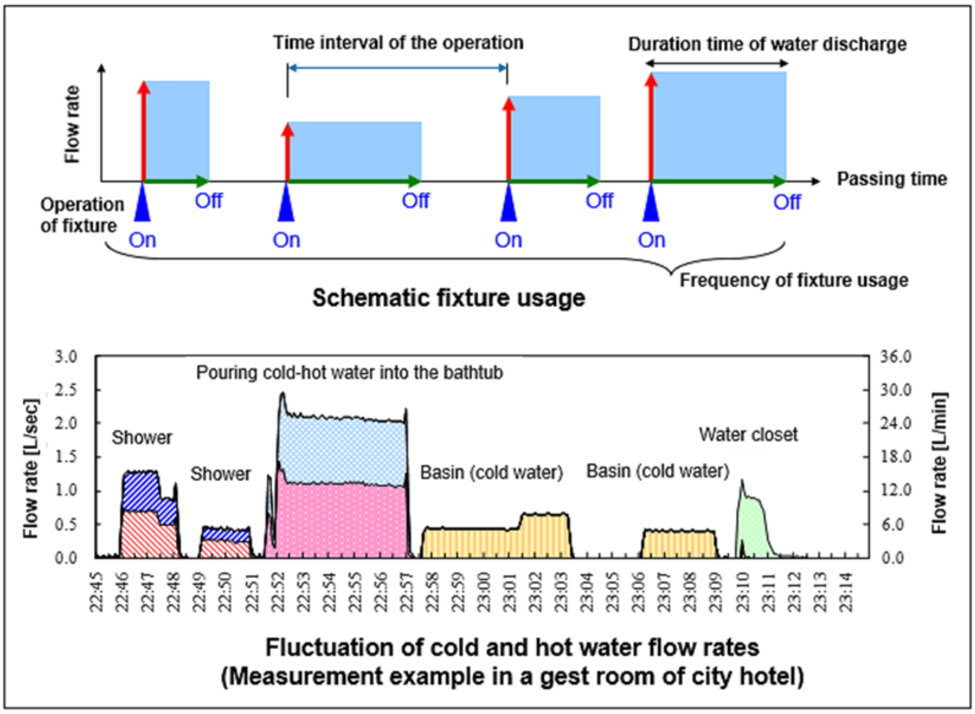


Figure 1 - Schematic occurrence of water demands and measurement of flow rates

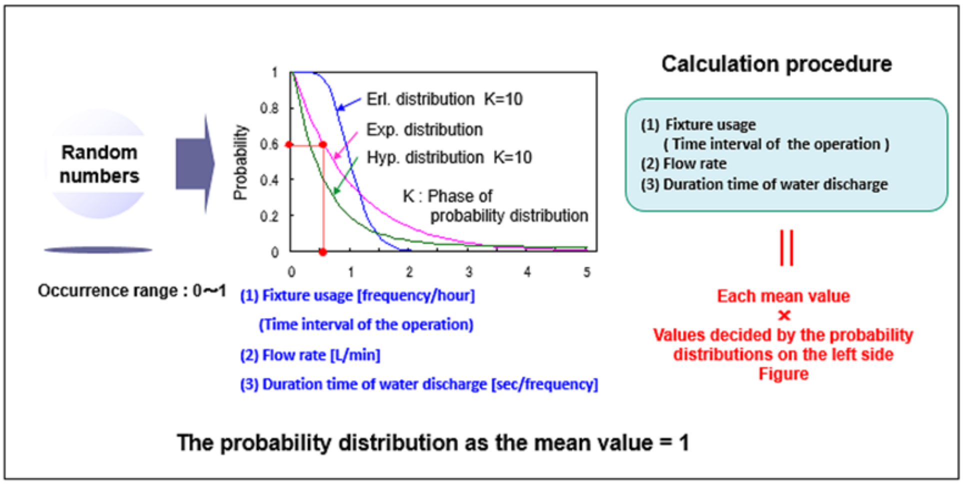


Figure 2 - Outline of the simulation based on the Monte Carlo technique

Usually, the simulation is carried out one hundred trials in classification of every hour through 24 hours. The behavior of fixture and water usage is detected with 0.1 second or 1.0 second interval depended on the required accuracy. The water demands are summarized with one minute interval as data bases. Under the basic values of one minute interval, the maximum flow rate, hourly and daily water consumption can be calculated statistically.

3. Analysis of Cold and Hot Water Usage in the Guest Rooms

As shown in Figure 1, each fixture usage in the guest rooms is analyzed based on the measurement data.

The frequencies of fixture usage are counted with opened and closed operation for one time flowing of water. And also, flow rates [L/min] and duration time of water discharge [sec] are checked per frequency of each operation. The flow rates by taking shower or by discharging into bathtub are distinguished by the situation of flow rates and the frequencies of fixture operation because both the flow rates are measured with one water-meter. The flow rates of shower head with constant flow regulating valve are the upper-limit of 7.4 L/min, and the flow rates of spray shower head with non-constant valve have the optimum value of 8.5 L/min.

The frequencies of fixture usage per day, flow rates, duration time of water discharge and temperature of water usage are analyzed on the basis of data which were measured in five guest rooms. Table 1 shows the statistical values which were analyzed in each fixture usage. The frequencies of fixture usage and temperature of water usage have different values among the three seasons which are winter, middle and summer. However, the values of flow rates and duration time of water discharge per operation are totalized with the data throughout the year because it is difficult to find out the differences of fixture usage among the three seasons. The approximate distributions for the duration time of water discharge, flow rate and temperature of water usage in each fixture are shown with one of Exponential distribution, Erlang distribution and Hyper-exponential distribution. These approximate distributions and cumulative frequency distributions calculated by the measurement data are shown in Figure 3, Figure 4 and Figure 5 as some examples of each fixture usage. The distributions for temperature of water usage in Figure 5 were processed with all samples throughout the year.

Table 1 - Statistical values and distributions for cold and hot water usage in each fixture

Item	Fixture		Frequency of usage [times/day]				Duration time [sec]		Flow rate [L/min]		Temperature [°C]							
			Total	Winter	Middle	Summer	Avg. value	Distribution	Avg. value	Distribution	Total	Distribution	Winter	Distribution	Middle	Distribution	Summer	Distribution
Toilet	Water closet; conventional type	Cold water	4.9	4.8	5.1	4.8	90	Erl.20	9.5	Erl.20	18.6	Erl.20	14.0	Erl.10	19.1	Erl.50	22.6	Erl.100
	Water closet; super water-saving type	Cold water	6.1	5.9	6.5	5.9	43	Erl.100	6.7	Erl.100	20.1	Erl.20	16.0	Erl.20	20.8	Erl.50	23.4	Erl.100
Wash basin faucet	Two handle type	Total	9.7	11.0	7.5	10.5	22	Hyp.2	4.5	Erl.3	22.1	Erl.3	18.4	Erl.3	22.0	Erl.5	26.5	Erl.10
		Hot water	0.5	0.5	0.2	0.9	18	Hyp.3	3.4	Erl.3	60.0	Erl.100	60.0	Erl.100	60.0	Erl.100	60.0	Erl.100
		Cold water	7.6	8.1	5.6	8.8	13	Exp	4.2	Erl.3	16.9	Erl.10	11.4	Erl.10	17.3	Erl.30	22.4	Erl.100
		Cold and Hot water	1.6	2.3	1.7	0.8	66	Exp	6.5	Erl.5	33.6	Erl.10	34.1	Erl.10	32.9	Erl.10	33.1	Erl.30
	Single-lever	Total	11.6	11.1	13.0	10.6	20	Hyp,2	3.0	Erl.2	37.1	Erl.10	35.1	Erl.5	38.1	Erl.10	37.9	Erl.10
		Hot water	1.4	1.1	2.1	1.1	16	Hyp.3	1.5	Exp	57.2	Erl.100	60.0	Erl.100	57.4	Erl.100	54.0	Erl.100
		Cold water	2.3	2.4	2.4	2.2	13	Hyp.2	2.7	Erl.2	19.0	Erl.20	15.1	Erl.20	18.9	Erl.50	23.6	Erl.100
		Cold and Hot water	7.8	7.6	8.5	7.3	23	Hyp.2	3.4	Erl.3	38.8	Erl.20	38.0	Erl.20	38.8	Erl.20	39.8	Erl.50
	Eco-single lever mixing faucet	Total	10.7	9.7	14.5	9.4	19	Hyp.3	2.4	Erl.3	26.9	Erl.5	25.0	Erl.3	26.3	Erl.5	29.1	Erl.10
		Hot water	0.6	0.4	0.8	0.6	7	Hyp.2	0.9	Exp	60.0	Erl.100	60.0	Erl.100	60.0	Erl.100	60.0	Erl.100
		Cold water	7.0	5.6	10.1	6.5	12	Hyp.2	2.1	Erl.3	19.9	Erl.20	15.4	Erl.10	19.7	Erl.50	23.2	Erl.100
		Cold and Hot water	3.1	3.8	3.6	2.3	38	Hyp.3	3.3	Erl.5	36.7	Erl.20	35.7	Erl.20	37.5	Erl.30	37.5	Erl.30
Shower	Spray shower	Cold and Hot water	3.4	3.4	3.8	2.8	162	Hyp.2	9.5	Erl.5	38.4	Erl.50	39.8	Erl.100	38.1	Erl.100	36.6	Erl.100
	Air-in shower	Cold and Hot water	3.0	2.7	3.5	2.9	176	Hyp.2	5.7	Erl.20	40.3	Erl.50	41.4	Erl.50	40.6	Erl.50	38.8	Erl.50
Bathtub faucet	Type of two valves	Cold and Hot water	1.6	1.5	1.9	1.5	242	Exp	24.9	Erl.5	39.4	Erl,10	41.3	Erl,10	38.1	Erl,10	37.4	Erl,20
	Mixing faucet with thermostat	Cold and Hot water	1.8	1.6	2.1	1.6	291	Hyp.2	18.7	Erl.5	40.0	Erl.100	42.2	Erl.100	40.0	Erl.100	38.4	Erl.100
	Mixing faucet with constant flow valve	Cold and Hot water	2.2	2.2	2.4	2.2	185	Exp	19.7	Erl.20	41.7	Erl.100	42.6	Erl.100	41.1	Erl.100	41.0	Erl.100

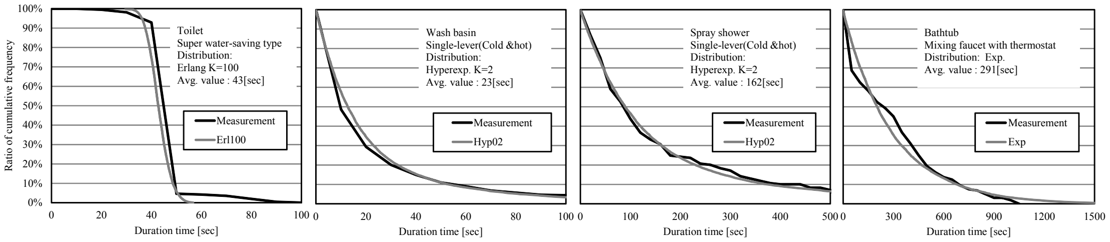


Figure 3 - Cumulative frequency distributions and approximate distributions for the duration time of water discharge in each fixture

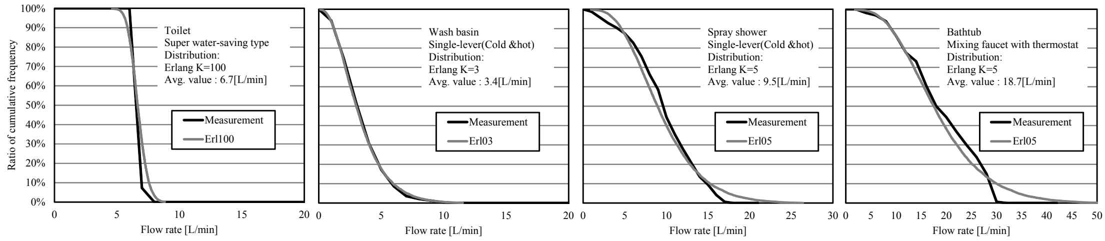


Figure 4 - Cumulative frequency distributions and approximate distributions for the flow rate in each fixture

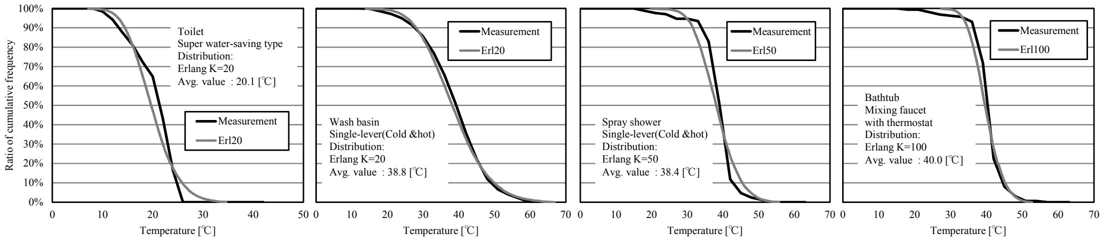


Figure 5 - Cumulative frequency distributions and approximate distributions for the temperature of cold and hot water usage in each fixture

4 Construction of the Simulation Models

As shown in Table 1, the frequency of fixture usage and the temperature of water usage are totalized in each season. However, there are not sufficient samples to set up the simulation models in each season. In this paper, the simulation models are set up with all samples throughout the year. As for the water closet, not only conventional type; flushing volume of 13L, and super water-saving type; flushing volume of 4.8L, which are installed in the business hotel, but also standard type of water-saving; flushing volume of 8L, are applied for the models to calculate the loads of water consumption. The flow rates of conventional and standard type, and super water-saving type are applied with the values of 20L/min and 7L/min respectively, which are decided with reference to the measurements and manufacture's catalogues. The frequencies of using toilet in one room are set up with five times per day, and the number of operations for flushing per occupancy are set up with the unified number of 1.1 times though the different types of water closet. The each temperature of cold and hot supply water is set up at 18 degrees Celsius and 60 degrees Celsius respectively. In the case of cold and hot water that is directly used at the fixture outlet, the heat loss of the pipe lines is not supposed for the calculation.

Table 2 shows the simulation models to estimate the loads of cold and hot water consumption, which are constructed on the basis of the results shown in Table 1. In each of the single room that is subject for the calculation of water consumption, the installed fixture types are put with circles on the table. Also, the conventional type, standard water-saving type and super water-saving type are added to the subjects of single room, which are installed by the fixtures marked with circle on the table.

Table 2 - Calculation models of cold and hot water consumption in each fixture and each room type combined with different fixtures

Item	Fixture		Frequency of usage [times/day]	Duration time [sec]		Flow rate [L/min]		Temperature [°C]	Guest room						
				Average value	Distribution	Average value	Distribution		SSd	SS	SD	SU	Conventional type	Standard water-saving type	Super water-saving type
Toilet	Water closet; conventional type	Cold water	5.0	39	Erl.20	20.0	Erl.20	18.0	○	○	○		○		
	Water closet; standard water-saving type	Cold water	5.0	24	Erl.20	20.0	Erl.20	18.0						○	
	Water closet; super water-saving type	Cold water	5.0	41	Erl.20	7.0	Erl.20	18.0				○			○
Wash basin faucet	Two handle type	Hot water	0.5	18	Hyp.3	3.4	Erl.3	60.0			○		○		
		Cold water	7.6	13	Exp	4.2	Erl.3	18.0							
		Cold and Hot water	1.6	66	Exp	6.5	Erl.5	33.6							
	Single-lever	Hot water	1.4	16	Hyp.3	1.5	Exp	60.0	○	○				○	
		Cold water	2.3	13	Hyp.2	2.7	Erl.2	18.0							
		Cold and Hot water	7.8	23	Hyp.2	3.4	Erl.3	38.8							
	Eco-single lever mixing faucet	Hot water	0.6	7	Hyp.2	0.9	Exp	60.0				○			○
		Cold water	7.0	12	Hyp.2	2.1	Erl.3	18.0							
		Cold and Hot water	3.1	38	Hyp.3	3.3	Erl.5	36.7							
Shower	Spray shower	Cold and Hot water	3.4	162	Hyp.2	9.5	Erl.5	38.4	○				○	○	
	Air-in shower	Cold and Hot water	3.0	176	Hyp.2	5.7	Erl.20	40.3		○	○	○			○
Bathtub faucet	Type of two valves	Cold and Hot water	1.6	242	Exp	24.9	Erl.5	39.4			○		○		
	Mixing faucet with thermostat	Cold and Hot water	1.8	291	Hyp.2	18.7	Erl.5	40.0	○	○				○	○
	Mixing faucet with constant flow valve	Cold and Hot water	2.2	185	Exp	19.7	Erl.20	41.7				○			

The hourly frequencies of each fixture usage as the percentage to the total frequency per day are shown in Figure 6, Figure 7, Figure 8 and Figure 9-a), b), c). Peak hourly zones of using water closet, taking shower and using wash basin appear in the morning from 6:00 a.m. to 9:00 a.m. The hourly ratios of using bathtub faucet show about 10-15 percentage both of in the morning and night. These tendencies are different from the investigation results for the city hotel that was carried out in the past [4] [7]. In the case of the city hotel, the loads of cold and hot water consumption in the night were larger than the loads in the morning. The hourly frequency of fixture usage in a guest room is calculated by multiplying the total frequency per day to the each percentage of fixture usage shown from Figure 6 to Figure 9.

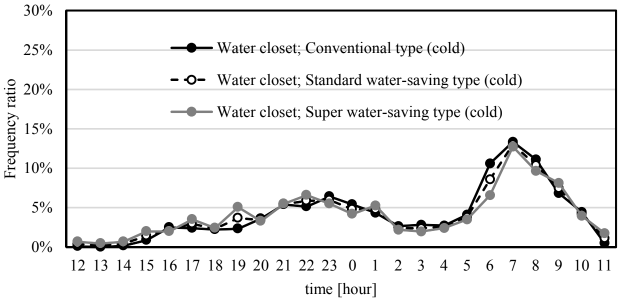


Figure 6 - Models of hourly frequencies of using toilet

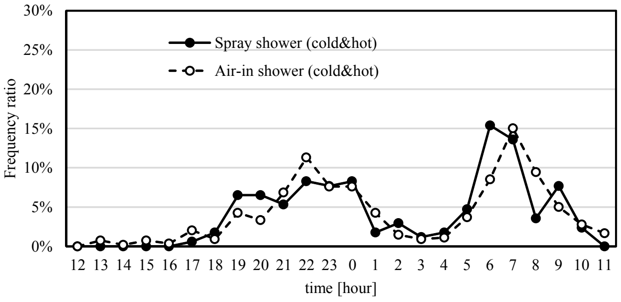


Figure 7 - Models of hourly frequencies of taking shower

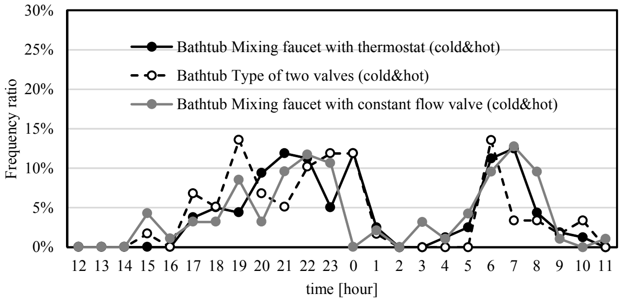
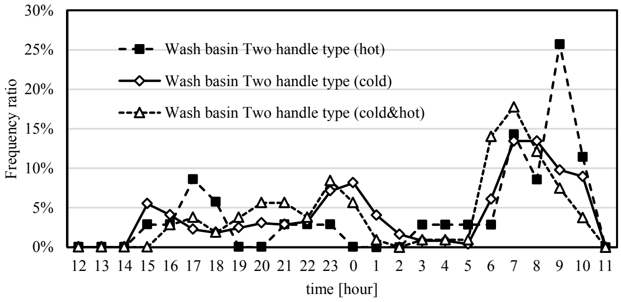
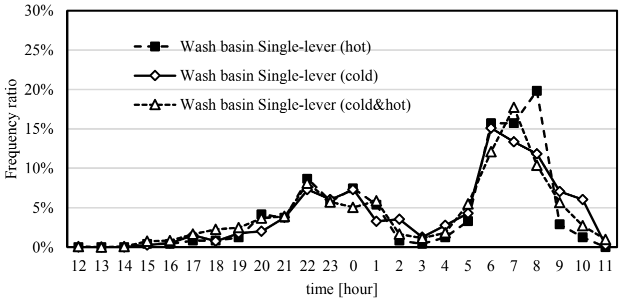


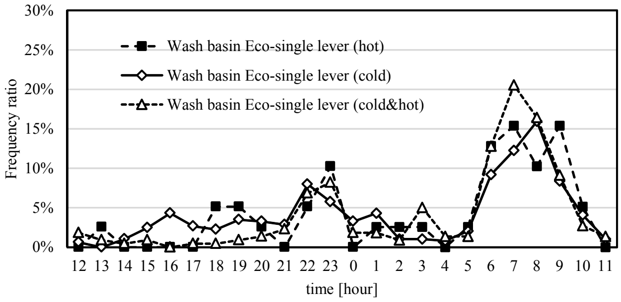
Figure 8 - Models of hourly frequencies of using bathtub faucet



a) Type of two valves



b) Type of single lever



c) Type of Eco-single lever

Figure 9 - Models of hourly frequencies of using wash basin faucet

Incidentally, the values of each fixture shown in Table 1 and Table 2 were totalized with the values that were extracted exactly from the fixture usage throughout the year. Probably, there are some guests without taking shower or bath in accommodation overnight. Therefore, the authors suppose that the calculation results of cold and hot water consumption by using the models show larger values than the measurement results shown in the previous paper as Part 1.

5. Dynamic Calculation Results by Simulation

5.1 Comparison with the simulation and measurement results

Based on the simulation models shown in Chapter 4, the authors calculate the loads of cold and hot water consumption by using the MSWC program.

The calculation results for seven types of the single room are shown in Table 3 and Figure 10 in comparison with the measurement results. The simulation results present the average values per room that are calculated by ten single rooms consisting of same kind of plumbing fixtures. The simulation is carried out under the conditions shown in Table 2 and from Figure 6 to Figure 9. The calculation values show larger than the measurement values because we apply the calculation conditions of which the gusts use exactly the installed plumbing fixtures as being described at the last paragraph of Chapter 4.

Table 3 - Calculation and measurement results per room and per day in each type of single room

Guest room		SSd	SS	SD	SU	Conventional type	Standard water-saving type	Super water-saving type
Measurement	Cold and hot water consumption [L/room/day]	243.4	175.5	244.0	165.6			
Simulation	Cold and hot water consumption [L/room/day]	303.0	265.9	305.7	220.2	347.7	280.2	231.9
	Cold water consumption [L/room/day]	185.1	164.6	190.0	114.2	213.1	160.7	125.7
	Hot water consumption [L/room/day]	118.0	101.3	115.8	106.1	134.5	119.5	106.1

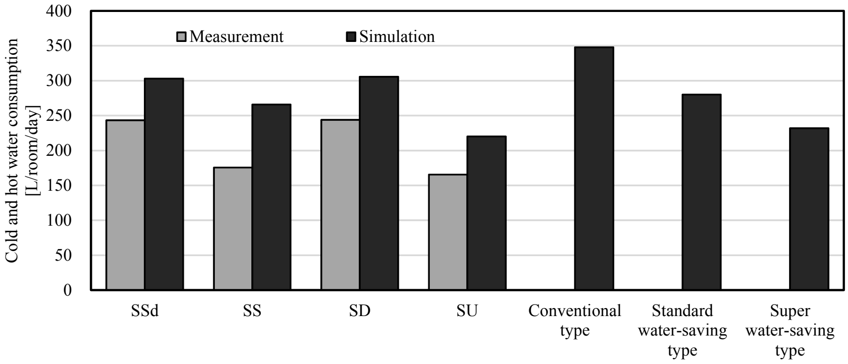


Figure 10 - Calculation and measurement results per room and per day in each type of single room

Figure 11 and Figure 12 show the hourly loads of cold and hot water consumption in each room type. The hourly peak values have not differences among four single rooms; SSd, SS, SD and SU. However, the single room SU has a little small peak value in the morning. As for the hourly peak value among the three types of single room, the conventional and super water-saving type has the largest and the smallest value respectively. These simulation trends also appear in the time zones of morning and night. The differences in the morning are particularly remarkable.

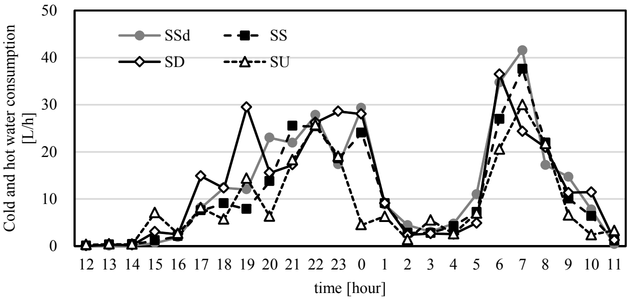


Figure 11 - Hourly calculation loads of cold and hot water consumption per room (In the case of guest room SSd, SS, SD and SU)

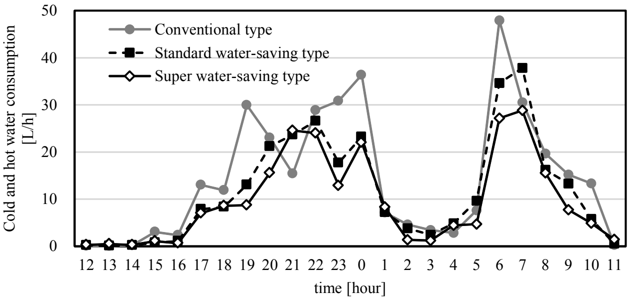


Figure 12 - Hourly calculation loads of cold and hot water consumption per room (In the case of conventional type, standard type and super water-saving type)

5.2 Comparison of the simulation results modified the same number of rooms in the subject hotel

Assuming the same number of rooms as 151 rooms in the subject hotel, the authors compare the effects of saving cold and hot water among the three types of single room which are installed with conventional type, standard type and super water-saving type.

As the calculation results of the business hotel, Figure 13 shows the comparison of cold and hot water consumption per day in each type of room. The total cold and hot water consumption of the standard type and super water-saving type show the decrease of 19.7% and 36.2% respectively against the conventional type. Each consumption of cold and hot water in the standard type and super water-saving type; decreased 25.1% and 11.1% respectively in the standard type, decreased 43.3% and 24.9% respectively in the super water-saving type, are grasped as the reference to the conventional type. These reduction ratios are different depending on the specifications of the plumbing fixtures.

Figure 14 shows the fluctuation of the hourly average loads of cold and hot water consumption in each plumbing fixture type. Both in the morning and night, the peak loads of cold and hot water consumption in the standard type and super water-saving type are lower than that of the conventional type.

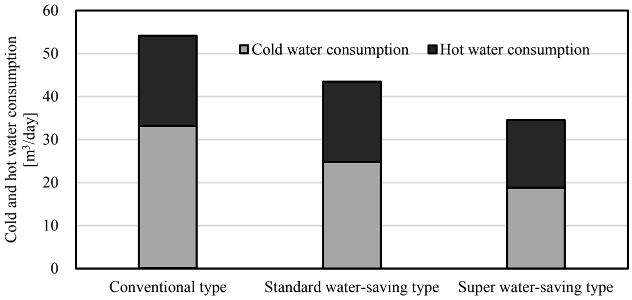


Figure 13 - Daily calculation loads of cold and hot water consumption in the business hotel composed of 151 single rooms which are distinguished from the three types

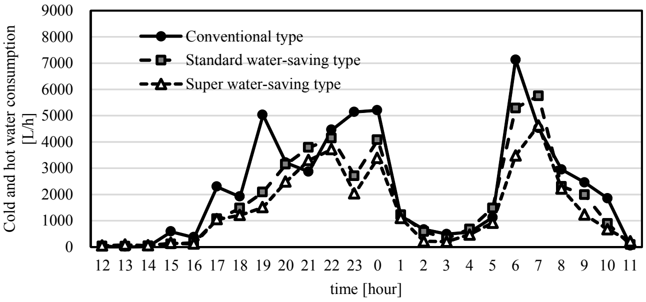


Figure 14 - Hourly calculation loads of cold and hot water consumption in the business hotel composed of 151 single rooms which are distinguished from the three types

As for the instantaneous flow rates per minute, the loads of cold and hot water consumption have been statistically calculated for each hourly time zone. The values of the maximum and failure factor; 0.1, 0.2, 1, 5 and 10%, in each hourly time zone are shown in Figure 15, Figure 16 and Figure17. Also, Figure 18 shows the values of the maximum and each failure factor that appear in the peak time zone of morning and night. On the instantaneous loads of the maximum and failure factors among the three types of single room, the conventional and super water-saving type has the largest and the smallest value respectively both in the morning and night. The values of failure factor 0.2% in the standard type and super water-saving type show the decrease of 14.4% and 25.1% respectively against the conventional type in the peak time zone of morning.

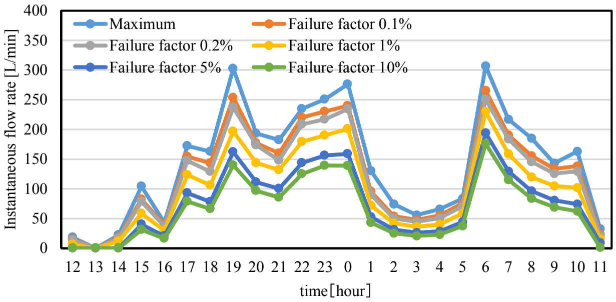


Figure 15 - Instantaneous flow rates of the maximum and each failure factor in the case of the conventional type composed of 151single rooms

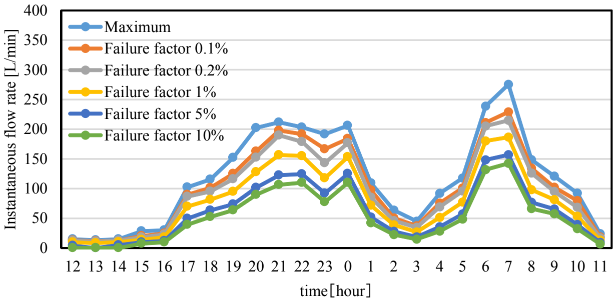


Figure 16 - Instantaneous flow rates of the maximum and each failure factor in the case of the standard type composed of 151single rooms

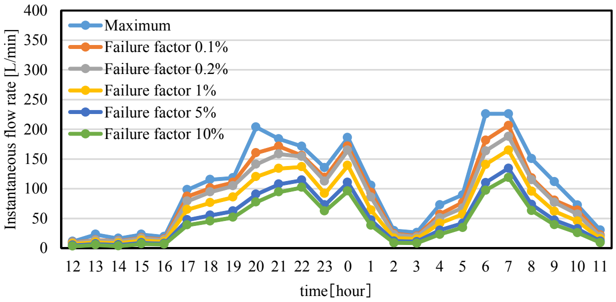


Figure 17 - Instantaneous flow rates of the maximum and each failure factor in the case of the super water-saving type composed of 151single rooms

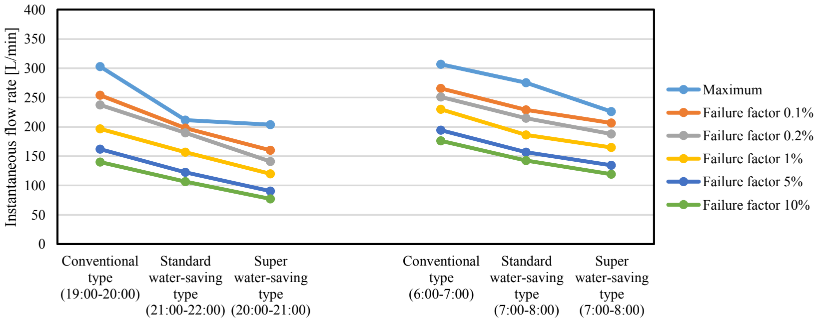


Figure 18 - Instantaneous flow rates of the maximum and each failure factor in the peak time zones of morning and night

6. Conclusion

In this paper, the authors constructed simulation models to estimate the loads of cold and hot water consumption in business hotel based on the investigation results for the guest's behavior of water usage in the five rooms of the subject hotel throughout the year. The results are as follows.

Based on the analysis of plumbing fixtures usage which were installed with the different specifications, the values of frequency of fixture usage, duration time of water discharge, flow rate and temperature of cold and hot water usage were statistically clarified.

The simulation models to apply the MSWC program for the estimation of the dynamic loads of cold and hot water consumption through a day were constructed for business hotel consisting of single rooms. In the case of business hotel, it was clarified that the peak values of fixture usage appeared in the morning although the peak values of city hotel appeared in the night.

In comparison with the simulation results and measurement results in the single rooms, the differences were supposed that the measurement values in the subject business hotel were included guests without taking shower or bathtub usage. Therefore, the authors consider that the suggested conditions for simulation indicate the safe side for the design of plumbing systems.

Assuming the three types of single room which were installed with the different specifications of plumbing fixtures under the same scale of the subject business hotel composed of 151 rooms, the authors attempted the simulation and clarified the effects of saving cold and hot water. It was confirmed that the MSWC program was useful for the estimation of the dynamic loads of cold and hot water consumption in business hotel.

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8. Presentation of Author

Dr. Saburo Murakawa is the Emeritus Professor of Hiroshima University. His special fields are building and city environment engineering, plumbing engineering and environmental psychology. He is now making a contribution to spread the new dynamic calculation methods for cold and hot water consumption in building that is referred to as the MSWC program.

Shower Comfort in Different Water Supply Pressure Conditions in Taiwan

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Abstract

Water pressure always impacts the performance of water supply, especially shower period is often longer than other water using behavior in the residential building. Gravity and pressured water supply system for residential buildings are mostly adopted in Taiwan. The water supply pressure usually relates with the users' physiological and psychological sensation. This study focuses on the users' sensation（Concentrated, Dense, Soft）in shower comfort with different water supply pressure conditions. The investigation hold in Taipei (pressure ＞ 0.1MPa) and Taichung (pressure ≦ 0.1MPa) via questionnaire and measurement to compare the shower comfort in different water supply pressure conditions. The results show that the samples with Concentrated Sensation are long-term staying in high water supply pressure conditions, and the samples with Dense Sensation are long-term staying in low water supply pressure conditions. The original water supply pressure conditions involve the shower head selected with Concentrated Sensation or Dense Sensation by users.

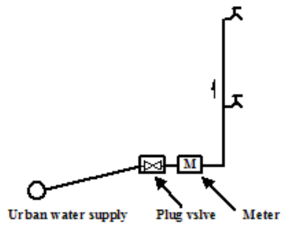
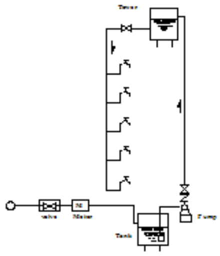
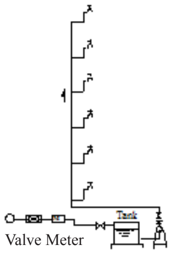
Keywords

Shower comfort sensation, water supply pressure conditions, investigation, shower head selected

1. Introduction

Water pressure always impacts the performance of water supply, especially shower period is often longer than other water using behavior in the residential building. The main kinds of water supply system for residential buildings in Taiwan is organized as Table 1. As the direct water supply system, water is supplied by direct urban water system that controlled by water department. Gravity water supply system which serves water downward from rooftop tower is mostly adopted in Taiwan. However, there' s often lack of decompression installation and relay pumps, and some plumbing were improper set. For these reasons, residents in different floor use water of pressure. Sometimes, for example, water pressure upstairs is smaller when water downstairs is used, or water pressure in the bathroom is smaller when water in the kitchen is running on the same floor. Therefore, the heated water may get cooler when the gas heater shuts down due to unstable water pressure.

Table 1 Feature of water supply system and defect

Types	Direct water supply	Gravity water supply	Pressurized water supply
Diagram			
Illustration	Water is supplied by direct urban water system and is controlled by water department.	Water supply system serves water downward from rooftop tower by gravity.	Water supply system serves water upward from underground level or basement tank.
Defect	Users at the end of the system may not be served with normal water pressure.	Water pressure upstairs is smaller than downstairs, causing of low water head.	Water pressure is unstable when other faucets are used.

According to the standard of urban water pressure by water department in Taiwan, 1.5-4.0 kg/cm^2 is the suitable pressure of water supply. The water pressure is also dedicated by direct water supply system, as listed on Table 2. But most designers consider the piping joints and equipment damaged by large water pressure, they usually design the pressure under 1.0kg/cm^2 by gravity and pressurized water supply system for conservation in Taiwan. The standards of water supply pressure in other countries are marked in Fig. 1, some standards only regular high water supply pressure, such as Water Sense (US, CA) and GB (China), some include high water supply pressure and low water supply pressure, such as WELS (AU, NZ) and Eco Label (EU).

Table 2 Water pressure dedicated by direct water supply system

Floor height	Under 3 floor	Under 4 floor	Under 5 floor	Under 6 floor
Pressure (kg/cm^2)	1.5-2.0	2.0-2.5	2.5-3.0	3.0-3.5

The field survey was measured in nine different flats with different height of floor, the water supply systems are gravity and pressurized water supply system in this nine buildings. The results are marked in to the diagram of different water saving standard, as shown on Figure 1. Figure 1 shows the water pressure and flow rate in the building with gravity and pressurized water supply system are under 1.0 kg/cm^2 (0.1MPa) and 9L/min. They all belong to the low water pressure zone. It means to develop the high performance shower head with low water pressure, Taiwan should be a choice to setup the different type shower head and get the objects vote in the comfortable one.

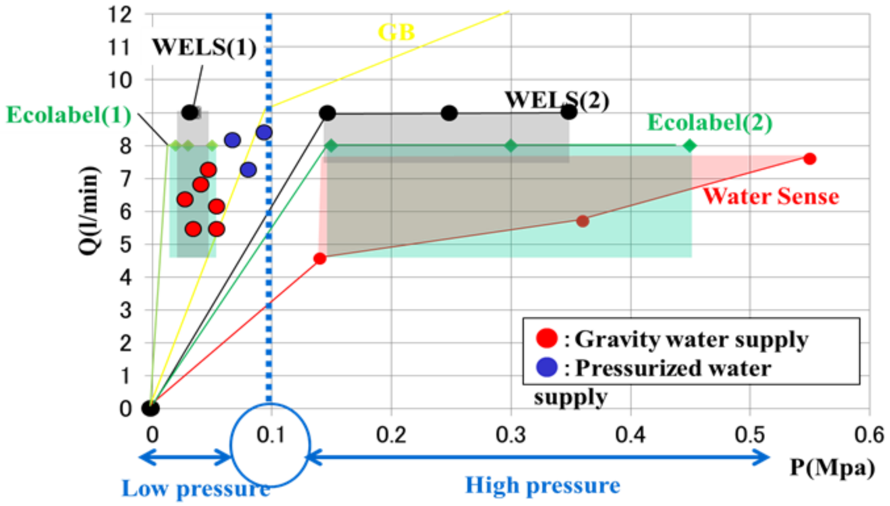


Fig. 1 Comparison between the field Survey results with other water saving standard

2. Methodology

To understand the shower comfort in different water supply pressure conditions in Taiwan. This study investigates the real site shower conditions with the Eco showers (ES) and the Investigated showers (IS) to compare the shower comfort of subjects in the same water supply pressure in each sample. The investigation was divided into field survey for physical parameters and questionnaire for user sensation, as shown in Fig. 2.

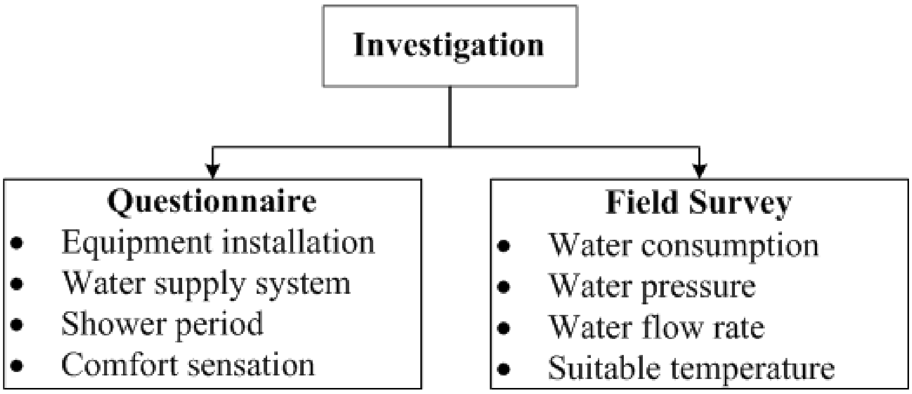


Fig. 2 Two phases of observation in investigation

Before field survey, 3 pre-tests were operated in 3 different residential buildings to confirm the operation steps and questionnaire. The measure instruments setup idea and real site installation were shown as Fig. 3, one pressure meter and one flow mater were installed higher than the faucet in every cases to measure the water supply pressure and flow rate in ES and IS. The test recorders were listed in water pressure, water supply types (gravity or pressurized) and located floor in the building, flow rate, temperature, shower period, and shower comfort sensation votes in ES and IS while showering. The shower water demands could be evaluated by water flow rate and shower periods. The water supply pressure could be checked by measured flow rate of ES, it could be double check the water pressure between measure device and shower head, because of resistance consideration, as shown in Table 3.

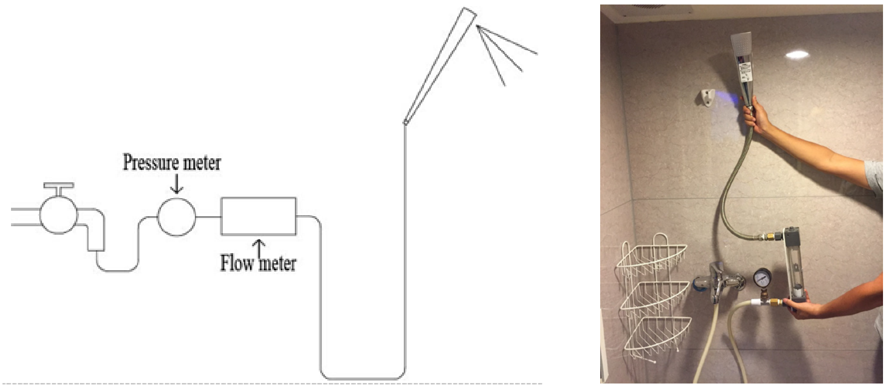
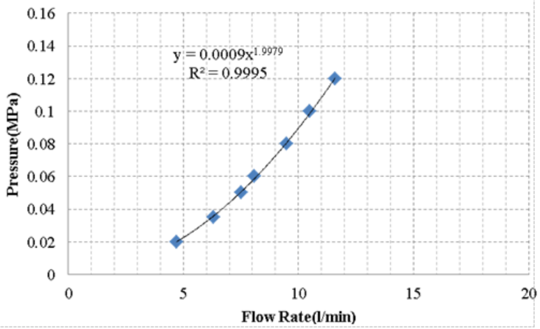


Fig. 3 Measure device schematic and field survey installation

Table 3 Water supply pressure could be checked by measured flow rate of ES

Water Pressure (MPa)	Flow Rate (L/min)	
0.02	4.7	
0.035	6.3	
0.05	7.5	
0.06	8.1	
0.08	9.5	
0.1	10.5	
0.12	11.6	

The questionnaire is divided into 3 parts, the first part is the basic water supply condition in the residential building, the second part is comfort sensation of subjects, the third part is the measuring values, as shown in Table 4.

Table 4 Questionnaire design

Part. 1 The water supply conditions in the residential building

1.What was the type of your dwelling?
2.How many floors does your residence have?
3.Which floor do you live?
4.What kinds of water supply system does your house have?

Part. 2 Shower comfort sensation of subjects

5. How well does the water flow“Soft Sensation”compared with your previous showerhead?
6. How well does the water flow“Dense Sensation”compared with your previous showerhead?
7. How well does the water flow“Concentrated Sensation”compared with your previous showerhead?

Part. 3 Measuring in water supply pressure, flow rate, temperature, and periods.

Measuring values Shower Head type	Water pressure (MPa)	Flow rate (L/min)	Temperature (℃)	Shower periods (Sec.)
NS				
IS				
ES				

3. Investigation

Confirmed the test steps and questionnaire, the test was operated for one week in each sample. This study totally investigated 44 households (includes 3 pre-test) in Taichung city (most high apartment with pressured supply water system) and Taipei city (most house with gravity supply water system) for different water supply pressure area. For getting more comfort sensation votes, 71 samples were investigated (33 in Taichung and 38 in Taipei) in 44 households. The 44 invested shower head types (IS) and 1 Eco shower head type (ES) are shown as Fig.4. This investigation was held on the summer days in hot and humid Taiwan, the average shower temperature was around 38℃ (depending on the ambient temperature) to reduce the temperature impact factors.

The process of this investigation is descripted as follow: The first step is measuring the water pressure and flow rate without any shower head (NS) then records the measuring values into the questionnaire. The second step is setting up the old shower head as IS to measure the water flowing conditions in the first and second day, and filled up the measured values and the using sensation. The third step is to exchange the shower head into the ES to measure the water flowing conditions to record every measured value in the questionnaire during third day to sixth day and filled up the measured values every day and filled up the final sensation of ES. The final step is uninstalled the measure devices on the seventh day. The investigation process is shown as Fig.5.

Fig. 4 1 Eco shower head type and 44 Investigated shower head types

Fig. 5 The field Survey was operated with measure device in different households

After field survey, the original water supply pressure measurement results (without any shower head) are analyzed by box-plot and show the different in Taipei and Taichung, as shown in Fig. 6.The average water pressure in Taipei is a little bit higher than it in Taichung, and the upper and lower quartile in Taipei is significant higher than it in Taichung. Most of water supply pressure in Taipei (pressure ＞ 0.1MPa) is higher than it in Taichung (pressure ≦ 0.1MPa), therefore we can compare the shower comfort sensation votes in two different water supply pressure areas. Also can organize the fit water supply pressure and flow rate for water saving.

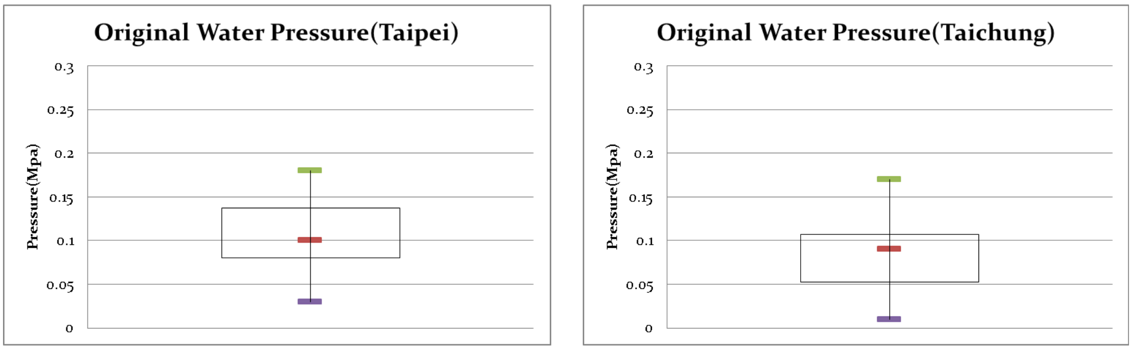


Fig. 6 The original water supply pressure analysis in Taipei and Taichung

4. Discussion

The investigated results could be analyzed into two parts, one is about shower comfort sensation votes in different shower head and different water supply pressure, the other is about the relationship of water saving critical value between water supply pressure and flow rate in shower comfort sensation.

4.1 Shower comfort sensation votes

Based on the investigated results, the water pressure is significant different between Taipei (many apartments with pressure water system) and Taichung (many houses with gravity pressure water). The comfort sensation votes of users by using ES are shown as Fig. 8, the results show the feeling of users in high water supply pressure area is much acceptable concentrated feeling than the feeling of the users in low water supply pressure area. Because users in Taipei are long-term staying in high water pressure, users have already accustomed by strong feeling, other feelings between high pressure and low pressure are similar in dense feeling and soft feeling.

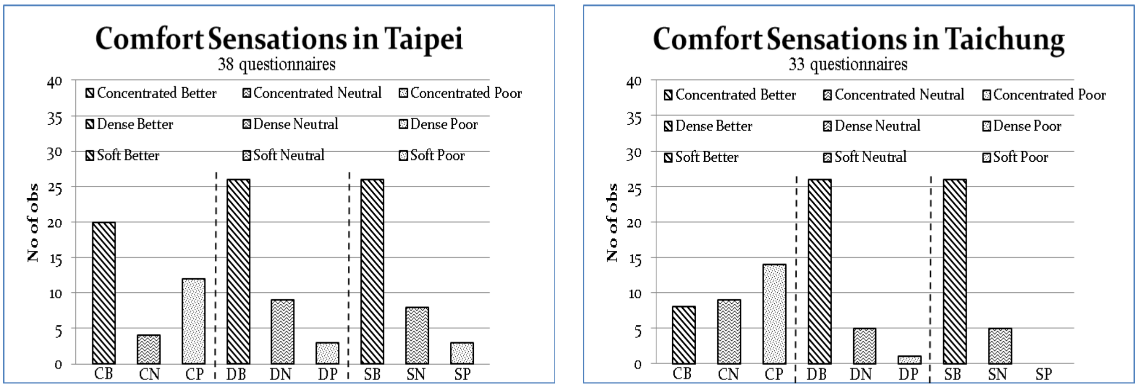


Fig. 8 The Comfort Sensation in Taipei and Taichung

Compare with the shower period and water consumption between ES and IS, the average of shower period in ES is longer than it in IS in Taichung, but it is opposite in Taipei. The reason is related with the water supply pressure and comfort sensation with air-in shower head (ES). When the water pressure is large, the users feel comfort with concentrated sensation in high pressure area, they do not spend much time to take shower. When the water supply pressure is lower, the users need more time to drop the water o their body to extend the shower time, as shown in Fig.9.

Water demand (Q, liter) is related with shower periods (t, sec) and flow rate (V, L/min), the evaluated equation is estimated by Eq.1. The water demand is shown as Fig.10, it shows the water demand in ES is less than the water demand in IS, caused of body sensation and shower head type (Concentrated (strong), Dense (many small holds) and Soft (tender)), referenced by “Hot water saving via shower using behavior and water demand in Taiwan[5][6][7]”.

$$Q = V \times t \qquad \text{Eq.1}$$

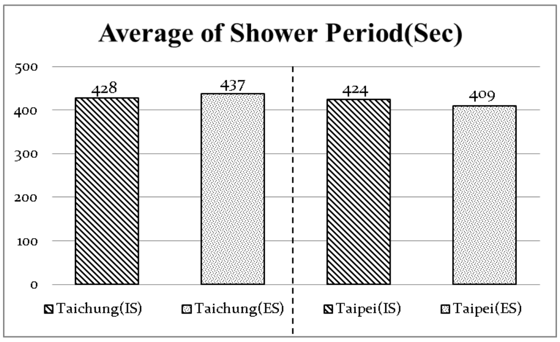


Fig. 9 The average of shower period

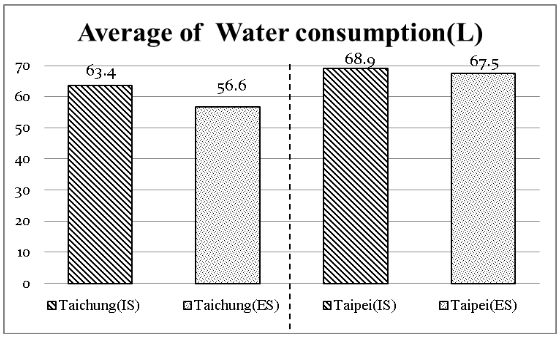


Fig. 10 The average of water consumption

4.2 Critical value of water pressure and flow rate for water saving

The water saving is related with the shower comfort analysis via water pressure and flow rate. Unsuitable water pressure and flow rate may cause uncomfortable shower sensation and water consumption while long shower period and strong or tender water flowing. Setup critical values of water pressure and flow rate via shower comfort sensations could be saved the water in different shower heads.

Based on the investigated water pressures with comfort shower sensation in Taiwan and Japan in the same Eco shower head (ES) and referenced by the standards of other countries to draw the diagram of frequency, accumulated percentage, and water pressure as shown in Fig.11. There are 80% acceptable water pressure around 0.04MPa between Taiwan and Japan. The water pressure in 0.04MPa is similar with WELS in 0.35MPa and Eco Label between 0.02MPa and 0.05MPa (half in 0.35MPa). Therefore, this study setups the minimum critical value of water pressure for water saving via the investigated values, WELS, and Eco Label in 0.35MPa.

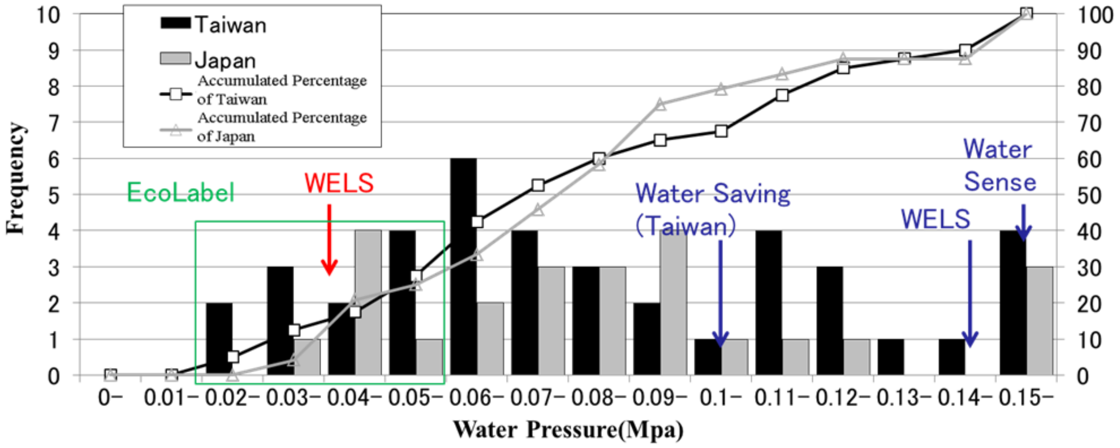


Fig. 11 The accumulated percentage of comfortable water pressure in Taiwan and Japan

Following the water pressure of comfort shower sensation, the investigated water flow rate is also organized as shown in Fig.12. The average water flow rate is 8.6 L/min in Japan and 9.9 L/min in Taiwan, the water demand over the average value is defined as wasted water. The accumulated percentage in 9.9L/min decrease the accumulated percentage in 9 L/min to save 9% water demand, in 8 L/min is saving 19%, and in 7 L/min is saving 29% in Taiwan. The same idea is used in Japan, as shown in Table 5. Referenced the water saving percentage from Table 5 to define 3 levels in water saving via flow rate. The flow rate in lower saving level (one star) is between 8.5 to 10.0L/min, the second level (two stars) is during 7.0-8.5 L/min, the top level (three stars) is under 7.0 L/min, as shown in Table 6.

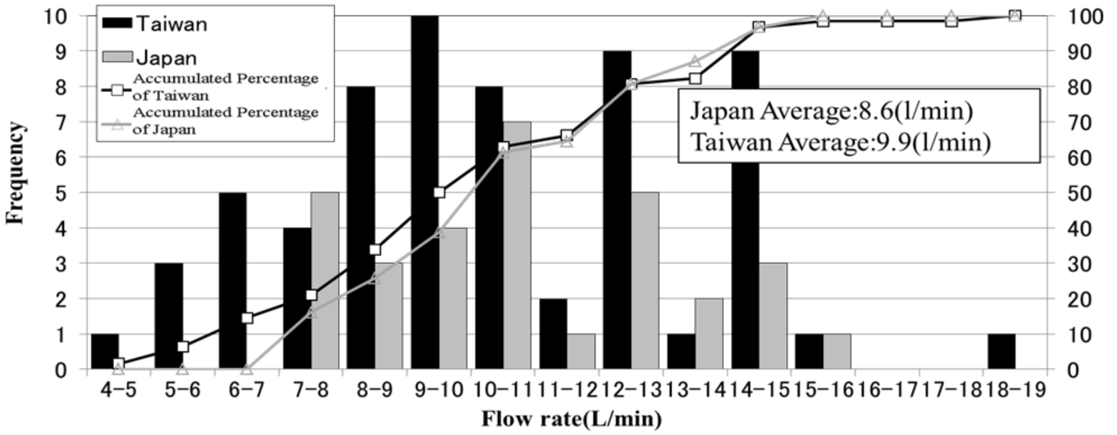


Figure 12 The accumulated percentage of comfort water flow rate in Taiwan and Japan

Table 5 Water saving percentage in different flow rate in Taiwan and Japan

Flow Rate (*L/min*)	Taiwan (%)	Japan (%)
9	9	0
8	19	7.5
7	29	20

Table 6 Water saving level via water flow rate

Level	Water Flow Rate (L/min)
★★★	~7
★★	7~8.5
★	8.5~10.0

5. Conclusion

The study presents the different water supply pressure system and flow rate impacting the shower comfort while showering. The results show that the samples with Concentrated Sensation are long-term staying in high water supply pressure conditions, and the samples with Dense and Soft Sensation are long-term staying in low water supply pressure conditions. The original water supply pressure conditions involve the shower head selected with Concentrated Sensation or Dense, Soft Sensation by users.

Besides, the comfort water supply pressure is defined as 0.35MPa in low water supply pressure area (Taiwan and Japan). Following to the comfort water supply pressure, the water flow rate is divided into 3 level for water saving. The water saving flow rate in the top level is under 7.0 L/min, in the second level is during 7.0-8.5 L/min, the low level is during 8.5-10.0 L/min. This results could be referenced by shower designers, water demand managers, and architectures.

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Rapid Detection of Total Bacteria in Water Quality with Flow Cytometry

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Abstract

Rapid detection of total bacteria has important significance in water quality monitoring.The standard method currently used is flat colony counting method, but it exists following disadvantages: 1) measurement period is more than 48 h; 2) steps are cumbersome, which tend to pollution that reduces measurement accuracy; 3) counting method is manual counting, which may increase subjective errors; 4) the measure is the total number of aerobic bacteria suitable for the growth at 37℃ . This study proposes the use of flow cytometry for rapid detection of total bacteria in water quality. It is mainly divided into two steps, bacteria pretreated , analysis and calculation by flow cytometry ,so that quantitative analysis can be digitized. The results indicate that flow cytometry and plate count method show a weak linear correlation, and the degree of correlation is significant correlation. This method greatly reduces the detection time. It has the advantages of a small interfering determination process, good discrimination, simple and rapid operation, accurate and reliable results, and multi-parameter measurements.

Keywords

Bacterial enumeration method; HPC; Flow cytometry.

1. Introduction

Drinking water presents a unique low-nutrient environment where diverse indigenous microbial communities proliferate. Accurate qualitative and quantitative knowledge of the bacterial concentration and composition is essential to detect specific events and to understand and control treatment processes in order to ensure good drinking water quality. Methods and bacteriological parameters to monitor treatment processes and assess drinking water quality were established over 100 years ago and comprise the detection of index organisms such as Escherichia coli and the enumeration of heterotrophic plate counts (HPC) [1].

In recent years , microbiological tools for the characterization of complex bacterial communities and processes have been greatly developed. With the innovation of methods and the improvement of instruments, and a variety of methods used in combination,the related measuring methods have been improved,at the same time, some new methods have sprung up and gain increased attention.

2. Bacterial Enumeration Method

The general microbial quality of drinking water is normally monitored by heterotrophic plate counts (HPC). This method has been used for more than 100 years and is recommended in drinking water guidelines. However, the HPC method is significantly handicapped. It is time consuming that measurement period is more than 48 h and results are only available days(sometimes weeks) after analysis. In addition, only a small and variable part of autochthonous drinking water bacteria are also growing on conventional agar plates,and most of the bacteria are in “viable but non-culturable” (VBNC) state, whose cells are intact and alive and can resuscitate when surrounding conditions are more favorable[2]. Besides that, The steps are cumbersome, which tend to cause pollution and reduce measurement accuracy.And counting method is manual counting, which may increase subjective errors. Since enumeration of HPC bacteria has these disadvantages, reliable evaluation of the effects of microbial processes in water quality with this parameter is nearly impossible.These shortcomings have resulted in a situation where HPC as a parameter has justly been removed from drinking water legislation in the European Union. Hence, with regards to the general microbiology,drinking water authorities and utilities have at the moment no methods or guidelines enabling a satisfactory monitoring,optimization and maintenance of drinking water treatment and distribution systems[1].A convenient and quantitative bacterial enumeration method is therefore required as an indicator of bacteria contamination or disinfection to replace existing methods.

Adenosine tri-phosphate(ATP) bioluminescence method is a kind of rapid detection technology based on bioluminescent reaction .Through the extraction of microbial cells ATP, using bioluminescence method to measure the content of ATP, the amount of bacteria in the samples is calculated, and the detection process can be completed in ten minutes[3]. ATP bioluminescence method for the detection of bacteria has the advantages of simple operation and fast detection[4], but the detection range and detection accuracy need to be improved.

Fluorescence in situ hybridization (FISH) technology is a new technology developed in the biological field in recent years. DNA probe is labeled by specific fluorescein, and combined with complementary nucleic acid sequence specifically in intact cells,then optical detection was observed and analyzed by fluorescence technique such as fluorescence microscopy [5]. FISH counting method is safe, simple, sensitive and rapid. Besides, FISH is considered the gold standard of quantification techniques, however, it is expensive and offers low sample throughput, both of which limit its wider application[6].

Flow cytometry (FCM) has developed during the last 30 years into a multidisciplinary technique for analysing bacteria. When used correctly, FCM can provide a broad range of information at the single-cell level, including (but not limited to) total counts, size measurements, nucleic acid content, cell viability and activity, and detection of specific bacterial groups or species. The main advantage of FCM is that it is fast and easy to perform. It is a robust technique,which is adaptable to different types of samples and methods, and has much potential for automation[7].

3. The Situation of Flow Cytometry

3.1 The basic principle of flow cytometry

FCM is a technique for analysing individual particles by suspending them in a flow stream that passes through an excitation light source,typically a laser beam. Interaction between the light beam and the particle causes specific scattering of light and excitation of fluorochromes; scattered light and emitted fluorescent light are then detected and measured with photomultipliers. Light scattering is detected either at a low angle, commonly referred to forward scatter (FSC),or at a high angle (sideward scatter; SSC), whereas the fluorescence is detected at a high angle after selection with appropriate wavelength filters. Instruments with multiple lasers and/or detectors allow users to assess different fluorescence and scatter parameters simultaneously. A key feature of FCM hardware is that the suspended particles are passed individually through the light beam in single file in a process known as hydrodynamic focusing, thereby allowing analysis of a microbial community on a single-cell level. Thus, when combined with fluorescent cell-staining methods, FCM allows quantitative, multiparametric analysis of the detected particles, including their fluorescence intensity, the scattered light and an enumeration of particles. Digitalized data of the fluorescence or scattered light intensity characteristics of each particle are collected and presented as either single-parameter histograms or dual-parameter dot plots.The basic principles of flow cytometry analysis are given in Fig. 1.This choice of the data presentation style is the prerogative of the FCM operator.In addition, most FCM software allows the operator to select specific areas of interest (e.g. separation of bacterial clusters from the background) in a process called“gating”(Fig. 2)[7].

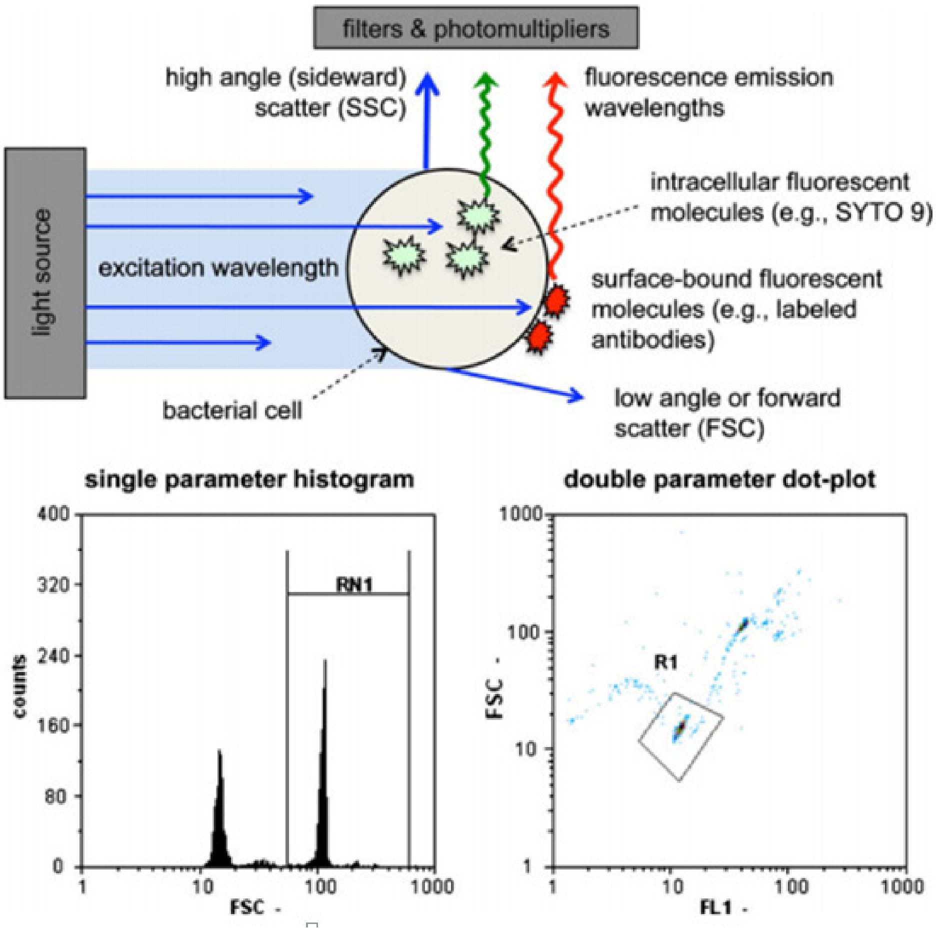

Figure 1 - The basic principle of flow cytometry

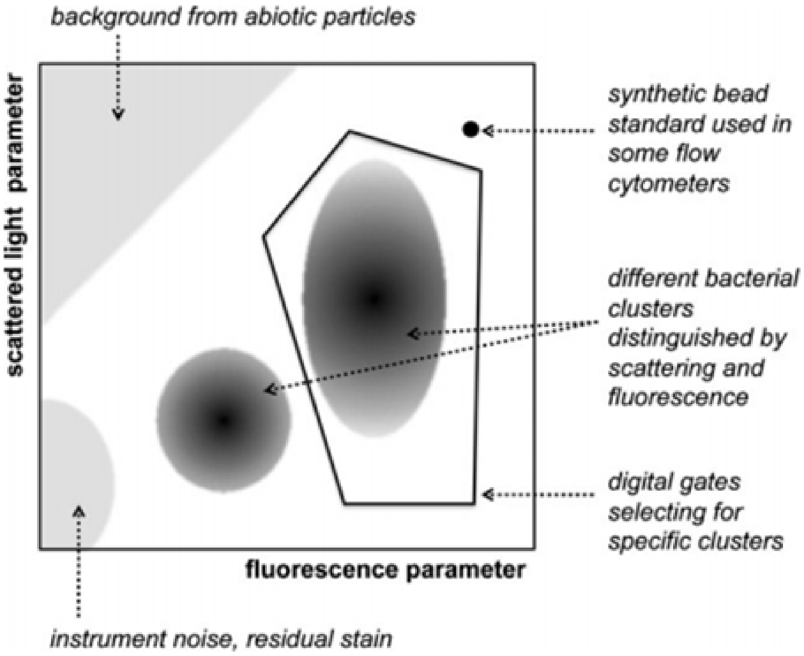

Figure 2 - Typical features of flow cytometry data

3.2 The development history of flow cytometry

In 1930, Casperrsson and Thorell began to count the cells.In 1934, Moldaven envisioned the automation of the cell detection for the first time, and he tried to record the number of cells passing through a capillary by a photo electric apparatus.In 1936, Caspersson introduced the micro spectrophotometry.In 1940, Coons proposed to label the specific proteins in the cells with the antibody labeled with fluorescein.In 1947, Guclcerl used the principle of laminar and turbulence to develop smoke particle counter. In 1949, Coulter proposed the method of counting the particles in the suspension and got the patent.In 1950, Caspersson detected the cells by a micro spectrophotometer in the ultraviolet (UV) and visible spectral region.In 1953, Croslannd-Taylor successfully designed red cell optical automatic counter with the principle of layered sheath flow,and Parker and Hutcheon described a whole blood cell counter device,which became the prototype of the flow cytometry.Beirne and Hutchcon invented the photoelectric particle counter in 1954,and Coulter B counter come out in 1954.In 1965, Kamemtsky proposed two assumptions: (1) quantitative cell components using a spectrophotometer; (2) combined with the measured values to classify cells. In 1967, Kamemtsky and Melamed proposed cell sorting methods based on the method of Moldaven.In 1969, Van Dilla Fulwyler and his colleagues invented the first cell fluorescence detection meter at LosALmos, NM (now known as National Flow Cytometry Resource Labs).In 1972, Herzenberg developed a improved cell sorter,which can detect the weak fluorescent signal of the cells stained by fluorescent labeling antibody. In 1975, Kochler and Milstein proposed monoclonal antibody technology.In 1975, Kochler and Milstein proposed monoclonal antibody technology, which lay the foundation for the application of a large number of specific immune reagents in the research of cells.

Nowadays, with the further development of photoelectric technology, flow cytometry has begun to the development of a modular, namely the optical system, detector unit and electronic system can be replaced at random as required.In twenty-first Century, flow cytometry has been more and more perfect, and has become an important tool in the field of cytology.

4. Application of Flow Cytometry in Rapid Detection of Total Bacteria

Established already for more than 30 years in medical research and routine diagnosis,the technique of flow cytometry analysis has witnessed a phenomenal rise of its use in the field of aquatic microbiology during the last two decades, with considerable and continual increases in the average number of publications per year. This can be attributed to three main facts: (1) specific technological developments (mainly for routine medical diagnostics) have transformed flow cytometers into easy-to-operate instruments available for standard laboratory research, (2) the continuous emergence of novel stains, fluorescent markers and related methods that are compatible with microorganisms and (3) improvement in hardware that allows detection of ever-smaller particles with low fluorescence intensity[7].This review deals exclusively with rapid detection of total bacteria.However, it is noted that FCM is equally useful for the measurement of yeast cells, algae, protozoaand viruses in aquatic environments.

Rapid detection of total bacteria is one of the most straightforward and useful functions of FCM. This method includes two steps: sample preparation and analysis of testing by flow cytometry, so that quantitative analysis can be digitized. The challenge for the FCM operator is to be able to separate small bacterial cells from abiotic particles and background signals in a water sample.This is accomplished by staining the bacterial DNA (or other typical cell components) with a fluorescent dye such as SYBR Green I, SYTO 9 or DAPI (4′,6-diamidino-2-phenylindole).A first selection step is then triggering the selective bacterial parameter (e.g. green fluorescence in the case of SYBR Green I staining); thereby, non-fluorescent background particles would automatically be filtered out of the data set generated. The signals obtained are subsequently visualized either as single-parameter histogram data or as dual-parameter dot plot data[7]. Eva L. Joachimsthal et al.[8] stain the samples (1 mL) by 10μL of a 1 mg/mL solution of DAPI ,and then the samples were filtered through a 0.2 lm membrane filter and cells with blue fluorescence were counted using an epifluorescence microscope .Using forward scatter histogram analysis, a comparison of cell number and microsphere number allowed calculation of the cell concentration. Frederik Hammes et al. [9] have used fluorescence staining of microbial cells with the nucleic acid stain SYBR Green I together with quantitative flow cytometry (FCM) to analyse total cell concentrations in water samples from a drinking water pilot plant.In addition,Frederik Hammes et al.[7] have demonstrated that the combination of two fluorescence signals (e.g. green vs. red fluorescence) originating from the same dye can also be used (Fig.3),and that it is in some situations the superior approach. For a working solution, SYBR Green I was diluted 100×in anhydrous dimethyl sulfoxide (DMSO) and propidium iodide (PI; 30 mM) was mixed with the SYBR Green I working solution to a final PI concentration of 0.6 mM. In addition, it should be noted,to avoid the overlap of the signal in the flow cytometry, the low permeability buffer EDTA was used for the dilution of the cells before bacterial staining.

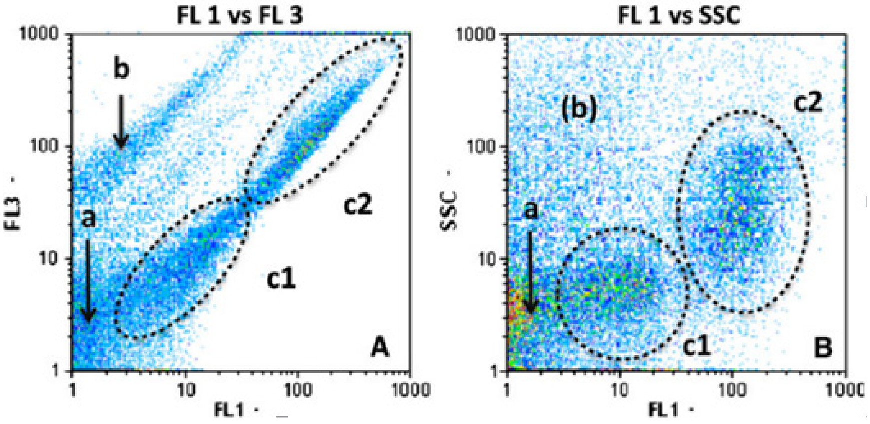

Figure 3 - bacteria stained with SYBR Green I and plotted a sagreen fluorescence versus red fluorescence (FL1/FL3) and b green fluorescence versus size (FL1/SSC).

As a rapid and accurate detection method to assess microbial activity and determine the total cell concentration in drinking water,it is necessary and important for drinking water quality control to understand the relationships among the conventional and new methods,and extensive field-testing coupled with comparisons to conventional methods are required. Hammes et al.[10] studied the biological stability in a full-scale drinking water treatment and distribution system of the city of Zurich (Switzerland). Chemical and microbiological parameters, notably dissolved organic carbon (DOC), assimilable organic carbon (AOC), heterotrophic plate counts (HPC) and flow-cytometric total cell concentration (TCC), were measured over an 18-month period. They observed a direct correlation between changes in the TCC, DOC and AOC concentrations during treatment; an increase in cell concentration was always associated with a decrease in organic carbon. This pattern was, however, not discerned with the conventional HPC method. In study,Total cell concentrations (TCC) from the drinking water samples varied in the range of 0.37-5.61 × 105cells/mL. E. Siebel et al. [11] studied the relationships among the conventional and new methods, and the results showed that the rapid determination methods (i.e., FCM and ATP) correlated significantly (R_2=0.69), but only a weak correlation (R_2=0.31) was observed between the rapid methods and conventional HPC data. With respect to drinking water monitoring, both FCM and ATP measurements were confirmed to be useful and complimentary parameters for rapid assessing of drinking water microbial quality. Conventional heterotrophic plate counts (HPC) results were on average two orders of magnitude lower than the TCC from flow cytometric measurements. No more than 8.6% (average 1.6%) of the TCC were detected with HPC. And the result was consistent with Van der Kooij’s studies that heterotrophic bacteria usually form a fraction 10 below 1% of total cell counts[12].Marius Vital et al.[1] studied the alternative possibilities of flow cytometry to evaluate major bacteriological changes in drinking water treatment and distribution systems,and showed that only a minute fraction (0.04%~5.99% depending on the cultivation method) of intact cells detected by flow cytometry was also cultivable, and conventional cultivation-based methods were not able to satisfactorily describe water treatment processes in all cases. In addition, Hammes et al.[13]studied the reproducibility of flow cytometric TCC measurements,and the result showed that the standard deviation on triplicate FCM measurements was always below 5%, which is similar to former studies and underlines the high reproducibility of flow cytometric TCC measurements.

5 Discussion

Rapid enumeration methods are crucial for drinking water quality monitoring. Flow cytometry is sensitive and rapid method that can be performed easily without the handicap of a selective trait such as culturability. In comparison, the enumeration of heterotrophic bacteria is obviously more time and labour consuming. The studies have shown that there is a strong correlation between TCC and the ATP data, but only a weak correlation between the rapid methods and conventional HPC data. Quantitative test of flow cytometry instrument is a reliable, rapid counting method of bacteria with good reproducibility in water.

The main advantages of flow cytometry are that analysis is fast (less than 3 min per sample), accurate (less than 5% instrumentation error), sensitive (detection as low as 100 cells per millilitre) and compatible with a variety of staining and labelling methods providing broad information at the single-cell level. In addition, flow cytometry instruments are fairly easy to handle with considerable automation potential.However, FCM also has notable limitations and pitfalls. FCM is a single-cell method and, therefore, is not ideal for complex macroparticle analysis. Although proper dispersion protocols allow visualization of such samples, the three-dimensional spatial aspect—often important for such samples—is completely lost. Similarly, samples with inorganic turbidity often require special pretreatment (e.g. density centrifugation) before analysis can be done.An interesting FCM problem is the relative ease with which an immense wealth of data can be generated. Although this might appear as only a positive point, it calls for standardization on multiple levels.Different brands of instruments give different results, as do variations in the water matrix, the type of target cells and the particular staining method.Therefore, an absolute need exists for the correct reporting of FCM data, which would allow correct interpretation and evaluation of results.

After about three decades of successful research coupled with continual technological developments, FCM applications have reached an important crossroad. On the one hand,development will drive exciting technological innovations e.g. small, multiparameter instruments, coupled with singlecell sorting and postanalysis methods. Whereas cell sorting is already a well-established technique, automated FCM is expected to see considerable evolution in the foreseeable future. Online FCM instruments are already a reality in some applications. Coupled with online data processing,this has a real potential for online monitoring of drinking water. On the other hand, there is a need for the basic FCM methods to become established as standard methods with broad acceptance in the scientific community, and the establishment of simple instrumentation for common use in research laboratories and companies. The use of multiple fluorochromes in combination with bacteria is still limited and nearly no papers have described more than two labels coupled to bacterial cells[7]. As with all rapid-evolving methods,there is a definite need to safeguard against hastily produced/interpreted FCM data. Standardized methods, rigorous controls and continual comparisons with existing methods should be the checks and balances that accompany the exciting and innovative exploration of this field.

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7 Presentation of Authors

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Research of UV light–titanium dioxide oxidation technology to inactivate microorganisms efficiency

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Abstract

The UV light-titanium dioxide oxidation technology disinfection of microorganism was studied under different system flow rate, TiO_2 produce strong oxidizing hydroxyl radicals under irradiation of UV light, it's more efficient compare with traditional ultraviolet light sterilization. The variation of total number of bacteria, heterotrophic bacteria and Legionella pneumophila in the disinfection process of microorganism was investigated. The results show that when the flow rate through UV light-titanium dioxide oxidation technology turn to 1.2m^3/h. The killing rate of total number of bacteria and heterotrophic bacteria is 99.2% and 98%, and Legionella pneumophila was killed completely.

Keyword

UV light-titanium dioxide oxidation technology; Flow rate; sterilization; Legionella pneumophila

Widely used chlorine disinfection is the most cost-effective disinfection process for drinking water nowadays, but the by-product (DBPs), such as THMs and HAAs, can be a potential risk for health[1]. As the attractive of lots of alternatives, the research of UV/TiO_2 technology for inactivating microorganisms was raised. Its strong oxidizing property and non-selective sterilization is a great advantage in drinking water treatment. The TiO_2, as the catalyst in the process, is stable, harmless and readily available and can be recycled. These advantages make UV/TiO_2 technology a great future for both research and application.

Past researches have already shown that UV/TiO_2 technology can kill bacteria, remove toxin and eliminate odor[2-3]. Therefore, it applies to drinking water disinfection is feasible. Legionnella, as a pathogenic microorganisms presenting in natural and artificial water environment, was found widespread in hot water supply systems and other places in both domestic and foreign papers, and the positive rates of the pollution are always over 20%[4-5]. The efficiency of UV/TiO_2 technology has been studied by Li and Tseng et al[6]. It shows that under low UV illumination, UV/TiO_2 technology’s kill rate of Legionnella in pipes has already over log5, and is also effective for total bacteria and heterotrophic bacteria. Besides, operation time, system flow rate and microbe species can affect the result.

Due to the Legionnella problem in water system, by using original drinking water added Legionella pneumophila fluid, the effect of the UV/TiO_2 technology under different system flow rate was studied.

1. Materials and Methods

1.1. Water for the experiment

The raw water is groundwater. After filling the pipe system and the tank, turn on the circulating pump for 24 hours to cultivating bacteria, then the concentration of total bacteria and heterotrophic bacteria became to 7.4×10^2cfu/mL and 7.9×10^3cfu/mL. The Legionnella is mainly Legionella pneumophila (LP). Especially, the type Lp1 is the most virulent and has the closest relationship with humans. Thus, the type Lp1 fluid must be added. After blending, the concentration of Legionella pneumophila became to 8.4×10^4cfu/mL.

Raw water quality of the sample affects the effectiveness of the UV/TiO_2 oxidation reactor. As UV penetration is poor (it is difficult to pass through the opaque substance, even a layer of glass can filter a lot), water conditions also affect irradiation dose to TiO_2 and the amount of generated hydroxyl radicals, so the water clarity and the cleanliness of the lamp tube must be ensured. After circulating for 24 hours, analyses the raw water quality indicators. Results refer to Table 1. The conditions of raw water are appropriate and have little effect to the sterilization.

Table 1 experimental raw water quality

UV254	Turbidity	COD	Temperature	Basicity ($CaCO_3$)	Calcium Hardness ($CaCO_3$)	Magnesium Hardness ($CaCO_3$)	pH	residual chlorine
0.015A	1.21NTU	1.045mg/L	15℃	420mg/L	0.59mg/L	0.30mg/L	7.2	0mg/L

1.2 Experiment system

There are 800L and 900L 2 different stainless steel water tank in the system. Pipes are made by PVC. All the system is running by a Grundfos' hot water circulating pump type UPS40-185F, whose standard flow rate is 3.3m^3/h, and the overall flow rate can controlled by adjusting the pump or valves. The Pilot Piping Diagram is shown as figure 1. It is used to simulate domestic water disinfection process. The sample water in the 800L tank is mixed by the bypass pipe. When running the sterilization experiment, all the treated sample water is filled into the 900L tank. The tank is linked with a bucket which contains chlorine to prevent the sample from contacting with air. The chlorine treatment will ensure that there is no Legionella is discharged while after collection.

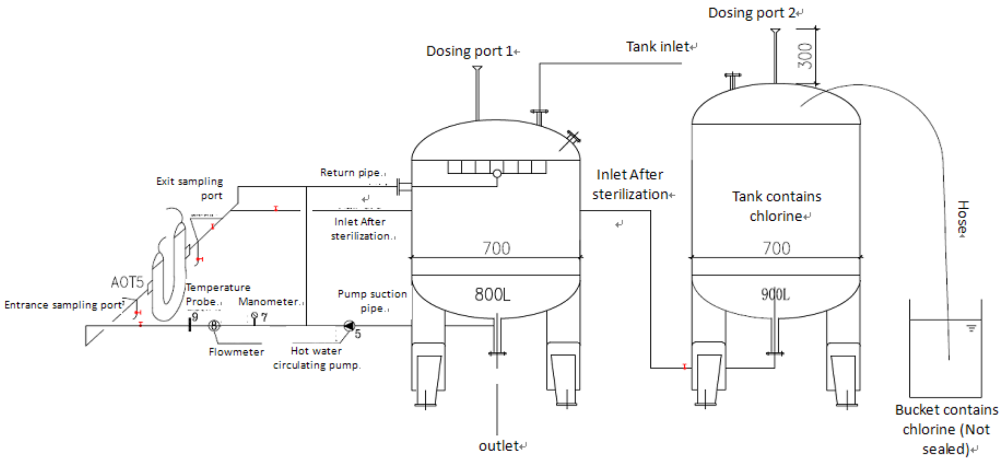

Fig 1 test pilot pipeline system

The light sources of UV/TiO_2 technology in the pilot system are two UV germicidal lamps, their wavelength is both 254nm, power is 42w. The capacity of the reactor is 740mL. As there is no UV light at the bottom, its available capacity is 670mL. The maximum flow rate when working is 5m^3/h. TiO_2, as a catalyst, is immobilized on the inner wall of an AOT Titanium tube, as shown in Figure 2. When the sample get through the reactor, TiO_2 will produce photoelectrons and photogenerated holes under UV light lower than 385nm. Photogenerated holes and H_2O or OH- on the catalyst will react to produce hydroxyl radicals (▪OH) which is strong oxidizing. Photoelectrons and oxygen molecule will react to produce superoxide anion radicals (O-2), then become to hydroxyl radicals (▪OH) and H_2O_2 etc.[7] The photocatalytic sterilization of TiO2 is a collective effect of hydroxyl radicals (▪OH) and other strong oxidizing substances (▪O-2、▪OOH、H_2O_2)[8]. Refer to both domestic and foreign study, the mechanism of The photocatalytic sterilization of TiO_2 is mainly because ▪OH and other strong oxidizing substances can destroy cell wall (membrane) and their genetic materials.

Fig 2 UV/TiO_2 combined oxidation sterilization reactor (wallenius water)

The formula of irradiation dose of UV:

$$W=I*t$$

In which:

W--- the irradiation dose of UV, mJ/cm^2
I--- the average UV intensity, mW/cm^2
t--- the irradiation time, s

The UV intensity in the pilot system is 14.5mW/cm^2. When the system flow rate is 2.1 m^3/h, the time of reaction for sample in the reactor is 1.15s, then the irradiation dose of UV in the reactor can be known as 14.5 mW/cm^2*1.15s=16.7mJ/cm^2. It' s compliance with the rule of UV disinfection of drinking water (CJ/T204-2000), which stipulate that the irradiation dose of UV for sterilizer with new lamps must over 12mJ/cm^2 (when fill with water), and must over 9mJ/cm^2 when proper functioning.

1.3.The sampling methods under different flow rate

Sampling ports are set before and after the UV/TiO$_2$ combined oxidation sterilization reactor. After cycling the raw water for 24 hours, use sterilized sampling bottles to get samples. Wipe the sampling ports with alcohol cotton before sampling to prevent pollution. Wait for the reactor to get the reach the best condition after its start-up and then adjust the flow rate in 5 different conditions to carry on the sterilization, which are 3.3m^3/h、2.7m^3/h、2.1m^3/h、1.8m^3/h and 1.2m^3/h. Get samples after 2min from the sampling port at the outlet side. Wipe the sampling ports with alcohol cotton before sampling. The experiment process is shown in Table 2.

Table 2 experiment system flow and sampling time

System Flow Rate (m^3/h)	2.1	1.8	1.2
Sampling time (Counting since the flow rate is changed, min)	2.5 5 7.5	2.5 5 7.5	2.5 5 7.5

1.4.Detected indicator and method

The total number of bacteria is the total number of colonies contained in 1mL' s sample water which is cultured under specific environment (medium composition, temperature and time, pH, aerobic nature etc.). Use nutrient agar pour method to culture for 48 hours under 37℃ , then count it. The culture of heterotrophic bacteria use R2A medium. Count after culture for 7 days under 22℃ . As Legionella pneumophila is a kind of pathogenic bacteria, the samples are sent to the Disease Control and Prevention Centers for detection. Detecting measure is used as international ISO 11731-2 standard.

2.Results and Discussion

2.1.Effects of different system flow to total bacteria and heterotrophic bacteria

As the total number of bacteria in the water is related with the degree of organic pollution, the total number of bacteria and heterotrophic bacteria killing rate are always seen as important indicators of water pollution. The drinking water sanitary standard of China (GB5749-2006) also stipulates that the total number of bacteria in running water cannot be over 100. The variety of the total number of bacteria and heterotrophic bacteria killing rate are studied among the experiment, its results is shown in Figure 3 (system flow is 3.3 m^3/h、2.7m^3/h、2.1m^3/h、1.8m^3/h and 1.2m^3/h).

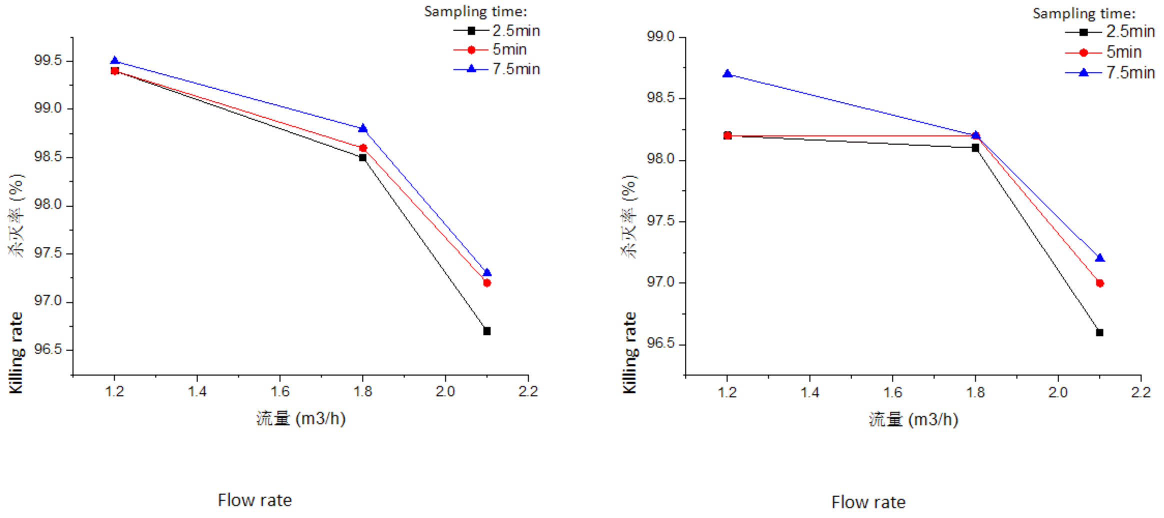

Fig 3 total number of bacteria (a) and heterotrophic bacteria (b) killing rate

Shown as in Figure 3, when the system flow is 2.1m^3/h, the killing rate of advanced oxidation process to the total number of bacteria and heterotrophic bacteria are 97.1% and 96.9%, in which the total number of bacteria is reduced from 7.40×10^{2}cfu/mL to 23cfu/mL, and heterotrophic bacteria is reduced from 7.9×10^{3}cfu/mL to 2.43×10^{2}cfu/mL. When the system flow is 1.2m^3/h, the killing rate of advanced oxidation process to the total number of bacteria and heterotrophic bacteria are over 99.4% and 98.4%, in which the total number of bacteria is reduced from 7.40×10^{2}cfu/mL to 4cfu/mL, and heterotrophic bacteria is reduced from 7.9×10^{3}cfu/mL to 1.27×10^{2}cfu/mL. The amount of bacteria is reduced while the system flow becomes lower. This is consistent with the result get by Mitsunage et al[9] who also used UV/TiO_2 combined oxidation in flowing system for heterotrophic bacteria, and complies with the limit value 100cfu/mL of total number of bacteria for drinking water in GB5749-2006 and limit value 500cfu/mL of heterotrophic bacteria count by US Environmental Protection Agency. It is also approaching the demand in Drinking Water Quality Regulations (98/83/EEC) by The European Council.

2.2 Effects of different system flow to Legionella pneumophila

Legionella pneumophila is the most closely related to human in Legionella. The Pneumonia caused by Legionella pneumophila without proper treatment can easily kill people. As water (including natural and artificial water) is the main source of Legionella, the key to the Legionella Prevention is to prevent and control Legionella in these places. Thus, the variety of Legionella pneumophila in sterilization process is studied. The result is shown in Figure 4 (system flow is 3.3 m^3/h、2.7m^3/h、2.1m^3/h、1.8m^3/h and 1.2m^3/h).

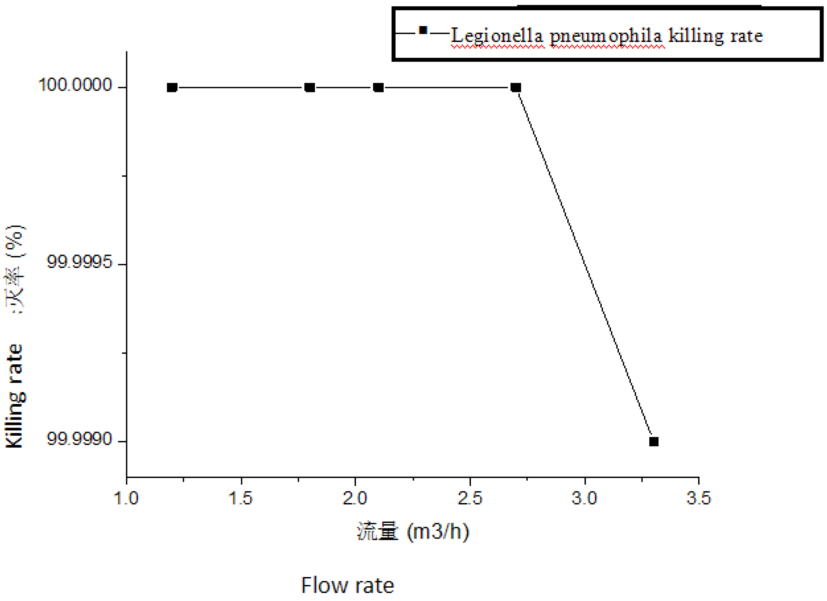

Fig 4 Legionella pneumophila killing rate

As shown in Figure 4, when the system flow is $3.3m^3/h$, the killing rate of UV/TiO_2 combined oxidation sterilization technology to Legionella pneumophila can be over 99.999%, in which the Legionella pneumophila count is reduced from 8.40 × 104cfu/mL to 1cfu/mL. When the system flow is $2.7m^3/h$、$2.1m^3/h$、$1.8m^3/h$ or $1.2m^3/h$, the killing rate of UV/TiO_2 combined oxidation sterilization technology to Legionella pneumophila can be 100% in short time, in which the Legionella pneumophila cannot be detected. This result ,that UV/TiO_2 combined oxidation sterilization technology can kill all Legionella pneumophila with the system become lower, is consistent with the result get by Li and Tseng et al[6] who used it for Legionella pneumophila by low power UV lamp. Comparing with the study by Muraca P et al[10], who used only UV or UV combined with other technology, the UV/TiO_2 combined oxidation sterilization technology is more effective. As shown in the result, its effect to Legionella pneumophila is better than to total bacteria and heterotrophic bacteria, this is the same with the study by Li and Tseng[6]. This may be because total bacteria and heterotrophic bacteria contain lots kinds of bacteria, while Legionella pneumophila is just one. Therefore, hydroxyl radicals demanded is higher for killing all total bacteria and heterotrophic bacteria. Legionella pneumophila is also more sensitive than the others.

The water treated by UV/TiO_2 combined oxidation sterilization technology should accord with the demand in the forthcoming Public Health Indicators and Limit Demand (GB9663) by Ministry of Health of China. It should also meet the requirements in Drinking Water Hygienic Standard (GB5749-2007) that Legionella pneumophila should not be detected in the water for the public, and in Public Baths Water Quality Standard (CJ/T325-2010) that Legionella pneumophila should not be detected in the water for spring water or hot water.

3. Conclusions

1)The UV/TiO_2 combined oxidation reactor used in the experiment is very small. It can be linked with domestic water pipeline directly, which can be easily applied in real life production for sterilization and has practical significance of application.

2)When the system flow is 2.1m^3/h, the killing rate to the total number of bacteria, heterotrophic bacteria, and Legionella pneumophila is 97.1%, 96.9% and 99.999%. When the system flow is 1.8m^3/h, the killing rate to the total number of bacteria and heterotrophic bacteria is 98.6%, 98.1%, and all the Legionella pneumophila is killed. It is obvious that the amount of total number of bacteria, heterotrophic bacteria and Legionella pneumophila is reduced while the system flow becomes lower. By decreasing the system flow to expand reaction time of UV/TiO_2 combined oxidation technology, the effect of sterilization can be improved.

3)Comparing the results of the effect of UV/TiO_2 combined oxidation technology to the total number of bacteria, heterotrophic bacteria and Legionella pneumophila, it shows that the technology is better to Legionella pneumophila than the total number of bacteria and heterotrophic bacteria.

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The Effects of Anthocanin on The Tea Polyphenols Disinfectant Properties

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Abstract

Due to the harmful disinfection by-product which comes from the chlorine disinfectants, people are exploring new disinfectants with higher safety in recent years. Tea polyphenols are some kind of pure natural non-toxic organics with disinfection effect. However, the water chromaticity has yet to meet drinking water standards using tea polyphenols as disinfectant for drinking water. Anthocyanins are known to be natural pigments containing in tea polyphenols, the influence of the water chroma caused by anthocyanins in the disinfection process was explored. Furthermore, to understand the effect of anthocyanins on the antibacterial performance of the tea polyphenols, the concentration of anthocyanins and species in tea polyphenols were detected by pH differential method and high performance liquid chromatography (HPLC), it took the anthocyanin standard for disinfection test. The results indicated that most of anthocyanins in tea polyphenols existed in form of glycosides. The concentration of anthocyanins which accounted for 14.3% of chromaticity value in the tea polyphenols, was only 0.011%. Despite the bacteriostasis ability shown by anthocyanins, its effect on the antibacterial performance of tea polyphenols hasn't be seen due to very low concentration. Theoretically, the chromaticity caused by anthocyanins could be easily eliminated by some method that depend on the unstable character of glycosides. The removal of the anthocyanin from tea polyphenols doesn't affect the antibacterial performance of the tea polyphenols as disinfectant.

Keywords

Drinking water; anthocyanin; tea polyphenol; disinfect; chromaticity; bacteriostat.

1. Introduction

Please in the drinking water disinfection process, chlorine disinfectants has a history of 100 years, it is recognized as the best drinking water disinfectant in the world. since the 1970s , the cincern of the chlorinated disinfection by-products has become a hot spot [1-2]. Since then new disinfectant reseach was prevalenting, we have made some achievements in recentyears .Fuwanxia [3], have confirmed polyphenols can be used as disinfectant in polyphenols dosage of 300mg/L, 30min contact, the disfected water quality can meet the standards of the total number of colonies of less than 100 (CFU/mL) , the total coliforms, thermotolerant coliforms were not detected, etc.after continuous contact for 24 hours, microbial indicators are still prescribed range, but the color value of the water was far beyond the quality standards for drinking water value of 15. Zhang Yanqiu [4], also have studied tea polyphenols disinfectant, who quantified the polyphenols as effluent color index out of the specific circumstances of the standard value.

Tea polyphenols is polyphenols collectively , including flavanols (catechins), anthocyanin (anthocyanin), flowers flavin class (flavonoids) and phenolic acids and so on in tea . Anthocyanins (Anthocyanin), are flavonoids 2-phenyl-benzopyran structure, the basic structure shown in Figure 1.

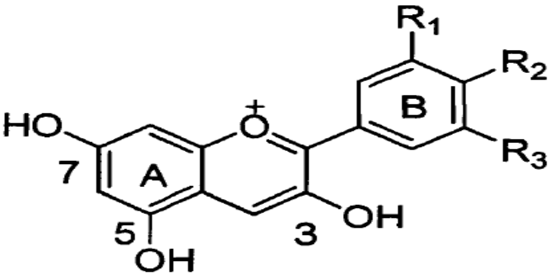

Fig.1 Anthocyanin basic structure

Anthocyanin varieties because of the substituents on the Anthocyanins B ring group , as shown in Table 1. Anthocyanin is a flavonoid polyphenol compounds who has a variety of physiological activity of plant stems and leaves floral color rendering natural pigment. different pH conditions, the petals, leaves or fruit, etc. showing the red, purple and yellow colorful colors in plant vacuoles. Due to the high anthocyanin content in tea, it shoots showing purple [6] [14- 15], 80% of angiosperm flower color is determined by the anthocyanins [7].

Table 1 Common anthocyanins in nature

Name	Substituted group		
	R1	R2	R3
Pelargonidin	H	OH	H
cyanidin	OH	OH	H
delphinidin	OH	OH	OH
Peonidin	OMe	OH	H
petunidin	OMe	OH	OH
Malvidin	OMe	OH	OMe

In natural , most anthocyanins exist in the form of glycosides, anthocyanins basic structure shown in Figure 1, the glycoside general located in the C3 and C5 positions, as well as some glycoside formed at C7 position with glucose , rhamnose, xylose and arabinose. Tea anthocyanin content is generally around [6] 0.01% in the dry tea, but the anthocyanins is the main component of plant pigments, the impact on the water disinfection process polyphenols color can not be ignored.

According to the studys, the anthocyanins have the following effects: prevention of diabetes, enhanced vision, inhibit cancer cell growth, mitigating the effects of age on the transmission of nerve signals, thereby reducing the loss of cognitive and motor abilities. Meanwhile, anthocyanins also have antibacterial properties, who can resist inflammation from human gastric epithelial cells caused by H. pylori, a number of other pathogens also be resisted. many studies have shown that moderate drinking of red wine can reduce the onset of coronary heart disease , coronary heart disease is suppressed ,it is considered to be the anthocyanins who reduced platelet coagulation, slowing the formation of high-density cholesterol. Anthocyanins play a role in wine antibacterial effect , as well as some studies show that the more amount of extract anthocyanins, the more help to curb the incidence of coronary heart disease. However, the mechanism of inhibition has no conclusions. this paper focused on the content and types of anthocyanin polyphenols disinfectants, and the relations between categories anthocyanin polyphenols, anthocyanin content and water color and antibacterial properties of tea polyphenols impact .respecting to provide the basis for the polyphenols use as disinfectants in drinking water areas.

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1. Materials and Methods

1.1 Materials and equipment

1.1.1 Experimental materials and reagents

Papers 98% polyphenols disinfectant powder (green tea extract, Hangzhou Yi BeiJia Tea Co. provided), formic acid (AR), concentrated hydrochloric acid (AR), potassium chloride (AR), sodium acetate (AR) , methanol (AR), acetonitrile (AR), Secondary Effluent (Beijing Qinghe water Plant), ultra-pure water (laboratory-made), cornflower-3-galactosidase standard (99% purity, North Carolina Institute of Biotechnology).

1.1.2 experimental facilities

UPLC (MassLynx TMSoftware, Waters Corp, Milford, MA, USA) and mass spectrometry (Waters) the column (Waters) BEH C18 (1.7um 1.0×100mm), pH meter (Shanghai San-Xin Instrumentation), spectrophotometer (UV-6000), colorimeter (Hana), analytical balance (Mettler - Toledo Instruments - Shanghai).

1.2 Experimental method

1.2.1 pH differential method to determine total anthocyanin content in the tea polyphenols

pH differential method is commonly used to detect the total anthocyanin content. Preparation of buffer solution pH = 1: Weigh accurately 1.49g potassium chloride and use the ultrapure water to volume to 100mL, weigh accurately 1.7mL hydrochloric acid to volume 100mL with the ultrapure water , dub 0.2mol/L hydrochloric acid solution, mixture potassium chloride solution and hydrochloric acid solution in 25:67 proportions and use potassium chloride solution to adjust pH to (1.0±0.1); Prepare pH = 4.5 buffer solution: Weigh accurately 1.64g of sodium acetate to volume to 100mL with ultrapure water and use hydrochloric acid to adjust pH (4.5±0.1) [8-11]. Weigh accurately 1g polyphenol powder with a dilute solution of diluted alcohol and then diluted with ultrapure water to volume to 100mL, take two sample solution 10mL respectively, with pH1.0, pH4.5 Buffer solution to volume to 100mL, after 1 hour, measure the absorbance of the solution respectively.

1.2.2 UPLC-MS-MS Detection of type anthocyanins in the tea polyphenols

The 800mg/L TP solution was filtered through the 0.22um ultrafiltration membrane, using ultra high performance liquid chromatography mass spectrometry（UPLC-MS-MS）to detect the tea polyphenols, detection wavelength at 520nm; injection volume is 5uL; flow rate is 0.2mL/min; mobile phase A: 0.1% formic acid; mobile phase B: 100% methanol; linear elution gradient: 0.0 min, 13% B; 8.0 min, 24% B; 22 min, 100% B; 24.0 min, 3% B, 3% B maintained to 26 min.

After the the ultra high-performance liquid chromatography test solution into the atmospheric pressure ionization (API), with electrospray ionization (ESI) probe multimode ionization (ESI APCI), all spectra were separated positive ionization and negative ionization modes, MS scanning range (m/z) from 100-1900; MS parameters: Capillary voltage: 3000V, the injection cone voltage: 30V, ion source temperature: 100℃ , desolvation temperature 210℃ , the flow rate is 50L/h, desolvation gas flow:600L/h [16-18].

1.2.3 anthocyanins effect on water chromaticity and bacteriostasis experiment

Added 500mL water which were secondary effluentcome from the sewage treatment plant in the preparation of 576 CFU/mL to 123/4th flask Respectively. The 1st is blank control, add 300 mg/L the tea polyphenol to the 2nd water sample. Add the equivalent anthocyanin as well as the 2nd to the 3rd , wherein the total amount of anthocyanins are calculated basing on the percentage of anthocyanin content, namely cyanidin-3-galactosidase standard 0033mg/L. Add 033 mg/L the anthocyanins into the 4th water sample. After 30 min contaction,chromascope measure the three water samlpes,chromatic value.plate count method measure the four water samlpes,total number of bacteria.

2. Result and Analysis

2.1 The determination of total anthocyanins content in tea polyphenols

PH differential method is used to measure the total anthocyanin content, The absorbance value take into the type (1),the total anthocyanin content in tea polyphenol was 0.011%.

Total anthocyanin content

$$(\%, w/w) = \frac{A}{\varepsilon L} \times MW \times DF \times \frac{V}{W_t} \times 100 \tag{1}$$

A- absorbance;

ε — molar extinction coefficient 26900；

DF—dilution facter established;

MW— 449.2 (g/mol)for cyanidin-3-glucoside；

V— final volume, mL；

Wt— product weight, mg；

L—optical length, cm；

Mote: In some cases, the predominant antyocyanin in a material may be known and different from cyanidin-3-glucoside,it is critical that the wavelength, molecular weight, and absorptivity used be specified if results are not expressed as cyanidin-3 glucoside equivalents.report results as momomeric anthocyanins,expressed as cyanidin-3-glucoside equivalents in mg/L.

2.2 The type of anthocyanins in the tea polyphenols analysis

As the literature researches shown [18-20], the result relative molecular by mass spectrometry, positive and negative scan can infer the type material, and to precisely determine the pattern of the corresponding composition according to the order of the peak, this paper combine the retention time and the UV Atlas, molecular fragments and documents on various peaks to identify, according to the literature [16-17] separat anthocyanin by chromatographic peaks,order: delphinium-3-galactosidase>delphinium-3-glucoside> vector cornflower -3-galactosidase> delphinium-3-rutinoside> cyanidin-3-glucoside> cyanidin-3-rutinoside> geranium-3-glucoside. Using UPLC-MS-MS, and the order of the peaks to derive polyphenols anthocyanins species. By UPLC-MS-MS, mass spectrometry positive ion mode and negative ion mode, the results are shown.

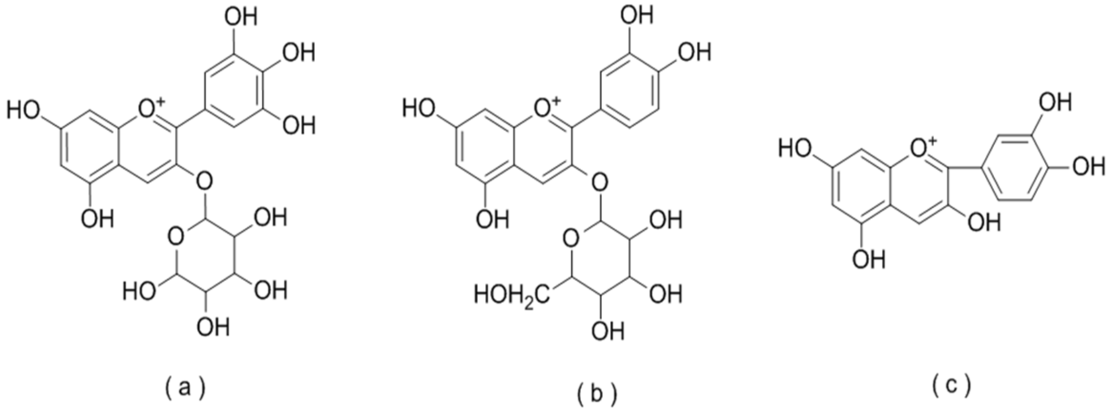

Fig. 2 the molecular structure of anthocyanin was obtained from negative ion mode.

（a）Delphinium -3- galactosidase (retention time 7.758min)
（b） Centaurea -3- galactoside (retention time 9.493min)
（c）Cornflower (retention time 13.814min)

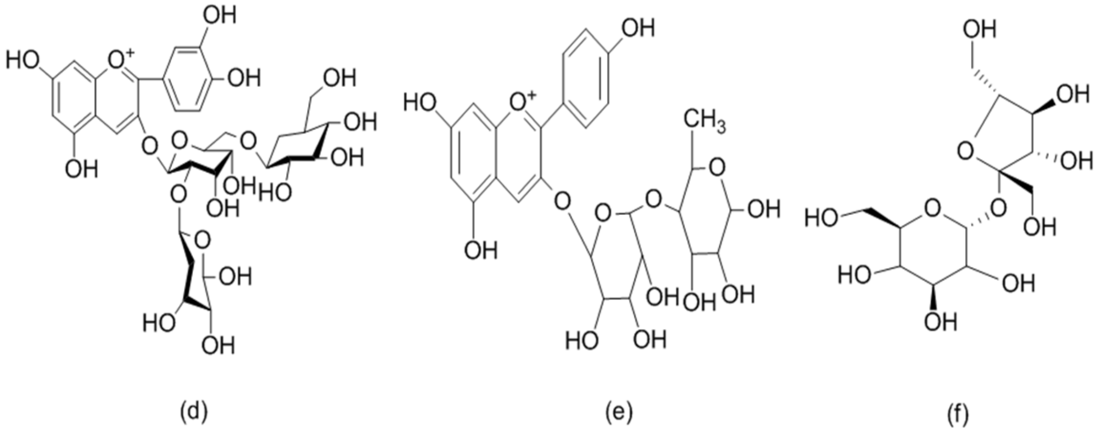

Fig. 3 the molecular structure of anthocyanins in the positive ion mode

（d）cornflower-3-6 malonyl glycosidase (retention time 0.698min)
（e）Geranium -3- kaempferol-3-o-rutinoside (retention time 0.970min)
（f）Delphinium -3- glucoside (retention time 13.797min)

Anthocyanins are typical of 3,5,7-trihydroxy-2-phenyl flavonoids benzopyran structure flavonoids, the molecules are in large conjugated system in plants,so it shows different colors, mother kind of substituents on the nuclear ring, location, different numbers, different types of anthocyanins, anthocyanins different colors, different number of hydroxyl groups of different types of anthocyanins which contains different categories and the number of sugar-based. the positionthey they connected , the kinds and the number of acids in sugar substituents are different[24]. UPLC-MS-MS analysis showed that the Institute disinfectant contein anthocyanins number is total of six, but mostly in the form of glycosides, respectively, delphinium -3- galactosidase, cyanidin -3- galactosidase glucoside, cyanidin, geranium -3- rutinoside, geranium -3- rutinoside, cyanidin -3- malonyl-glucoside.

The anthocyanins, color is different, anthocyanins basic structure shown in Figure 5, as the number of hydroxyl groups on the ring B increasing [24], the anthocyanins changes from pelargonidin (brick red) to cyanidin (red), the color changes gradually; when the methyl in 3,5 positions in B ring and the 7 positions in A ring were substituted ,the red effect increases.

More anthocyanins exist in the form of glycosides in nature, anthocyanins structure shown in Figure 7, the above experimental studies, anthocyanin species in tea polyphenols were respectively delphinium-3-galactosidase, cornflowers-3-galactoside, cyanidin, rutinoside -3- geranium, Pelargonium 3- rutinoside, cornflower -3-6 malonyl-glucoside, according to the literature [27], the color of delphinium, cornflower , geranium anthocyanin are red, orange and, yellow red, the orange color of the cornflower anthocyanin is in the middle of delphinium and geranium anthocyanin. Anthocyanins are the anthocyanin which combines with sugar, add glycosylation to the basis structure of the anthocyanin , anthocyanins are more redder than the color of the original anthocyanin, the formation of anthocyanin glycoside make maximum UV absorption spectrum move to The ultraviolet end [25]. Therefore, the color of cornflower anthocyanins is in the middlen between delphinium anthocyanin,s color and geranium anthocyanin,s color [28] [29] .we want to know about the color of tea polyphenols, cyanidin -3- galactosidase pure product is the best choice.

2.3 Anthocyanins in the aquatic chromaticity impact analysis

Contrast the Color of Cyanidin -3- galactosidase standard to the polyphenols disinfectants , the color of the cornflower anthocyanin between the delphinium anthocyanins,s and geranium anthocyanins,s[24], it has been detected by UPLC-MS -MS in the reault that the polyphenols contained cornflower anthocyanins and the cyanidin anthocyanins. and the cornflower anthocyanin content in higher than other anthocyanins [25], therefore the cornflower-3- galactosidase colorimetric test standards have a strong representation. The sterilization effect is best untill the time reach to the 30min when the disinfectant was additioned into water[3], therefore the present studychoice a contact time of 30min. The results shown in Figure 4, the blank of the original water color is value of 20; the water where disinfectant wae added into has a chroma of 160; the water adding anthocyanins standard which equivalent to tea polyphenols,contentis reach the chroma of 40 . The above data show that tea polyphenols disinfectant,s effect to water color is significant. Although anthocyanins content is extremely low in the tea polyphenols , which accounts for 0.011% in polyphenols, the chroma caused by the anthocyanins in the tea polyphenols accounted water color which produced by the tea polyphenols disinfectant 14.3% , it indicats a very small amount of anthocyanin in the tea polyphenols disinfectant could lead to greater impact to color, the color effect of anthocyanins can not be ignored.

Further explore on anthocyanin in the tea polyphenols disinfectant,s properties, high chroma reason is a must , the properties should be improveand so as to reduce the color effect of tea polyphenols disinfectant.

It reveals a strong instability [26],when analysis the anthocyanin structure , which is not stable by many factors, such as pH, temperature, concentration, light and oxygen. Anthocyanins are more sensitive to pH [27], when the pH of the solution is 1:00, anthocyanins exists in the form of red yellow salt cation , the solution was purple or red, with the increase of the pH to 5, the structure of B ring changes , oxygen double in the 2 position change into a fake base or chalcone. At the moment the solution is colorless, this process is reversible reaction. When enhance the alkaline of the solution , the anthocyanins more easily degraded ,and they will be degraded into different substituents [28]. Therefore, the anthocyanin,s instability could be starting point to removed the tea polyphenols chroma impact on drinking water .

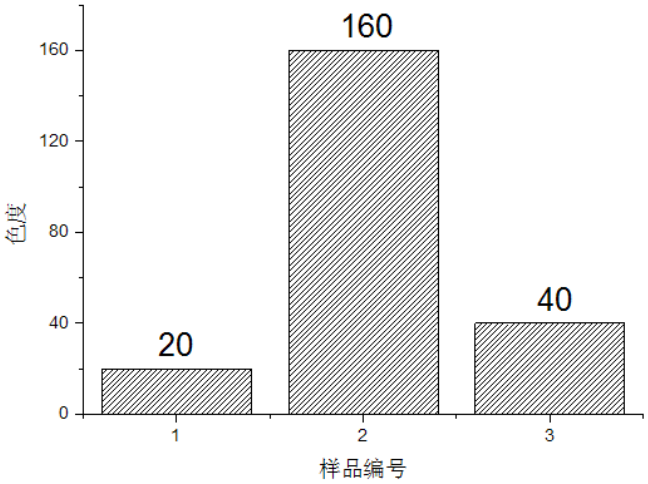

Fig.4 the molecular structure of anthocyanins in the positive ion mode

2.4 Anthocyanins of tea polyphenols bacteriostatic impact analysis

According to the experimental data, the bacterial count decreased obviously in No.2 water sample where additioned the tea polyphnol. The bacterial count had no change in the No.3 water sample where additioned the anthocyanin. The bacterial count had a little decrease in the No.4 water sample where additioned more anthocyanin than 3. According to literature studies,the anthocyanin has revealed the ability to inhibit growth of the bacteria to some extent.

When the anthocyanin react with The negative bacterium e. Coli and the positive red gold staphylococcus, it maybe enhance the permeability of cell membrane to inhibition of logarithmic phase of cell division, or inhibite the formation of bacterial proteins, then the cell grow abnormally or result in death. The anthocyanin dosing quantity has already reached 330ug/L in the 4 water sample. After 30min , the water quality does not meet microbiological standards within drinking water 100CFU/mL. Thus, we concluded that because of the anthocyanin content is too small, there is no obvious contribute to antimicrobial resistance.

3. Conclusion

Polyphenols disinfectant contains only a little amount of anthocyanins,pH differential method can measure the total amount of anthocyanins, the anthocyanins quality occupys the tea polyphenols 0.011%. The tea polyphenols contains six kinds of anthocyanin which were Delphinium -3- galactose glucoside, cornflower -3- galactose glucoside, cornflower, geranium - 3-rue glucoside, delphinium-3-glucoside, cornflower-3-6 malonyl glycosidase by UPLC-MS-MS.Mostly due to the anthocyanins,unstable glucoside form, 0.011% content in the tea polyphenols disinfectant and anthocyanins did not significantly contribute antibacterial properties. So some measures could be taken to decrease the anthocyanins color in application.To further meet the requirements of tea polyphenols as a drinking water disinfectant.

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A New Grey−water−using System in Private Housing

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Abstract

A new kind of flushing cistern was developed, which directly collects the grey water from the shower and wash basin in the bathroom to be used for toilet flushing. Prototypes were installed in several houses and tested for one year. During the test period a few essential improvements were carried out. The investigation led to a few changes in the system. The results and gained experience are presented.

Keywords

Grey water; Toilet flushing; Water hygiene, Water saving, Potable water substitution

1. Introduction

Water consumption in Germany has decreased in the course of the last two decades by 26 % [1]. However, this is mainly due to the industry's water-saving measures and a decline in many production fields of the heavy industry and in mining. On the other hand, the number of households and small businesses has increased by more than 10 %, which means that there is an even higher potential to save water.

In recent years the water consumption in Germany has levelled off at 123 litres per capita and day,with a volume accounting for

Bath/shower/personal hygiene of	44 litres p.c./d.	36%
Toilet flushing of	34 litres p.c./d.	27 %

These data show that it is possible to cover the required volume of flush water completely by grey water accruing in the household. Grey water is defined as being wastewater clean of any fecal matter, which is particularly applicable to wastewater from bath and shower tubs as well as wash basins. The idea was to collect the grey water accrued in the bathroom directly in a suitably dimensioned flushing cistern and to use it for flushing the toilet. For this purpose a grey-water-collection and flush-system was developed, its functionality tested and a one-year field test carried out. In this connection FreeFlush-prototypes installed in industry, small businesses and private households were examined for microbiological and olfactometric (odour) parameters. After some weeks' operation, time an increased number of germs and odour formation was found. The odour formation could be stemmed by disinfecting the flushing cistern with activated oxygen for a period of about two weeks. Further examinations carried out to analyze the risk showed that an increased number of germs do not impair the users' health.

2. Experiments

2.1 FreeFlush–System

The developed system works as follows (Figure 1): Water from the wash basin, shower and bath tub is pumped by a small sewage lifting station (a) directly into the flushing cistern, thus being immediately available for flushing. The storage volume is about 100 l. As soon as the flushing cistern is full, the surplus water is carried through a overflow pipe (b) directly into the drainage system. In case there is not enough grey water available, the flushing cistern is automatically filled with potable water via a filling valve (c), leaving the toilet flushing ready for use at any time. Once a day, mostly at night, the flushing cistern is emptied via the toilet and refilled with 6 liters of potable water. Two low-noise pumps, which have proved successful in the market for years, were chosen for pumping the water into the flushing cistern and flushing the toilet. The covertly mounted electronic control system is individually adaptable to the users' habits and is actuated over the pneumatic hose of a common flush button (d). The control of these prototypes also includes a data collecting system (e) measuring the consumption of potable water, grey water and electric power.

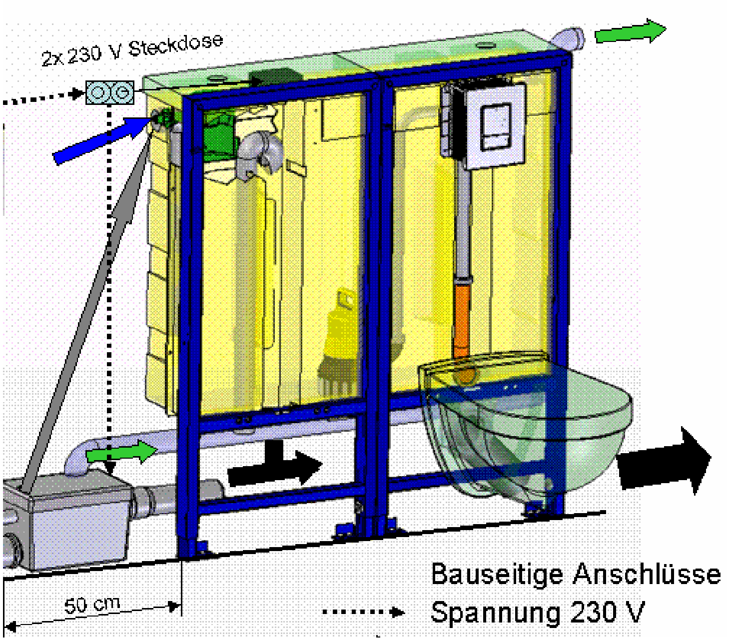

Figure 1 -Scheme of FreeFlush-System

2.2 Field tests

Six installations were tested for one year: 2 in industrial facilities, 1 in a small business and 3 in one-family houses. Figure 2, e.g. shows the FreeFlush-Installation in a one-family house. The complete system including the sewage lifting station and grey water supply pipe is mounted in a pre-wall in the bathroom, which is equipped with a small bath tub, a toilet, a double washstand and a walk-in shower.The grey water of the shower is carried through a plastic pipe DN 50 to the lifting station. There are no other sanitary facilities connected to the pumping system. This is the simplest installation situation, as all the objects are arranged at the same wall and in the correct order. In this sequence the pump follows the shower and is followed by the FreeFlush-system. The tank of the lifting station is connected to a vertical DN 50 vent-pipe with a carbon filter. The flushing cistern is filled via a DN 32 PCV-C pipe, which is equipped with a check valve.

At least once a month, grey water samples were taken from each installed system. At the start, in between and at the end of each field test samples of potable water were also taken in order to rule out any contamination of the potable water installation.

It was supposed that the physico-chemical parameters of the grey water for the toilet flushing were no potential danger to human health. Only microbiologically contaminated grey water could be a health hazard in case there was too much strain on the toilet user. For this reason, the samples were only analyzed with regard to the following parameters given in the German Drinking Water Ordinance [2]:

(1) Cultivatable microorganisms – number of colonies at 22℃ and 36℃
(2) Coliform bacteria
(3) Enterococci
(4) Pseudomonas aeruginosa

The samples were directly taken from the flush water running from the outlet into the toilet bowl. At this point the grey water is supposed to have reached the peak level of contamination after running through all the pipes, the wastewater lifting station and the immersion pump, and stagnating in the flushing cistern until running through the flush pipe into the toilet bowl.

Figure 2 -Example of a FreeFlush installation

Furthermore, swabs were taken of the biofilm in the flush cistern 5 cm below the maximum grey water level and at the front of the toilet bowl.

It was also necessary to take air samples in the closer surrounding of the toilet bowls in their respective locations in order to examine the contamination of the ambient air caused by germs from grey water flushings.

Both swabs and air samples were analyzed with regard to the microbiological parameters described below.

The swabs were taken with a cotton swab in the form of a big Q-tip. After the cotton swab had been moistened with sterile water, it was rubbed against a surface part of 5 x 5 cm, put into a tube filled with 2mL of sterile water, which was then sealed (Figure 3). At the laboratory the same parameters were then analyzed like in grey water.

Figure 3 - Taking the swab

With the help of an air pump (Sartorius) within 5 minutes 250 L of ambient air were sucked off at a height of 65 cm measured from the floor directly above the toilet bowl (Figure 4)

Figure 4 - Taking an air sample

During the sucking off time the flushing was actuated five times, with the air flowing through a sterile wafer-filter, which catches any kind of air germs. The wafer was divided up in the laboratory and examined for various microbiological parameters.

3 Result

3.1 Potable water analysis

At the beginning, in the middle and at the end of the testing phase, samples were taken of grey water as well as potable water. Taking the samples was carried out according to a realistic use without removing faucet aerators or shower heads etc. at the taps and fittings for potable water. This measure was taken for the assessment of the initial contamination by germ-infested water. Samples were taken of warm water as well of cold water, as both can carry germs into grey water.

With each installation the counts of E. Coli, Enterococci and P. Aeruginosa were below detection limit. Therefore, they are to be regarded as counting for „0“. The highest CFU-level (colony-forming unit) found in cold water samples was 2900 cfu/ml, in warm water it was 4260 cfu/ml, the elimination of which was achieved by means of countermeasures and treating the cause.

3.2 Grey water

For the analysis of the highly contaminated grey water samples, dilution series had to be carried out
The result of the first dilution, which made a complex counting of germs possible, was recalculated. But the counts determined like that are highly inaccurate. For this reason, with such counts only the power of ten is relevant.

According to Herbst [3], e. g., the E. coli counts for household grey water are to be expected to range from $10^3 – 10^8$.

According to Ackermann [4] compiled level ranges of microbiological parameters for grey water from bath and shower tubs as well as washstands are given in Table 1.

Table 1: Microbiological Contamination according to Literature

Reference water volume	n /100 ml
Colony-forming microorganisms	10^2 - 10^8
E. coli	$10^1 – 10^7$
Streptococci	$10^1 – 10^6$
P. aeruginosa	$0 – 10^3$

These results only apply to untreated grey water. In case of sedimented and/or filtered grey water the number of decimal powers are expected to go down by 2 to 4.

3.2.1 Cultivatable Microorganisms

The entirety of all bacteria, yeasts and fungi, which are able to form colonies in the mentioned medium under aerobic conditions, are called cultivatable microorganisms. The result of the analysis shows the level of microbiological contamination of the medium, in this case, of the grey water.

Depending on the temperature sensitivity, the results achieved with the incubation temperature of 20 (± 2) °C and 36 (± 1) °C are different. Owing to the level of the analysis results, it is not possible to make any statement concerning hazards to human health (Table 2).

Table 2: Range of Counts of Cultivatable Microorganisms per Installation

Installation	1	2	3	4	5	6
CFU / ml (20 ± 2)°C	$10^5 – 10^6$	$10^4 – 10^5$	$10^4 – 10^6$	$10^5 – 10^6$	$10^5 – 10^6$	$10^5 – 10^6$
CFU / ml (36 ± 1)°C	$10^4 – 10^6$	$10^4 – 10^5$	$10^4 – 10^6$	$10^4 – 10^6$	$10^5 – 10^6$	10^5

3.2.2 Escherichia Coli

Escherichia coli, in particular, serve as a proof of contamination of (grey) water with coliform bacteria of human origin. They are released into the grey water, for instance, by washing your hands after using the toilet/bidet or washing the anus under the shower or in the bath tub. Thus E. coli is an indicator organism for fecal contamination and an unhygienic running of a household or procedure. They exist in form of nonhazardous intestinal bacteria as well as pathogenic strains of bacteria. Coliform bacteria can be of fecal origin, but they also belong to the normal plantal flora of a large number of foodstuffs, e. g. mixed salads. A detection of these bacteria is a hint to fecal or non-fecal contamination. (Table 3).

Table 3: Range of counts of E. coli per installation

Installation	1	2	3	4	5	6
E. coli / 100 ml	$10^1 – 10^5$	$10^0 – 10^2$	$10^0 – 10^4$	$10^0 – 10^4$	$10^1 – 10^4$	$10^2 – 10^3$

3.2.3 Enterococci

The same as Escherichia coli, Enterococci are part of the natural intestinal flora of warm-blooded creatures and are suitable indicators of fecal contamination of water. However, there are also so-called non-fecal Enterococci originating from vegetable matter. Two species, E. faecium and E. faecalis, occur in the human intestinal tract. They play an important role in food production with fermentation and maturing aids. This is why they are found in some sorts of cheese and raw sausages. But it is also known that some E. faecalis strains, in particular, can trigger infections with persons whose immune system is fairly weak.

Enterococci do not reproduce in water and are considered more resistant than E. coli or coliform bacteria. Enterococci can, therefore, help to prove past contaminations.

The range of counts resulting from the analysis concerning Enterococci can be seen in table 4.

Table 4: Range of Counts of Enterococci per Installation

Installation	1	2	3	4	5	6
Enterococci /100 ml	$10^2 – 10^4$	0	$0 – 10^4$	$0 – 10^3$	$10^3 – 10^4$	$10^2 – 10^3$

3.2.4 Pseudomonas aeruginosa

Pseudomonas (P.) aeruginosa is a facultative pathogenic bacterium or disease-causing agent which is widely spread in water and aquatic environment because of its high resistance and low nutrient demands. It can cause inflammations of the skin, the lungs and urinary tract. This is especially true for immunocompromised persons, whereas P. Aeruginosa rarely causes disease in healthy individuals.Pseudomonas Aeruginosa is also known as hospital pathogen. According to the Hospital-Infection-Surveillance-System 10 % of all hospital infections are said to be caused by P. Aeruginosa.

The range of counts resulting from the analysis concerning Pseudomonas can be seen in table 5.

Table 5: The Range of Counts of Pseudomonas per Installation

Anlage	1	2	3	4	5	6
P. aeruginosa / 100ml	$0 – 10^4$	$10^1 – 10^4$	$10^2 – 10^4$	$0 – 10^4$	$0 – 10^4$	$0 – 10^1$

3.2.5 Odour

The odour measurement was carried out subjectively by the human nose. This is the reason why only qualitative statements could be made. With the exception of one installation, there were more or less strong odours in the installation area of all systems. The unpleasant musty odour is a result of the anaerobic decomposition in the grey water tank.

One installation was experimentally treated with 5 g (¼ of a tablet) of activated oxygen. By the addition of oxygen the anaerobic state was stopped. The measure had an immediate effect and was taken when necessary – also with other systems. The effect lasted for 1-2 weeks. In order to counteract this anaerobic condition permanently, 1 litre of air was admixed to the grey water in the flushing cistern of the system by means of an aquarium air pump and an air stone. Afterwards there were only slight odours around the installation 1. But this measure failed in the other installations. A possible explanation may lie in the fact that the installations 1 and 2 were very well-maintained. Technical problems of the other installations were noticed much later.

3.2.6 Distribution of Germs

At first glance, the large number of germs in grey water seems to be a potential hazard to human health. But a worrying condition only arises if the germs spread in the environment get into the food chain or mucous membranes, resp. wounds or chaps.

For this reason air flow images were taken during flushings. Disco-fog was used to make air motions visible. Based on pre-examinations it was assumed that the air motion mainly happens in the toilet bowl where it „swirls". This is true if the flush water temperature is significantly lower (12 - 17 °C) than the room temperature. With the flushing there is a little emission to the top in the area of the water trap of the flushdown toilet, then, especially in the front area, the air moves over the rim of the bowl.

The same experiment was carried out with the installation 4. Caused by the effect of the warm water, the air rose turbulently prancing to the top. The fog rose up to 50 – 70 cm.

For the purpose of verification, experiments with a water temperature of 26 and 32°C were carried out with test installations using commercially available standard flush cistern.

Figures 5 to 10 show flow images of air motion before and after flushing at these water temperatures. A vertical upward movement of the air was clearly to be seen from inside the toilet bowl into the room.

These examinations were made to find out if and how germs spread from inside the toilet bowl into the environment by air and aerosol movement while flushing. The flow visualization showed two hazardous zones:
(1) With cold flush water: The outer surface of the bowl, especially in the front
(2) With warm flush water: The area above the bowl

Therefore, microbiological examinations were made at the front rim of the bowl (swab tests) and of air samples above the bowl (wafer filters).

Figure 5 and 6 -Flow visualization with cold water: start and end of flushing

Figure 7 and 8 - Flow visualization at 26 °C: start and end of flushing

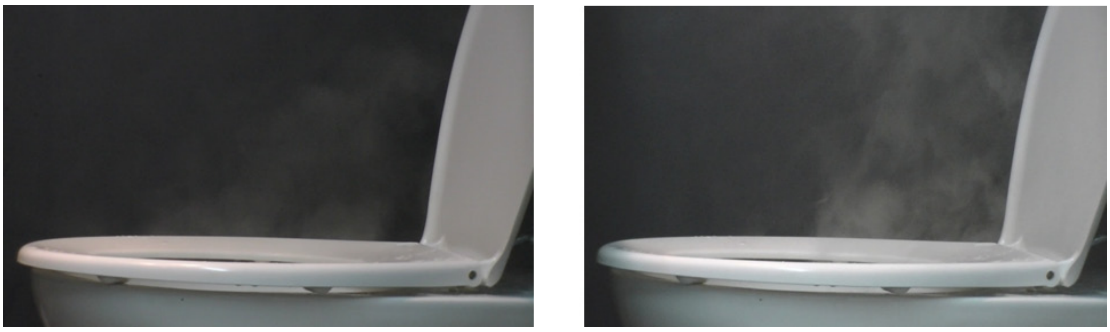

Figure 9 and 10 - Flow visualization at 32 °C: start and end of flushing

3.2.7 Hygiene-Swabs

With cold flush water the air"spills" “ from inside the bowl over the rim, with the front rim being especially affected. The swabs served to find out how much the bowl rim was contaminated by the air carrying grey water aerosol. Reference measurements in normally equipped bathrooms showed the following average results:

（1）CFU 20 ℃ C /100mL:23
（2）CFU 36 ℃ /100mL: 330
（3）E. Coli / 100 mL:0
（4）Enterococci / 100 mL:0
（5）P. Aeruginosa / 100 mL: 0

Measurements were made on door handles, toilet seats and actuating plates. No E. coli, Enterococci or Pseudomonas Aeruginosa were found.

Table 6: Range of Counts of Pseudomonas per Installation

Installation	**1**	**2**	**3**	**4**	**5**	**6**
P. aeruginosa / 100ml	$0 – 10^4$	$10^1 – 10^4$	$10^2 – 10^4$	$0 – 10^4$	$0 – 10^4$	$0 – 10^1$

In each swab-sample the counts of E. coli-, Enterococci- and Pseudomonas Aeruginosa were below detection limit.

Although the general germ counts of these installations are higher than the reference counts, they do not show any indicators of fecal contamination. A detection of Pseudomonas Aeruginosa in any sample was likewise not possible.

3.2.8 Air Samples

Air samples were taken directly in front of the toilet bowl at a height of 65 cm measured from the floor. While taking the samples the flushing was actuated five times in order to create a current of air suspected of carrying grey water aerosol. There was one air sample taken at each installation.

No sample could furnish proof of fecal contamination.

4. Conclusion

(1) At first glance, the relatively high number of pathogenic germs in grey water give reason for thinking about reduction measures and are not to be avoided without any kind of disinfection. These germs might cause disease in healthy persons, but only if the germs are of a cumulatively facultative type. In case of such strains a high number of bacteria must get into the body at suitable vulnerable spots of the body in order to cause any health hazard. On the contrary, 10 – 100 bacteria of obligate pathogenic strains can cause serious diseases. One example is the coliform bacteria EHEC, which may cause an infection leading to kidney damage and kidney failure. There was special focus on this bacteria five years ago.
(2) Odour formation was found at almost all the installations, but could be reduced for about two weeks by adding activated oxygen.
(3) By adding activated oxygen, anaerobic bacterial activity and thus also the odour formation could be stopped, but the number of aerobic microorganisms, particularly of P. Aeruginosa increased.
(4) After admixing air there was only slight or no odour at all detected at almost each installation.
(5) Swabs (11 samples) and air measurements (10 samples) did not prove any fecal contamination of the environment caused by air flow. The toilet bowl rim also showed average germ counts for toilet bowls.
(6) Since the wastewater area begins below the upper rim of the toilet bowl, it is quite allowed to use untreated grey water.
(7) The timing for the hygiene-flushing is important and should be adapted to the users' habits. The point of time chosen should avoid that grey water stagnates in the flushing cistern unused for a long time.
(8) The installation is able to substitute approximately 25-30 % of the overall daily potable water of a private household by grey water.

5. Summary

The number of germ counts found under a field test with six FreeFlush-installations did not exceed the ones mentioned in specialist literature. As untreated grey water was used for flushing, swab and air samples and a visualization of air flow delivered the proof that FreeFlush-installations do not bear any higher risk than ordinary toilet facilities.

In the flushing cistern, a biofilm forms which cannot be removed by the hygiene-flush. Mechanical, flow-related and chemical-biological measures to reduce the biofilm still have to be thought through.

Odour formation was stopped temporarily by means of admixing activated oxygen. The disinfection carried out with "Sagrotan Laundry Hygiene-Conditioner" at the end of the examination period had a lasting effect and is suitable for killing both anaerobic and aerobic germs.

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Domestic Hot Water Consumption in Apartment Buildings

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Abstract

Domestic hot water consumption has been measured in 12 apartment buildings of different sizes (11 to 378 apartments) in Belgium. Each building was monitored for a period of 1 or 2 months with a measurement interval of 1 second. Peak flow rates were deduced from these data for each building. The measured peak flow rates were converted to reference conditions in order to obtain flow rates which can be compared and be used for dimensioning purposes. In this article, a new conversion method is suggested and the different steps are discussed. These standardised peak flow rates are then compared to the peak flows as calculated in accordance with existing guidelines in order to determine the relevance of these guidelines for Belgium. DIN 1988-300:2012 [1] was found to be most appropriate.

Keywords

Water consumption, peak flow rate, domestic hot water , domestic cold water , pipe sizing

1 Introduction

As the energy-use for space heating continues to diminish in the European Union, due to better performances of the building envelope and the use of high performance heating appliances, the energy use for hot water production becomes increasingly relevant. Since the recast of the Energy Performance of Buildings Directive [4] stipulates that by 2020 all new buildings in the European Union should be almost near zero energy buildings, reducing the energy use for hot water production, whilst maintaining the desired comfort level for the buildings occupants, will become one of the challenges for the future.

Therefore it becomes ever more important to design hot water production and distribution installations inside our buildings -of which apartment buildings are an important part- in a more efficient way.

Also an optimal design of the drinking water system (hot and cold) is an even more important necessity in order to guarantee the hygienic quality of the water at the taps: avoiding Legionella-problems means, between others, no stagnation of the water in oversized hot water vessels and avoiding too low velocities due to the oversized pipes. This concern requires also a better knowledge of the water consumption in our buildings.

Given the fact that Belgium has no national standard, complementing the simplified pipe sizing method of NBN EN 806-3:20016 [5], foreign methods are since long commonly used. As these methods were in general issued already many years ago -the most commonly used methods for sizing hot water distribution systems rely on methods based on consumption data of the seventies of the past century [6], [7]-, while as well the equipment level, the sanitary comfort as the technology greatly evolved since then, it is evident that there is an urgent need to get actual and reliable data on water consumption in buildings. This need was also recognized in other countries, which led them to review already their guidelines, leading -in general- to smaller peak flows and thus smaller pipe sizes, eg: Germany in 2012 [1] and The Netherlands in 2013 [8].

In previous articles we have described the first results of our domestic hot water (DHW) and domestic cold water (DWC) measurement campaigns [2] and we reported, last year in Brazil, on the fact that the hot water consumption depends significantly on the season, mainly due the seasonal variation the cold water temperature, as a result of our the latitude (about 50° N). This seasonal variation was shown to affect as well the mean daily DHW consumption as the peak flow [3].

In this paper, we will discuss the latest results of our measurement campaign on the DHW peak flow. First we propose a method for the conversion of the measured data ("raw data") into "reference" peak flow, ie. the corresponding peak flow at 60°C, given a cold water temperature of 10°C, called "DHW6010 peak flow". It is this "reference value" which normally is used for the sizing of the supply pipes.
Besides taking into account a conversion for correcting the measurements with temperatures differing from 60°C (hot) and 10°C (cold), correction is also made for the above mentioned seasonal variation.
But a correction is also made for the fact that the temperature measured at the outlet of the heating device, is not –in the mean- the temperature of the hot water just before the taps.
We also discuss some of the limitations of our conversion method and hypothesis and hope hereby to contribute to a better understanding of our measurements for other research teams and maybe open a debate to deduce a uniform method, since it seems probable to us that other teams would be confronted with some of the same challenges.

2 The BBRI measurement campaign

Since 2011 domestic hot water consumption was measured in 12 apartment buildings of different sizes (7 to 378 apartments) with centralised hot water production. Each building was monitored for a period of about 1 to 2 months.

For the measure of the water consumption, ultrasonic flow meters were used, measuring the flow rate of the water qDWH at the entrance of the heating appliance. Since these meters have sensors which are fixed on the pipes outer wall, no modification of the installation in the building was needed [2]. The cold (Tc) and hot water temperatures were measured as well, using thermocouples. For DHW systems with a circulation system, both departure (Tdepart) and return temperatures (Treturn) were measured at the level of the heating appliance. The data were stored on a data logger with a measurement interval of one second. All measurements points are located in the central boiler room as shown in figure 1.

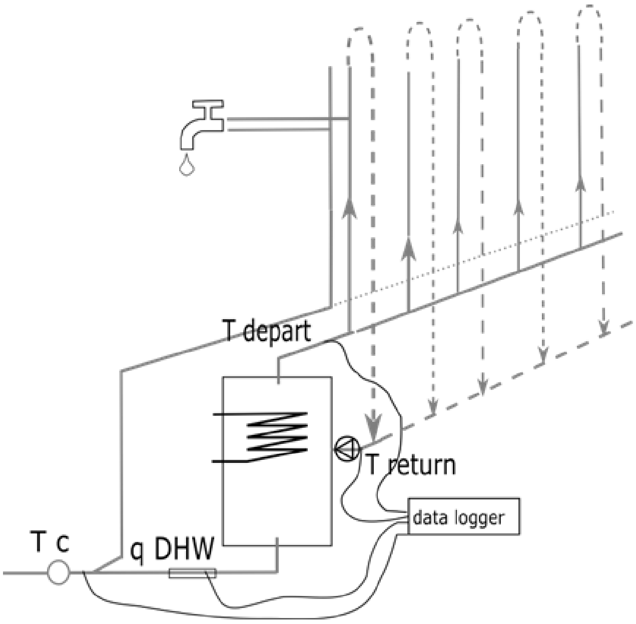

Figure 1 - Identification of measuring points in the boiler room

Table 1 gives for the different buildings the total number of apartments, as well as the length of the measurement period and the average hot (T DHW) and cold (T DCW) water temperatures.

Table 1 Measured apartment buildings and characteristics

Building number	Number of apartments	Measuring period (days)	average T DHW (°C)	average T DCW (°C)
1	11	30	45	17
2	36	22	70	18
3	57	32	55	20
4	62	58	65	20
5	93	86	52	14
6	96	81	50	13
7	113	58	53	16
8	124	78	68	13
9	277	70	50	11
10	312	64	52	12
11	320	64	57	17
12	378	36	49	13

Table 1 shows a rather large variation in both average DHW and DCW temperatures, which confirms the need of a data conversion to reference conditions in order to be able to compare the results for different buildings.

3 Results

3.1 Measurement data

Table 2 gives the measured DHW peak flow rates, the peak flow converted to standardized DHW_{6010} peak flow rates “standardized” for DHW at 60℃ for DCW at 10℃ [3] and the “reference” DHW_{6010} peak flow rates, in which further data conversions are integrated. We would suggest using these latter values for dimensioning purposes.

Table 2 Measured and converted DHW peak flow rates

Building number	Raw DHW peak flow rate (1s) (L/min)	DHW_{6010} peak flow rate (2 s) (L/min)	"Reference" DHW_{6010} peak flow rate (L/min)
1	28,2	31,2	34,4
2	42,4	47,4	54,5
3	36,7	45,2	54,8
4	69,7	60,7	73,5
5	80,5	74,4	80,8
6	82,2	79,0	90,8
7	60,5	58,3	82,2
8	77,6	86,1	118,0
9	134,7	110,9	116,4
10	143,0	66,6	72,3
11	196,0	136,8	148,4
12	100,2	84,2	84,2

The different steps of our conversion method are discussed in paragraph 3.2.

3.2 Conversion method

The conversion method we applied to the measurement data contains different steps.

1)*Step 1: visual check* of the measured data (flow rates and temperatures) through daily graphs. In case of potentially abnormal data, and if the technical reason can be discovered (for instance: refilling of space heating circuit, maintenance intervention on DHW system, leakages, etc.), the data for day where the abnormal event occurred are supressed.

2)*Step 2: conversion to standardized* DHW_{6010} *peak flow rates*

A frequently used formula of conversion into standardized DHW_{6010} is given in equation 1:

$$\mathrm{q\ DHW}_{6010} = \mathrm{q\ DHW}_{\square} * \frac{(\mathrm{T\ DHW} - 10)}{(60 - 10)} \qquad \text{(eq. 1)}$$

In this equation, the actual cold water temperature is totally ignored. However, if cold water temperature is 25℃ , the hot water flow will be less than the flow in the same building if the cold water is around 10℃ . Each building facility had his own DHW production temperature and his own cold water temperature. The conversion of their DHW flows into standardized DHW_{6010} flows should therefore take into account both the measured cold and hot water temperatures. This formula also ignores the fact that the temperature measured at the outlet of the heating appliance, decreases in the installation due to the heat losses of the pipes, so that a tap near the heating appliance will have a lower consumption, than an the same tap with an identical use, at the end of the piping system.

The measured DHW flows were therefore converted into standardized DHW_{6010} flows according the equation (2):

$$q\ DHW_{6010} = q\ DHW_{\square} * \frac{\frac{(T\ DHW - Tc)}{(Tu - Tc)} * (Tu - 10)}{(60 - 10)} \qquad \text{(eq. 2)}$$

Where:

q DHW6010: the standardized flow of DHW_{6010} (L/min)
q DHW : the measured flow of the domestic hot water (L/min).
T DWH: the average temperature of the hot water at the taps -see remark below- (℃)
Tc: the average temperature of the cold water at the taps -see remark below- (℃)
Tu: the mean temperature of the mixed water at the taps -see also remark below (℃).

Remarks:

Due to the practical difficulty of measuring the flows and the temperature of both cold and hot water at each tap in larger apartment buildings, the following assumptions and evaluations were made, with respect to the following parameters of the above formula

-Tc: we assumed no warming up of the cold water while flowing through the pipes at moments of peak consumption. So the temperature value measured on the main domestic water pipe inlet, was used without correction.

-Tu: For the average temperature of the mixed water at the taps a value of 38℃ was considered. This value is more “secure” than 40℃ when used in the formule (2), because Tc is often greater than 10℃ .

-T DWH : the average temperature of the domestic hot water at the taps was estimated from the measurements of DHW temperature departure and the return of the circulation system. This T DWH was estimated by using equation (3).

$$\mathrm{T\ DWH}\ = T\ \ depart - \left(\frac{T\ depart - T\ return}{4}\right) \qquad \text{(eq. 3)}$$

Where:
T depart: the temperature of the domestic hot water at the outlet pipe of the hot water heat exchanger or the storage tank (℃)
T return: the temperature of the domestic hot water at the inlet of the return pipe in the heat exchanger or storage tank

3)Step 3: averaging DHW_{6010} peak flow rates to 2 second time step - this step results in the DHW_{6010} peak flow rate (2s) in Table 2

4)Step 4: correction for the seasonal variation in DHW consumption, by applying the previously determined monthly correction factors [3] - this step results in the "Reference" DHW_{6010} peak flow rate in Table 2

3.3 Limitations and need of future improvements

During our measuring campaign we have encountered several difficulties and limitations, linked to either the measuring method or the conversion method.

With regard to the measuring method
Because we only measured in the central boiler room, we needed to make assumptions concerning the average tap temperature, in order to be able to take into account the cold water temperature (eq. 2 and 3).. Also the pressure at the taps could influence the peak flow. This aspect wasn’t covered in our measuring campaign. Furthermore, our ultrasonic flow meters were not compatible with certain types of multilayer pipes.

With regard to the conversion method
Short-term fluctuations in the DHW temperatures in the circulation system may have a significant impact on the standardized DHW_{6010} peak flow rates. We found it very useful to verify visually the impact of each data correction. Furthermore, if the temperature of the cold water rises above 38℃ , the conversion equation (eq. 2) should not be used. Another important need for future improvement is to take into account the time lag due to the circulation of the hot water in the circulation system. The conversion would be more correct if based on T° depart at time t, in combination with T return at time t + time lag.

3.4 Comparison with existing guidelines

Figure 2 represents, for the building in the measuring campaign, the reference DHW peak flow rates compared to the calculated peak flow rates following the different guidelines.

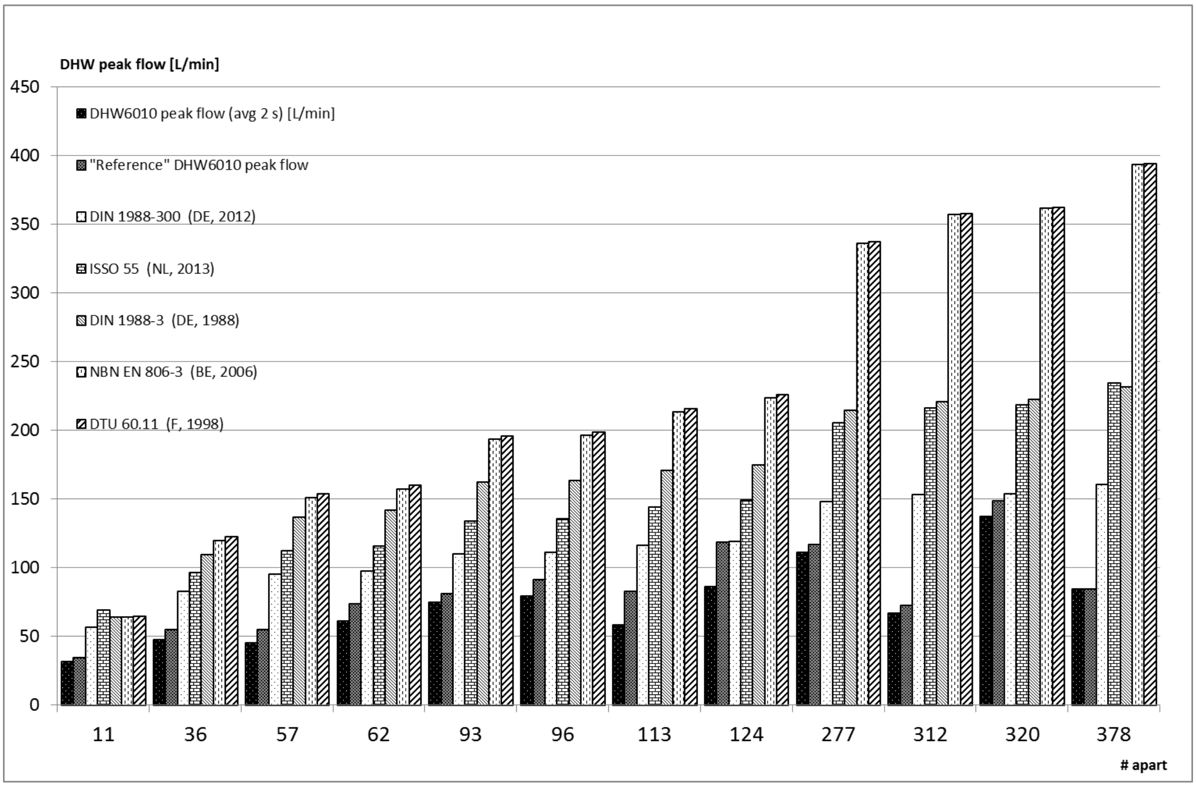

Figure 2 - Reference and calculated peak flow rate in apartment buildings of different sizes

The calculated DHW peak flow rates according to the different guidelines are systematically higher than the reference DHW6010flow rate. The European standard (EN 806-3) even results in a peak flow rate which is 4 times the reference peak flow rate. Most existing guidelines overestimate the peak flow rate, especially EN 806-3 [5] and DTU 60.11 [7]. Calculations following DIN 1988-300 [1] are closest to the reference peak flow rates, followed by ISSO 55 [8]. The difference between calculated and reference peak flow rates becomes more important for larger buildings.

4 Conclusions

Most existing guidelines over-estimate the DHW peak flow rate, especially in larger apartment buildings. Overestimations up to a factor of 4 and more are no exeption. DIN 1988-300:2012 was found to be most relevant for the Belgian situation. In most buildings this standard seems still to contain a (to?)high safety margin.

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Evaluation Model and Baseline of Water Efficiency for Green Building in Taiwan

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Abstract

Low carbon policy including water efficiency has been adopted as a crucial implement for global warming and climate change. Taiwan green building evaluation system initially assigned the building water efficiency as the threshold index for application from 1999. There are more than thousands buildings approved as green building levels for these periods. The quantitative saving water effect should be the positive feedback to policy maker. Theoretically, the water efficiency design and adoption of water saving facilities can benefit the building water efficiency. However, the practical water usage is complex including behaviors and factors are diversity. This paper offered a calculation model to estimate the quantitative volume of water saving from these practical green buildings. Firstly, the baseline of water usage for all kind of buildings should be confirmed and built as comparison base for saving water effect. Investigation has been executed to validate the estimation results and identify the individual issues which are not fit to the target. Monte Carlo simulation and statistical analysis were used to improve the accurate of estimation. As the results, the average water saving rate was confirmed as around 30% with wide range of frustration.

Keywords

Green building, low carbon society, water resource, saving water

1. Introduction

Mitigation of global greenhouse gas and effective use of water resources have become important issues that every country in the world must address. In Taiwan, policies on energy conservation and carbon reduction have generally received support from Taiwanese people. With the institutionalization of green architecture and proactive promotion of certification systems, water saving design and facilities of architecture have seen rapid progress in recent years. The water conservation planning, utilization of rain water, recycling of reclaimed water and water-saving sanitary appliance to buildings has direct, significant impacts on effective use of water resources and also has positive benefits on energy-saving and carbon-reduction policies. According to statistics from existing studies, daily water consumption per capita in Taiwan is above 250 liters, and even exceeds 400 liters in urban area. From the calculation based on the population of Taiwan, which is around 23 million, the water consumption per year is considerably high; therefore, its water conservation potential shall not be underrated.

Regarding the issue of effective use of water resources, however, the actual water consumption of a building with certification of green architecture is different from that of an ordinary one. The questions on whether the substantial water-saving effects are achieved and the benefits of energy-saving and carbon-reduction are obtained are widely discussed among the public in Taiwan. To date, there is no solid verification recognized. This study is intended to, at first, establish a water-saving benefit estimation model for the issue over the effective use of water resources, and set out an approach to an empirical investigation for buildings with green architecture certification, and then verify the quantified values of data after statistical analysis. Accordingly, the quantified values of reasonable water saving benefits for Taiwan every year from 2000 to 2013, after the launch of the green architecture certification system, will be derived to examine the effects of water conservation.

2. Reviews and Mythology

According to 2010 statistics of Taiwan Water Resources Agency (Fig. 1), the annual water consumption is around 17.064 billion cubic meters. For domestic water is 3.256 billion cubic meters, which accounts for 18.23% of the overall water use. Agricultural water consumption takes the first place, which is 12.205 billion cubic meters water (accounts for 71.53%). The industrial water consumption accounts for 8.98% of total water consumption (1.603 billion cubic meters of water).

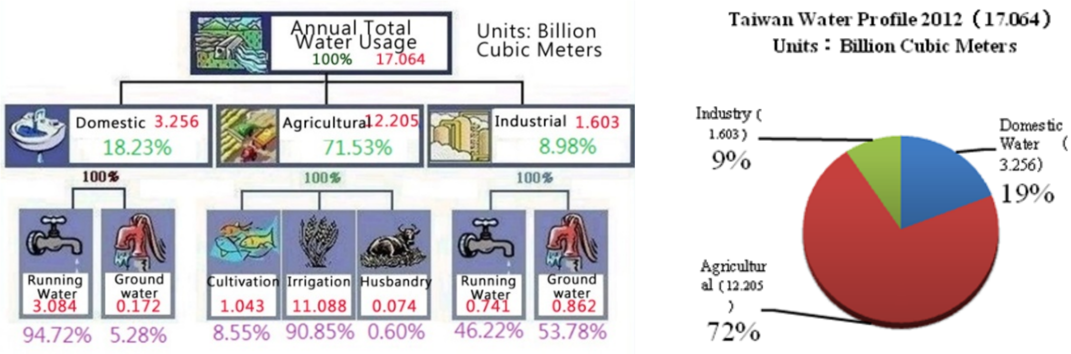


Fig. 1. Taiwan Water Profile 2010 (1)

The water factor of CO_2 emission is high related to the water consumption. Fig. 2 shows the shifting volume of daily water consumption per person in Taipei city and other areas of Taiwan. It is obvious that the metropolitan area such as Taipei city has greater water consumption of around 30% up in the other areas of Taiwan. It also shows that water consumption is increasing during 1980s and with peak value in 1990s. The tendency is approximately stable after year of 2000 with Taipei city of around 350 liter per day and the other areas of Taiwan of around 270 liter per day.

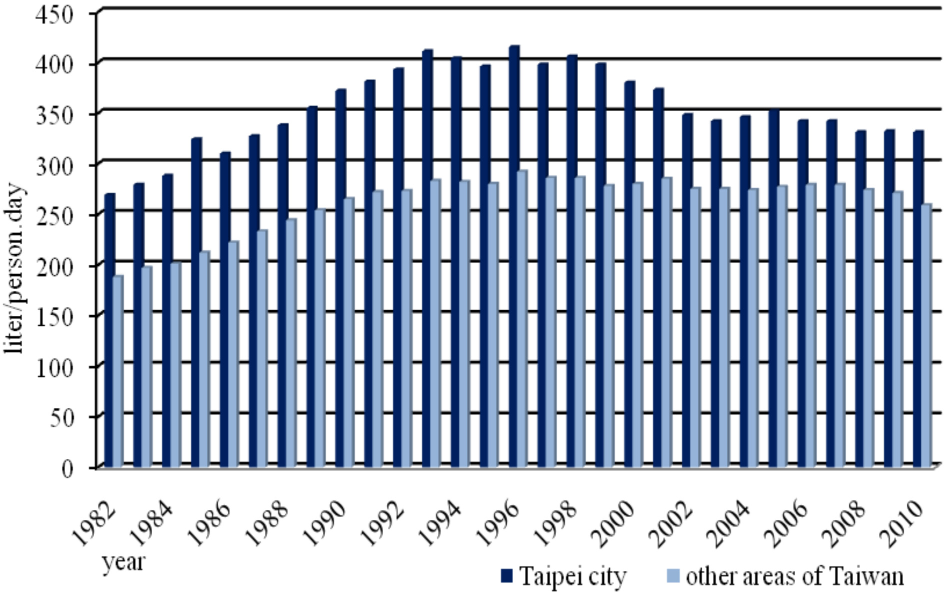


Fig. 2 the shifting volume of daily water consumption in Taiwan

3. Evaluation Model

To control relevant water saving assessment strategies and water saving benefits for a building, this study proposes to estimate the quantity of water demanded through a water saving measurement model and uses limited sample cases of green architecture for an empirical investigation. Using statistical methodology to modify relevant calculation parameters for the water saving estimation model, the actual water saving effects for the building in recent years is validated by investigation.

To estimate more precise quantity of water actually consumed for a green architecture case, the factors of operating time is added to the categories of architecture for the estimation baseline of the quantity of waster consumed. After the water consumption for per unit construction floor area of a building with green architecture certification is acquired, this study uses statistical quantitative methods and empirical investigation for comparison and analysis, rectifying the actual gross water consumption as a basis for estimation of the quantity of a building annual water conservation. Accordingly, the baseline for annual water consumption of each category of architecture W_{ty} (m^3/year) is established, and the formula for the estimated quantity of annual water conservation W_{st} (m^3/year) is provided below.

$$W_{ty} = A_f \times WUI \qquad (1)$$

W_{ty}: annual water consumption of each category of architecture (m^3/year)

A_f: The gross floor area of building (m^2)

WUI : water consumption density per unit area of the building (m^3/m^2.year)

$W_{st} = W_{ty} \times (RS8 \div 8) \times 0.6 \times Cr$ (2)

W_{st}: The estimated quantity of building’ s annual water conservation (m^3/year)

W_{ty}: annual water consumption of each category of architecture (m^3/year)

RS8: Score of green building’ s water resource indicator system ($0.0 \leq RS8 \leq 8.0$)

Cr : Empirical modified coefficient

The score of water resource indicator system for the green building rating assessment system, RS8, is the key parameter for estimation. This study introduces a statistical method, Sample Monte Carlo Simulation (SMS), where we establish 10,000 simulation sample data to calculate the average values of the water resource indicator rating scores 2007-2013 (RS8n), most of which are normally distributed between 3.0 and 5.0. Table 3 and Figure 3 show the average values of RS8 for the green building case each year.

Table 3.The annual of the RS8 average value in the different building type

Building type	2007	2008	2009	2010	2011	2012	2013	Average
office	4.92	5.75	5.06	4.61	5.13	4.92	5.6	5.14
department stores	-	-	-	-	5.66	5.83	6.5	6.00
hostel	-	-	-	-	-	-	6.05	6.05
hospital	-	-	-	5.5	5.56	5.56	5.29	5.48
school	4.55	5.18	5.19	4.32	5.39	5.34	5.26	5.03
residence	5.08	5.01	4.43	6.39	4.98	6.24	6.2	5.48
others	5.65	5.49	5.42	5.42	5.1	5.44	5.39	5.42

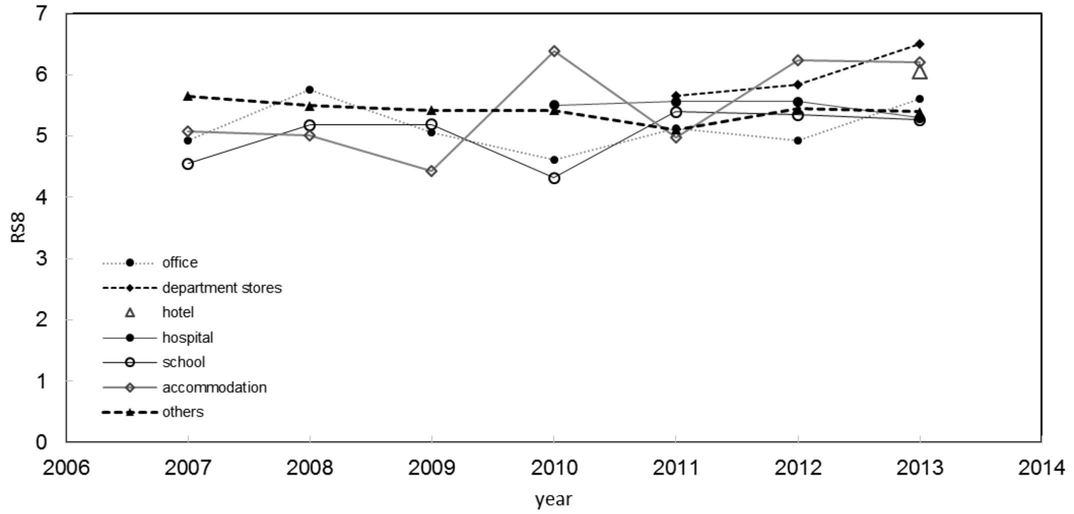


Fig. 3 Average of water saving indicator for building category

Concluding the average values RS8n of water resource indicator rating scores helps to streamline the estimation of water saving benefits for the year's water resource indicator. Formula (3) represents the water consumption baseline of the building of the year, while Formula (4) represents the estimation of the quantity of water saving for the building of the year (n, 2000~2013).

$W_{tyn}=A_{fn}\times P_{ri}\times Q_{wi}\times P_{dm}$ (3)

W_{tyn}： the water consumption baseline of the building of the year (n, 2005~2013) (m^3/year)

A_{fn}： The gross floor area (m^2) of the building with green architecture certification of the year (n, 2005-2013).

$W_{stn} = W_{tyn}\times(RS8n \div 8)\ \times 0.6\ \times Cr$ (4)

W_{stn}： the estimation of the quantity of water saving for the building of the year (n, 2000~2013) (m^3/year)

RS8n： Score of the water resource indicator system of the year (n, 2000-2013)

Cr： Empirical modified coefficient

According to the conclusion of the average values RS8n of water resource indicator rating scores, this study further uses a regression formula to estimate the reasonably predicable parameters obtained for green architecture labeling cases prior to the enforcement of the green architecture rating system in 2005. Therefore, this study can control the gross water saving benefit of buildings with green architecture certification from 2000, the year when the green architecture labeling was enforced, to 2013. The estimation formula for the gross water saving benefit is provided as follows.

$$W_{gst} = \sum_{n=1}^{n} W_{stn} \qquad (5)$$

W_{gst}: The estimated quantity of gross water saving (m^3) for buildings with green architecture labeling 2000-2013.

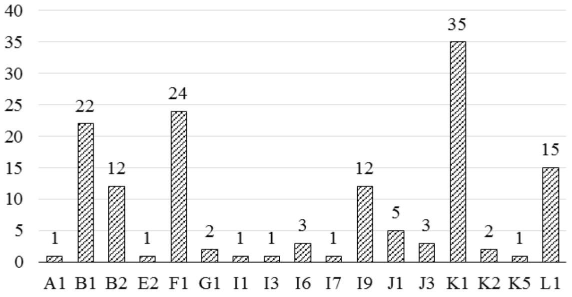
W_{stn}: The estimated quantity (m^3/year) of the building of the year (n, 2000-2013).

4. Investigation and Validation

This study is designed to use the actual quantity of water consumption for cases with green architecture certification in Taiwan and the standard quantity of water demanded for verification. There are 141 sample obtained. The average unite quantity of water consumption per person will vary with the category of the building and will also be categorized for the type of architecture based on the use time. Table 5 shows the statistics of category for cases investigated by Taipei Water Company.

Factors that affect a building’ s water conservation efficiency are relatively complicated. To verify the standard of reasonable average water saving rate, this study selects cases with the low standard water saving rate (-60%-60%), medium standard water saving rate (-20%-60) and high standard water saving rate (0%-60) for discussion and eventually selects the cases with water saving rates 0-60% as empirical subjects for analysis.

Table 5. Statistics of category for cases investigated by Taipei Water Company

usage time	24H					18H	12H		
space type	A1	B1	B2	E2	F1	G1	I1	I3	I6
number	1	21	12	1	24	2	1	1	3
usage time	12H				10H				
space type	I7	I9	J1	J3	K1	K2	K5	L1	
number	1	12	5	3	35	2	1	15	
analysis figure									

To enhance the accuracy and reliability of the estimation with the standard water consumption quantity established in this study, we compare the actual quantity of water consumption given by Taipei Water Company with the standard water consumption quantity calculated in this study and then review and verify the value Cr of the formula as a basis for modifying the error between the estimated value and the measured one. As a result, there are 42 effective samples, with an average water saving rate of 38.82%. At last, this study, based on 29 samples with calculable system score RS8 and the theoretical water saving rate derived through the replacement of the system score RS8 of the actual cases in the formula, obtains a modified coefficient Cr, making the theoretical water saving rate meet the practical and current status.

$$W_{st}=W_{ty}\times(RS8\div 8)\times 0.6\times 0.115 \qquad (6)$$

W_{st}: The estimated quantity of building's annual water conservation (m^3/year)
W_{ty}: Annual water consumption of each category of architecture (m^3/year)
RS8: Score of green building's water resource indicator system ($0.0 \leq RS8 \leq 8.0$)

This study, based on the estimating model for the quantity of water demanded and the quantity of water saving of buildings, proceeds with theoretically reasonable calculation of water saving benefits, with major estimation factors including the baseline for annual water consumption of building (W_{ty}), score of the water resource indicator system (RS8), to estimate the quantity (W_{st}) of annual water saving for building with green architecture labeling accordingly.

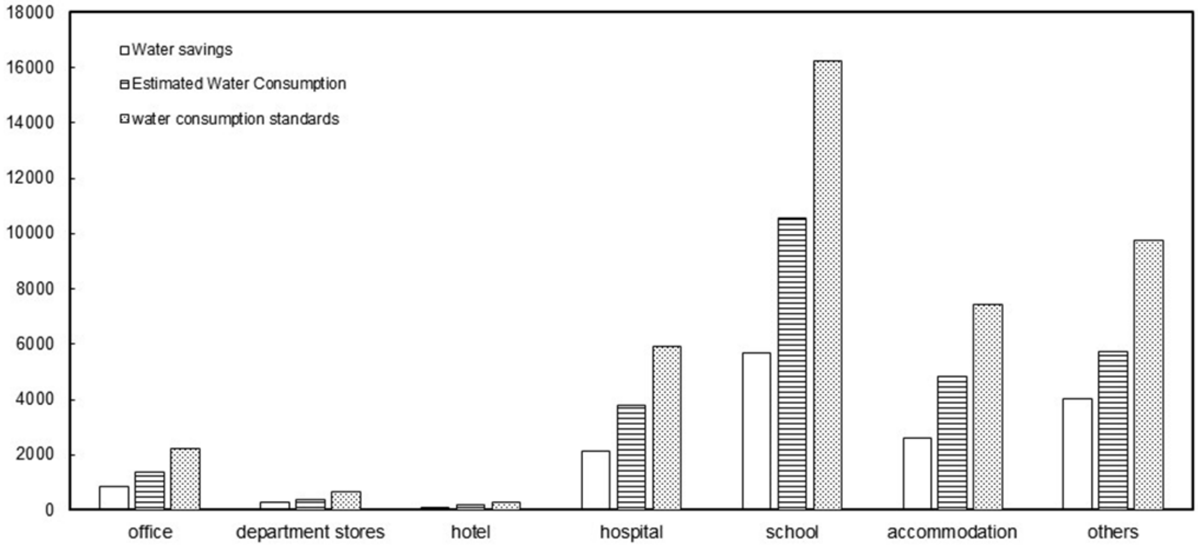


Fig.4 The comparison of quantity of water consumption and water saving for each category of building (2000-2013)

Table 6 the quantity of gross water saving for each category of building

	office	department stores	hostel	hospital	school	residence	others	total
2000	31.64	-	-	-	-	-	-	31.64
2001	-	-	-	-	-	61.38	-	61.38
2002	-	-	-	-	-	46.98	-	46.98
2003	11.82	-	30.57	-	-	23.84	0.92	67.15
2004	21.46	-	-	-	17.51	111.05	73.86	223.88
2005	98.33	-	-	-	66.88	96.51	43.95	305.66
2006	172.71	1.39	-	12.52	153.16	120.18	145.65	605.62
2007	220.10	11.20	-	26.09	216.97	182.26	308.03	964.66
2008	434.45	-	-	251.35	229.80	260.93	101.57	1,278.10
2009	264.00	103.61	-	509.50	323.39	541.06	304.10	2,045.66
2010	371.44	-	-	81.17	226.73	301.35	217.75	1,198.43
2011	329.65	6.38	-	108.07	369.00	524.66	414.94	1,752.70
2012	499.92	52.93	34.29	77.60	536.97	500.56	1,082.88	2,785.15
2013	839.53	13.07	95.95	1,727.98	505.33	708.33	1,228.58	5,118.79

（unit：$\times 10^3$ m^3,kiloton）

Figure 4 demonstrates the standard quantity of water consumption, estimated quantity of water consumption, and the gross water saving benefit for each category of building every year since the enforcement of green architecture labeling system in Taiwan. Table 6 shows the quantity of gross water saving for each category of building and the estimated results of the gross water saving year by year.

Regarding the estimation of water saving benefits for water resource indicators, the average quantity of water saving for cases with green architecture labeling is estimated to reach 38.82% which is close to initial estimation for the water saving result of green building leveling request. As the comparison between estimation of Taiwan Building Center and this study, the difference is around 10-20% annually and total difference is 7.6％ . The comparison is shown as table 7 and figure 5, which are indicating that most of the figures are verified.

Table 7 Comparison of estimated values for water saving effects of building

year	The estimated quantity of water saving (W_{stn1}) in this study	The estimated quantity of water saving (W_{stn2}) for the architecture center	Differentiation Percentage ((W_{stn2}-W_{stn1})/W_{stn2})%
2000	31.6	0.0	
2001	61.4	60.0	-2.3%
2002	47.0	46.0	-2.1%
2003	67.1	70.4	4.6%
2004	223.9	187.4	-19.5%
2005	305.7	318.7	4.1%
2006	605.6	722.4	16.2%
2007	964.7	1054.8	8.5%
2008	1278.1	1191.0	-7.3%
2009	2045.7	1997.5	-2.4%
2010	1198.4	973.9	-23.1%
2011	1752.7	1719.5	-1.9%
2012	2785.2	2724.9	-2.2%
2013	5118.8	4252.3	-20.4%
Total	16485.8	15318.8	-7.6%

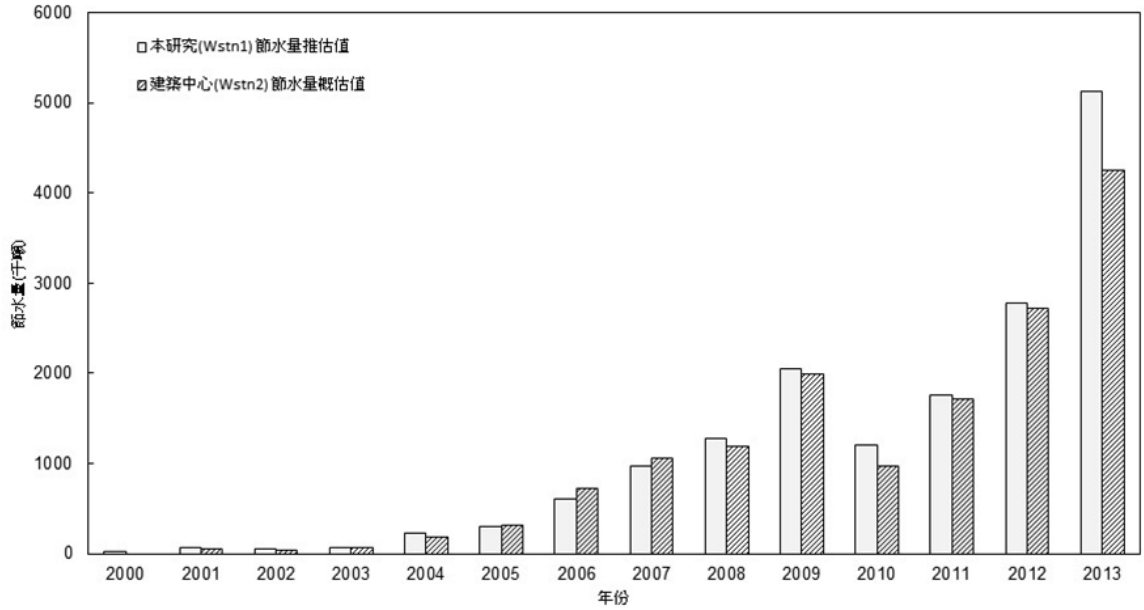


Fig.5 Comparison between the estimated water saving effects in this study

5. Conclusion

In terms of effective use of water resources, this study, through current status investigation and empirical methods, verifies the quantified water saving effects for buildings with green architecture labeling in Taiwan. At first, the building’s unit floor area baseline WUI as the basis for estimation of water saving benefits is summarized. A quantification estimation model for water saving benefits is established and the current status of water resource utilization and water saving benefits is used as the study scope. According to the data provided by Taipei Water Department, the difference between the actual quantity of water consumption for green buildings and that for ordinary buildings is validated and the water saving effects are evaluated.

The investigation result shows that the average water saving rate for 1,320 cases with green architecture labeling during 2000-2013 in Taiwan accounts for 38.82% approximately. The verification results for the water saving estimation model established in this study shows the alteration between the values of effects year-by-year is around 10-20% annually, and the total estimated difference is 7.6%, suggesting that the water saving benefit for building with green architecture labeling is higher than the existing estimated value. The building’s unit floor area baseline WUI is established in this study, in conjunction with the quantification estimation model for water saving benefits, can be used as a reference basis for quantification of building’s water saving benefits in the future.

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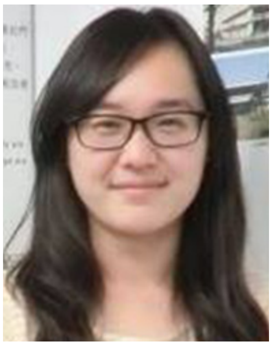

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Green Roof and Water Cycle Role in It

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Abstract

Water cycle, also called hydrologic cycle. Cycle that involves the continuous circulation of water in the Earth-atmosphere system. The most important processes involved in the water cycle are evaporation, transpiration, condensation, precipitation, and runoff. Although the total amount of water within the cycle remains essentially constant, its distribution among the various processes is continually changing. Because of land being full of concrete and asphalt, impervious surface, water flows off surfaces and reduces infiltration into ground water. Agricultural fields, suburban and urban lands are being replaced with non natural surfaces. Water cycle in areas like this is broken. Necessity of recovering green areas is becoming increasingly critical. Broken water cycle is one of the reasons. One of the potential remedy for this problem is green roof, worldwide agenda. Aim of this article is to picture green roof as a tool of improving urban water cycle.

Keywords

Cycle, Condensation, Green roof, Precipitation, Runoff

1 Introduction

It seems that humans are continually confronted with the duality how to surround ourselves with plants but without letting propagate freely. And yet it is precisely this form of freedom of the plant world that most fascinate us. Today, more than half of the human population on earth lives in cities. Images of agriculture are only present in the minds of those people who live in certain villages that are remote or carved into rugged topographies. Integrating nature and water into dwelling has been applied for thousands of years. Cities and buildings all around the world have been being covered in green since ancient times to maintain balance between artificial and natural environment.

Many communities today are inventing and formulating questions of sustainability. Improving the quality of life is a goal people want to achieve. Climatic changes caused by human activity are major reasons of these questions. Humans with everything else on and in the planet belong to the Earth system. However, humans have developed over time, the ability to drastically affect, or even completely destroy, the Earth system. In fact, humans are arrogant, certain that they are responsible for all of Earth´s trouble.

Humans are so powerful, so intelligent. Our status approaches our ability to disrupt climates. Why not compare ourselves to Zeus or Poseidon. The climate is warming up and we know that it is hot in hell. Humans have brought evil, can we figure out how to bring good as a form of redemption in order to return to the tranquility of the past [1]?

We are undoubtedly responsible for modifications in the landscape, excepting certain deserts, high mountains and tundra regions that have been of little interest to us. Each modification entails the destruction of local vegetation, affecting a range of agricultural exploitation. The global increase in carbon dioxide is the result of human activity, primarily in industrialized nations. We must keep in mind the thought that every human being, whether rich or poor, breathes out the same amount of carbon dioxide. The concentration of carbon dioxide is rising [2].

2 Water

There is about 1400 million km3 of water on the Earth. The water in the seas, the water on the land, the water in the atmosphere and the water in living organisms. Of course water meant in all its states. The gaseous state, liquid state and solid state.

2.1 Seas

The water of the seas and oceans covers 70,8% of the Earth's surface and forms the largest part, up to 97,25%, of all water on the Earth. The seas and the oceans the planet would be suffering from changing of extreme temperatures, what would make life as we know it impossible. Even a slight fluctuation of temperature compared to the current temperatures could have fatal consequences for food security on our planet. Among other functions of the seas and the oceans is interesting water supply to precipitation on the land [3].

2.2 Land

The water on the land. The water is often being fixated on the water in the rivers or natural or artificial lakes. Water in solid form ice, snow) forms 2,05 % of all water on the Earth and shelters up to 70% of the world's freshwater supplies. Visible surface water in rivers forms only 0.00001 % and in lakes (including salt lakes and inland seas) 0,01 % of all water on the Earth. Groundwater and water forming soil moisture 0,687 % presents besides eccentrically placed glaciers the greatest wealth on the land that exceeds several times the volume of water in all rivers and lakes of the entire world. Water in the soil in terms of the quantity of benefits is more important than water in rivers. This undiscovered treasure is misunderstood and overlooked, neglected and destroyed [3].

2.3 Atmosphere

The water in the atmosphere. The volume of the water in the atmosphere, in all three states is approximately 10 times bigger than the volume of water in all the rivers. Theoretically, if all the water in the atmosphere felt in time in the form of precipitation, it would create on the imaginary ground surface 25 mm layer of water. Just like the seas and oceans have key global thermoregulation role on the planet, the water in the atmosphere has crucial local thermoregulation function [3].

2.4 Biota

The water in the biota. The water surrounds us. It is not just around us, but it is inside us. In living organisms, water volume is about 0,00004% of all the water on the Earth, what is the smallest amount of total volume of the water, but what is lacking on the volume is the highly balanced in crucial importance of this water for daily individual form of life. For example, the human body contains more than 60% of water, and all the physiological processes take place in a medium whose main component is water. The water content in plants varies depending on the species and often is much higher than water content in animal perionyx. The volumes of water accumulated in the vegetation cover are not negligible, just like the volumes of water stored in the soil due to the existence of vegetation. The vegetation on the land, among other functions, has in particular the critical role in the regulation of evaporation from the soil. Therefore, on the land greatly aids thermal stability. Upon which depends its own prosperity and even its existence. On the existence and prosperity of vegetation depends consequently all higher life on the Earth [3].

3 Water and Heat

Water is very unique. At temperatures common on Earth can naturally exist in all three states. The solid state, the liquid state and the gaseous state. During the change of state heat is consumed, respectively released. During the change of state from solid or liquid state to gaseous state, it gains high mobility thanks to which it is capable of quick motion. Thanks to the motion, is capable of quick moving in large volumes in horizontal and vertical directions. Water also has the highest specific heat capacity, thus the ability to receive thermal energy from known materials. With its ability to bind and release energy, and transfer skills, reflection and dissipation of energy, water in all its states according to the needs cools or heats the planet. It is keeping it at a temperature that supports life on Earth.

3.1 Water and its balance qualities

Water balances the temperature differences between day and night, between seasons and between different areas. Thus water also reduces weather extremes. Water vapor is the most wide-spread greenhouse effect in the atmosphere. The content of water vapor in the atmosphere is highly variable, but its typical range is 1-4 % (for comparison , the CO_2 content is 0,0383%). The more water in the atmosphere, the stronger effect of temperature balance. Thus there are less weather amplitudes. The less water in the atmosphere, the weaker effect of temperature balance Thus there are more extreme weather amplitudes. Where is the lack of the water in the soil and lack of the water in the atmosphere, extreme temperature conditions usually persist. Water and water vapor affect the climate in the most significant way on the Earth. Nevertheless, the role of water and water vapor in the atmosphere is poorly understood and little discussed issue [4].

4 Water and Its Cooling Effect

Incident solar radiation evaporates water from the seas, lakes, rivers, wetlands, soil from plants into the atmosphere. Evaporation of each molecule of water consumes heat, which cools the Earth's surface. Evaporated water creates clouds in the atmosphere (including fog, rain-fall or ice crystals). Rised vapor higher in the atmosphere condense under the influence of cold, releasing heat. Cooled higher in the atmosphere return back in the form of rain. Repeating this process is an effective mechanism for the elimination of spare heat and is similar to the sophisticated refrigeration device. There is a rule that about half of the earth's surface is all the time in a cloud´s shadow. Clouds restrict the entry of solar radiation into the atmosphere and on the Earth's surface. Limitation of solar radiation that reaches the earth's surface, reduces evaporation and the formation of clouds [4].

4.1 Clouds and its thermoregulation function

Clouds play an essential role in regulating of energy balance of the Earth concerning the sun radiation. They reflect part of shortwave solar radiation, thus limiting its entry into the atmosphere and on the Earth's surface, thus protecting the Earth from overheating. Clouds capture part of the longwave (thermal) radiation from the Earth, which otherwise would escape to the space, what has a warming effect. The cooling or warming effect of clouds depends on their type and height. Low situated cumulous clouds (cumulus) cool the Earth, high situated thin clouds (cirus) warm the Earth. The research of thermoregulatory effects of clouds and their balance, with regard to the current problems of mankind proves to be very promising and interesting [4].

4.2 Vegetation and its evaporation function

When the solar radiation hits water well-stocked area, most of the solar energy is consumed for evaporation and only the rest is consumed for sensible heat, heating the soil, reflection, or photosynthesis. When the solar radiation hits the drainage area, most of the solar energy turns into sensible heat, in the year-long sufficiently humid areas, most of the solar energy is consumed for evaporation. Therefore, water areas, soil saturated with water and vegetation have important role in the water cycle on the land. Functional vegetation fulfills the function of the valve between the soil and the atmosphere. It protects the soil from excessive overheating and thus drying out and optimizes the amount of the water evaporation through the transpiration of amount of air channels on the leaves. Vegetation well stocked with water thus has a significant cooling and air conditioning feature. Vegetation, its quantity, type and quality significantly affect the runoff in the watershed. Deforestation, agricultural and urban activities are changing the amount of water in the country. Man unwittingly changes flow of huge amount of water and energy [4].

4.3 Cleaning and its function

Heat (and gravity) is the engine of the global water cycle consisting of a large and a small water cycle. The water in the water cycle is blood and sap of life, which under the influence of the solar energy and gravity flows, circulates and vibrates between seas, lands and atmosphere in all forms of its occurrence. Passing the atmosphere it absorbs carbon dioxide, ammonia, and other gases and impurities. Similarly, it enriches various additives during the run- off, during the infiltration through the soil and subsoil. Water in all these movements meets, cleans and thermoregulate ecosystems, but also erodes the soil. The amount of minerals that water per year takes to the seas and oceans is estimated at 3,5 billion tons. Soil transport and soil nutrients transport is one of the reasons why we should slow the drain of rainwater in the countries and why rivers should divert to the seas only those surpluses which do not "fit" into optimally saturated soil and the atmosphere [4].

5 Green Roofs and Their Qualities

Question of maintaining full valued urban vegetation in contemporary town development with water management problems is an issue, today´s society is heading towards sustainable development. Green roofs offer measurable benefits. They fulfill many functions at the same time. They have expressive aesthetic, ecological, shading, psychological etc. benefits. They depress city temperature through water evaporation, control noise, air pollution and health. They create positive micro climate, positive air quality, absorb water and provide water retention. They fulfill the tasks of investors, governments, expert and amateur community with economic usefulness.

5.1 Green in architectural concept

Integrating nature into dwelling has been applied for thousands of years. Buildings have been being covered in green since ancient times. Hanging Gardens of Babylon are the very first example. Scandinavian sod roofs are another one. Bringing nature into cities and urban dwellings has always been an amenity for many landscape architects and engineers. Bringing nature into our lives makes deep statement about the way we see the world. Or it is teaching us the way how we should see the world. Wildness, green, plants should fascinate us in nature, in city, anywhere. No matter how idealistic it seems, this is how we should start [5].

5.2 Aesthetic performance

Besides environmental helpfulness, very important is aesthetic aspect of these roofs, because they are part of urban environment. Idea is to make buildings transparent or invisible among plants. The plants are present. The colorness and purity of the air close to a vegetative roof evokes mental images of forests, waterfalls. Green roofs create new living spaces for people, for fauna and flora.

5.3 Plant performance

Different plant species can be planted in different areas based on soil depth and expected heat, light and water conditions. Some species can perform well over the other species. Because of the fact that very long hot and dry season can come, there were created breeding plants for moderate climatic zone that can also live in extreme conditions such as roofs of the buildings. Green gardens are proof that concrete is not an obstacle to a biodiversity, it provides a support permitting the growth and survival of numerous fragile plant species [6].

5.4 Air quality

Green roof can create micro climate, lower surrounding air temperature through water evaporation.

Humidify dry air, lower presence of allergens. It can also filter dust and harmful substances. Green roof can also participate in forming oxygen and capturing CO_2. It can also absorb light smog and UV radiation [7].

5.5 Energy savings

Green roof can create reduction in a building energy use during winter months and negligible differences in the summer.

5.6 Temperature differences

Green roof can be 15°C cooler than conventional roof. Temperature differences are greatest on the hottest days. It can prevent building from overheating and cooling (Fig. 22). Roof can protect the building from extreme temperatures and climatic changes [8].

5.7 Economical aspects

Green roof create reduction in a building energy use. Therefore, green roof helps lowering charges for cooling and heating building. Catching water means also lowering charges for surface draining. Green roof helps to duplicate building construction´s life, it can also help the price of a building (Fig. 23) [9].

5.8 Water quality

Green roof do not add any nitrogen to the runoff. Water quality testing shows that the water runoff contains fewer pollutants than typical water runoff [10,11].

5.9 Water retention

Green roof can retain nearly 75% of the total rainfall, depending on the roof layers. It means, it can keep 105 000 liters out of the city sewer system. Water retention means (Fig. 1) also unloading surface drainage [10,11].

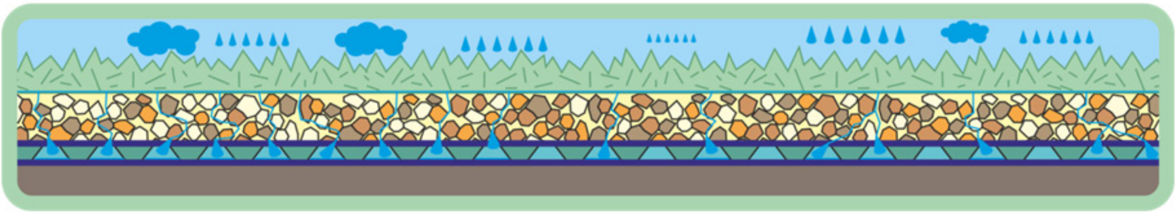

Figure 1 - Water retention

6 Green Roofs and Retention

In this part, two examples of different roof system solutions are pictured. Lightweight (Tab. 1, Tab. 2) and retention (Tab. 3, Tab. 4) roof is described. Its construction layers and features of each roof are named. Features: water retention, discharge coefficient and water storage are important, because of realizing the fact, how different the features of roof are depending on its construction and design.
Lightweight roof in terms of water retention can be considered as a roof with less retention features. It is able to retain 18L/m^2. Retention roof has the best water retention qualities, it can retain 38-53 m^2.

Table 1 Lightweight roof layers

Optigreen Pre-cultivated Sedum Vegetation Mat Type SM/G
Optigreen Low Density Substrate Type L (30 l/m²)
Optigreen Drainage Board Type FKD 25 (25 mm)
Optigreen Protection and Storage Fleece Type RMS 300
Waterproofing membrane
Suitable substructure

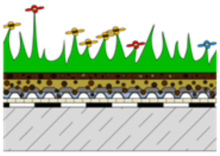

Table 2 Lightweight roof technical specifications

Weight	53 kg/m^2
Layer height	50 mm
Roof pitch	0-5° (0-9%)
Vegetation form	moss-sedum
Water retention	**40-50%**
Discharge coefficient	**C=0,63-0,65**
Water storage	**18 l/m^2**
Ecological value	■ ☐ ☐ ☐ ☐
Maintenance costs	■ ■ ☐ ☐ ☐
Cost factor	■ ■ ■ ☐ ☐

Table 3 Retention roof layers

Perennial plants and/or Optigreen Seed Mix Type E
Optigreen Extensive Substrate Type E (60 - 90 mm)
Optigreen Filter Fleece Type 105
Temporary water reservoir
Optigreen Meander Panel 60 (60 mm)
Permanent water reservoir
Optigreen Protection and Storage Fleece Type RMS 300
Waterproofing membrane
Suitable substructure

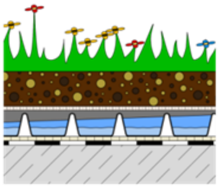

Table 4 Retention roof technical specifications

Weight	120-140 kg/m^2
Layer height	120 mm
Roof pitch	0-5° (0-9%)
Vegetation form	herbs-grasses-sedum
Water retention	**>80%**
Discharge coefficient	**C=0,05-0,17**
Water storage	**38-53 l/m^2 temporarily**
Ecological value	■ ■ ■ ■ ■
Maintenance costs	■ ■ ☐ ☐ ☐
Cost factor	■ ■ ☐ ☐ ☐

7 Conclusion

Green architecture is one potential method to beat destruction of natural environment. Green architecture concept needs to be understood and reinterpreted. Urban ecology and environmental issues need to become an integral of development, construction, but also policy and way people think and live. Green architecture provides great opportunities. Useless architectural places like roofs. These typical out of office spaces in our towns are becoming a remedy of constructing healthier environment through more sustainable practices. Green roof as benign integration of artificial and natural environment with water retention qualities. How much water would we be able to keep above our heads and what would be the possibilities for us now and for our future generations. Green roofs offer solutions how to find a place for nature, wildness and water in designed world.

Acknowledgments

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Development of Hyper–water–saving System Corresponding to Large–scale Disaster

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Abstract

In Japan, after the Great Hanshin Earthquake, disruption after disaster of power, water and sewage infrastructure had been assumed to be about one week at the longest.

However, in the Great East Japan Earthquake, in addition to the damage to building and equipment by the earthquake, over large-scale and long-term power, gas, water and wastewater infrastructure disruption by Tsunami were occurred.

In this earthquake, a few months or more were required for power supply and water supply recovery. And in case of functional recovery of sewer, in some case, more than a few years were required.

By the loss of these infrastructure function, the function of building as the base of life for disaster-affected people were lost.

Treatment of sanitary waste is one of the most important issues for to preserve the life of disaster-affected people, and to support the precise recovery.

However, in case of wide-area and large-scale disasters, such as Nankai Trough huge earthquake etc. , population to be assisted is too much, and period to be supported is too long, it is very difficult to correspond to this kind of disaster.

On the other hand currently, flash-toilet rate in Japan is over 90%, and this wash water become major burden for water supply of post-disaster.

Building Research Institute of Japan has been developing "Hyper-Water-Saving System", and in this system, Hyper-Water-Saving toilet is used.

By utilizing this system, the burden to water supply of post-disaster is expected to be significantly reduced. So in this paper, concept, configuration, effect, etc. of this system are reported.

Keywords

Water-Saving, Hyper-Water-Saving, Sanitation

1 Introduction

1.1 Lessons Learned from the Great Hanshin Earthquake

The Great Hanshin Earthquake in 1994, gave extensive damage to the Hanshin area (Kobe, etc.).
This disaster made major impact on Japanese society.
Overview of this earthquake disaster, is as follows.

1) Maximum seismic intensity 7
2) Magnitude 7.3
3) Maximum acceleration 818 gal (Kobe Marine Observatory)
4) Maximum speed 105 Cain (Kobe Marine Observatory)
5) Damage to human
   Dead person : 6,434 people
   Missing person : 3 people
   Injured person: 43,792 people
   Evacuation persons (at peak) : 316,678 people

In case of Non-conforming buildings to new seismic standards based on Building Standard Law of Japan revised in 1981, damage caused by this earthquake were enormous.
On the other hand, in case of the conforming buildings to this new standard, damage were very low.
Therefore, effectiveness of this new seismic standards were proved by this earthquake.
However, some water tank were damaged by sloshing.
Therefore, some of the new seismic standard were strengthened.

In addition, if functions of urban infrastructure (electric power, communications, water supply and sewerage systems) were lost, continuation of urban life becomes difficult .
In Great Hanshin Earthquake, serious damage has occurred in function of infrastructure (disruption of transportation networks, outage of electric power, function loss of water supply and sewerage, etc.).
From this experience of disaster, by the following assumptions, disaster prevention plan has been drafted.

- Up to 3 days : Outage of electric power supply
- Up to 1 week :Outages of water supply and sewerage

1.2 Frightful Impact of the Great East Japan Earthquake in 2011

After the Great Hanshin Earthquake, disaster prevention plan corresponding to this disaster had been actively promoted.
However, in 2011 the Great East Japan Earthquake occurred.
Overview of this earthquake disaster, is as follows.

1) Maximum seismic intensity 7
2) Magnitude 9.0
3) Damage to human
   Dead person : 15,826 people
   Missing person : 3,846 people
   Injured person: 5,942 people
   Evacuation persons (at peak) : about 400,000 people

In this disaster, serious damage was caused by tsunami .
The Great East Japan Earthquake caused huge tsunami.
Coast cities were destroyed by these tsunami.
And many people's life and property was lost by this disaster.
Landfill ground was liquefaction in many cities by this earthquake.
Because of this liquefaction, sewage pipe lines were damaged over wide area.
Recovery of these sewage pipe lines required a lot of time.
In some cases, several years or more period are required to repair these sewage pipe lines (Urayasu city, etc.).
As a response to this disaster, debate concerning the following matters has started.

- Disaster-prevention plan corresponding to long-term power outage
- Disaster prevention plan corresponding to long-term dysfunction of water supply and sewerage

1.3 Damage Estimation of the Nankai Trough huge earthquakes

March 2013, the Japanese government announced damage assumption (Second Report) of the Nankai Trough huge earthquake.
In the First Report, published in August 2012, damage of building and human casualties are reported.
In this Second Report, damage of infrastructure and economic loss are reported.
In this Second Report, as damage assumption of the Nankai Trough huge earthquake, following matters are assumed.

- Outage of electric power supply : About 27.1 million people affected
- Outage of water supply : About 34.4 million people affected
- Outage of sewerage : About 32.1 million people affected

(Outage of electric power supply is assumed up to 2weeks, and outages of water supply and sewerage are assumed up to 2 months.)
The Japanese government decided to promote disaster prevention measures based on this second report in the future.
For the above reasons, Building Research Institute of Japan is trying to develop Hyper-Water-Saving System Corresponding to Large-Scale Disaster.
The concept of this R&D is "Hyper-Water-Saving technology is the key technology for disaster prevention improvement".
For disaster prevention, in this R&D, water-saving of toilet system is especially emphasized.

2.Various Significance of Water–Saving

2.1 Responding to water resource depletion

Fresh water accounts for merely 2.5% of the water on Earth.
The proportion of usable water in rivers and lakes is as small as 0.01% (Figure 1).
At present, safe drinking water is not always available to 16% of people in developing countries, or to 13% of the worldwide population.
Forty-seven percent of those living in developing countries or 38% of people around the world lack reliable access to toilets and other sanitary facilities.
The contamination of water sources with human waste exacerbates the shortage of drinking water.
In urban districts of developing countries, demographic growth and concentration are intensifying.
In these areas, it is a top priority issue to secure drinking water, to save water by controlling water demand, and to achieve sanitation by means of wastewater treatment to prevent the pollution of drinking water

sources and infectious diseases.

However, it is becoming difficult to maintain the sanitary level and to preserve drinking water in a way that keeps pace with population growth and concentration using the traditional approaches of different countries.

The modern water supply and sewerage system was established as a system for developed countries in the nineteenth century in which the global population was still less than one billion.

It is premised on massive consumption of water and energy.

Given the limited capacity of water resources, this makes it very challenging to respond to worldwide population growth and to the modernization of developing countries.

The global population has been climbing rapidly since the advent of the modern age.

It reached nearly 6.9 billion in 2010, according to the 2010 edition of the State of World Population report from the United Nations Population Fund.

All environmental issues derive from population issues and problems with water resources are no exceptions.

Needless to say, population control is ultimately essential.

In recent years, the population increase has been slowing after a number of measures were adopted.

Even so, many researchers forecast that the worldwide population will reach around 10 billion at the end of the twenty-first century.

It is essential to take this scale of population into consideration when studying water-related systems.

To effectively utilize water sources and build a social foundation that is resistant to various issues arising from the water resources, it is necessary to work strategically to secure water sources and to make effective use of water.

In Japan as well, these issues attracted public attention as a matter of water security and became increasingly recognized as pressing problems. In 2007, the Water Security Council of Japan, also known as Team Water Japan for Global Water Security, was established.

Initiatives for ultra and hyper water saving in buildings have been sporadically implemented in areas facing difficulty in water supply and for economic reasons.

They are helpful to construction of a water system that can serve 10 billion people in many different respects, including minimization of the water supply and sewerage infrastructure, advanced and recycling treatment of wastewater taking advantage of the effect of the reduction of the wastewater volume, and prevention of environmental contamination with sewage water by means of separated treatment.

The ultra water saving technology in buildings is consequently drawing attention as one of the fundamental technologies of a water system for 10 billion people.

- Benefits of Ultra and Hyper water saving -

(i) Ultra and Hyper water saving for reducing water consumption

Domestic water consumption constitutes about 60% of water consumption for urban use.

Nearly 80% of it is household water and the remaining 20% is for use in urban activities.

Household water consumption could be lowered to around 50% of the current level by intensively using water saving technologies.

The water consumption of black water may be cut by 95% or more.

In addition to mere water saving, the option of full recycling and reuse on site is becoming viable in economic terms.

(ii) Ultra and Hyper water saving for reducing the burden on the existing water supply and sewerage infrastructure

Water saving in buildings is expected to reduce the burden on the existing water supply and sewerage infrastructure as well as long-time social costs for operation and maintenance.

(iii) Ultra water saving for easing the burden for infrastructure construction

The economic burden for the construction of new infrastructure can be minimized by planning a minimized

water supply and sewerage infrastructure premised on buildings that incorporate water saving technologies.
(iv) Ultra water saving for reducing the impact that pollutes the water environment
It is possible to attenuate the environmental impact by introducing advanced treatment with sewerage, septic tanks and suchlike, and to treat nutrient salts by capitalizing on the surplus capacity of the existing treatment facilities generated from the water saving.
The water saving will also dramatically boost the applicability of recycling treatment technology, which hitherto has not been economically viable.
It also enables a separated treatment technology involving individual treatment of the sewage water.

Building Research Institute of Japan has been studying the construction of a water saving society in collaboration with the industrial, governmental and academic sectors through its activities in Team Water Japan and in the Water Week Commemorative Symposium.
With respect to water saving, considerable progress was made in technical development by technological development efforts in the private sector.
For further stepping up the water saving, it is indispensable to overcome technological issues involved in water saving, ultra water saving and hyper water saving.
Building Research Institute of Japan has developed a system with a hyper water saving toilet bowl consuming 600 milliliters or less of water per flush (micro flash water toilet).

2.2 Necessity of Water−Saving after huge disaster

In order to preserve the lives of disaster victims and support the accurate recovery, sanitary treatment of human waste is the most important issue.
However, the Nankai Trough huge earthquake, etc. is wide-area large scale disaster.
So Population to be addressed becomes too much, and period becomes also too long.
In this kind of case, correspondence with temporary toilets etc. is very difficult.
In case of outages of water supply and sewerage, water and filth must be stored or conveyed by some way.
So,After the disaster, heavy use of water is not reasonable.
The requirment of drinking water is about 2-3L / person-day.
Since the amount of drinking water is small, it is not difficult to supply by PET bottles etc. and convey by human being.
However, in case of ordinary flash toilet, it does not go well.
Ordinary flash toilet requires 13-20L of washing water every time.
For this reason, in ordinary home, 50L / person-day of flash water will be required .
Even after disaster, it is said that 1 / 2-1 / 3 of flash water will be required as compared to usual case.
Therefore, 16.6-25L / person-day of water will be consumed as flash water.
As compared with drinking water, the amount of this flash water is very large.
Supply, convey or treatment of flash water will be large burden of post-disaster.
For these reasons, after huge disaster, it is difficult to continue using ordinary flush toilet. Thorough Water-Saving is essential.
To achieve effective use of flush toilet system after huge disaster, Hyper-Water-Saving System is the must item.
In case of using Hyper-Water-Saving System, flash water is able to be reduced to 0.8-2.4L / person-day.

3. Development of Hyper−Water−Saving System Corresponding to Large−Scale Disaster

3.1 Composition of Hyper−Water−Saving System

Building Research Institute of Japan developed Hyper-Water-Saving System.
Composition of this system is shown in figure 1.

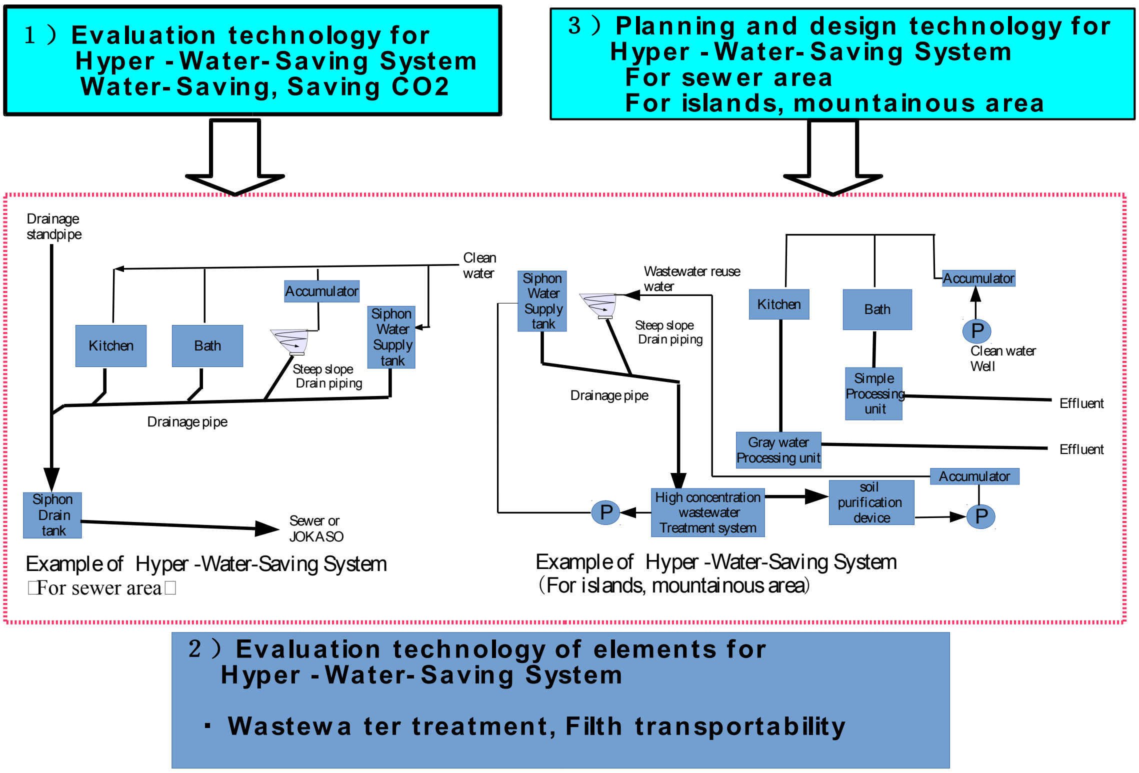

Figure 1 Composition of Hyper-Water-Saving System

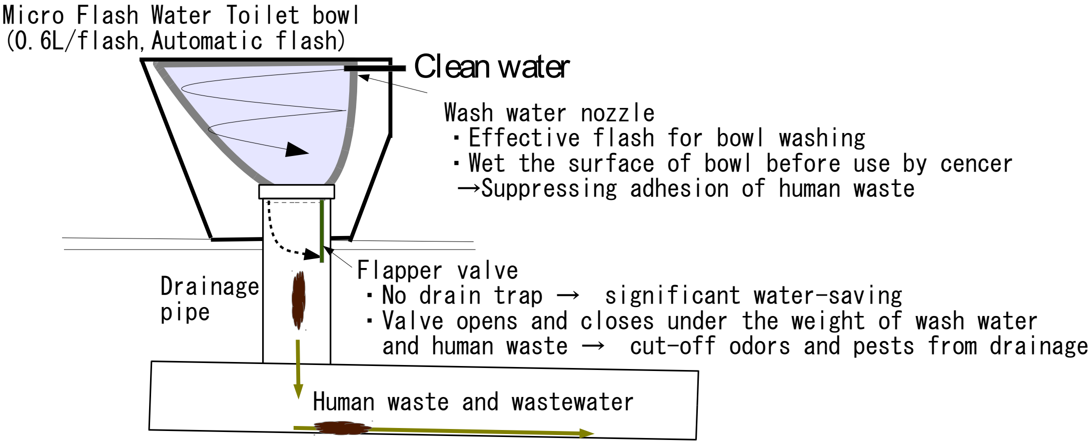

Figure 2 Structure of Micro Flash Water Toilet(Example)

This system is composed by Hyper-Water-Saving equipment and special water supply and drainage system for Hyper-Water-Saving equipment.
Figure 2 shows a example of micro flash toilet.
Using this micro flash toilet, flash water is able to reduced to 0.2-0.6L/Flash.
Usually, this system requires electric power, water supply and drainage destination.
So in case of using this system after Large-Scale Disaster, these problems should be solved by R&D.

3.2 Hyper–Water–Saving System Corresponding to Large–Scale Disaster

Now, Building Research Institute of Japan is trying to developed Hyper-Water-Saving System Corresponding to Large-Scale Disaster in R&D project (Figure 3).

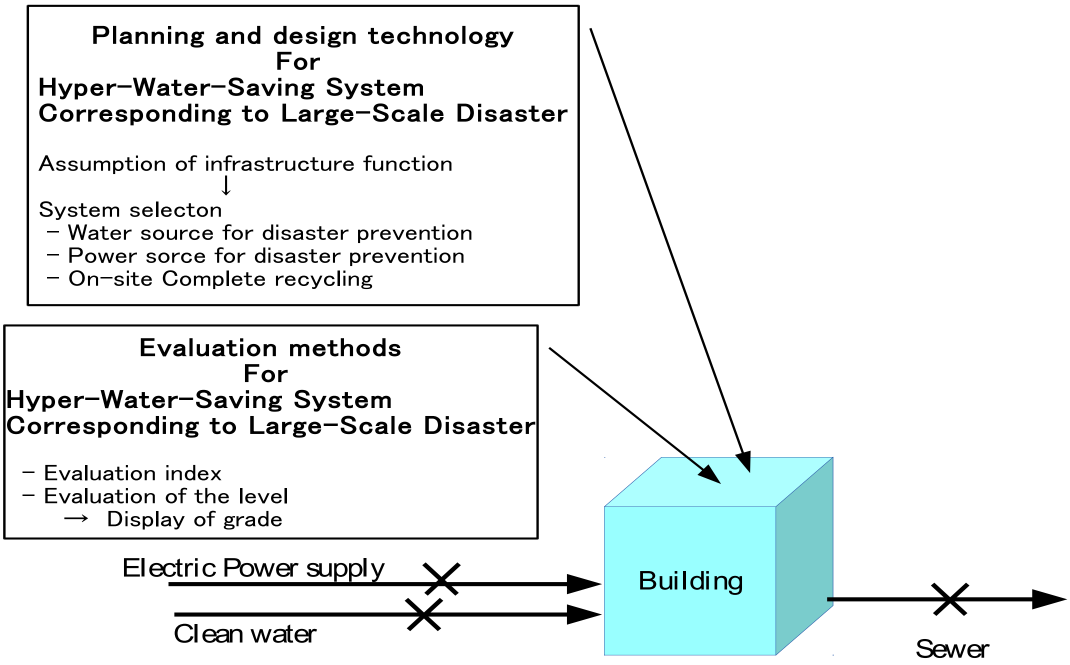

Figure 3 Hyper-Water-Saving System Corresponding to Large-Scale Disaster

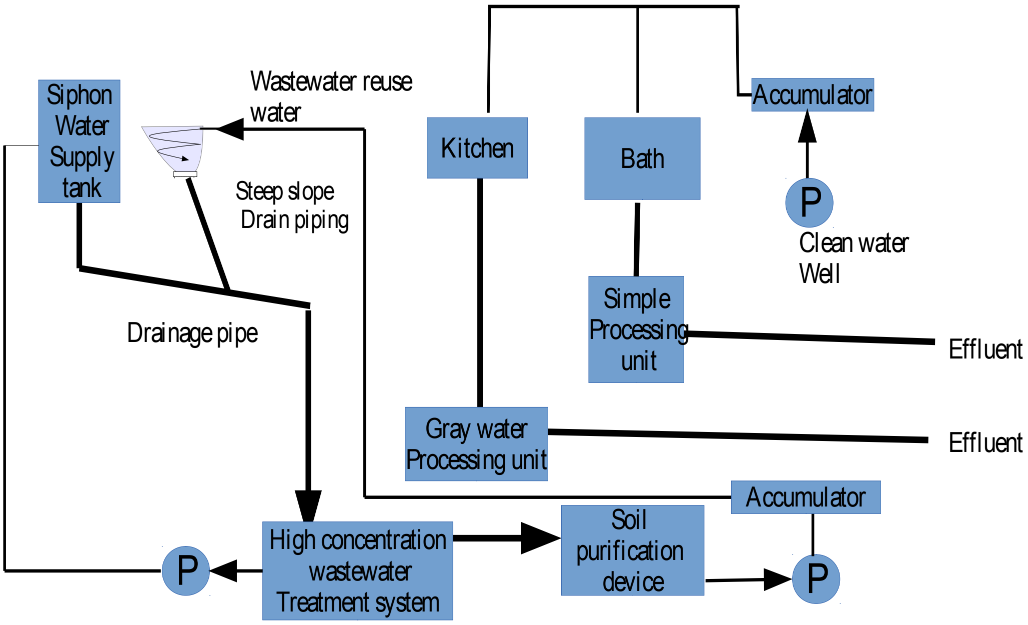

Figure 4 Rainwater use and drainage storage type

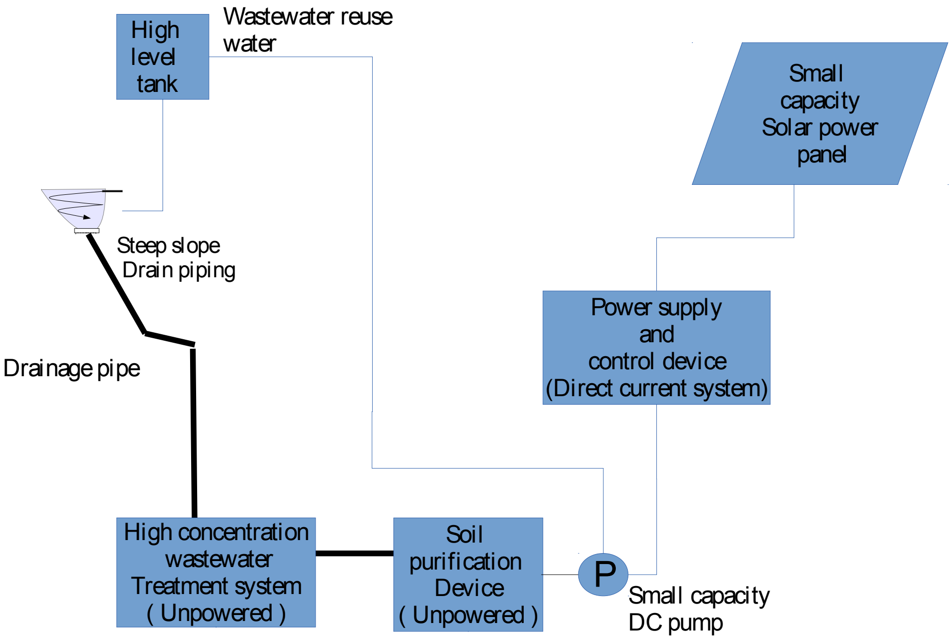

Figure 5 On-site Complete recycling type

In this R&D project, many kind of system are going to considered and evaluated..
In this paper, two cases are introduced as a basic system.
Figure 4 shows rainwater use and drainage storage type.
Figure 5 shows On-site Complete recycling type

4. Rainwater Utilization Effect by Use of Hyper–water–saving System

4.1 Conditions of estimates

In case of using system in figure 5, effect of rainwater utilization after huge disaster was estimated. Conditions of estimation is as shown in Table 1.

Table 1 Conditions of estimation of Rainwater utilization effect

1. Detached house (4 people residence)
2. Installing rainwater storage tank(200L,300L,3000L)
3. Use rainwater as flash water of toilet
4. Setting of value of flash water of toilet
(1)□ 200L/Day (13L/Flash) Ordinaly toilet
(2)□ 80L/Day (5L/Flash) Water-Saving toilet
(3)□ 12L/Day (0.6L/Flash) Hyper-Water-Saving Toilet
5. Precipitation
Use AMeDAS data (Daily precipitation data) , 2011 Tsukuba City
6. Rainwater catchment area
□ 60□
7. Conditions of calculation
(1) fter disaster, amount of flash water is assume to be 1/3 of normal time
(2) Half of the rainwater storage tank is exclusive use for emergency. Water in Half of the rainwater storage tank is not used except in case of disaster.
(3) *1 Minimum number of days that evaluated precipitation of rain after disaster.
(4) *2 Average number of days that evaluated precipitation of rain after disaster

Precipitation of Tsukuba City, was shown in Figure 6.

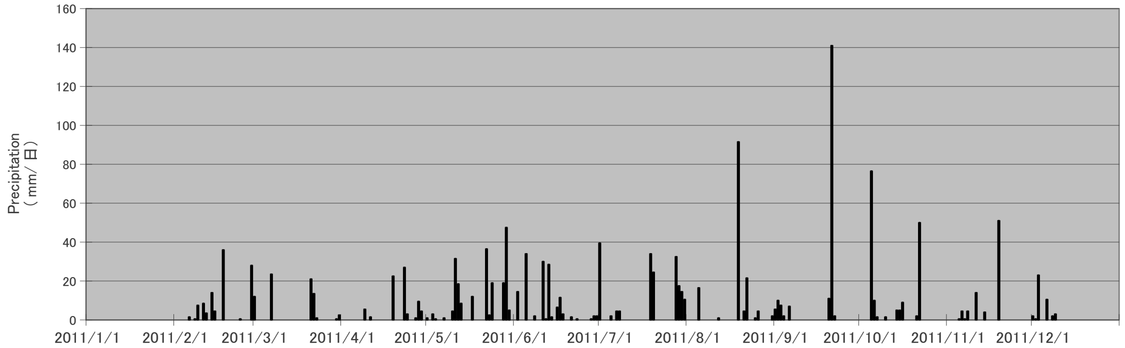

Figure 6 Daily precipitation of Tsukuba City in 2011

4.2 Results of estimates

Results of calculations are shown in Table 1.

(1)Case of using 13L/Flash system

-In case of using 3000L of rain water storage tank, available period of toilet use is about 30.1 days. In this case, benefits for disaster prevention is observed somewhat.

But other case, benefits for disaster prevention is Insufficient.

(2)Case of using 5L/Flash system

-In case of using 3000L of rain water storage tank, available period of toilet use is about 92.6 days. In this case, benefits for disaster prevention is sufficient.

But other case, benefits for Disaster prevention is Insufficient.

(2)Case of using 0.6L/Flash system

-In case of using 3000L of rain water storage tank, available period of toilet use is about 365 days. In this case, benefits for disaster prevention is sufficient.

-In case of using 300L of rain water storage tank, available period of toilet use is about 62.3 days. In this case, benefits for disaster prevention is sufficient.

-In case of using 200L of rain water storage tank, available period of toilet use is about 39.6 days. In this case, benefits for disaster prevention is quite.

Table 2 Results of calculations

Volume / Type of toilet	Rainwater storage tank 200L			Rainwater storage tank 300L			Rainwater storage tank 300L		
	Ratio of rainwater	Available number of days - after disaster*1	Available number of days - after disaster*2	Ratio of rainwater	Available number of days - after disaster*1	Available number of days - after disaster*2	Ratio of rainwater	Available number of days - after disaster*1	Available number of days - after disaster*2
Ordinary toilet 200L/Day (13L/Flash)	12. 4%	1. 5	1. 9	17. 1%	2. 3	2. 8	58. 9%	22. 5	30. 1
Water-saving toilet 80L/Day (5L/Flash)	28. 7%	3. 8	4. 8	36. 0%	5. 6	7. 3	87. 8%	56. 3	92. 6
Hyper-Water-Saving toilet 12L/Day (0.6L/Flash)	77. 8%	25. 0	39. 6	85. 9%	37. 5	62. 3	100. 0%	365. 0	365. 0

5. Conculusions

(1) In terms of rainwater use after huge disaster, use of 13L / Flash or 5L / Flash toilet is not reasonable.

(2) In terms of rainwater use after huge disaster, use of 0.6L / Flash toilet system is reasonable.

(3)By use of 0.6L / Flash system (Hyper-Water-Saving system), construction of disaster prevention system corresponding to the damage estimation of the Nankai Trough earthquakes can be expected.

(4)By this effect, corresponding potential of natural energy use, after huge disaster is high. By the same reason, corresponding potential of using human power (sending water to high place) is high.

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High Efficient Irrigation Technology

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Abstract

Green roof and green wall play an important role in reducing the overall solar gain of a building and also providing a landscape area for leisure and increasing the public awareness of environmental protection. However, the maintenance of these green roof or wall creates a lot of headaches to building operators. One of the issues is the method of irrigation to those landscape areas especially green walls. Besides, the water and power supply, control and durability of an irrigation system also need to be considered to be durable, saving water and electricity. An automatic dripline irrigation system using solar powered with weather station will be demonstrated which is a very suitable irrigation technology for green roof and green wall nowadays.

Keywords

Automatic irrigation system; Dripline; Green roof; Green wall.

1. Introduction

Green roof and Green wall become more popular nowadays specially in high density cities like Hong Kong. It is not only provide shading from the sun, improved the aesthetic and environmental quality of the area but also help reducing building heat gain.

In order to encourage the project with more greening but also with water saving feature, Hong Kong SAR Government rolled out policies that ‘Plot Ratio’ can be increased if the project successfully accredited by BEAM Plus – a Green Labelling system in Hong Kong accredited by BEAM Society. This makes intelligent automatic irrigation systems for Green roof and Green wall more popular.

Those greenings need manual irrigation will cost a lot of manpower. Whereas the Green wall which using planting plots is hardly for manual watering. This creates a lot of headache if no automatic irrigation system is provided for these planters. As such a lot of automatic irrigation systems have been installed for projects nowadays.

2. Why Greening

As the project of Hong Kong Reconstruction of Tuen Mun Highway Project (HY/2009/03), a trial panel was built to monitor the Green roof & Green wall performance included automatic irrigation system.

Temperature data was collected at the 500mm above soil level, 50mm above and under soil level with different kind of plants.

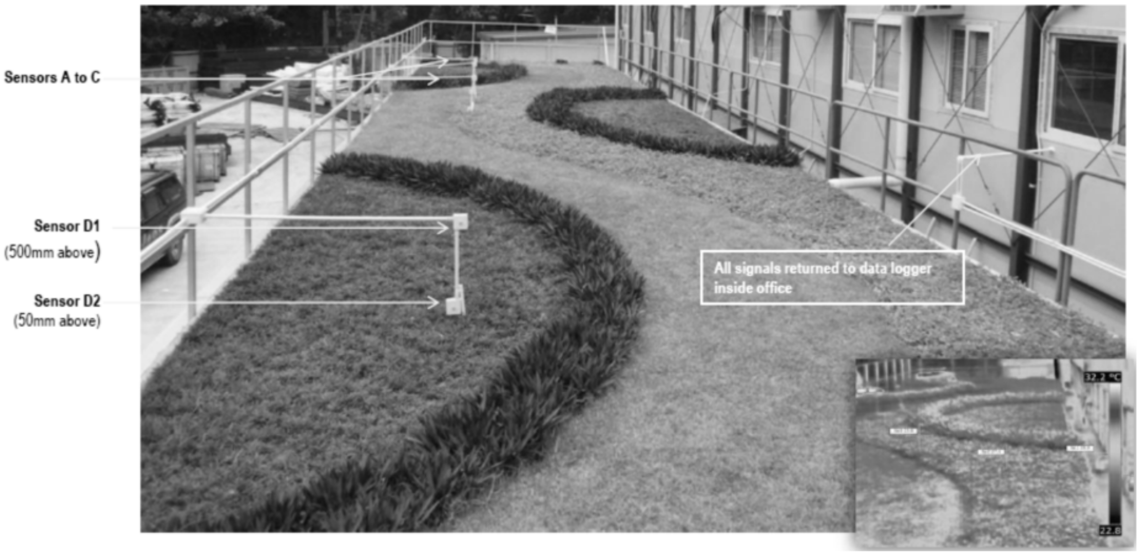
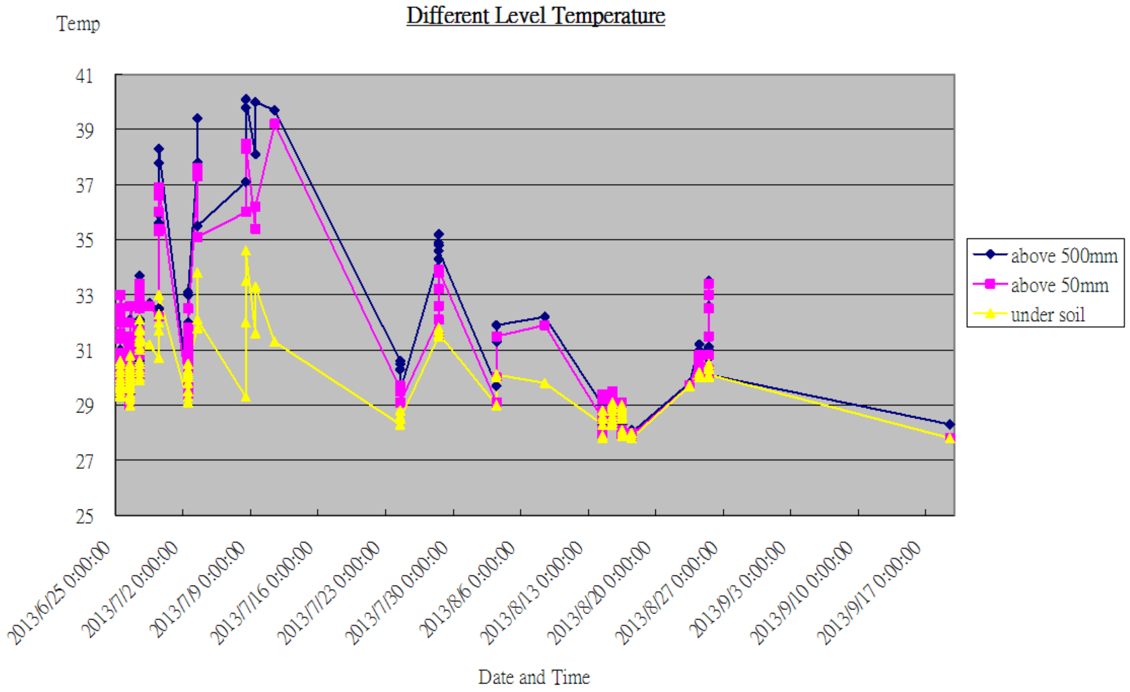


Figure-1

It was noticed that the temperature under Green roof soil level provided a more stable temperature environment. Even if outdoor temperature increases, the temperature under soil remains lower than above soil level. The maximum different in temperature can be as high as 8 degree Celsius in very hot day as shown in Figure-2.



Data source from GreenWall Bioengineering (HK) Ltd

Figure-2 Temperature in different levels of greening panel

3. Automatic Irrigation Design

Proper irrigation design is not only applies water to the planter, but also need to consider:
a.Different plants require different amounts of water
b.Understand exactly what will be irrigated
c.Divide the area by zones
d.Use the right products for the right applications
e.Consult a professional

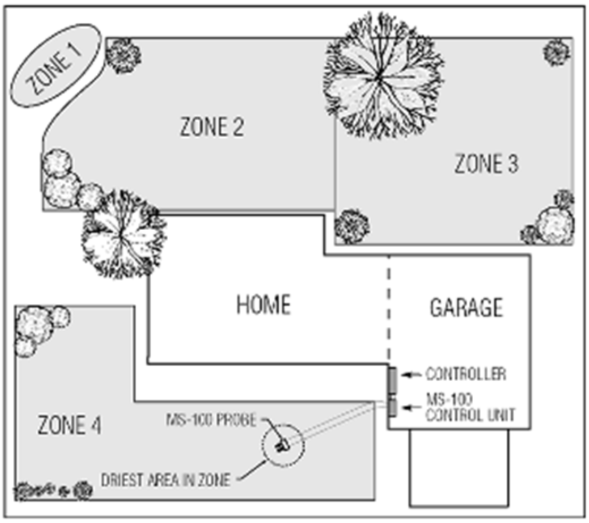


Figure-3 Landscape area divides into zones

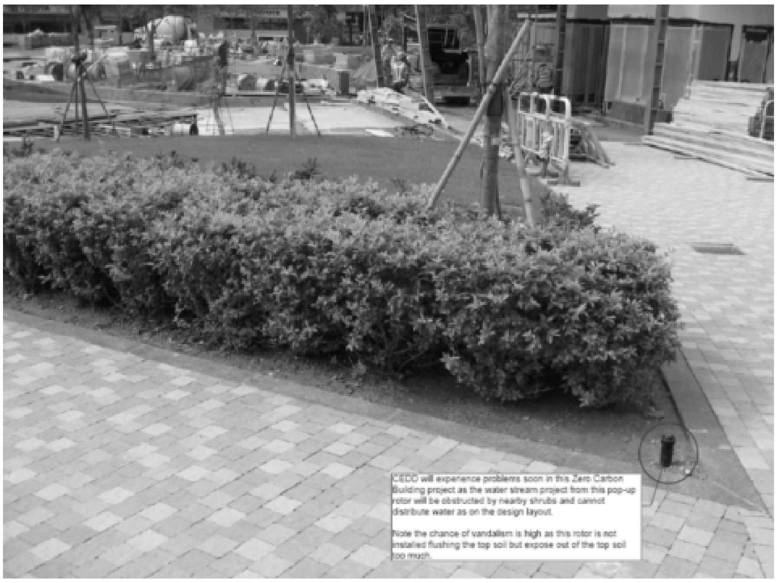
3.1 Sprinkler against Dripline System

Sprinkler and dripline are the two most prevailing irrigation devices for landscape irrigation. In the past, a lot of operators prefer to use sprinkler because it is easily seen. Good selection and correct spacing of sprinklers under correct pressure will result uniform water distribution, whereas improper selection, inadequate water pressure or wrong spacing of sprinklers will result in a wasteful and inefficient irrigation system.

Depending on the nozzle selected, sprinklers typically apply water to a radius from 1.5m to 30m.

Figure-4

Pop-Up Sprinklers usually work well with groundcovers and turfs. But it needs to be very careful about the planter with shrubs. Incorrect location and position of the sprinkler will create problem about water cannot spray to the right area.



CEDD will experience problems soon in this Zero Carbon Building project as the water stream project from this pop-up rotor will be obstructed by nearby shrubs and cannot distribute water as on the design layout.

Note the chance of vandalism is high as this rotor is not installed flushing the top soil but expose out of the top soil too much.

Figure-5

In order to avoid sprinklers to be obscured by shrubs growing, sprinkler heads are installed on risers, making it visible and in many cases are quite eyesore.

Figure-6

Over-throw water is a serious problem of sprinklers because of incorrect design and ignore the plant species. Some are due to the effect of wind and incorrect choosing of sprinkler nozzle for spray distance, leading to major fresh water wastage and energy wastage.

Figure-7

In general, the following situations are typically not suitable for watering with pop-up sprinklers:
1.Narrow planters (Less than 3 meters width)
2.Irregular shaped planters with curvatures
3.Green roof planters (effects of wind)
4.Mix-planting of species with different watering requirements

Nowadays, especially for the high efficient irrigation system, dripline is nearly the only option. Operators are not willing to use dripline in the past is because emitter with clogging problem and also easy broken if exposed under sunlight for long period. This problem had been solved nowadays. Good quality dripline are made of polyethylene (PE) and adding carbon black with UV protection. Avocardo Green colour dripline is available in the market for better looking.

Figure-8

DIG CORPORATION

EXCEL™ CV Green-line Series PC Dripline

Manufactured from the finest quality grade resins on a state-of-the-art production line to ensure uniform emission and reliability over a wide range of pressures.

Exhibits a combination of outstanding environmental stress-cracking resistance, burst strength and flexibility under extreme operating conditions.

The dripline emitter's cylindrical labyrinth has a large, low profile inlet filter that is continuously flushed by water flow during each irrigation cycle to ensure consistent operation.

Construction includes a built in silicon diaphragm with check valve, which seals and protects the dripline from contaminants being siphoned back into the emitter when the system is turned off.

The dripline emitter's dual and oppositely oriented water passage outlets form a physical barrier to root and debris intrusion under any application.

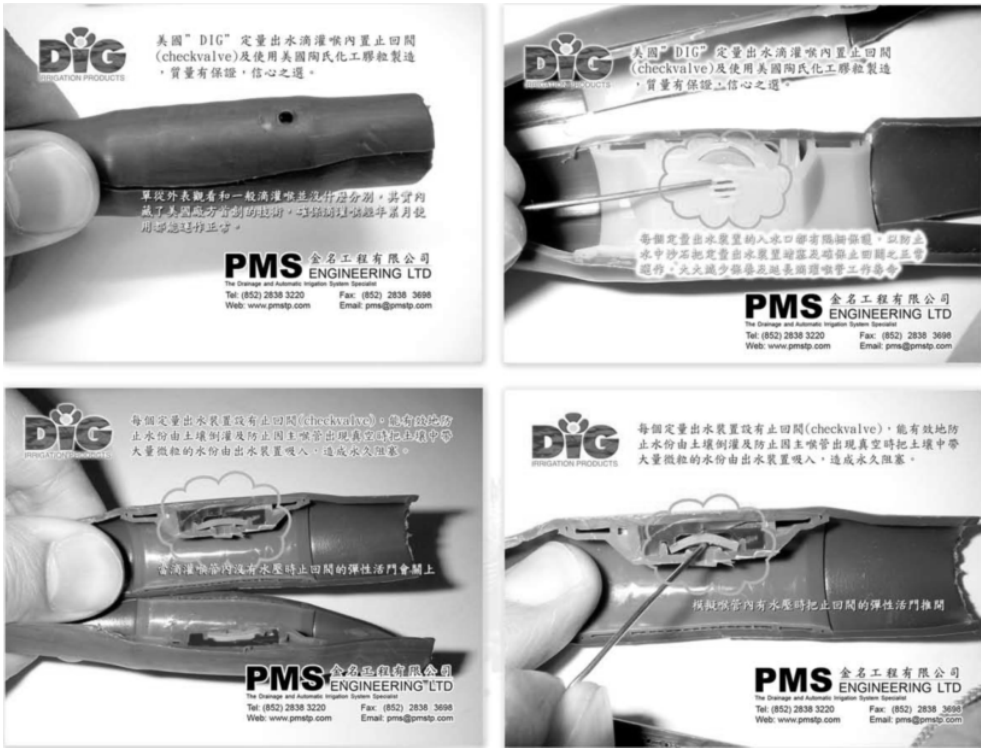
Excel™ CV Green-line Series pressure compensating dripline is designed and manufactured to meet the needs of today's irrigation efficiency requirements, while providing trouble free operation, long life and optimum plant growth.

Easy to read labels provide a clear description of tubing information

Figure-9

3.2 Innovative Dripline Technology –Build–in check valve (CV) on each inline emitter

In the past, clogging is the major problem for dripline. It is because back siphoning of soil particles / debris back into the PE tubing via the inline emitters and block the passage of water.
It can be tackled by specifying dripline with check valved emitters.



美國"DIG"定量出水滴灌喉內置止回閥(checkvalve)及使用美國陶氏化工膠粒製造，質量有保證，信心之選。

單從外表觀看和一般滴灌喉並沒什麼分別，其實內藏了美國廠方首創的技術，[illegible]年累月使用都能運作正常。

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美國"DIG"定量出水滴灌喉內置止回閥(checkvalve)及使用美國陶氏化工膠粒製造，質量有保證，信心之選。

每個定量出水裝置的入水口都有隔柵保護，以防止水中沙石把定量出水裝置堵塞及確保止回閥之正常運作，大大減少保養及延長滴灌喉管工作壽命

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每個定量出水裝置設有止回閥(checkvalve)，能有效地防止水份由土壤倒灌及防止因主喉管出現真空時把土壤中帶大量微粒的水份由出水裝置吸入，造成永久阻塞。

當滴灌喉管內沒有水壓時止回閥的彈性活門會關上

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模擬喉管內有水壓時把止回閥的彈性活門推開

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Figure-10

Each dripline emitters have a floating silicon diaphragm, apart from its pressure compensating effect, together with the special mould design of the emitter inlet chamber; they form a check valve. The check valve closes every time you turn off the valve, and the pressure drop below the sealing pressure of 1.5 psi (0.11 Bar). This feature protects the dripline from siphoning of small soil particles into the drippers, making it ideal for both sub-surface and on grade drip installation.

As the city with high rain level like Hong Kong, most of the planter will fill in water fast drain soil like sand, especially used in Green roof. For such fast water run planter, water cannot distribute far so we need to choose 300mm emitter spacing dripline and placing 300mm apart. If the soil is clay then can consider larger spacing.

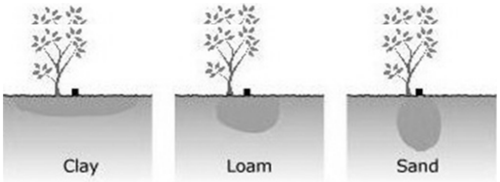


Figure-11

Figure-12

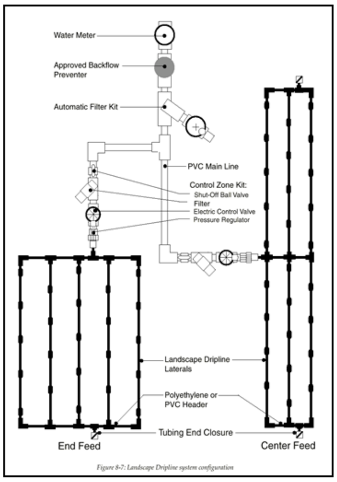


Figure-13

Re-exploration of buried dripline was requested by the consultant after nine months below grade installation. The Resident Landscape Architect was satisfied with the performance of check valve dripline.

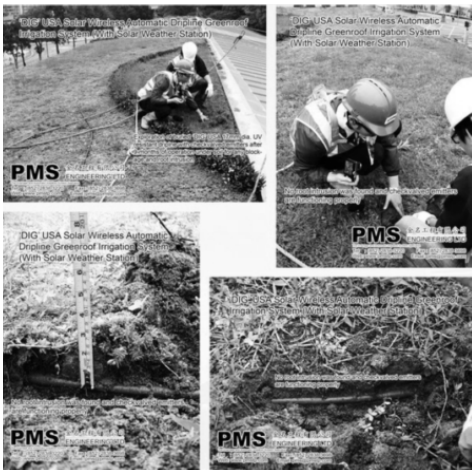


Figure-14

3.3 Comparison summary

We can summarise the characterises of Dripline and Sprinkler performance below:

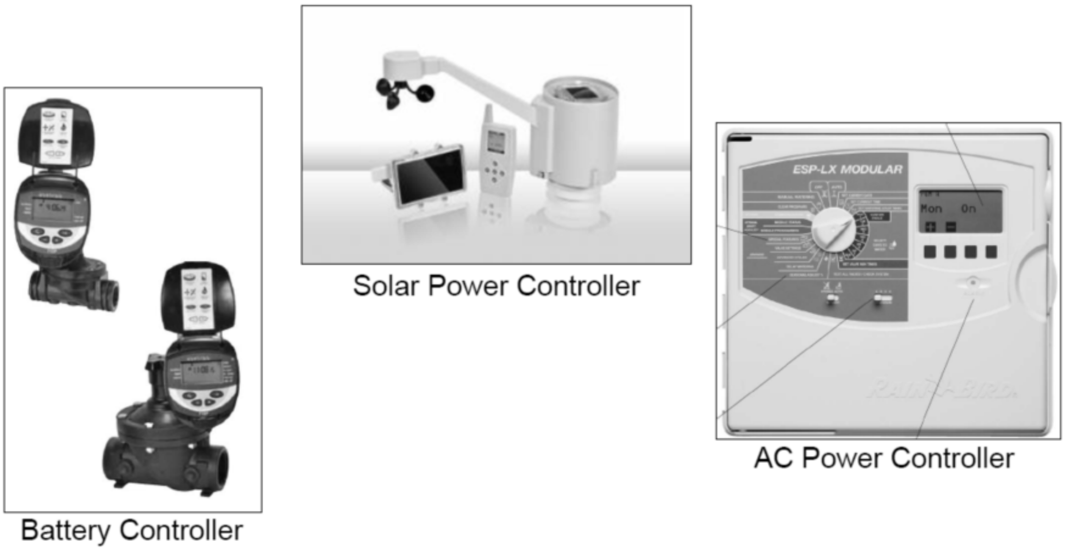
Table 1

	Dripline	Sprinkler
Water Efficiency (Water Saving)	> 90% (High)	60 ~ 75% (Low)
Irrigation to Tall Vegetation type	No problem	May mount on tall riser to ensure achieving design coverage
Min. Operating Pressure	0.8 bar	1.7 ~ 3.8 bar
Flow Rate (per emitting device)	2.3 LPH	108 ~ 1044 LPH
Over Spray Problem	No overthrow problem	easy overthrow onto the street or pedestrian right-of-way due to effect of wind/ design issue
Visible	In-visible specially if installed below grade	Visible
Maintenance	Nearly no maintenance needed unless dripline is damaged by workers	Need to check about the spray range whether inside the planter. Need to keep cutting the plant to prevent obstruction to the sprinkler Check pressure and any blockage of nozzle
Find out broken pipeline	Easy to notice if install above grade. If install below grade then need sometime to check	Easy to notice the problem area

4. Automatic Irrigation System

4.1 Controller

In market, there are three major kinds of irrigation controllers:



Battery Controller

Solar Power Controller

AC Power Controller

Figure-15

For the battery and solar power controllers, they are easily to install because they do not necessary to install cable conduit. However, battery controller needs replacement of battery regularly which should be cost higher and not environmental. Therefore, using solar power controller becomes more and more popular except indoor planter.

Apart from irrigation controllers provide fixed time irrigation, most of the controllers can connect with environment sensor with water saving function.

4.2 Rain Sensor

Most of the controllers can connect with rain sensor. The concept is once the rain reaches the setting amount then it will by-pass the automatic irrigation program. However, this is just like a on and off switch. If the rain reaches the setting level, program will be totally cancelled otherwise, it is fully follow program setting for irrigation.

Water saving can perform only at high rain level so this saving is not too conspicuous.

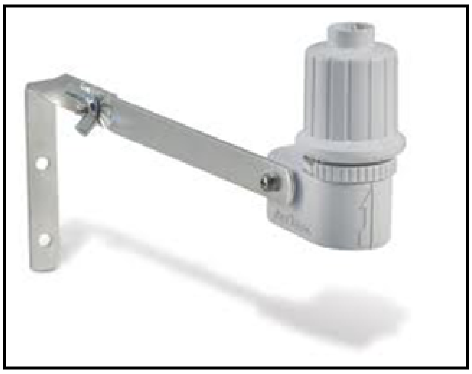


Figure-16

4.3 Soil Moisture Sensor

Soil moisture sensor would be another option because it provides direct measurement of soil and a lot of people think it is more directly.

However, the installation of soil moisture sensor needs experience workers to install. It is because the soil moisture level is different in different depth of soil. So user needs clearly understand about the soil characteristic for set up the sensor. Besides, the soil moisture will be different if the

Figure-17

landscape is in a slope.

In most cases, operators don’t know how to setup the level of soil moisture sensor. This end up nearly all the operators set this figure at very high level and the sensor will send out signal when planter already under flooding.

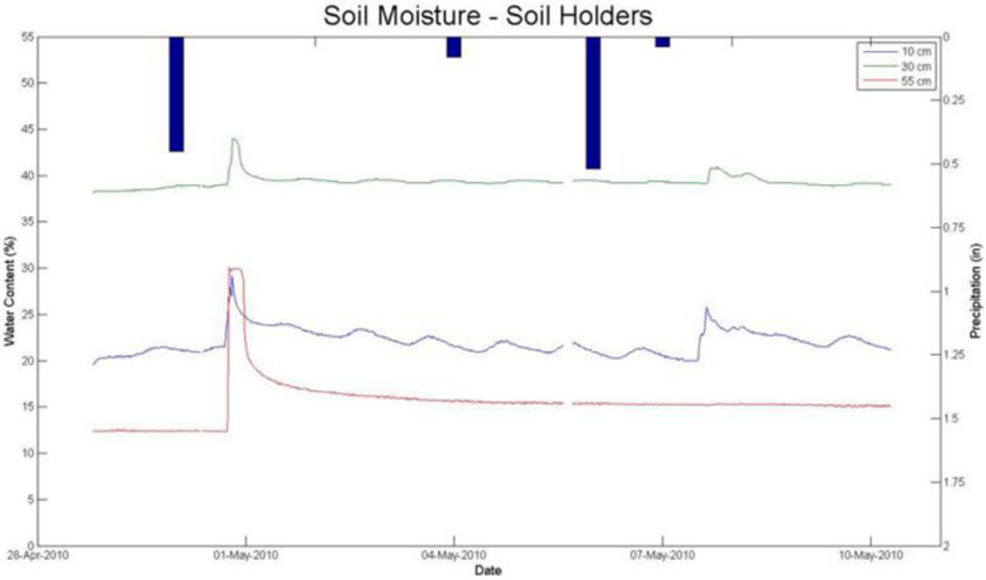


Figure-18

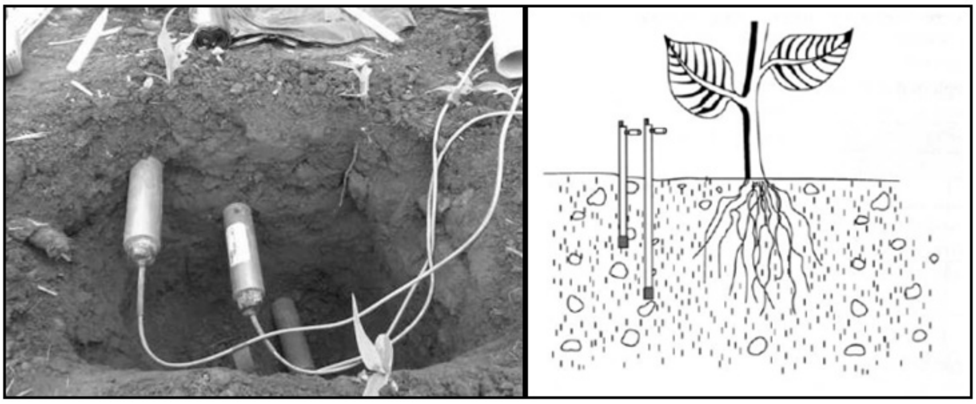


Figure-19

4.4 Weather Station

Weather station is acting as an actual weather monitoring station of the site. It includes five measurements:
a.Solar Radiation,
b.Rainfall,
c.Wind speed,
d.Humidity, and
e.Atmosphere temperature.

This unit provide a precision weather detection we called Evapotranspriation (ET). Evapotranspiration (ET) is the sum of evaporation and plant transpiration from the Earth's land and ocean surface to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapour through stomata in its leaves.

Through this ET rate and the factor of crop, we can calculate the valve of ET. Using this ET, the actual irrigation duration can be fine adjusted to suitable amount and avoid over irrigation. So we can irrigate the plant with higher efficiency and achieve water saving.

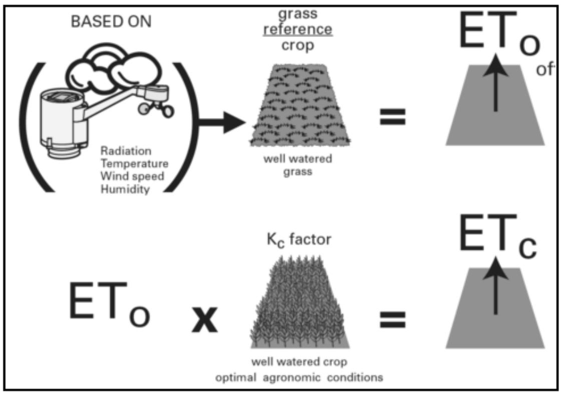


Figure-20

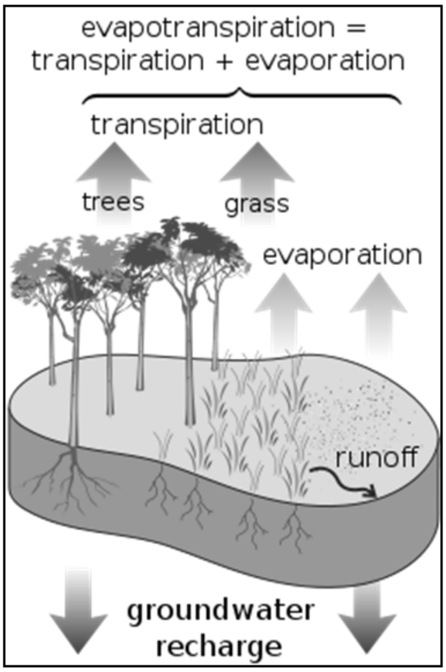


Figure-21

4.5 Solar powered solenoid valve with wireless receiver

Besides controllers, traditional control valve requires power supply and data transmission from control panel through wiring cable inside conduit. Wiring and power supply are no longer needed as this valve will be powered by solar energy and consists of wireless receiver. The weather station will be programed through handset. Signal will be send from the weather station to control the on/off of this valve.

Figure-22 Solar powered solerioid valve-solenoid valve inside valve box

Figure-23 Solar powered solenoid vaive-solar cell

4.6 Solar–powered Irrigation System

A solar powered automatic irrigation control system is a low-maintenance and environmentally friendly design. This irrigation control system is programmed to monitor, control, and adjust irrigation schedules for several zones as far away as 100m through the data received from the weather station on the site condition. A typical solar wireless automatic irrigation control system is shown in Figure-2.

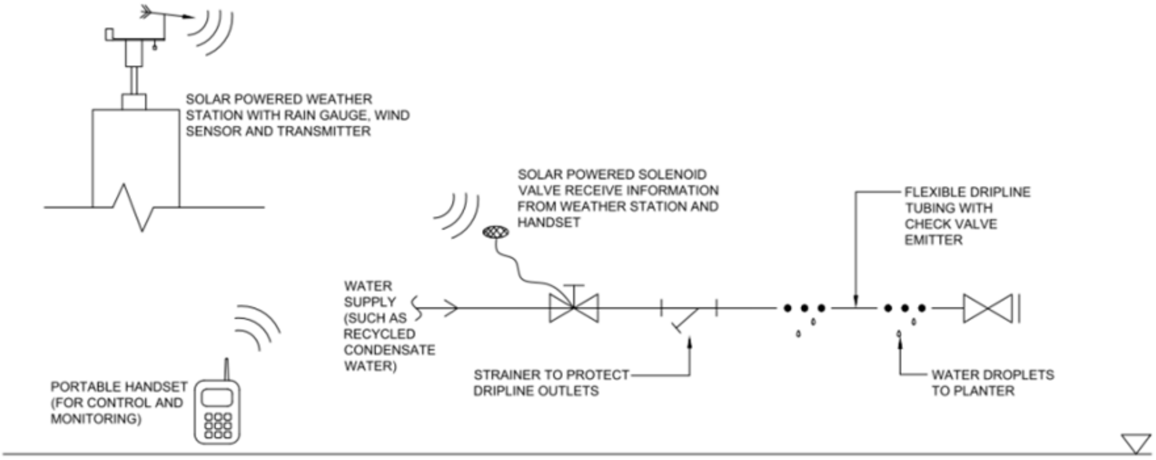
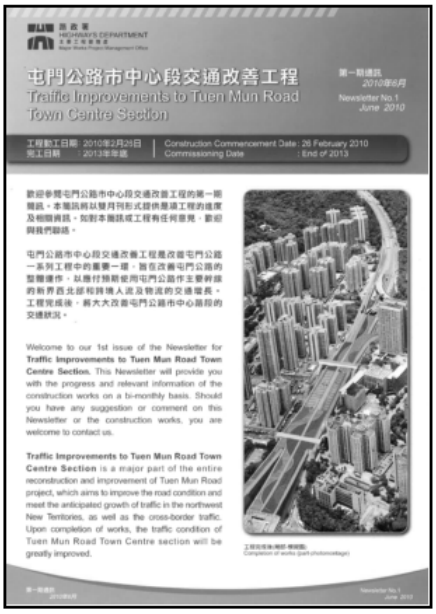


Figure-24 Solar-powered wireless automatic control dripline irrigation installation

5. Case Studies

From the same project of Hong Kong Reconstruction of Tuen Mun Highway Project (HY/2009/03), we had monitored the water saving using DIG solar wireless automatic irrigation system with weather station.

Figure-25



路政署
HIGHWAYS DEPARTMENT
主要工程管理處
Major Works Project Management Office

屯門公路市中心段交通改善工程
Traffic Improvements to Tuen Mun Road Town Centre Section

第一期通訊
2010年6月
Newsletter No.1
June 2010

工程動工日期: 2010年2月26日
完工日期 : 2013年年底
Construction Commencement Date : 26 February 2010
Commissioning Date : End of 2013

歡迎參閱屯門公路市中心段交通改善工程的第一期簡訊。本簡訊將以雙月刊形式提供是項工程的進度及相關資訊。如對本簡訊或工程有任何意見，歡迎與我們聯絡。

屯門公路市中心段交通改善工程是改善屯門公路一系列工程中的重要一環，旨在改善屯門公路的整體運作，以應付預期使用屯門公路作主要幹線的新界西北部和跨境人流及物流的交通增長。工程完成後，將大大改善屯門公路市中心路段的交通狀況。

Welcome to our 1st issue of the Newsletter for **Traffic Improvements to Tuen Mun Road Town Centre Section.** This Newsletter will provide you with the progress and relevant information of the construction works on a bi-monthly basis. Should you have any suggestion or comment on this Newsletter or the construction works, you are welcome to contact us.

Traffic Improvements to Tuen Mun Road Town Centre Section is a major part of the entire reconstruction and improvement of Tuen Mun Road project, which aims to improve the road condition and meet the anticipated growth of traffic in the northwest New Territories, as well as the cross-border traffic. Upon completion of works, the traffic condition of Tuen Mun Road Town Centre section will be greatly improved.

Completion of works (part photomontage)

第一期通訊
2010年6月
Newsletter No.1
June 2010

Figure-26

The landscape contractor set the automatic irrigation around 15 liter/sq.meter/day watering consumption for the planter in the program. After we enable DIG LEIT-2 automatic irrigation system weather station function, we got significant saving daily. Figure-3 shows this daily saving from 1 June, 2012 to 28 Feb, 2014.

From the chart, it can be noted that the water consumption can be higher than 15 liter/sq.meter/day with –ve saving % in several days. This shows that the system is really reflect the actual weather condition to perform with suitable water amount for the planter.

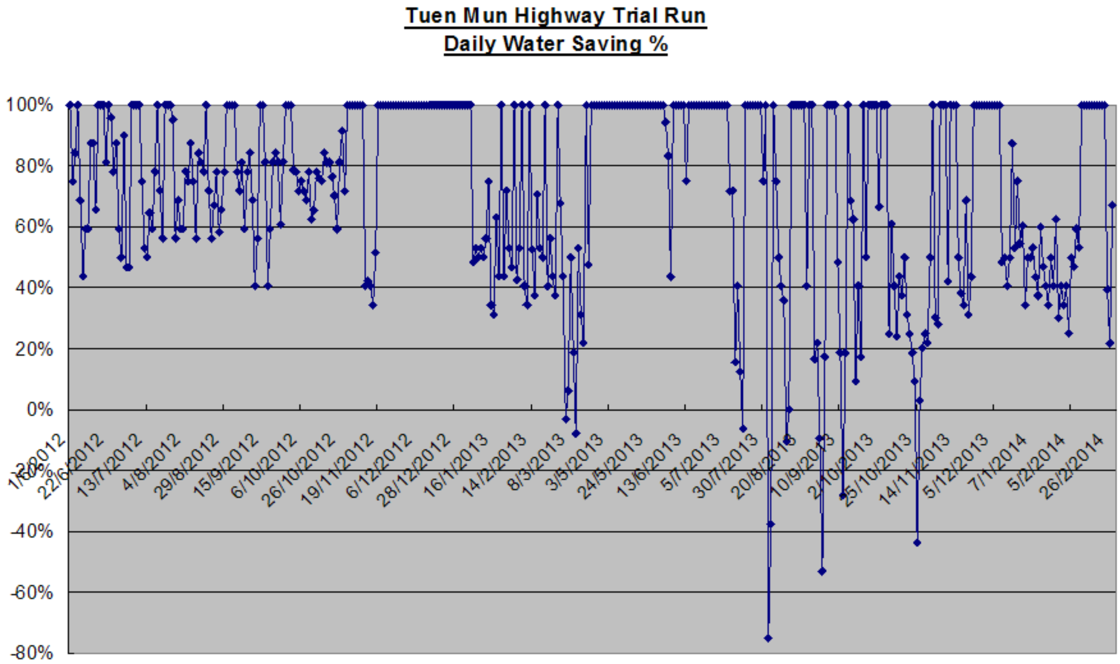


Figure-27 Daily water saving from 1 June, 2012 to 28 Feb, 2014

The actual water consumption of this irrigation system was accumulated again the irrigation program setting. The accumulated water saving chart as shown in Figure-4:

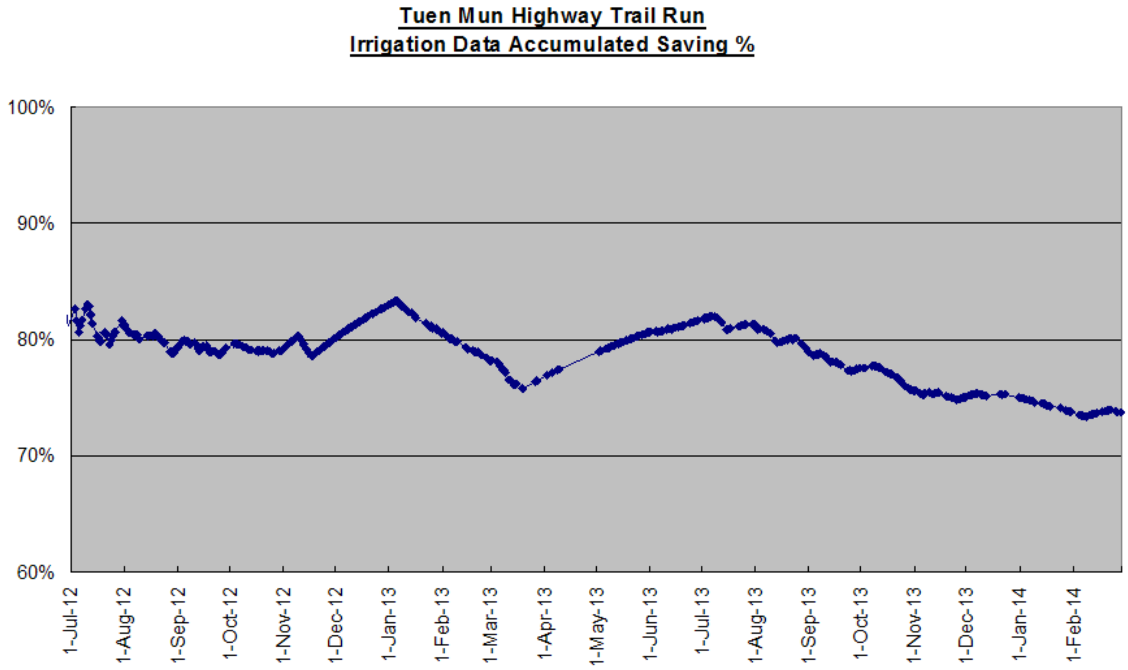


Figure-28 The accumulated water saving

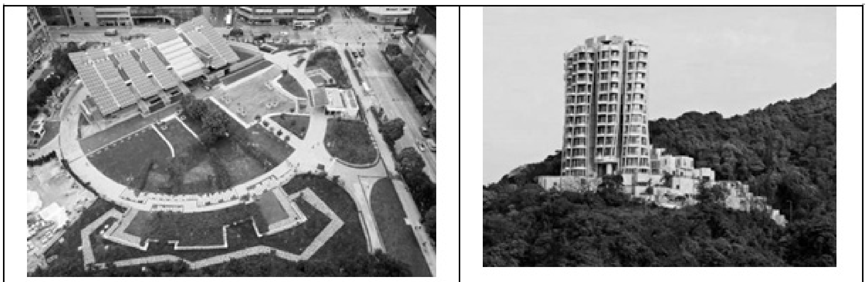
So the accumulated water saving in 28 Feb, 2014 is 75%. This means in general, the actual water consumption for the planter is only around 4 litre/sq. meter/day instead of program setting of 15 liter/sq.meter/day.

6. Conclusion

Greening is becoming popular especially Green roof and Green wall in Hong Kong nowadays. Water is one of the most precious resources. More developers and projects have not only applied automatic irrigation system but also have considered with high efficient irrigation method and controlling system. Solar wireless automatic irrigation system with weather station function can achieve the needs and provides a highly effective irrigation period which follows with actual weather and soil condition. Moreover, due to the solar controller is just mounted closed to the solenoid valve, it doesn' t need to install cable conduit which makes the installation faster at no extra cost.

Combining the solar wireless automatic irrigation system with weather station together with 17mm green dripline with check valve, that project can be easily to achieve the requirement of BEAM Plus with 50% water saving.

Projects Installed DIG Solar Wireless Automatic Irrigation System with weather station and 17mm Dripline with check valve are shown below.



Zero Carbon Building

OPUS – Hong Kong

HK University Centennial Campus

Forum – Exchange Square

Drainage Services Department – Kai Tak Jordan Valley Pumping Station

Figure-29 Projects Installed DIG Solar Wireless Automatic Irrigation System

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8. Presentation of Author(s)

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Improving Sustainable Water Management in Czech Republic and Slovakia

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Abstract

Water is becoming an increasingly scarce resource, although in countries where there is a sufficient resources of water, which is always available for users, is rather viewed that it is obvious. Slovak and Czech Republic can be regarded as countries of sufficient amounts of potable water, therefore it is common, that this water is used for all operations in building water cycle. In using water for purposes, where there is no requirement of its potable quality, it is without saying that it is wasting. As positive can be regarded gradually expanding concept of sustainable use of water in these countries. In particular it is about using various alternative sources of water, with focusing on optimizing the potable water consumption. Therefore this report deals with an alternative treatments with potable water in the Czech Republic and Slovakia and handle with improving the treatment of water but also ensuring safety management, either to user or surrounding environment.

Keywords

Water consumption, water flow, calculation method, measurement

1 Introduction

During the last decades the use of water increased, and in many places is water availability falling to crisis levels. This situation leads to the actual attitude in modern ecological thinking. The natural sources are used more wisely and we can say that the treatment with this source is rising with respect to sustainability. With regard on water sources, there is worldwide expansion of development by new and alternative approaches, of careful and economic treatment with potable water. Nowadays this development and sizing of building water system is currently hot topic also in Czech Republic and Slovakia [5,6]. The customary calculation methods are nowadays going through modifying and revising process. For instance the calculation methods used in Czech Republic and Slovakia, come from 40s of the 20th century. Improving the buildings water management design principles, can help us to create economically suitable systems, with accordance of preserving sustainability, synchronously we can improve hygienic operation of the system and make it more suitable for users and ecological for the water sources and nature.

How to proceed for achieve this requirements? In this article we mentioned one of example, which main aim is to recognize the water flow rate and water demand in selected buildings. Specifying of these values can give us the idea of the amount of water used in building water cycle and possibilities how to preserve with this source carefully. After all, this knowledge can brings economically suitable design of building water system and preserve sustainability at the same time.

2. Calculation and Measurement Basis

According to character of water collection, we distinguish three categories of buildings. Each category has specific relation of determination the water flow rate. To these categories we can include also buildings, mentioned in this paper.

Residential buildings and office buildings:

$$Q_D = \sqrt{\sum_{i=1}^{m} \left(Q_{Ai}^2 \cdot n_i\right)} \tag{1}$$

Dormitories:

$$Q_D = \sum_{i=1}^{m} Q_{Ai} \cdot \sqrt{n_i} \tag{2}$$

Buildings or groups sanitary appliances with mass using of connection points (showers and sinks in industrial halls):

$$Q_D = \sum_{i=1}^{m} \varphi_i \cdot Q_{Ai} \cdot n_i \tag{3}$$

Where Q_D - calculation flow (l/s);
Q_A - nominal discharge (flow of draining fixtures) for individual points of supply;
φ - coincidence factor of water collection, in same points of supply;
n - number of same points of supply;
m - number of points of supply.

Due to lack of measured water flows, could be during the revisions of Czech Standards CSN 75 5455 and Slovak Standards STN 73 6655 performed only minor changes in determination of the calculated water flow. Therefore is appropriate to perform the additional measurements. Due to these measurements is also determined water consumption in buildings.

This paper describes measurement of peak flows and water consumption at dormitories, residential buildings and in hygienic appliances of industrial buildings. Types and numbers of points of supply in these buildings are presented in table (Table1). Water flows were measured using flow meters AHLBORN FVA915VTH25 DN 25 and SIKA VTM 40 MS-410 DN 40, the data were written on memory card of AHLBORN ALMEMO A5690 2TS. Measured water flows were compared with calculated flows established according to Czech Standards CSN 75 5455, Slovak Standards STN 73 6655, European Standards EN 806-3 and when it was appropriate to German Standards DIN 1988-300.

Table 1 Types and numbers of points of supply and numbers of persons in measured buildings

Building	Total number of persons	Point of supply		Rated discharge Q_A according to CSN 75 5455 a STN 73 6655 (L/s)
		Type	Number	
Dormitories (water flow measurement on one standpipe of cold water, only for flushing cisterns and on one standpipe for other sanitary appliances)	34 till 36	Toilet flushing cistern	18	0,1 (STN) 0,2 ČSN)
		Sink	18	0,2
		Shower	18	0,2
		Kitchen sink	18	0,2
Residential building with 26 flats (2 flats of them uninhabited), Office building (water flow measurement on cold water supply into water heater)	72	Bathtub	23	0,3
		Sink	30	0,2
		Kitchen sink	25	0,2
		Shower	3	0,2
Industrial building (flow measurement on the water supply into the building)	120	Toilet flushing cistern	10	0,1 (STN) 0,2 (CSN)
		Urinal with pressure flushing	4	0,25 (STN) 0,3 (CSN)
		Sink	9	0,2
		Kitchen sink	3	0,2
		Cleaners sink	1	0,2
		Shower	3	0,2
		Drain valve DN 15	1	0,2
		Beverage automat	2	0,1

3. Water Flows and Water Consumption in VUT Brno Dormitories

Measurement was performed on standpipe supplying 18 sanitary devices in student rooms for 20 days period of November and December 2014. Water consumption for each room was not measured (without secondary water meters). Sanitary appliances used as supply points are shown in table (Table 2). During measurement for 16 days were in rooms accommodated 36 persons and for 4 days 34 persons. A recent reconstruction of sanitary devices established separated water supply for standpipes of cold water for flushing cisterns and separated for cold and hot water for other sanitary devices. According to this reconstruction, will be in future possible, to supply the flushing cisterns from alternative water sources. During the reconstruction were also applied saving measures for water outflow, by reducing it on 0,1 l/s and experimental measure by reducing temperature of water on 43 ℃ while monitoring its quality from microbiological point of view. After finished measurement was temperature of hot water increased. Temperature of cold water at outlet fitting was during the measurement 12 ℃ . During measurement was amount of cold water flow on both standpipes noted down each second, what allows determination of water consumption and maximal peak flow, which is relevant for pipelines sizing. According to measured consumption of cold water and temperature of cold and hot water was approximately recalculated the consumption of hot water.

Measured maximum of water flow is shown in table (Table 2), where are this amounts compared with calculated flows according to Czech Standards CSN 75 5455, Slovak Standards STN 73 6655 (calculated according to relations in paragraph 1) and German Standards DIN 1988-300. Measured values showed us evident influence of low temperature of hot water (43℃) on smaller collection of water flow, which is less drawn, what is caused by water temperature from mixing taps 40 ℃ . We can see that calculated flow for other points of supply shown in table (Table 2) which is established according to CSN 75 5455 or STN 73 6655 is significantly different from maximal measured flow. Mainly it is caused by inducting into the calculation standard values (Table 1), which are markedly different from actual values. German standard DIN 1988-300 allows to induct into the calculation actual values of flow from outlet fittings, therefore water flow calculated according to this standard is more similar to maximal measured flow.

Cold water consumption measured during work days, was recalculated according to number of accommodated persons and day. Hot water consumption was recalculated according to measured cold water consumption and temperature of water from outlet fittings. From values of recalculated water consumption shown in table (Table 3) it is obvious that accommodated students are consuming water disregarding on water consumption, hence the water consumption is higher even during application of saving measures. Low temperature of hot water (43℃) is causing its higher consumption.

Values of the water flows measured during the day, when was noticed the highest flow are shown on graph (Figure 1). On graph (Figure 2) are noticed percentage division of water consumption during days with highest consumption. Figure (Figure 3) is showing location of flow meters during the measurement.

Table 2 Comparison of maximal measured flow in dormitories with calculated flows according to standards

<table>
<tr><td rowspan="2">Water flow in standpipe for:</td><td rowspan="2">Maximal measured water flow (l/s)</td><td colspan="2">Calculated water flow (l/s) according to:</td></tr>
<tr><td>CSN 75 5455 or STN 73 6655</td><td>DIN 1988-300</td></tr>
<tr><td>Toilet flushing cistern</td><td>0,53</td><td>0,85 (ČSN)
0,42 (STN)</td><td>0,92¹⁾</td></tr>
<tr><td>Other points of supply (cold water)</td><td>0,28</td><td>2,54²⁾</td><td>0,39³⁾</td></tr>
<tr><td colspan="4">1) Calculated according to DIN 1988-300 for hotels. According to relation for residential buildings is the value of calculated flow 0,80 L/s.
2) According to relation for residential buildings (see paragraph 1) is the value of calculated flow 1,47 L/s.
3) Calculated according to relation for hotels. According to relation for residential buildings is the value of calculated flow 0,38 L/s.</td></tr>
</table>

Table 3 Water consumption in dormitories in litters recalculated on accommodated person and day

Average cold water consumption measured for toilets (during work days)	29,5
Maximal cold water consumption measured for toilets	33,3
Average cold water consumption measured for other points of supply (during work days)	10,3
Maximal cold water consumption measured for other points of supply measured	13,8
Recalculated approximate average hot water consumption (during work days)	96,6
Recalculated approximate maximal hot water consumption	128,8

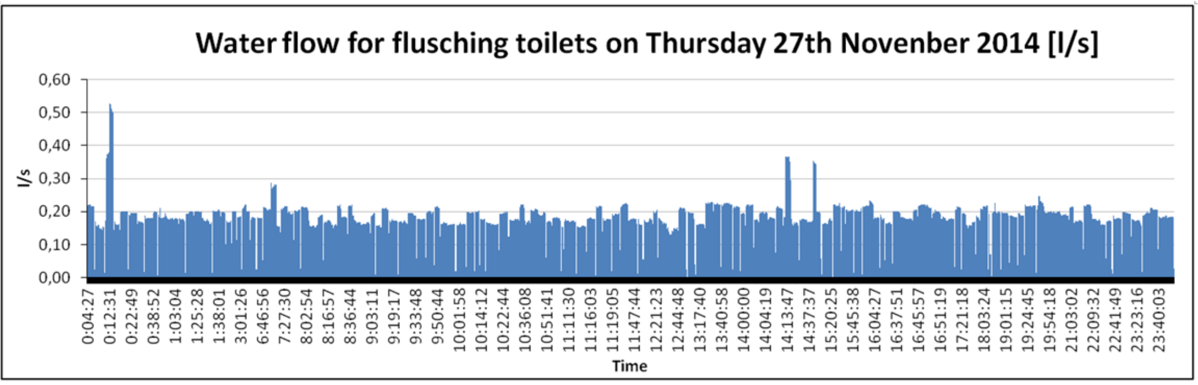

Figure 1a - Cold water flow in dormitories during the day with maximal water flow - in standpipe for toilets flushing cisterns

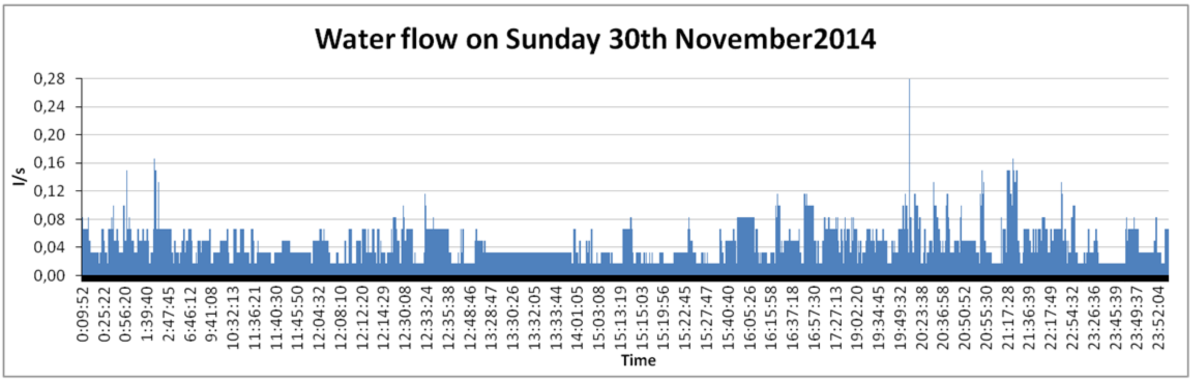

Figure 1b - Cold water flow in dormitories during the day with maximal water flow - in standpipe for other points of supply

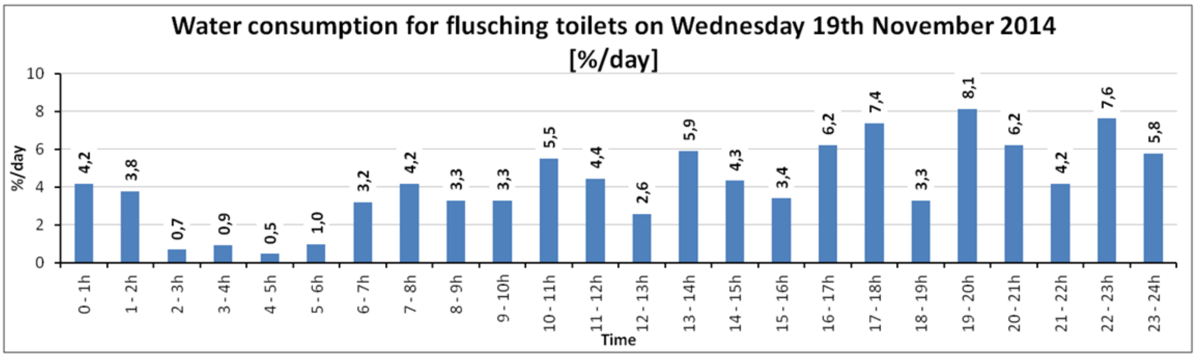

Figure 2a - Percentage division according to days with highest cold water consumption for toilets flushing in dormitories

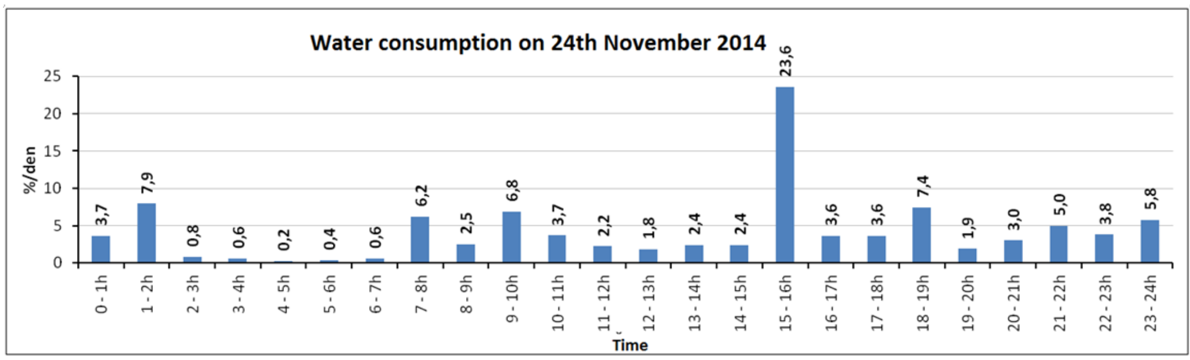

Figure 2b - Percentage division according to days with highest cold water consumption for other points of supply in dormitories

Figure 3 - Location of flow meters in dormitories

4. Water Flows and Water Consumption for Residential Building in Brno

Measurement was performed on cold water supply pipeline leading into the water heater for 46 days period at the turn of years 2014 and 2015. Cold water flow into the water heater corresponded with hot water flow from the heater. The pipelines supplied 26 flats (24 flats were inhabited), 2 shops and administrative premises of one company. The flats are equipped with bathtub (in some cases with shower) and kitchen sink. Administrative premises are equipped with 2 sinks, 1 shower and 1 kitchen sink, in shops is placed 3 sinks and 1 kitchen sink. Every water inlet into the flats or operating units is equipped with water meter and users are paying for actual water consumption. Temperature of water was measured on outlet fitting. Measured temperature of hot water was approximately 47℃ and cold water approximately 20℃ . During measurement was amount of cold water flow noted down each second, what allows determination of water consumption for either of time period.

Maximal measured water flow and its comparison with calculated flow, which was established according to several standards, is shown in table (Table 4). Calculated water flows were established according to points of supply in inhabited flats, shops and administrative premises. From values in table (Table 4) it is obvious that calculations according to Czech Standard CSN 75 5455 [2] or Slovak Standard STN 73 6655 [3] which are based on outlets of mixed water QA from outlet fittings (see Table 1) is the calculated flow to high, because the calculation method expects, that building is supplied just with hot or just with cold water. European Standard EN 806-3 [1] or German Standard DIN 1988-300 [4] expects mixing of hot and cold water in mixing outlets, hence the calculated flows are smaller using this types of standards. Comparison of measured peak flows and calculated flows (according to EN 806-3 and DIN 1988-300) showed that the value of calculated flows is either way higher.

Water consumption in flats was established for days, when the shops and administrative premises were not in operation, this values are noted in table (Table 5) and are showing that during measurement in flats is the consumption lower. Average and maximal water consumption per resident and day, was not possible to establish, because during other days of measurement was impossible to measured separately consumption in flats, shops and administrative premises. Residents are trying to save water, because they have to pay for the exact water consumption. On figure (Figure 4) we can see the water flows during the day when was noted the peak water flow. Figure (Figure 5) shows us percentage daily water consumption during non working day, when was noted the highest water consumption. On figure (Figure 6) we can see the location of flow meters.

Table 4 Comparison of maximal measured flow in residential building with calculated flows according to standards

Measured maximal water flow (l/s)	Calculated water flow (l/s) according to:		
	ČSN 75 5455 or STN 73 6655	EN 806-3	DIN 1988-300
0,76	2,09	1,40	1,24

Table 5 Water consumption in residential building in litters recalculated on resident and day

Hot water consumption measured only with flats	40,5
Recalculated approximate average cold water consumption in flats (established without toilet)	14,2

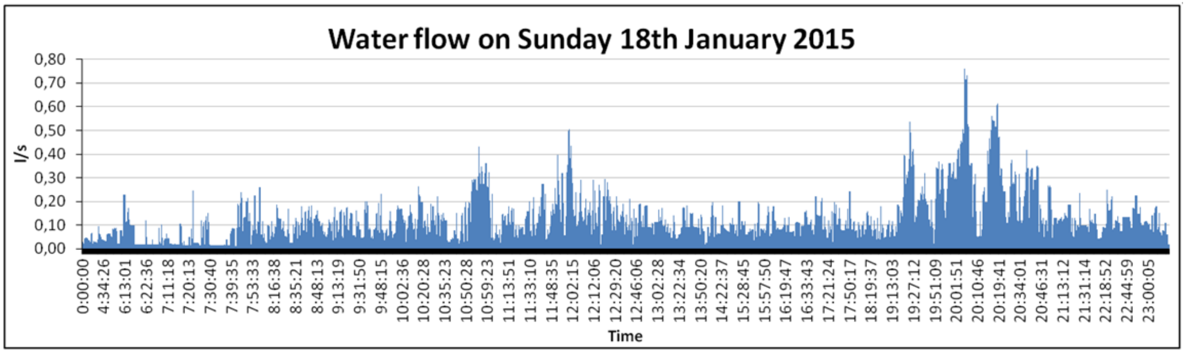

Figure 4 - Hot water flows in residential building during the day with peak flow

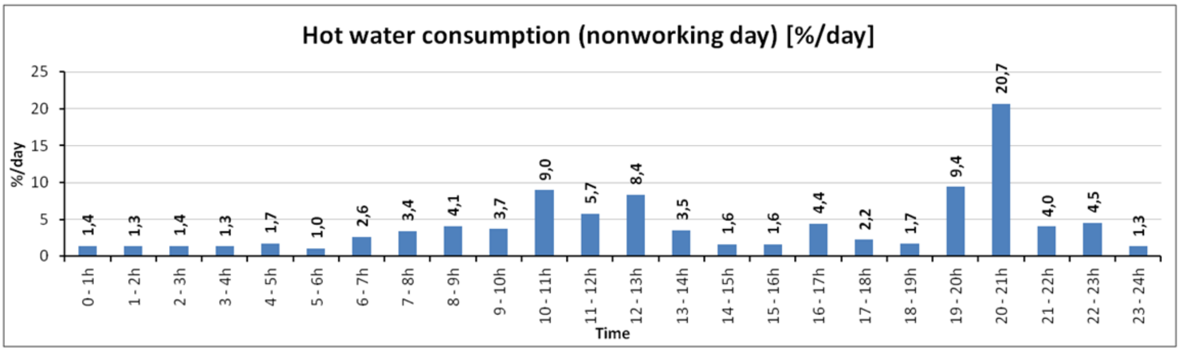

Figure 5 - Percentage division of hot water consumption, during the day with highest water consumption

Figure 6 - Location of flow meters in residential building

5. Water Flows and Water Consumption for Industrial Building in Rajhrade

Measurement was performed by student Bc. Jan Vacek for 13 days period in May 2015. For measurement was used flow meter, which was located on cold water supplying pipeline. Measured values will be used in students diploma thesis. Water heater is placed behind the location of the flow meter, therefore is supplying with cold water, which flow was the subject of measurement. In hygienic facilities can be found toilets, sinks and showers. Types and numbers of points of supply is shown in table (Table 1). During the day is in building occurring 96 workers and 24 persons in administrative part (total 120 persons). At the end of the shifts are some workers using the showers and sinks (collective use of showers and several sinks). During the measurement was cold water flow noted down every second, what allows to know water consumption for any of time period.

In the table (Table 6) we can see comparison between the maximal measured water flow and calculated water flows according to different standards. Peak flows which occurred at the end of shifts (collective use of deliver points) and during the shifts (balanced water consumption) were separately compared with calculated water flows. During the establishment of calculated water flow was expected that at the end of shifts are used just showers and 3 sinks, what may not correspondent to real use, but calculated water flow established according to this expectation correspondent to measured peak flow (was even higher). In European standard EN 806-3 and German Standard DIN 1988-300 is not mentioned the calculation method for water flow during the collective use of the delivery points, what is the reason why are not the calculated flows listed in table. When determining the calculated water flow during the shifts and balanced water consumption was expected use of toilets, urinals, cleaner's sinks, kitchen sinks, drink machines and sinks in the bathrooms. Outlet valve located in technical room was not included in the calculation.

Because the measurement was applied in clean operation, the specific water demands referred in Slovak decree for calculation of water demand for workers and administrative staff has similar values, the measured water consumption was recalculated per person and day by total number of persons (120 persons). Measured water consumption in building had very low character, what we can see in table (Table 7).

Figure (Figure 7) shows water flows during the day when occurred the peak water flow. Figure (Figure 8) shows percentage of daily water consumption during the day of the highest measured consumption.

Table 6 Comparison of maximal measured flow in industrial building with calculated flows according to standards

Type of water consumption	Measured maximal flow (L/s)	Calculated flow (l/s) according to:		
		CSN 75 5455 or STN 73 6655	EN 806-3	DIN 1988-300
Collective consumption	0,82	1,08	--	--
Balanced consumption (administrative part)	0,52	1,09	0,86	1,05

Table 7 - Measured water consumption for industrial building in litters, recalculated per person (employee) and day

Average water consumption	16,3
Maximal water consumption	20,5

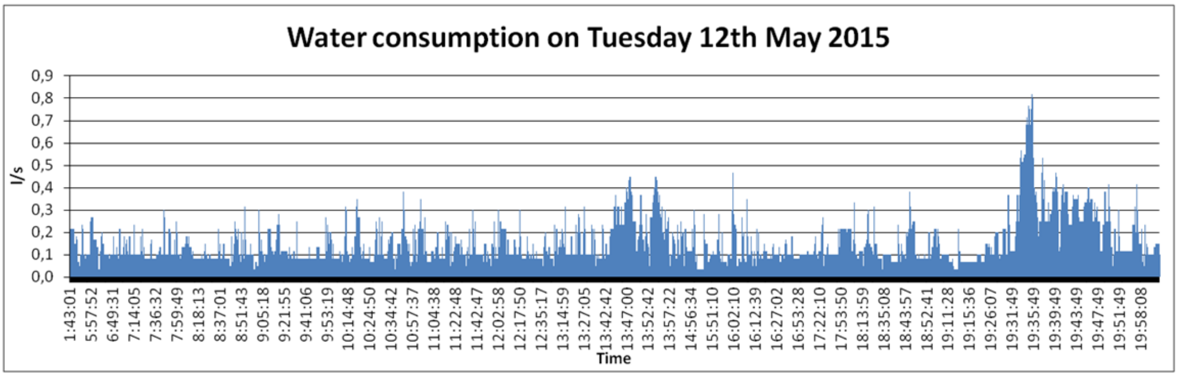

Figure 7 - Water flows for industrial building during the day with peak water flow

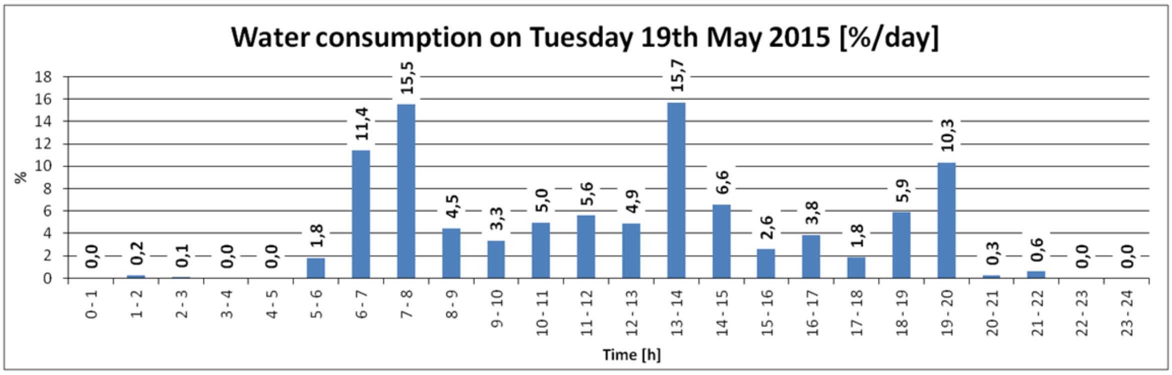

Figure 8 - Percentage division of water consumption, during the day with highest water consumption

6. Conclusions

Systematic implementation of water flow measurement in indoor pipelines for various buildings is organisationally and financially challenging. Installation and then the subsequent removal of flow meter have to be performed by qualified installers, and not every owner of the building will allow the flow meter installation [7,8]. According to mentioned measurements, the calculation method described in Slovak and Czech Standards currently can't be updated. The relation for determination of calculated water flow in indoor pipelines could be updated after measurement of water flows in larger quantity of different sized buildings of the same type (residential buildings, dormitories, industrial buildings, etc.). Updated calculation relations should allow optimal pipelines sizing, what should also contribute to their hygienic operation, because the value of stagnating potable water will be minimized. Measured water consumption could be used during water demand calculation [10,11]. Separation of measurement of water consumption for water from toilets and other points of supply is important for determination of water demand and production of grey water which can be used in building as an alternative source of water.

It is clear that financial savings are often the most important factors for users, hence when you will prove that system has some economical savings it may become attractive for them. But also we can say that nowadays, when the world is also trying to think ecological, is definitely considered as effective solution to save some material, in this case - potable water. In our conditions we have enough sources of potable water; therefore it is common to not use alternative water supply systems. However, in the context of sustainable thinking we should take responsibility for the environment as ultimately our future, and when we have opportunity, look for solutions which can preserve the water.

Acknowledgements

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Building Installations of Water Supply and Drainage in the Face of Climate Change

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Abstract

Introduction and aims: Climate changes are affecting all regions worldwide. There is growing expectation that the enlarged concentration of greenhouse effects resulting from human activity will lead to increasingly substantial changes in climate. Negotiations to formulate a mitigation strategy against post-Kyoto climate change are progressing slowly while the ability of the Earth to naturally absorb the greenhouse gas effect is declining. The expected impacts over the next few decades may differ from region to region, but it is foreseeable that we will see a rise in the level of the sea and an increased frequency and intensity of heavy rainfall and other extreme weather events such as heat waves. Therefore, it is imperative to assess the effects of these changes in the systems of water supply and drainage in buildings, as well as study mitigation measures to be implemented in new constructions or in building rehabilitation. Method: Based on a review of existing research literature on the predictable effects of climate change, we reflect on the impact of these changes in buildings and on the possible contributions of building installations of water supply and drainage to mitigate these effects. Results and conclusion: An evaluation of the effects of climate change on buildings is presented, as well as an assessment of several mitigation measures of these effects. Contributions: Mitigation measures of the effects of climate changes are proposed, as well as measures for the adaptation and increase of resilience, for implementation in the building systems of water supply and drainage.

Keywords

Climate change; drainage and water supply in buildings; mitigation measures; adaptation and resilience.

1. Introduction

Increasing attention is being paid to the potential impacts of climate change on urban environments. According to the United Nations, about 54% of the planet's population currently lives in cities, but it is expected that this percentage will rise to 66% in 2050. Projections show that urbanization combined with the overall growth of the world's population could add another 2.5 billion people to urban populations by 2050, with close to 90% of the increase concentrated in Asia and Africa [1].

Over the 21st century, climate change will continue under a range of possible greenhouse gas emission scenarios. By the end of this century global average temperature will rise 2.6 to 4.8 ºC higher than at present, and sea levels will be 0.45 to 0.82 meters higher [2].

More frequent and intense extreme weather events have resulted in a higher incidence of floods and droughts around the planet. Increased frequency of heavy rainfalls will affect many areas of the world, leading to a higher risk of floods, while the proportion of land in extreme drought and many semi-arid and arid areas (like the Mediterranean Basin, the western U.S.A., southern Africa and north-eastern Brazil) are exposed and may suffer a decline in water resources. Prolonged drought will also reduce groundwater recharge, so levels will gradually be lowered. The subsequent adverse impacts on water and sanitation services constitute a clear danger for development and health [3]. A large number of developing countries are already facing shortages of drinking water and often occupy high-risk areas such as flood plains and coastal zones [4].

For this reason, climate change impacts in urban areas and buildings will be very significant. Urban life will have to adapt and create resilience to more extreme weather conditions, which is likely to put strain on existing infrastructures such as water supply, drainage, health and energy.

Foremost, it is necessary to implement mitigation measures, consisting in intervention to reduce the sources or enhance the sinking of greenhouse gases. At the same time, adjustments to climate and its effects will become necessary, seeking essentially to prevent or moderate the damage, known as an "adaptation" process, and to increase "resilience", that is, the capacity to manage harmful events, disturbances or trends, responding in ways that the buildings maintain their essential function, identity and structure [2].

In addition to its great contribution for the mitigation of the phenomenon through greater energetic efficiency, the building installations of water supply and drainage should contribute to the adaptation to these changes and to the acquisition of more resilience in the buildings. It is very important to know what can be done to improve the technologies and systems that exist in order to maximize their resilience and what needs to be done differently to ensure that installations in the future can handle the impacts of climate change.

2. Impacts of Climate Change in the Built Environment

An important impact of climate change that is expected to intensify in the next decades is the increased intensity and frequency of heavy rainfall and other extreme weather events, such as heat waves [5].

It is expected that precipitation changes differ from region to region with some areas becoming wetter and others drier. These phenomena can promote the occurrence of floods and a decline of water quality as well as causing decreased availability of water resources in some regions. Precipitation will increase more over the high-latitude regions, while it will decrease in most subtropical areas [6]. The equatorial regions show a high level of uncertainty in forecasting changes in precipitation [7].

Regarding the European continent, southern and central Europe face heat waves, forest fires and droughts increasingly more frequently as well as the Mediterranean area, which is becoming gradually dry and thus even more vulnerable to droughts [8][9]. Northern Europe is getting increasingly wet and winter floods are likely to become more common. Being exposed to heat waves, floods or rising of the sea level, urban areas are often ill-equipped to adapt to climate change [10].

Changes in mean precipitation will impact groundwater recharge rates which may affect the water supply. In developing countries, a failure in water supply and irrigation systems can lead to poor sanitation in urban areas and provoke a shortage of food resources and reduction of energy production [11].

With higher temperatures, there will be an increased demand for cooling (and hence power) in the summer and a decreased demand for heating in winter. In semi-arid and arid areas, salinization of shallow groundwater will intensify due to increased evaporation and water uptake from vegetation.

More frequent and intense winter rains lead to flooding in riverine areas and overloading of drainage systems. It is important to take special care regarding coastal buildings due to rising sea level, storms and high tides. Where long-term rainfall increases, groundwater levels may rise, decreasing the efficiency of natural purification processes, increasing risks of infectious disease and of exposure to toxic chemicals [12].

The increase in rainfall intensity is expected to lead to enhanced transport of pollutants and will also more often overload the capacity of sewer systems and wastewater treatment plants. The urban water supply can be disturbed by the deterioration of quality, as climate change has the potential to affect the water quality in several ways. For example, lower summer flows in water reservoirs will reduce the volume available for diluting the treated effluents or uncontrolled discharges of sewage [13]. In coastal areas, rising sea levels may also adversely affect groundwater resources through saltwater intrusion into coastal freshwater aquifers and estuaries.

Water resource managers who experience a decrease in precipitation may have to explore new sources of supply, implement demand management activities, invest in new treatment techniques or enhance the resilience of buildings. On the other hand, resource managers who experience an increase in precipitation may have to make investments in infrastructure to mitigate an increased risk of flooding and higher levels of reservoir along with the development of new treatment processes. In contrast, these regions may benefit from an increase in water supply [14].

3. The Contribution of Buildings to Climate Change Mitigation

The impacts of climate change affect urban ventilation and cooling, urban drainage and flood risk and water resources, increasing the risk of disruptions in water supply. Primary mitigation strategies comprise carbon efficiency, energy efficiency of technology, system and infrastructure efficiency and service demand reduction through behavioral changes.

In the world, it is estimated that the building sector contributes as much as a fifth of total global annual greenhouse gas emissions, making buildings the largest contributor to global greenhouse gas emissions and also consuming more than 32% of global final energy [2]. The major causes of this contribution are the extensive use of fossil fuel-based energy for thermal comfort, lighting, water heating, water supply and drainage, electrical equipment and appliances, as well as in the production of construction materials [15].

Given the massive growth in new construction, if nothing is done, greenhouse gas emissions from buildings will more than double in the next 20 years [16]. However, considering their whole life cycle (construction, operation or use and demolition), to obtain a significant reduction of CO_2 emissions, effective measures must be taken during its use or operation phase, because the latter represents 80-90% of the total energy consumed throughout its entire life cycle.

The use of green roofs on buildings can bring great advantages, not only in terms of mitigation but also in terms of increased resilience and adaptation, since it reduces the flow of surface water and rises the number of green infrastructures as well as all its associated benefits. Green roofs can provide multiple benefits for air quality, mitigating excessive heat and enhancing biodiversity. Hard engineering solutions will continue to play a role in adapting to climate change, but will also improve forecasting and preparedness, along with risk avoidance through planning controls. There is also an over-arching need for higher-resolution weather data for testing the future performance of buildings, urban drainage and water supply systems at city scales [13].

Regarding the building envelope, with its renovation and rehabilitation, significant energy savings can be obtained as a result of the decrease in consumption of thermal and electric energy. In certain situations it may become unnecessary to use active cooling systems. Depending on the boundary of performance, an effective rehabilitation of an inefficient building can offer up to 30% of energy savings.

Taking into account the water-energy nexus, reduction of water consumption in the building cycle is also reflected in significant energy efficiency, considering the reduction of energy consumption needed to heat sanitary hot water and to pressurize water in buildings. This is also reflected in public systems, in the abstraction, pumping and treatment of water and wastewater. Therefore, the nexus between water efficiency and energy efficiency should be one of the most important aspects that must be noted when considering the contribution of buildings to mitigation strategies.

A study developed by the ANQIP (Portuguese Association for Quality in Building Installations) in a medium city in Portugal found that energy savings due to the use of efficient products (classified in the category “A” of the ANQIP labeling scheme for water efficiency) allow a reduction in emissions higher than 100 kg of CO_2 per capita and per year, in relation to the present scenario, taking into account only the heating of domestic hot water in the buildings and energy consumption in public networks [17]. It should be noted that in Portugal, energy consumption for heating domestic hot water represents over 30% of the total housing energy consumption.

Table 1 summarizes the savings obtained per component of the urban water cycle, per person and per household, considering an average value in Portugal of 2.3 persons per house and emissions of CO_2 weighted in 240 g/kWh. It is considered that these results can be extrapolated to other urban contexts, and may even be more relevant in cities with high-rise buildings, since in these cases pressurization needs in this type of building are significant [17]. There are other studies carried out in Portugal on this subject [18] [19] [20] that reinforce the results of this ANQIP study, some of them presented in previous editions of the International Symposium CIB W062.

The reuse of greywater and rainwater harvesting can also contribute to reducing energy consumptions. Compact installations for direct reuse of greywater (toilet and washbasin combined, for example), reducing water consumption in the building, also lead to the saving of water and energy in the urban water cycle. As rainwater harvesting systems also reduce water consumption in houses, they additionally entail reductions in water flows and energy consumptions in public networks. Although rainwater harvesting systems demand a pressurization system in the building, the corresponding energy consumption is equal to or less than those that occur when the supply is made from the public network.

With regard to large installations for greywater reuse, with the "conventional" treatment for this type of water, we find that the energy consumed in the treatment makes the system "neutral" from an energy standpoint, i.e. the energy expended in the treatment of greywater, about 1.8 kWh/m3, is close to the energy saved in the urban water cycle. However, since the temperature of greywater from showers, for example, is generally above 30 ℃, the utilization of this thermal energy for pre-heating hot water will allow a saving of about 3 kWh/m3, making these installations advantageous not only from the point of view of saving water, but also from an energy standpoint [18].

It should be noted that the nexus between water and energy has been the subject of special sessions in all the International Symposiums CIB W062 held over the last few years, with numerous presentations for the analysis of aspects like the production and use of sanitary hot water, systems with roof-tanks, carbon credit programmes, etc. All these documents refer, in essence, to the implementation of mitigation measures within the water supply and drainage installations in buildings.

Table 1: Estimated energy savings and CO_2 reductions with the use of water efficient products in buildings

Component of the urban water cycle	Annual energy savings and CO_2 reductions with the use of water efficient products				
	Per person (kWh)	Per person (kg of CO_2)	Per family (kWh)	Per family (kg of CO_2)	Percentage of the total (%)
Building system (only sanitary hot water heating)	368	88.3	846	203.1	87.0
Public system of water supply	32	7.7	74	17.7	7.6
Public system of drainage and treatment of wastewater	23	5.5	53	12.7	5.4
TOTAL	423	101.5	973	233.5	100.0

4. The Role of Water Supply and Drainage Systems in Buildings within Processes of Adaptation and inCreased Resilience

Buildings face great risks of damage from the projected impacts of climate change, having already experienced a substantial increase in extreme weather damage in recent decades. More than half the urban areas projected for developing countries by 2030 have yet to be built, offering great potential for integrated adaptation planning, but special attention should be paid also to existing buildings. Furthermore, it would be of great interest to encourage good practice by incorporating climate change responses within engineering standards.

It would be extremely important to elaborate suitable construction and weather sensible planning projects in order to promote the design of buildings and public spaces that are capable of dealing with the effects of climate change without significant damage. The use of green roofs on buildings, for example, can bring great advantages, since it reduces the flow of surface water and increases the number of green infrastructures as well as all its associated benefits. Hard engineering solutions will continue to play a role in adapting to climate change, but will likewise improve forecasting and preparedness, along with risk avoidance through planning controls. There is also an over-arching need for higher-resolution weather data for testing future performance of buildings, urban drainage and water supply systems at city scales [13].

In addition to the contribution that buildings can make to mitigate the impacts of climate change on urban areas, for example reducing flood peaks through green roofs and gardens [21], it is important specify the role of the water supply and drainage systems in buildings in relation to the resilience and adaptation of the building itself.

There are two impacts of climate change that bind directly with building networks of water supply and drainage: the increased intensity of heavy rainfall and extreme heat waves. Table 2 summarizes the main measures to be adopted concerning the building installations of water supply and drainage with a view to promoting the adaptation and resilience of buildings against the impacts of climate change.

Table 2: Measures to be adopted for promoting the adaptation and resilience of buildings against the impact of climate change

Type of impact of the climate change	Measures to be adopted to promote adaptation and resilience of the building	
	New buildings	Existing buildings
Increased intensity of heavy rainfall	- Review of design standards with integration of new weather data or higher safety coefficients; - Construction of green roofs (preferably mandatory); - Installation of rainwater harvesting systems (preferably mandatory).	- Review the sizing of the drainage system, especially stacks and drains (in gravity systems) and analysis of the need for new emergency overflow outlets (specifically in siphonic systems); - Installation of rainwater harvesting systems (if possible).
Extreme heat waves (water scarcity)	- Review of design standards considering greater capacity in water tanks (when they exist); - Installation of rainwater harvesting systems and/or greywater reuse systems; - Application of water efficient products (preferably mandatory).	- Conducting water efficiency audits; - Installation of rainwater harvesting systems and/or greywater reuse systems (if possible); - Exchange of the devices installed by more efficient ones or application of reducers of flow or volume.

In the case of increased intensity of heavy rainfall, it will be necessary to adjust the design standards for new buildings and review the design of rainwater drainage in existing buildings. The latter aspect is more delicate with regard to rainwater siphonic systems [22], whose capacity to respond to unforeseen flow increases is practically nonexistent. The placement of more emergency overflow outlets could be the solution. The review of the design standards shall include new weather data and/or higher safety coefficients.

Regarding extreme heat waves and the inherent risk of water scarcity, the adjustment of the standards is again necessary, with regard to reviewing the sizing of water tanks and increasing efficiency in the use of water in buildings. Rainwater harvesting and the reuse of greywater shall be promoted. The first solution is particularly suited to answer the many impacts of climate change because it simultaneously reduces the flood peaks in urban areas and promotes additional water storage in buildings.

5. Conclusions

Dealing with climate change is one of the major challenges facing mankind in the 21st century. It is necessary simultaneously to implement mitigation measures, consisting of intervention to reduce the sources or enhance the sinking of greenhouse gases and adjustments to the climate and its effects. This intervention seeks essentially to prevent or moderate the damage, which is known as processes of adaptation and increasing resilience.

Buildings play an essential role in these processes, not only in relation to mitigation measures, but also to the need to be adapted and acquire higher resilience. Building installations for water supply and drainage make specific contributions in all these processes, and can significantly contribute to mitigation; they are also essential to processes of adaptation and increasing resilience, in the face of some of the projected impacts of climate change.

Review of design standards and the increase of water efficiency in buildings should be considered priority measures, but some solutions – such as green roofs or rainwater harvesting systems in buildings – can contribute greatly to a very appropriate response to the impacts of climate change. These solutions should be widely generalized, preferably with a mandatory character in some regions.

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A Study on Hot Water–saving Effects of Hot/Cold Water–saving Kitchen Faucets Having Various Types of Spout Designs and Water–ejection Modes

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Abstract

The study involves 24 different types of hot/cold water-saving kitchen faucets having various types of spout designs and water-ejection modes, and aims to quantitatively clarify the hot water-saving effects thereof. The study also involves volunteers who take part in a simplified experiment and a questionnaire survey, thereby determining the optimum flow rate for each type of faucet. A washing-up experiment is then carried out in order to identify the amount of hot water saved and reduced on each type of faucet, when used at the determined optimum flow rate, with respect to a standard-type faucet.

Keywords

Optimum flow rate, hot water supply system, energy conservation, single-lever-faucet

1. Background and Objectives

In Japan, approximately 30% of the primary energy is consumed for domestic hot water supplies, as shown in Fig. 1. Fig. 2 shows the daily consumption of hot water by the intended use thereof and the number of people per household, and apart from the hot water used for baths and showers, faucets account for more than 30[%] of the consumption. In relation to hot water saving, faucets must satisfy the standards set by the Japan Valve Manufacturers' Association, shown in Table 1, as defined as A1, B1 and C1in the light of energy conservation in houses and buildings, and A and B in the light of the construction of houses and buildings, and in accordance with the standards, faucets, such as those in Fig. 3, have been developed and made commercially available. Nonetheless, there is not an energy conservation in houses/buildings standard corresponding to B1 to regulate kitchen faucets. Performance evaluations of hot water-saving faucets are carried out by the manufacturers thereof, individually, through experiments with volunteers, and it is therefore necessary to re-examine the hot water-saving effects of the faucets quantitatively as well as to propose criteria and methods for evaluating the same. As the continuation of the study4) reported at the International Symposium of CIB W062 in 2014, this study aims to identify the hot-cold water-saving effects of various types of commercially-available water-saving kitchen faucets provided with different spout designs and water-ejection modes by carrying out two experiments; a simplified experiment and a washing-up experiment, plus a survey regarding ease of use, with the help of volunteers, and subsequently collect basic data conducive to the analysis of energy conservation criteria.

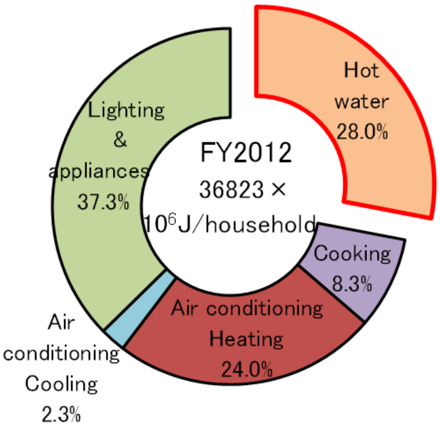


Fig. 1 Domestic energy consumption $^{1)}$

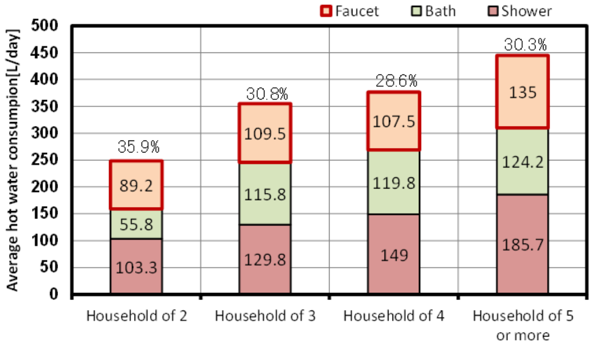
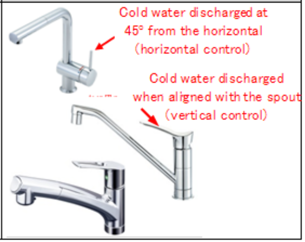


Fig.2 Hot water consumption$^{2)}$

Table 1 Definition of Hot Water-saving Faucet$^{3)}$

Standard		Energy conservation in houses/buildings		Housing/building construction	
Types and effects	Operated by switch	A1	Kitchen: 9% more efficient than the conventional type Bath/shower: 20% more efficient than the conventional type	A	kitchen: 9% more efficient than the conventional type (must be easy to turn off manually) Bath/shower: 20% more efficient than the conventional type
	Shower faucet	B1	Bath/shower: 15% more efficient than the conventional type	B	Kitchen: 17% more efficient than the conventional type (optimum flow rate: 5L/min. or less) Bath/shower: 15% more efficient than the conventional type
	Operated by single lever	C1	Kitchen: 30% more efficient than the conventional type Washbasin: 30% more efficient than the conventional type		

Table 2 Hot water-saving types and examples

Type	A1 Operated by switch	C1 Operated by single lever
Kitchen		

2. Experiment overview

Fig. 3 is a study and experiment flowchart. The simplified experiment and the washing-up experiment were carried out using the experimental system shown in Fig. 4. The experiment overview is also shown in Table 3. The experiments were carried out between 07 Nov. 2013 and 02 Oct. 2014 with the help of 15 volunteers; housewives in the age range of 36 to 66 (the average age of 51).

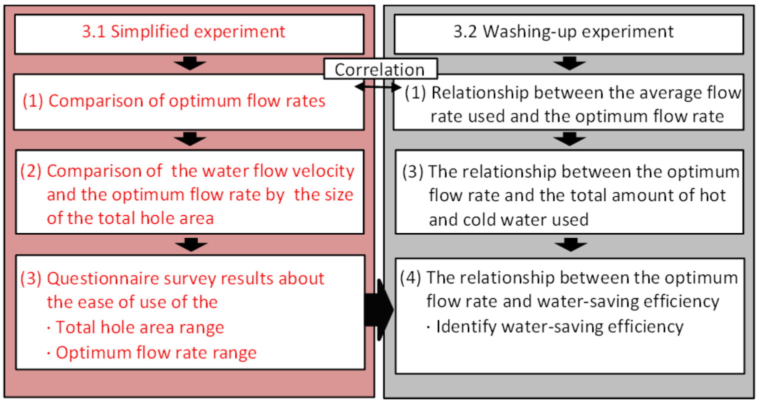
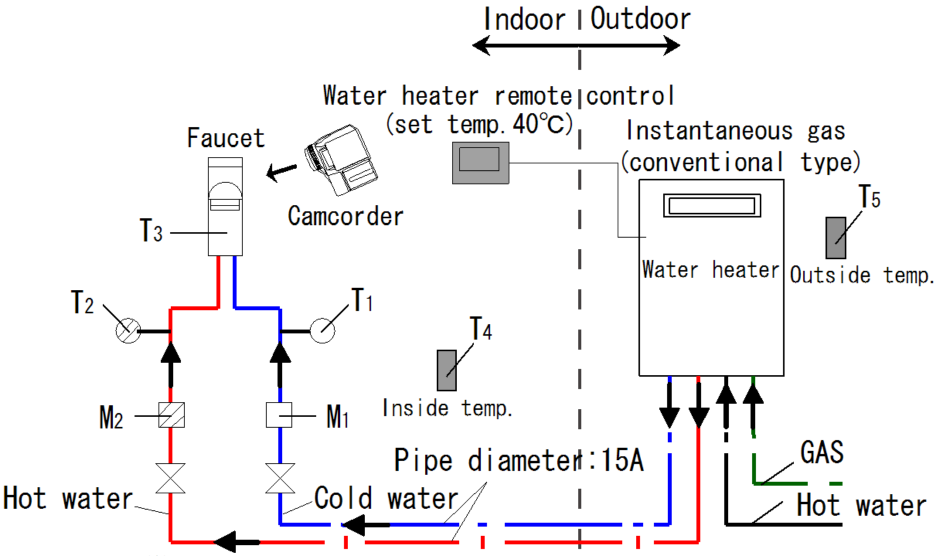


Fig. 3 Study and experiment flowchart



※Pipe length from the water heater to the faucet: approx. 11[m]

※T3: measured only prior to the experiments

Fig. 4 Experimental system

Table 3 Experiment Overview

Period		Autumn	Winter	Spring	Summer
Faucet type (No.)		4 types(No.7、No.15、No.18、No.22)			
					30 types(No.1～No.30)
Duration [yy/mm/dd]		2013/11/07～11/28	2013/12/06～2014/02/12	2014/05/21～06/26	2014/07/04～10/02
No. of volunteers *		11(10)	15(13)	10(9)	27(23)
Age range		43～70(53.0)	40～68(51.7)	41～69(54.1)	36～59(49.2)
		Average age throughout the period:36～70(51.7)			
Temp. set on the remote control[℃]		40[℃]			
Room temp. [℃]		Set to22[℃]		Set to25[℃]	
Outside temp. [℃]	Average (±standard deviation)	16.2(±2.7)	6.9(±3.6)	23.7(±3.4)	24.7(±2.3)
	Max. temp.	20.9	17.5	29.0	32.5
	Min. temp.	13.4	1.5	16.9	20.9
Water temp.[℃]	Average (±standard deviation)	17.8(±2.2)	11.2(±2.8)	21.1(±1.1)	25.3(±1.4)
	Max. temp.	22.3	16.4	22.6	28.4
	Min. temp.	15.4	6.1	18.4	22.1
(1)Simplified experiment	No. of washing-ups	1 washing-up/faucet x 5 types with different spout designs = 5 washing-ups (the flow rate is adjusted in the following sequence: ①. optimum flow rate, ②. appropriate upper limit, ③. usable upper limit, ④. optimum flow rate, ⑤. appropriate lower limit, ⑥. usable lower limit, ⑦. optimum flow rate)			
	Plates and cutlery	1 medium-sized plate (diameter: approx. 20cm) with some foam of a washing-up detergent applied thereto			
(2)Washing-up experiment**	No. of washing-ups	1 washing-up (a set of 11 items to be washed/person x 4 people = 44 items)/faucet x 5 types with different spout designs = 5 washing-ups			
	Plates and cutlery	11 dirty items/person; plates (large, medium and small), rice bowl, soup bowl, tumbler, teacup, spoon, fork, knife and a pair of chopsticks (44 items***) are washed			

* The number of volunteers who were involved in the analysis process is indicated in the brackets.

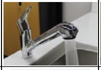
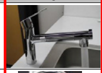
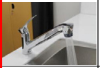
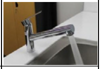
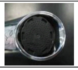
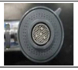
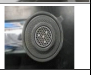
** The simplified experiment was carried out on the same day.

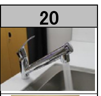
*** The items to be washed comply with “Methods of Testing Performance of Quality House Components, Dishwashers, BLT DW: 2005 Standard Specification”, and the dirty state of the items was simulated by using real food ingredients.

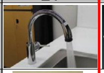
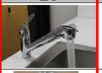
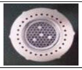
2.1 Simplified experiment

Table 4 lists 30 water-saving type faucets (No. 1-30), of which 24 shower spray types were used for the simplified experiment. During the experiment, volunteers were each asked to wash a medium-sized plate with some detergent foam adhered thereto under running water, using different flow rate settings; optimum (1), appropriate upper limit, usable upper limit and optimum (2), and appropriate lower limit, usable lower limit and optimum (3). The average optimum flow rate, for later use, was calculated from the optimum flow rates (1) to (3) which were measured as the washing-up activity was repeated three times. The questionnaire survey was also carried out, after the experiment was completed, focusing on eight items including ‘the degree of splash’, ‘the force of water’ and ‘the degree of satisfaction of use’ to mainly identify the influence of ‘the degree of satisfaction of use’ on the ease of use of the faucets.

Table 4 Data of experimental kitchen

Faucet [No.]*	1	2	3	4	5	6	7	8	9	10
Spout design										
Water-ejection plate										
Total number of holes	180	90	60	135	1	135	126	66	76	150
Total hole area [mm^2]	50.9	39.7	16.9	44.8	—	32.1	24.7	13.0	21.5	29.4
Average hole diameter [mm]	0.60	0.75	0.60	0.65	—	0.55	0.50	0.50	0.60	0.50
Water-ejection plate diameter [mm]	39.0	40.0	27.2	26.7	—	30.0	19.6	18.0	28.6	24.0
Optimum flow rate [L/min] (measured by each manufacturer)	6.4	4.8	4.0	5.0	4.4	3.9	3.1	3.6	4.7	4.8

Faucet [No.]*	11	12	13	14	15	16	17	18	19	20
Spout design										
Water-ejection plate										
Total number of holes	180	90	80	115	120	180	168	215	171	215
Total hole area [mm^2]	35.3	17.7	26.7	57.8	28.5	35.3	32.9	30.2	24.0	30.2
Average hole diameter [mm]	0.50	0.50	0.65	0.80	0.55	0.50	0.50	0.42	0.42	0.42
Water-ejection plate diameter [mm]	39.0	35.5	38.6	39.8	15.3	39.0	32.0	30.5	25.5	32.0
Optimum flow rate [L/min] (measured by each manufacturer)	4.3	4.7	4.2	6.5	4.3	3.8	4.0	5.0	4.9	5.0

Faucet [No.]*	21	22	23	24	25	26	27	28	29	30
Spout design										
Water-ejection plate										
Total number of holes	180	1	1	—	142	28	72	182	48	96
Total hole area [mm^2]	35.3	176.6	—	33.7	33.7	29.1	27.7	22.9	84.8	18.8
Average hole diameter [mm]	0.50	15.0	—	—	0.55	1.15	0.70	0.40	1.50	0.50
Water-ejection plate diameter [mm]	26.7	—	—	—	—	23.8	24.3	34.4	42.6	43.5
Optimum flow rate [L/min] (measured by each manufacturer)	5.0	—	—	3.8	4.1	4.0	4.0	4.7	4.7	3.5

□ : The faucets used for the washing-up experiment described later.

※No. 22: reference faucet with a straight flow. Faucets for the experiment: 5 aerator types (No. 5, 23, 24, 25 and 29) and 24 shower spray types

$$\boxed{\text{Optimum flow rate} = \frac{(1)+(2)+(3)}{3}}$$

∴Average of optimum flow rates (1), (2) and (3)

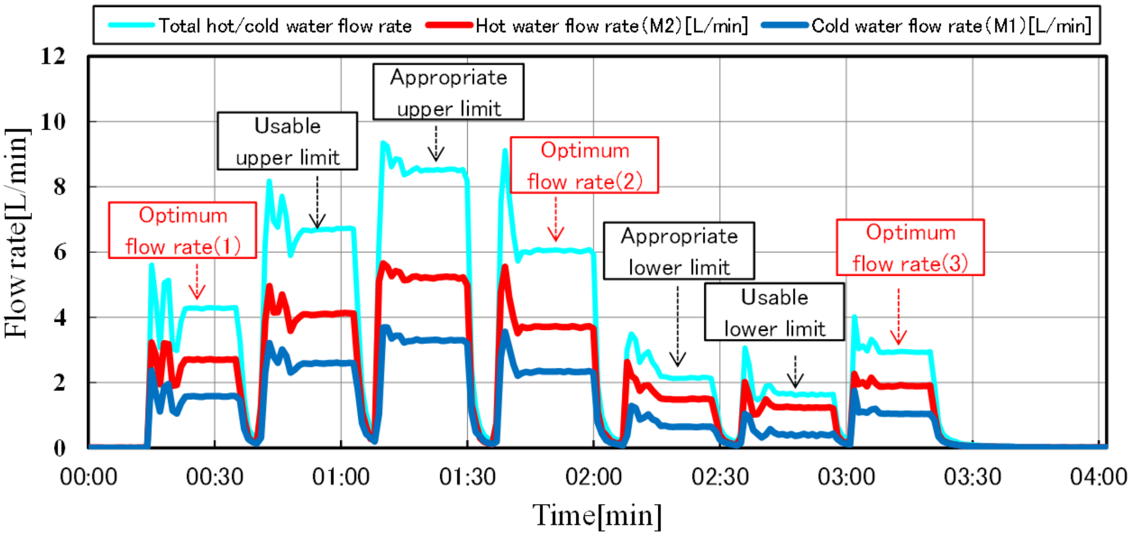
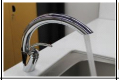
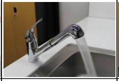
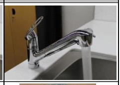
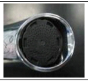


Fig. 5 Variations in the flow rate used during the simplified experiment - example

2.1 Washing–up experiment

The washing-up experiment involved eight representative types of faucets which were set in the same experimental system as in the simplified experiment. More precisely, the eight faucets used for the experiment are: one straight-flow type (No. 22), which is set as the reference faucet, and seven water-saving types with shower spray (No. 6, 7, 8, 14, 15, 18 and 28) (see Table 5). During the experiment, the volunteers were each asked to wash a total of 44 items, the dirty state of which was simulated by using real food ingredients, by using the respective faucets. In so doing, the amounts of hot and cold water used, the average flow rate used, the time spent on running water, etc. were measured. The questionnaire survey was also carried out, after the experiment was completed, focusing on the same items and by the same method as in the simplified experiment, to examine the influence of the experiment' s outcomes on the ease of use of the faucets.

Table 5 Data of experimental kitchen faucets

Faucet [No.]*	22	6	7	8	14	15	18	28
Spout design								
Water-ejection plate								
Total number of holes	1	135	126	66	115	120	215	182
Total hole area [mm^2]	176. 6	32. 1	24. 7	13. 0	57. 8	28. 5	30. 2	22. 9
Average hole diameter [mm]	15. 0	0. 55	0. 50	0. 50	0. 80	0. 55	0. 42	0. 40
Optimum flow rate [L/min] (measured by each manufacturer)	—	3. 9	3. 1	3. 6	6. 5	4. 3	5. 0	4. 7

3. Experiment Results and Discussion

3.1 Simplified experiment

(1) Comparison of optimum flow rates

Fig. 6 shows the average optimum flow rates of the respective faucets, which were obtained through the experiment. The flow rate values are sorted by the size of the total hole area; from small to large. According to the graph, there is a general tendency that the optimum flow rate increases as the total hole area increases. Meanwhile, the optimum flow rates of faucets No.1 and No.14 exceed the flow rate of 5.0[L/min] stipulated by Housing/Building Construction Standard B, and this suggests that the optimum flow rate of a water-saving type faucet having a total hole area of over 50[mm^2] exceeds 5.0[L/min] stipulated by Standard B.

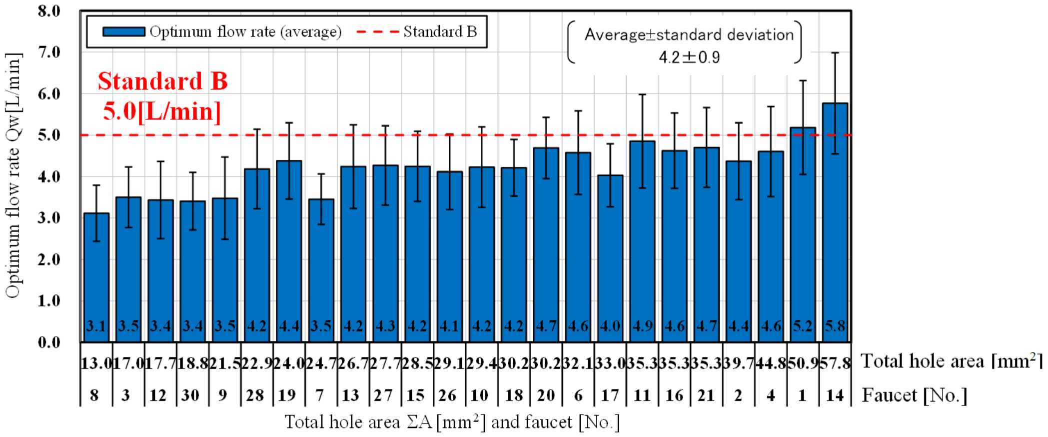


Fig. 6 Comparison of optimum flow rates by the size of the total hole area

(2) Comparison of the water flow velocity and the optimum flow rate by the size of the total hole area

Fig. 7 compares the water flow velocity and the optimum flow rate with respect to each total hole area. According to the graph, the water flow velocity decreases as the optimum flow rate increases. This behaviour suggests that the increase of the total hole area makes the water flow velocity insufficient for washing-up, thus, increasing the optimum flow rate. It is also inferred that the optimum flow rate and the corresponding flow velocity can be identified by determining the total hole area,

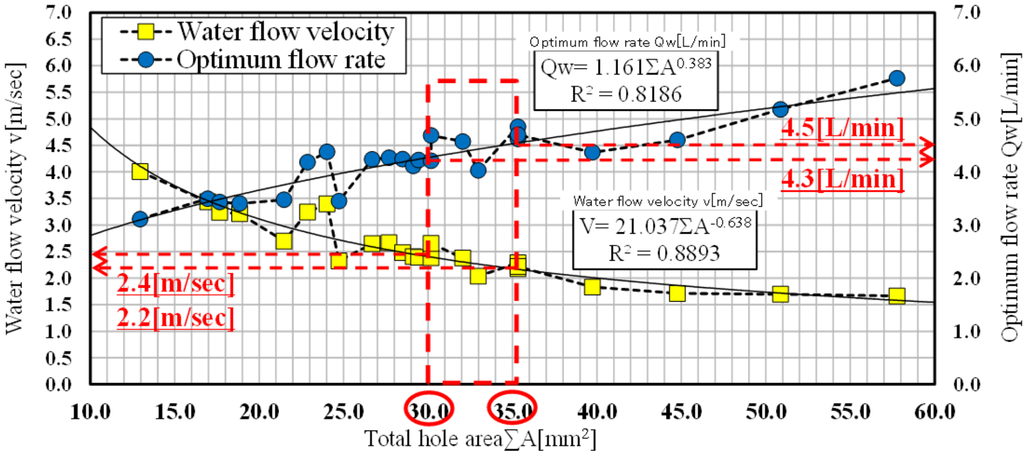


Fig. 7 Comparison of the water flow velocity and the optimum flow rate by the size of the total hole area

(3) Questionnaire survey results about the ease of use of the faucets

Fig. 8 shows the questionnaire survey results regarding 'the degree of satisfaction' with the respective faucets. The results are sorted by the size of the total hole area, from small to large, and are conducive to identifying the ease of use of the faucets. Meanwhile, Fig. 9 shows a comparison between the responses; 'satisfied' and 'somewhat satisfied', which indicates that among the volunteers, a majority of over 50[%] responded that they were either satisfied or somewhat satisfied with faucets No. 18 to 16 having a total hole area of between 30.2 and 35.3[mm2]. This suggests that faucets having a total hole area of between approximately 30 and 35[mm2] are generally easy to use. With reference to Fig. 7, these findings confirm that the total hole area range of 30.2-35.3[mm^2] corresponds to the water flow velocity range of 2.2-2.4[m/sec] and the optimum flow rate range of 4.3-4.5[L/min].

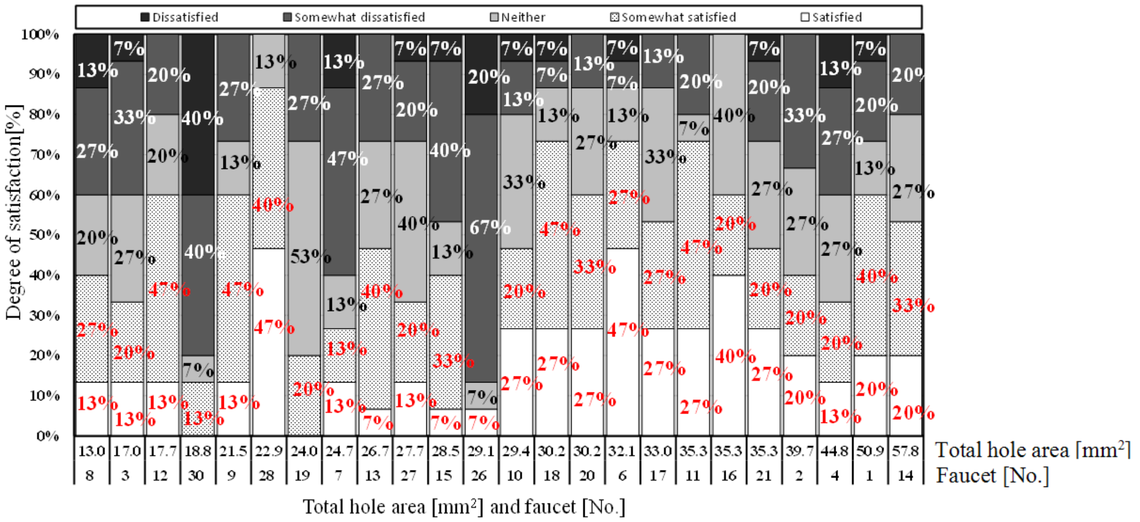


Fig. 8 Comparison of 'satisfaction degrees' by the size of the total hole area

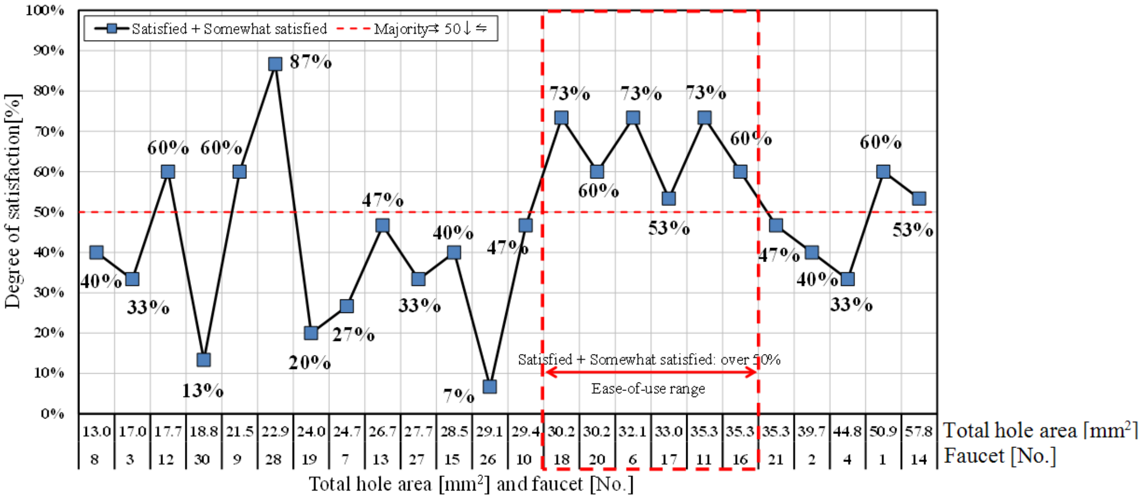


Fig. 9 Comparison of 'satisfied' and 'somewhat satisfied'

3.2 Washing–up experiment

(1) Relationship between the average flow rate used and the optimum flow rate

Table 6 shows a comparison between the average flow rates used (the values obtained by dividing the amounts of hot-cold water used by the running time) of the respective faucets, which were obtained through the washing-up experiment, and the optimum flow rates thereof, which were obtained through the simplified experiment. Meanwhile, Fig. 10 shows the relationship between the average flow rate used and the optimum flow rate. According to the diagrams, there is a tendency that the average flow rate used increases slightly more than the optimum flow rate, but the difference between them is only approximately 4[%], and therefore, it is appropriate to consider that the average flow rate used and the optimum flow rate more or less correspond to each other. On the basis of this, it is considered to be possible to roughly identify the average flow rate used during the washing-up experiment by obtaining the optimum flow rate in the simplified experiment.

Table 6 Comparison between the average flow rates used and the optimum flow rates throughout the experimental period

Faucet [No.]	6	7	8	14	15	18	28
Optimum flow rate[L/min]	4.6	3.4	2.8	5.0	4.7	4.3	4.2
Average flow rate used [L/min]	5.0	3.4	3.4	5.4	4.7	4.3	4.6
Difference [L/min]	0.4	0.0	0.6	0.4	0.0	0.0	0.4

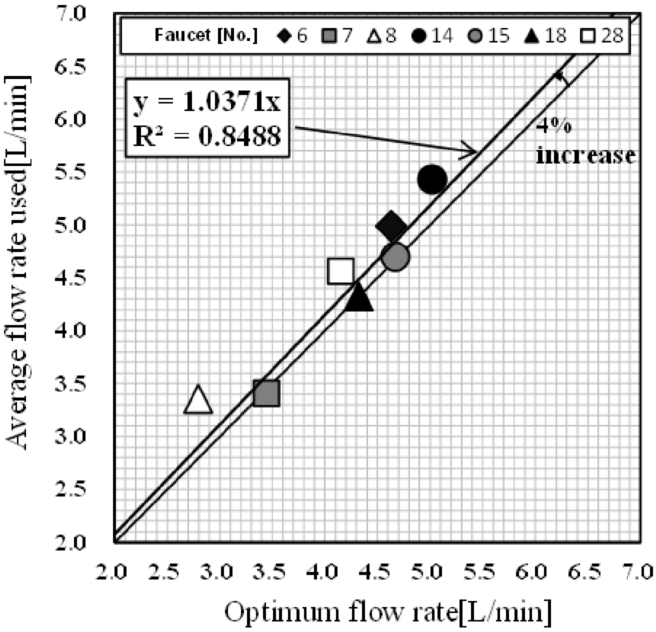


Fig. 10 Comparison between the average flow rate used and the optimum flow rate throughout the experimental period

(2) Comparison of consumption of hot and cold water using the straight-flow faucet

Fig. 11 shows the proportions of hot and cold water used per washing-up, using the straight-flow faucet, i.e., the reference faucet, which are compared among the experimental periods. According to the graph, the largest total amount of hot and cold water used, 40.5[L/washing-up], was measured in the spring period, while the smallest total amount of 28.9[L/washing-up] was measured during the summer period, creating a difference of 11.6[L/washing-up] therebetween. Taking into consideration that the proportions of hot and cold water used vary from period to period, the average total amount of hot and cold water used through the entire experimental period, 37.2[L/washing-up], was obtained to be used as a reference value.

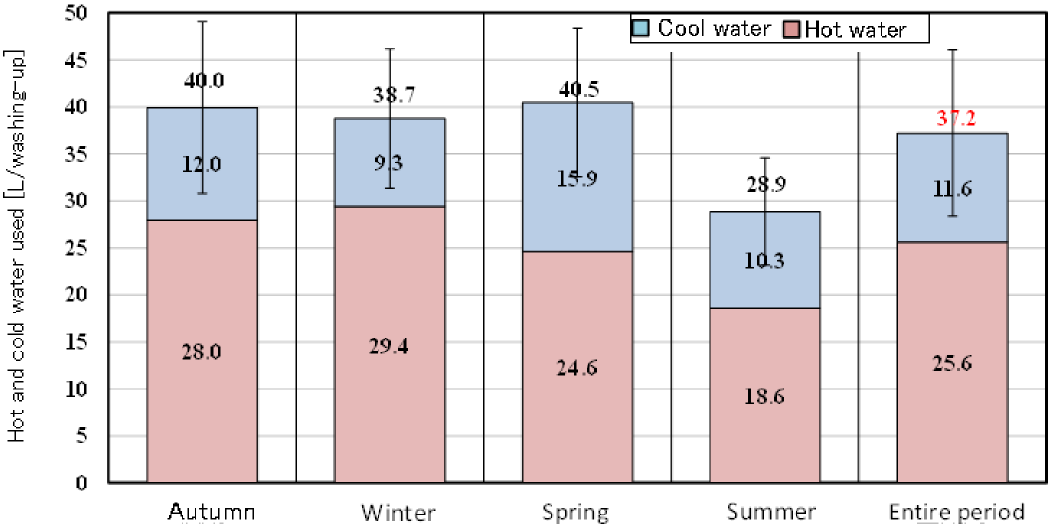


Fig. 11 The proportions of hot and cold water used per washing-up in each period

(3) The relationship between the optimum flow rate and the total amount of hot and cold water used

Fig. 12 shows how the optimum flow rates, obtained through the simplified experiment, relate to the total amounts of hot and cold water used from the respective faucets through the washing-up experiments, with respect to the volunteers who used the faucets. It is evident from the diagram that the optimum flow rates and the total amounts of hot and cold water used vary significantly from volunteer to volunteer. In response to this, the average total amounts of hot and cold water used from the respective faucets were sorted in order to identify the trend of use, as shown in Fig. 13, which indicates a strong correlation between the optimum flow rate and the total amount of hot and cold water used. Moreover, with reference to the optimum flow rate range of approximately 4.3-4.5[L/min], when the total hole area is within the ease-of-use range, which was calculated from the relationship between the total hole area and the optimum flow rate (see Fig. 7), Fig. 13 also indicates that the total amount of hot and cold water used per washing-up within said optimum flow rate range is approximately 30.5-31.5[L/washing-up].

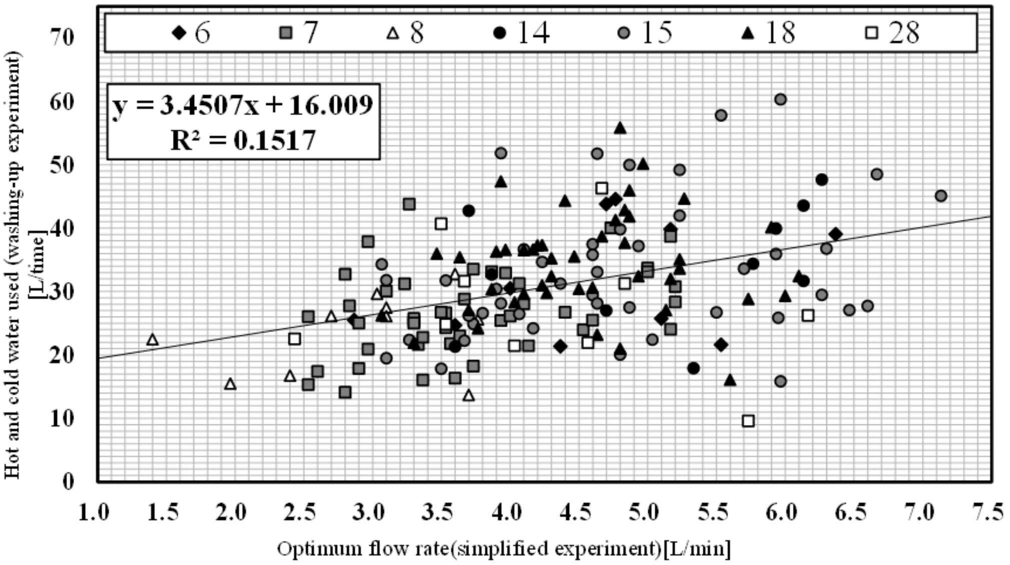


Fig. 12 The relationship between the optimum flow rate and the total amount of hot/cold water used per washing-up by each volunteer

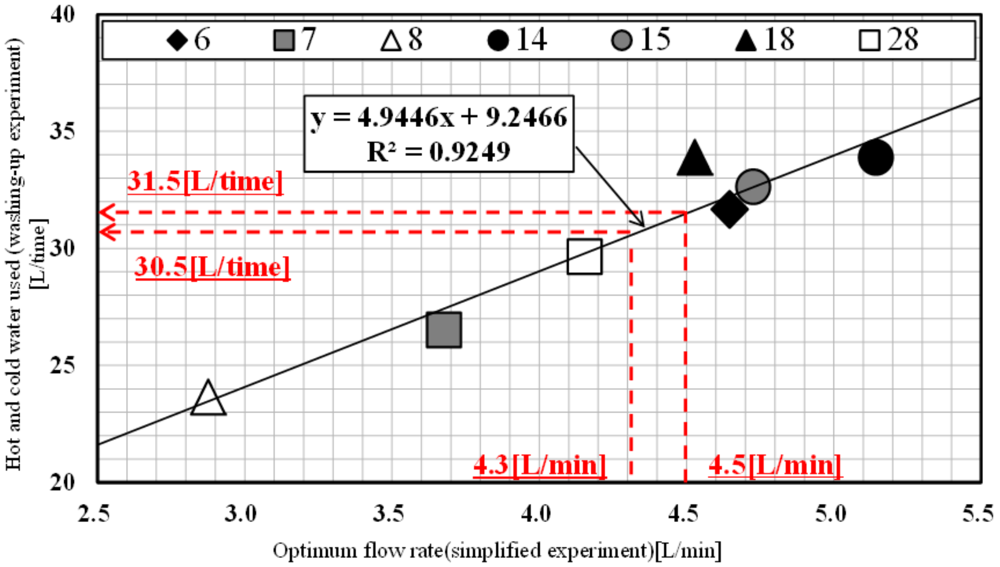


Fig. 13 The relationship between the optimum flow rate and the average total amount of hot/cold water used per washing-up

(4) The relationship between the optimum flow rate and water-saving efficiency

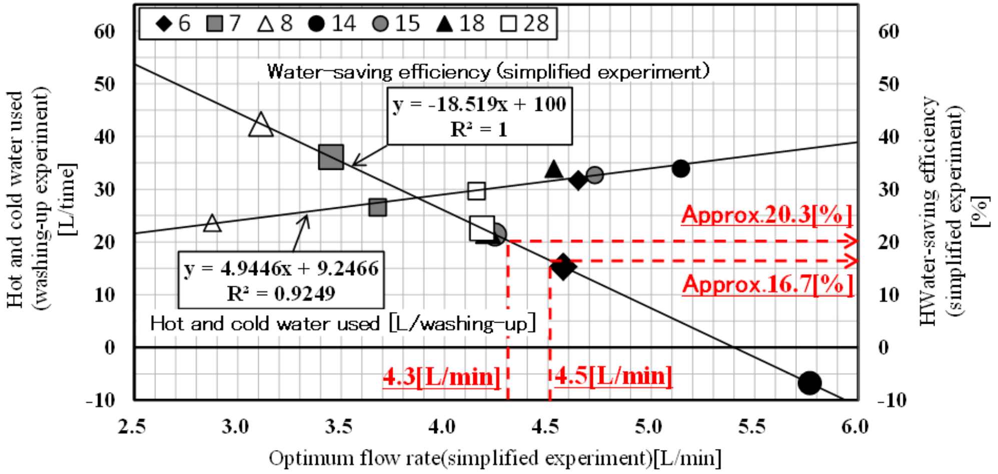
Fig. 14 (1) shows the water-saving efficiency achieved by using the optimum flow rates obtained in the simplified experiment, and Fig. 14 (2) shows the water-saving efficiency achieved by using the amounts of hot and cold water used obtained in the washing-up experiment. The water-saving efficiency is calculated by using formula 1. Fig. 4 (1) confirms that the water-saving efficiency achieved by using the optimum flow rates, which are within the ease-of-use range identified by the simplified experiment, is calculated to be approximately 16.7-20.3[%]. Similarly, Fig. 4 (2) indicates that the water-saving efficiency achieved by using the amounts of hot and cold water used, which are within said ease-of-use range, is calculated to be approximately 24.2-26.3[%]. These findings confirm that even on the basis of the results from the simplified experiment, which are not as good as the results from the washing-up experiments, the water-saving efficiency still more or less satisfies the efficiency value of 17[%] which is stipulated by Standard B

・・・ formula 1

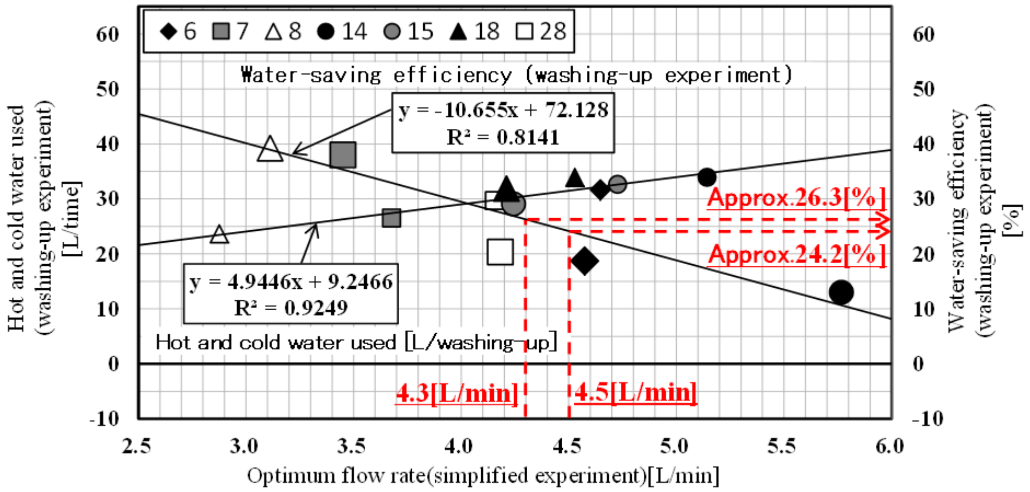
α: Water-saving efficiency [%]

A: Optimum flow rate [L/min] of straight-flow faucet, hot/cold water amount [L/time]

B: Optimum flow rate [L/min] of shower-spray faucet, hot/cold water amount [L/time]



(1) Water-saving efficiency achieved in the simplified experiment



(2) Water-saving efficiency achieved in the washing-up experiment

Fig. 14 The optimum flow rate and the water-saving efficiency in comparison between the experiments

5）Ease-of-use questionnaire survey results

Subsequent to the washing-up experiment, a questionnaire survey was carried out regarding ‘the degree of satisfaction’ with the faucets, respectively. Fig. 15 focuses on two responses; ‘satisfied’ and ‘somewhat satisfied’ which are compared to the same responses obtained subsequent to the simplified experiment. It is clear from the graph that ‘the degree of satisfaction’ indicates a very similar pattern between the experiments, and this suggests that the degree of ease of use was reflected in both experiments, thus, determining the hot/cold water-saving effects of the faucets .

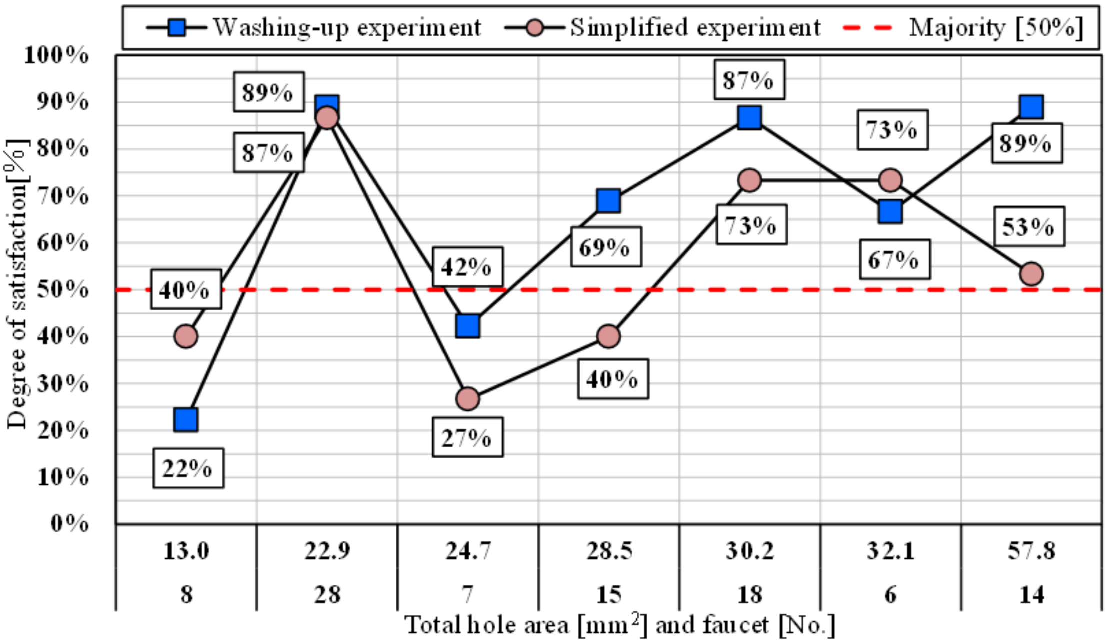


Fig. 15 ‘The degree of satisfaction’ in comparison between the washing-up experiment and the simplified experiments

4. Conclusion

Two experiments; a simplified experiment and a washing-up experiment were carried out on various types of hot water-saving kitchen faucets having different water-ejection modes and spout designs. A questionnaire survey was also carried out subsequent to the experiments. The following knowledge was acquired as a result:

(1) It has been confirmed through the simplified experiment that the total hole area range of 30-35[mm^2] and the optimum flow rate range of 4.3-4.5 [L/min] provide good ease of use.

(2) The optimum flow rates obtained in the simplified experiment more or less correspond to the average flow rates used obtained in the washing-up experiment, and therefore, it has been confirmed to be possible to determine the average water volume used in the washing-up experiment by carrying out the simplified experiment. According to this finding, the hot/cold water-saving effects of a kitchen faucet can be evaluated on the basis of the optimum flow rate thereof.

(3) The total hole area range and the optimum flow rate range that provide good ease of use were identified

in the simplified experiment, and it has been confirmed that the relationship therebetween enables the determination of the amounts of hot and cold water used from each faucet.

(4) Water-saving efficiency was calculated using the amounts of hot and cold water used obtained in the washing-up experiment and the optimum flow rates obtained in the simplified experiment, and the water-saving efficiency was approximately 24.2-26.3[%] when calculated from the amounts of hot and cold water used and approximately 16.7-20.3[%] when calculated from the optimum flow rates. This confirms that even a kitchen faucet using an optimum flow rate that provides low water-saving efficiency more or less satisfies the efficiency value of 17[%] which is stipulated by Standard B.

Acknowledgement

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Performance Evaluation of Showerheads for Hong Kong Residents

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Abstract

Increasing water and energy efficiency of shower bathing has been proposed as a measure addressing carbon reduction. A voluntary water efficiency labelling scheme (WELS) on shower heads was proposed by the Hong Kong Government in 2009. This paper examined the occupant acceptance of a sample WELS showerhead and compared with non-WELS showerheads installed in 10 Hong Kong residential apartments. The shower use characteristics are determined, water and energy implications associated with shower heads are discussed. The results showed that replacing household existing showerheads with the WELS sample showerhead could reduce water consumption per shower from 48.7L (sd=24L) to 44.3L (sd=17.4L). Correspondingly, the energy consumption would reduce from 2.29MJ (sd=1MJ) to 2.14MJ (sd=0.8MJ) per each hot water shower bathing. Outdoor temperature has no significant influence on the occupant required hot water temperature ($p>0.2$, paired t-test) and no significant difference of showering time was reported between the WELS showerhead and household exiting ones ($p=0.95$, paired t-test). The occupant acceptance to the WELS showerhead would be correlated to its supply flow rate and pressure ($p\leq0.05$, Chi-square test).

Keywords

Shower head; Water efficiency labelling scheme (WELS); Water saving; Energy saving.

1. Introduction

Water conservation is a measure addressed the concerns of energy conservation as well as reducing carbon emission. Energy is consumed at each stage of water supply in cities such as treatment, distribution, heating and disposal [1]. Household water supply systems accounted for nearly 5% of Japan's total CO_2 emissions, and over 50% of those emissions associated with hot-water supply system [2]. In Hong Kong, according to the Energy End-use Data 2013 [3], the residential energy end-use accounted for 21% of the total energy consumption in 2011 and will be increased by 15% in 10 years. It was reported that about one fifth of residential energy end-use was due to water heating. A recent water consumption survey reported that, in winter months, shower bathing accounted for over 40% of the daily per capita water consumption in Hong Kong domestic buildings of 125 L ps^{-1} d^{-1} excluding flushing [4]. The daily per capita shower water consumption in Hong Kong was 54 L ps.1 d1 (in months of 1.04 bath per day) and it was greater than those surveyed in Queensland, Australia (42.7 L ps^{-1} d^{-1}) [5].

The smart use of water in sustainable development is one of prime consideration and various measures have been specified in building evaluation assessments, e.g. BEAM and LEED certification [6,7]. Water consumption for showering was identified as a potential area of water conservation. A voluntary water efficiency labelling scheme (WELS) on showerheads was proposed in Hong Kong [8]. Showerheads fulfilled the WELS performance requirements can be registered under the scheme. It can be graded with a water efficiency label and water conservation in showering is served as an incentive for user adoption. The scheme graded with four water efficiency labels according to the water appliance nominal flow rates, namely Grade 1 for$\leq$0.15 Ls^{-1}, Grade 2 for 0.15-0.2 Ls^{-1}, Grade 3 for 0.2-0.27Ls^{-1} and Grade 4 for $\geq$0.27Ls^{-1}respectively.

This study evaluates the water use associated with different showerheads in 10 Hong Kong residential apartments together with the user's feedback on a WELS showerhead sample. The shower use characteristics are determined, water and energy implications associated with showerheads are also discussed.

2. Showerhead Performance

Water saving V_s (L) and associated energy saving Q_s (kJ) of a shower bathing using a WELS showerhead as compared with a non-WELS one can be evaluated by Equation (1) below, where V_1 (L), Q_1 (kJ) are the water and energy consumption of the bathing with the WELS showerhead; V_2 (L), Q_2 (kJ) are those with the non-WELS one,

$$V_s = V_2 - V_1; \;\; Q_s = Q_2 - Q_1 \qquad \dots (1)$$

The water consumption V (L) can be determined by showerhead water flow rate v ($Lmin^{-1}$) and the showerhead discharge operation time t (min) by Equation (2),

$$V = vt \qquad \dots (2)$$

Energy consumption Q (kJ) for heating water up is calculated by Equation (3), where c (42$kJkg^{-1}$ $℃^{-1}$) is specific heat capacitance, ρ (1000 kgm^{-3}) is density, T_i (℃) is the (cold) water supply temperature, T_o (℃) is the (hot) water supply temperature at the showerhead.

$$Q = \frac{c\rho V(T_o - T_i)}{1000} \quad \text{... (3)}$$

The cold water supply temperature for showers in residential buildings can be estimated by an expression below using the ambient temperature Ta (ºC) [9],

$$T_i = 10.4T_a^{0.29} \quad \text{... (4)}$$

User acceptance towards showerhead attributes i can be given by a logistic response where C_0 and C_1 are constants,

$$\varphi = \frac{\exp(C_0 + C_1\phi_i)}{1 + \exp(C_0 + C_1\phi_i)} \quad \cdots (5)$$

An installed shower head attributed by its water supply pressure P (kPa) and water flow rate v (Lmin^{-1}), and can be related by the resistance factor k ($\mathrm{kPa\ min}^2\ \mathrm{L}^{-2}$),

$$k = \frac{P}{v^2} \quad \cdots (6)$$

3. Method and Materials

A total of 10 families (n=37 volunteers) were recruited as volunteer basis to give feedback on their originally used showerhead and on a sample WELS showerhead. Sample WELS showerheads were purchased from the market and replaced the original showerhead(s) in the 10 apartments. The specified nominal flow rate of the WELS showerhead was 11.5 L min1. Self-reported showerhead operation time and water temperature for individual showering using the original showerhead was recorded in the first week of measurement and further recorded in the subsequent 3 months using the WELS showerhead. The overall measurement period was from end October 2013 to the mid-February 2014. The corresponding outdoor ambient temperature was also collected for reference.

The 10 families included 3 households of the well-off couples and families enjoying a comfortable lifestyle; 3 households of the stable and educated families of moderate; and 4 households of the mid-to-low income families living in urban and sub-urban homes [10].

Each participant was first interviewed to response for their showering experience with the original showerhead. A sample of interview questions is shown in Appendix A for households and their family members. Water supply pressure and flow rate of the existing showering facilities at the 10 families were measured using an in-house made apparatus shown in Figure 1. The measurement apparatus composed with a DN15 copper pipe, with a pressure gauge, a temperature meter and a timer. Water discharged was collected by a container and the average water supply flow rate was determined by dividing filling time. The measurement method referenced to those given by the Hong Kong Water Supplies Department (WSD) [11,12]. Measurements were conducted onsite to determine the operating condition as choice of the households and continue in a university piped service laboratory to determine the characteristics in a range of water supply pressures and flow rates.

At the end of measurement period, participants were interviewed again and sample questions are shown in Appendix B.

Figure 1 - Pressure and temperature gauge

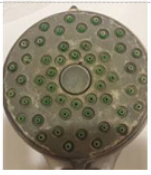
Shower heads (Households numbered)				
1 (*k*=0.54)	2 (*k*=1.39)	3 (*k*=4.05)	4 (*k*=0.70)	5 (*k*=3.24)
				
6 (*k*=0.59)	7 (*k*=2.31)	8 (*k*=2.43)	9 (*k*=0.84)	10 (*k*=1.75)
				
Water efficiency labelled scheme (WELS) shower head (the test sample)				
(*k*=2.46)				
				

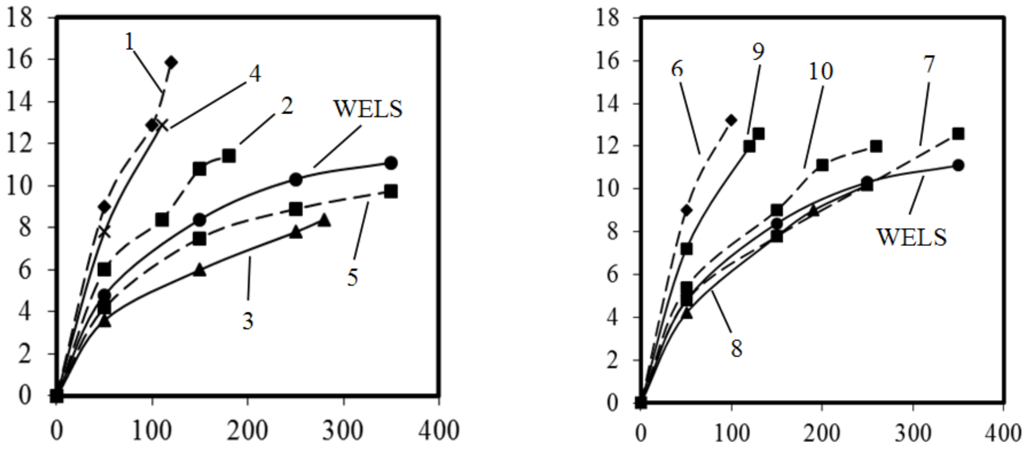
Figure 2 -Showerheads with resistance factork

4. Results and Discussion

Figure 2 shows the original showerheads and the WELS showerhead tested at the 10 families. A wide ranges of showerhead designs was reported for the number, size and distribution of holes as shown. Few of them were flow rate adjustable. All occupants preferred their existing shower facility supplying water to their satisfactory that 32 respondents preferred fine shower water spray and 5 preferred powerful ones. The existing showerhead settings to the respondent preference were kept for the testing the resistance factor

k. It was reported that no showerhead installed in the 10 families has been scheme labelled and confirmed all the original showerheads were non-WELS labelled. 5 (13.5%) participants did not satisfy with their existing showerhead performance. Though the survey carried by the HKWSD in 2011 indicated that 98.8% households supported water conservation and about 36.4% of them were aware of the WELS, the survey results of this study reflected that the adoption of WELS for showerhead was not high and may require further incentive.

The pressure-flow rate characteristic curves of showerheads were shown in Figure 3. Showerhead k-factors ranged from 0.54 to 4.05 as shown in Figure 2 and Table 1, where the WELS showerhead was k=2.46. The results showed that 2 showerheads (No. 3&5, k>2.46) having lesser water flow rates in the operating pressure range as compared with the WELS one; while 2 showerheads (No. 7&8) having flow rates very close to the WELS ones.



x-axis: water pressure (kPa); y-axis: flow rate ($Lmin^{-1}$)

Figure 3 - Shower head discharge pressure-flow rate characteristics

Occupants’ shower habits were studied, it showed that all the sampled participants used shower head without filling the bath during bathing. 36 (97%) participants expressed that they would take only one shower a day in the surveyed period. This agreed with an earlier surveyed results of 1.04 times per day in the period from mid-September to the next mid-January by the HKWSD [4].

The occupant estimated their bathing time was 10 minutes (n=20), 15 minutes (n=16) and 20 minutes (n=1) respectively. It was reported that in the bathing time, 29 (78%) participants did not keep showerhead operating continuously. The showerhead operation time was tested normality given mean time of 4.7 minutes (sd=1.8 minutes). 28 (78%) participants reported that they would shampoo every day, 8 reported shampoo once every two days and one reported once every six days. The showerhead operating time for shampoo was from 2 to 6 minutes (mean time is 2.9 minutes), and 24 (65%) would take 2 minutes for shampoo. The expected daily shower head operating time for shampoo is determined by the mean time weighted by the shampoo frequency and is about 2.6 minutes. The total mean shower head operation time is 7.1 minutes (sd=2.6 minutes), which do not have significant difference from the HKWSD surveyed one (6.7 minutes).

There were 34 (92%) participants would bath with hot water and energy saving potential was indicated for hot water bathing. The favorite hot water temperature was 38.6ºC (sd=2.5ºC) and 28 (76%) participants preferred temperature between 37 and 39ºC.

Table 1 Showering characteristics of 37 participants in 10 households

House-holds and Person	Exist- ing Showerhead k- factor	Cold water temp. T_i (℃)	(1. First week) Existing shower head (outdoor temperature 24 ℃)			(2. Second week) WELS shower head (outdoor temperature 24 ℃)			(3. Last week) WELS shower head (outdoor temperature 12 ℃)		
			Hot water temp. $T_{o,1}$ (℃)	Flow rate v_1 (Ls^{-1})	Operation time t_1 (s) (sd)	Hot water temp. $T_{o,2}$ (℃)	Flow rate v_2 (Ls^{-1})	Operation time t_2 (s) (sd)	Hot water temp. $T_{o,3}$ (℃)	Flow rate v_3 (Ls^{-1})	Operation time t_3 (s) (sd)
1(1)	0.54	26.8	37.3	0.265	458(27)	38.0	0.190	358(36)	37.8	0.170	407(15)
1(2)					165(26)			214(26)			199(13)
2(1)	1.39	26.2	38.7	0.140	192(15)	38.9	0.130	208(9)	39.1	0.110	201(11)
2(2)					434(23)			432(56)			494(21)
2(3)					323(80)			305(53)			309(11)
2(4)					368(88)			359(40)			377(7)
2(5)					275(114)			201(32)			199(15)
2(6)					274(35)			288(33)			301(12)
3(1)	4.05	26.2	38.8	0.100	375(15)	39.0	0.105	360(22)	39.0	0.090	343(27)
3(2)					137(17)			174(29)			201(16)
3(3)					305(14)			423(37)			414(96)
3(4)					308(27)			358(12)			376(20)
4(1)	0.70	26.5	36.9	0.130	331(13)	37.5	0.100	336(22)	37.2	0.085	365(11)
4(2)					260(17)			344(29)			403(18)
4(3)					236(16)			244(32)			282(20)
4(4)					254(34)			302(31)			275(5)
4(5)					193(48)			207(48)			218(10)
5(1)	3.24	28.5	42.7	0.162	427(27)	41.9	0.185	402(43)	41.3	0.170	576(45)
5(2)					255(52)			229(55)			242(74)
5(3)					172(25)			140(13)			178(37)
5(4)					200(12)			194(19)			191(38)
5(5)					162(9)			191(27)			354(142)
5(6)					297(30)			238(81)			355(150)
5(7)					168(23)			202(27)			220(26)
6(1)	0.59	26.8	36.8	0.220	244(27)	37.6	0.180	218(27)	38.3	0.165	220(28)
6(2)					200(40)			190(20)			188(21)
6(3)					315(34)			282(33)			268(40)
6(4)					313(47)			319(32)			319(12)
7(1)	2.31	26.5	36.7	0.210	207(29)	36.8	0.195	236(55)	37.0	0.180	231(37)
7(2)					159(40)			167(45)			146(26)
7(3)					350(9)			281(104)			293(16)
7(4)					155(35)			205(59)			216(34)
8(1)	2.43	25.4	34.0	0.150	441(38)	33.4	0.170	427(27)	35.0	0.160	468(41)
8(2)					381(12)			361(24)			365(19)
9(1)	0.84	27.0	36.2	0.200	602(32)	36.7	0.170	597(25)	37.0	0.155	642(24)
10(1)	1.75	27.0	38.1	0.200	421(20)	38.8	0.170	419(12)	38.5	0.160	420(8)
10(2)					386(16)			348(28)			348(9)
Mean	1.78	26.7	37.6	0.18	290	37.9	0.16	291	38.0	0.14	314
sd	1.21	0.8	2.3	0.05	107	2.2	0.03	99	1.7	0.04	115

sd—standard deviation

Table 1 summarizes the measured showering characteristics of 37 participants in 10 households, presented with the both WELS and non-WELS showerheads in two outdoor ambient air temperatures. The measured average hot water temperatures, shower flow rates and operating times of (1) the first week with the original shower heads, (2) the second week and (3) the last weeks of study with the WELS showerhead (30/10/2013 to 09/02/2014) are presented in the table. The outdoor ambient temperatures in the first 2 weeks were 24ºC (sd=1.6ºC) and the last week was 12ºC (sd=3.2ºC) respectively. The average cold water supply temperature was 26.7ºC (sd=0.8ºC) measured at the first measurement week. It showed no significant difference from the previous measurements at the same ambient condition) 26.1ºC ($p>0.05$, t-test) (Wong, Mui et al. 2010).

The hot water supply temperatures for those three periods (1), (2) and (3) were 37.6ºC (sd=2.3ºC), 37.9ºC (sd=2.2ºC) and 38.0ºC (sd=1.7ºC) respectively. No significant difference of the hot water shower temperatures among three periods was reported ($p>0.2$, paired t-test). Hence the required hot water shower temperature attributed to personal demand is assumed and a constant value can be adopted.

The showering periods (1), (2) and (3) were recorded as 4.8 minutes (sd=1.8 minutes), 4.8 minutes (sd=1.7 minutes) and 5.2 minutes (sd=1.9 minutes) respectively. No significant difference was reported between WELS showerhead and the original ones ($p=0.95$, paired t-test). However, longer showering time was reported for the period having lower ambient temperature ($p<0.01$, paired t-test). No significant difference of water consumption due to the lower ambient temperature ($p=0.4$, paired t-test) was found.

Replacement of the WELS showerhead would consume less water for showering and hence expect a reduction of energy required for hot water production (p0.05, pair t-test), where the water consumption per shower bathing was reduced from 48.7L (sd=24L) to 44.3L (sd=17.4L), corresponding to energy required for periods (1) & (2) of 2.29MJ (sd=1MJ) and 2.14MJ (sd=0.8MJ), respectively. More energy (3.12MJ, sd=1.5MJ) was used (i.e. in period 3) for a shower bathing and it would be due to lower cold water supply temperature.

Table 2 shows the correlations among showerheads attributes and the occupant acceptance. It is noted for the WELS showerhead flow rate and pressure, 22 participants did not feel satisfactory and they would like to use the original ones. Among 15 participants feel satisfactory, 8 preferred to use the original ones because they were more comfortable and 7 would keep using the WELS one. The occupant acceptance to the newly installed WELS showerhead would be correlated to its supply flow rate and pressure (p0.05, Chi-square test). The resistance factor k relating shower water supply pressure and flow rate as an explanatory parameter of occupant acceptance of a showerhead was reported ($p<0.05$, Chi-square test).

Table 2 Occupant acceptance to tested shower heads

Parameter, ϕ	C_0	C_1	p-value
WELS showerhead			
Water supply pressure	-1.82	0.007	0.018
Water supply flow rate	-4.88	28.22	0.008
All other showerheads			
k-factor	-1.54	3.13	0.001

5. Conclusion

Increasing water and energy efficiency has been proposed for many sustainable developments nowadays. In Hong Kong, a voluntary water efficiency labelling scheme (WELS) on showerheads has been proposed since 2009. This study examined the occupant acceptance of a sample WELS showerhead and compared with non-WELS showerheads installed in 10 Hong Kong residential apartments. The use of WELS showerhead could improve water efficiency for shower bathing that the per shower bathing water consumption was reduced from 48.7L (sd=24L) to 44.3L (sd=17.4L). The saving corresponds to a reduced energy consumption from 2.29MJ (sd=1MJ) to 2.14MJ (sd=0.8MJ) per shower bathing. It is also revealed that outdoor temperature has no significant influence on the hot water shower temperature ($p>0.2$, paired t-test) and no significant difference of showering time was reported between using WELS showerhead and household exiting ones ($p=0.95$, paired t-test). The occupant acceptance to the WELS showerhead would be correlated to its supply flow rate and pressure (p0.05, Chi-square test).

Acknowledgment

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Appendix A. Interview survey (Prior to the use of the water efficient labelled showerhead)

For households:

1.How many bathrooms in your apartment?
2.How many occupants in your apartment?
3.Are you using water efficiency labelled showerhead?
4.If yes, what is the water efficiency label? (Level 1-4)
5.If not, would you like to use one with water efficiency labelled?
6.What kind of energy is used for your water heater? a) Town Gas; b) LPG; c) Electricity.
7.Is your showerhead water supply having more than one way? (i.e. multiple types of spray)

For individuals:

1.Are you using the described showerhead for bathing?
2.How many times you used to shower bath every day?
3.How long you take a shower bath? You may give an estimated time range.
4.Do you keep the showerhead discharging during your bathing?
5.How long you would operate the showerhead for a bath in total?
6.Do you fill the bathtub during bathing time?
7.Do you fill the bathtub and use the showerhead at the same time?
8.How frequent you take a cold/hot shower bath?
9.How many days you bath with cold water in the past year?
10.How frequent you take shampoo? How long is it?
11.Do you feel satisfactory with your existing showerhead?
12.Would you give an estimate on your favorite shower water temperature?
13.What is your favorite feeling of shower water amount? Poor and weak or amount of sense?
14.What is your favorite feeling of shower water pressure is soft/fine/powerful?

Appendix B. Interview survey (After the use of the water efficient labelled showerhead)

1.Do you feel satisfactory with the performance of water efficiency labelled showerhead?
2.When compared with the original showerhead, which one do you prefer?
3.After trial of the water efficiency labelled showerhead, would you opt to use the water efficiency labelled showerhead now?
4.Do you feel satisfactory with the water pressure of the water efficiency labeled showerhead?
5.Do you feel satisfactory with the water amount of the water efficiency labelled showerhead?
6.How you prioritize bathing comfort and water saving?
7.Is your favorite shower water temperature the same in winter and summer? Would you give an estimate on them?
8.Would you extend your shower time in winter when compared with that in summer?
9.Do you reduce times for shampoo in winter?

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Carrying Performance Evaluation of a Horizontal Fixture Drain Branch System in Relation to Drainage Characteristics of Water–saving Toilets Installed Therein

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Abstract

The study aims to obtain knowledge that contributes to a design method for a piping arrangement with a focus on the carrying performance and carrying performance evaluation of a horizontal fixture drain branch system when multiple water-saving toilets for commercial buildings are installed therein. Using five toilets which are installed to a horizontal fixture drain branch, changes in fixture drainage characteristics are first identified while gradually increasing the number of drainage points from one point to multiple points. Experiments are then carried out to clarify how the carrying performance of the horizontal fixture drain branch system is affected by backflow, or blockage in the margining section, in the case of merged drainage from multiple toilets. The experiments' results are subsequently used to clarify points to be considered in designing horizontal fixture drain branch systems for commercial use.

Keywords

Carrying performance, water-saving toilets, horizontal fixture drain branch, back flow

1. Background and Objectives of the Study

Water-saving toilets have become more widespread, on a global scale, in preventing further global warming and preserving water resources. Meanwhile, using less water for flushing may degrade the performance of carrying waste, thus, causing trouble, such as blockage in the horizontal fixture drain branch, which raises concerns. Table 1 shows the transition of studies on carrying performance evaluation at CIBW062 alongside the development of related standards and water-saving technologies for toilets. There are three phases classified according to the researchers and the details of their studies: phase I (1975 to 1990) was a period during which the carrying performance of toilets was identified at the fundamental level; phase II (1990 to 2004) was a period during which the carrying performance of water-saving toilets and the standardisation of testing methods were examined; and phase III (2005 to present) is a period during which the carrying performance of different types of water-saving toilets and simulation methods using models have been studied.

However, the studies and experiments focus on systems comprising only one toilet and a single horizontal drain pipe connected thereto, and therefore, it is assumed that the studies and experiments are mainly intended for drainage systems for residential use. Meanwhile, public buildings, such as office buildings, in Japan and many other countries employ a water-saving toilet system in which multiple toilets are connected to one horizontal fixture drain branch, as shown in Fig. 1 , and this serial type of toilet system is becoming more popular. However, there have not been many studies that have reported on the carrying performance of toilet systems of this type.

This study focuses on a serial-type water-saving toilet system for office use, comprising five water-saving toilets that use 4.8L or 6.0L of water for flushing, and aims to identify the carrying performance of the system and issues that may be related to the system. The study also intends to acquire knowledge from the findings, which will be conducive to designing and planning horizontal fixture drain branch layouts. The study intends to identify the following key points:

(1) Fixture drainage characteristics (the influence of the backflow in the inflow section according to the configuration of the inflow section)

(2) Carrying performance (the influence of single flushing, combined flushing and pipe pitches, and the effects of scheduled follow-up flushing)

(3) The benefit of installing a loop vent pipe

Table 1 Transition of studies on carrying performance evaluation reported at CIBW062

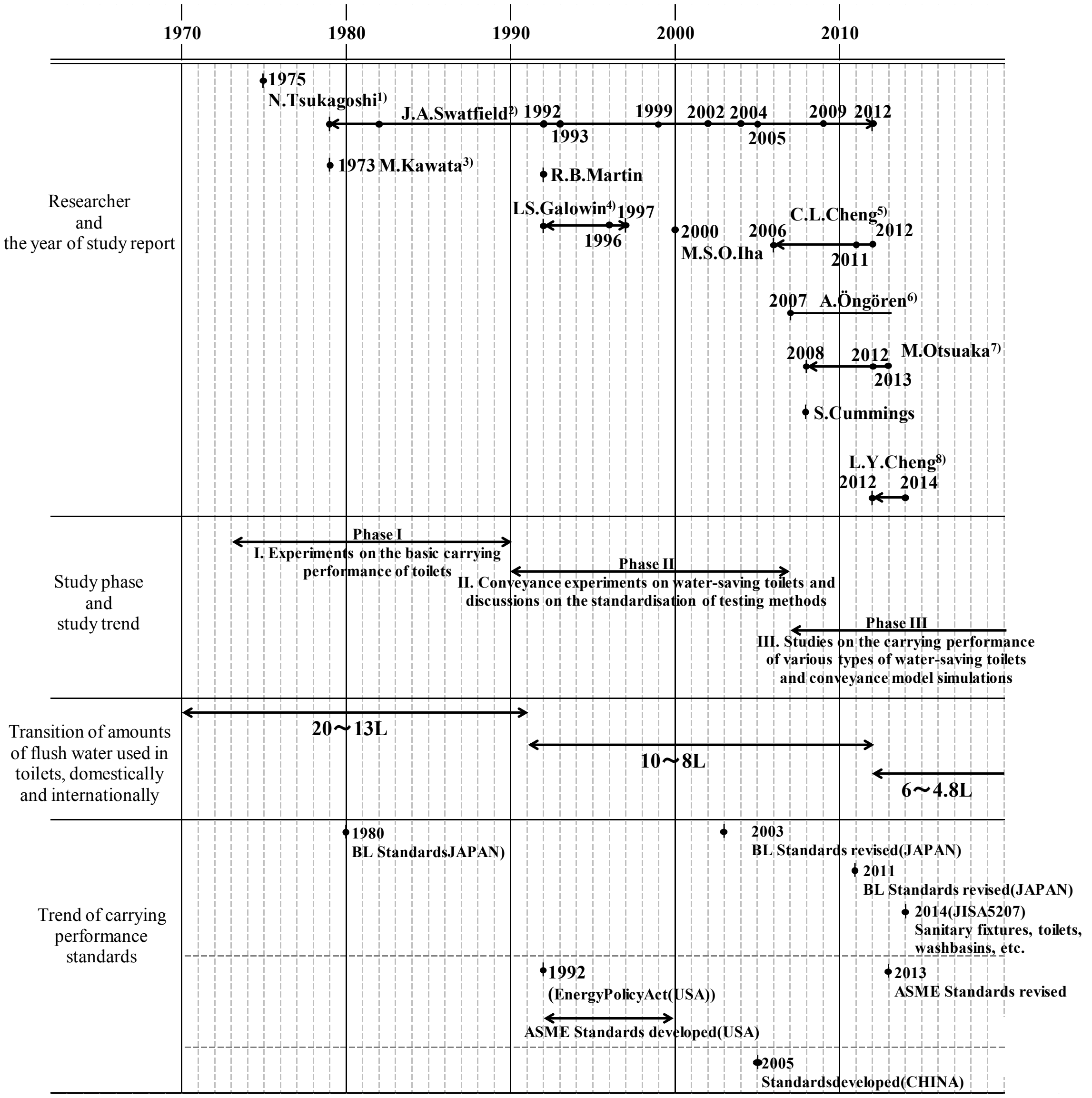


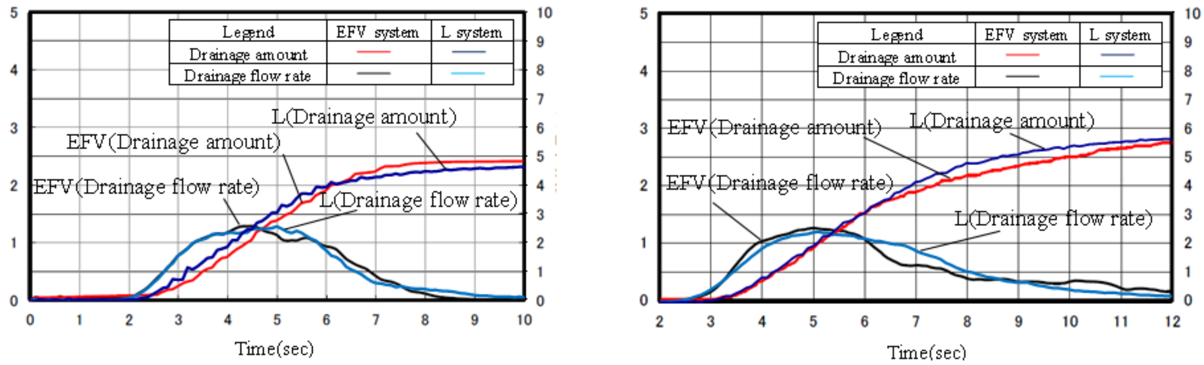
Fig. 1 Serial-type toilet system

2. Experiment Overview

2.1 Experimental fixture drainpipe system

The experiments carried out in the study involve two types of water-saving toilets, as shown in Fig. 2; one with 4.8L of flush water and the other with 6.0L of flush water. The toilets employ a low-tank (L) system and are used for identifying fixture drainage characteristics. In reality, toilets for office use often employ an electric flush valve (EFV) system, which causes variations in the water pressure in water supply pipes to toilets. However, for experimental purposes, the low-tank system with a certain amount of water retained therein is used, as an alternative to the electric flush valve system, in order to prevent the influence of water pressure variations, on the basis that fixture drainage characteristics values measured between the systems are almost equal to each other, as shown in Fig. 2.

		Amount of flush water, flushing system, water supply method			
		4.8L		6.0L	
		Washdown system		Washdown system	
		EFV system	L system	EFV system	L system
Fixture drainage characteristics	Average drainage flow rate qd[L/s]	1.1	1.1	0.8	1.9
	Maximum drainage flow rate qmax[L/s]	1.3	1.3	1.3	1.2



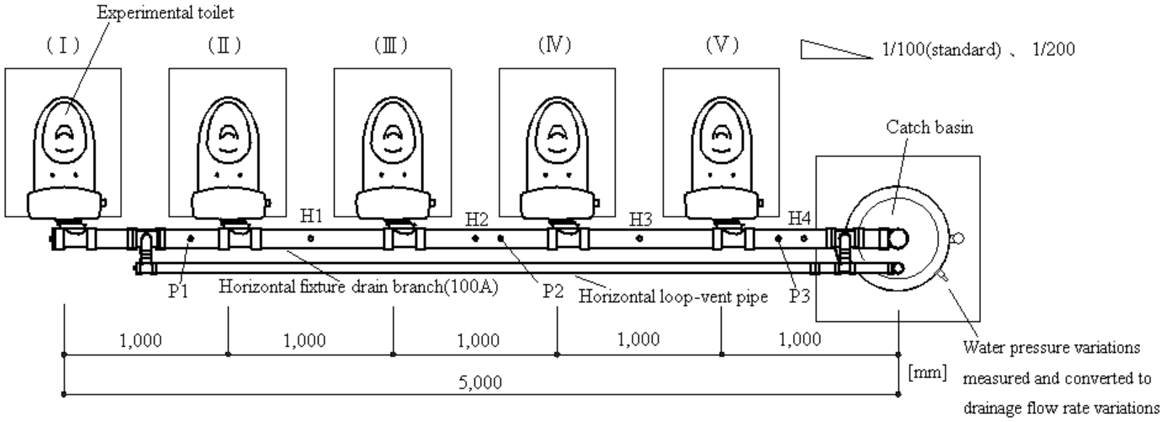
EFV: electric flush valve, L: low-tank

(1) 4.8L toilet **(2) 6.0L toilet**

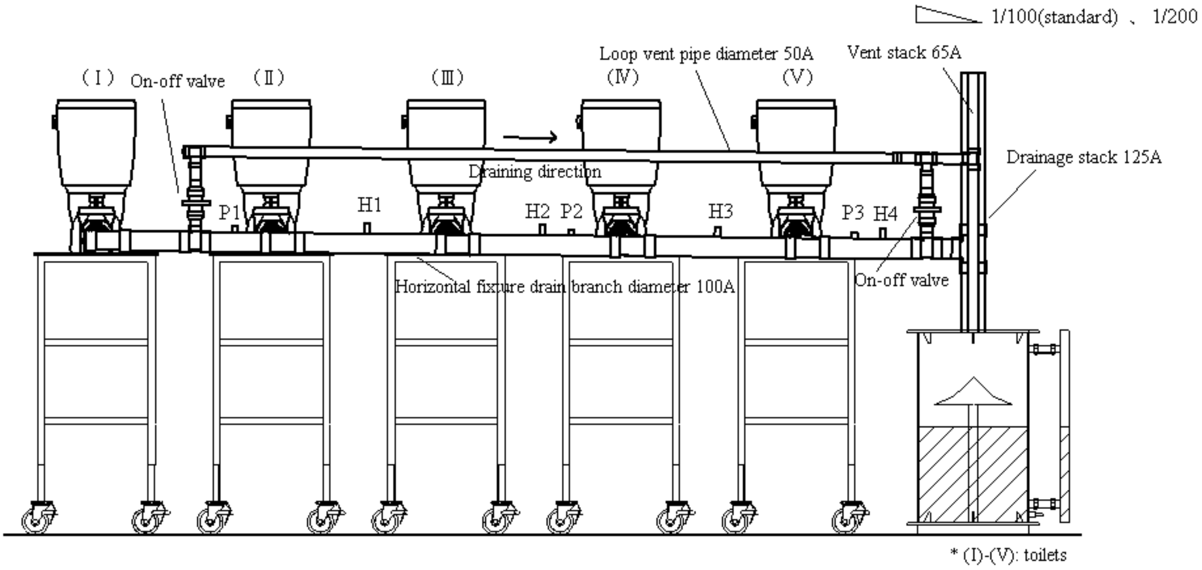
Fig. 2 Drainage characteristics of the experimental toilets

Fig. 3 and Fig. 4 show the experimental horizontal fixture drain branch system comprising five experimental water-saving toilets which are connected in series. The experimental system simulates a series of toilet booths connected to an above-floor horizontal fixture drain branch, which is a configuration typically seen in office buildings. The total length of the experimental horizontal fixture drain branch is 5m. The experimental toilets are installed in series at 1m intervals between the draining cores thereof. Toilet (I) is positioned at the uppermost stream side of the experimental horizontal fixture drain branch, and then toilets (II), (III) and (IV) are positioned down along the horizontal fixture drain branch. Toilet (V) is at the lowermost stream position. A transparent rigid PVC pipe is used as the experimental horizontal fixture drain branch, and the nominal diameter thereof is 100A ((inside diameter 103mm) and JIS-DT fittings (100 × 125) are attached to the ends thereof. Two different pipe pitches are also applied; 1/100 (standard) and 1/200.

Fig. 5 shows two fitting configurations that are used in the inflow section of the horizontal fixture drain branch; one is for 4.8L of flush water and the other for 6.0L of flush water. The fitting for 4.8L of flush water lets wastewater flow into the horizontal fixture drain branch smoothly, whereas the fitting for 6.0L of flush water allows wastewater to flow in almost vertically, thus, creating much resistance. The horizontal fixture drain branch is also provided with a loop vent pipe (50A), and on-off valves are installed in the parts connecting the horizontal fixture drain branch and the loop vent pipe together. The normal state of the valves is closed. Meanwhile, the study includes conveyance testing which involves three different types of waste substitutes which are shown in Table 2.



(1) Horizontal fixture drain branch length L=5m (in planar view)



(2) Horizontal fixture drain branch length L=5m (in elevation view)

Fig. 3 Experimental horizontal fixture drain branch

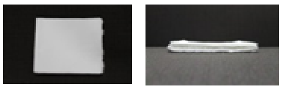
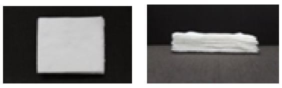
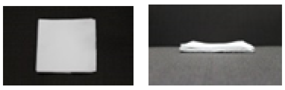
Fig. 4 Experimental horizontal fixture drain branch system

：inflow direction of drainage

(1) 4.8L toilet (2) 6.0L toilet

Fig. 5 Fittings for the horizontal fixture drain branch

Table 2 Experimental waste substitutes

Type	Waste substitute	Description
D		Toilet paper laid flat, 1m×6 pieces (1 ply)
D′		Toilet paper laid flat, 1m×6 pieces (2 ply)
BL*		Toilet paper laid flat, 0.9m× 4 pieces (1 ply)

* Better Living BLE WC:2013 Standard

2.2 Fixture drainage characteristics experiment

In the fixture drainage characteristics experiment, five 4.8L or 6.0L water-saving toilets are connected to the experimental horizontal fixture drain branch system (pipe pitch 1/100), as shown in Fig. 3, and fixture drainage characteristics are measured. Incidentally, the measuring methods refer to the previous study report7). Table 3 (1) and (2) show the flushing patterns applied in the experiment. The experiment is further divided into two experiments; a single-flush experiment and a combined-flush experiment. In the single-flush experiment, clean water without waste is flushed down toilets (I)-(V) one by one, while in the combined-flush experiment, two to five of toilets (I)-(V) are flushed successively to create merged drainage.

Table 3 Flushing patterns used in the experiment

(1) Single flushing

Flushing pattern No.			Flushing position				
			(Ⅰ)	(Ⅱ)	(Ⅲ)	(Ⅳ)	(Ⅴ)
Single flushing	1 position	No.1	○				
		No.2		○			
		No.3			○		
		No.4				○	
		No.5					○

(2) Combined flushing

Flushing pattern No.			Flushing position				
			(Ⅰ)	(Ⅱ)	(Ⅲ)	(Ⅳ)	(Ⅴ)
Combined flushing	2 position	No.6	○	○			
	3 position	No.7	○	○	○		
	4 position	No.8	○	○	○	○	
	5 position	No.9	○	○	○	○	○

○ Toilet(s) used for testing

2.3 Carrying performance experiment

In the carrying performance experiment, the experimental horizontal fixture drain branch system (pipe pitch 1/100 or 1/200) in Fig. 3 and the three types of waste substitutes in Table 2 are used. One of the waste substitutes is placed in one of the toilets, soaked in the water for 15 seconds, and then flushed down the toilet. Once the waste substitute stopped, the conveyance distance is measured from the core of the drainpipe of the uppermost stream toilet to the tail of the waste substitute. The measured distance is then translated as a carrying performance value. Similar to 2.2, the carrying performance experiment is further divided into two experiments; a single-flush conveyance experiment and a combined-flush conveyance experiment.

(1) Single-flush conveyance experiment

In this experiment, as shown in Table 4 (1), one waste substitute is applied to and flushed down each of toilets (I)-(V) at a time, and the conveyance distance is measured subsequently. The pitch of the experimental horizontal fixture drain branch is 1/100.

(2) Combined-flush conveyance experiment

In this experiment, as shown in Table 4 (2), two to five of toilets (I)-(V) have waste substitutes placed therein, respectively. The toilets are then flushed successively to create merged drainage. The conveyance distance is then measured in the same way as the single-flush conveyance experiment. As for the flushing timing, once a waste substitute is placed in each of the toilets, the toilets are flushed one by one, starting with the uppermost stream toilet (I), at 1-second intervals. The pitch of the experimental horizontal fixture drain branch is 1/100.

(3) The influence of the pipe pitch on the carrying performance

In the single-flush conveyance experiment, as shown in Table 4 (1), one waste substitute is applied to and flushed down each of toilets (I)-(V) at a time, and the conveyance distance is measured subsequently, as explained in (1). In this instance, however, two different pipe pitches, 1/100 and 1/200 are applied to the experimental horizontal fixture drain branch.

(4) Conveyance experiment by scheduled follow-up flushing

In the case of the single-flush pattern that causes the shortest conveyance distance, thus being disadvantageous to the carrying performance, once a waste substitute stopped after the initial flushing, the 2nd and the 3rd flushes are made with clean water from the uppermost stream toilet (I) at intervals of 0.5 hour, 1 hour, 3 hours and 12 hours, and the conveyance distance is measured again. As a measure for draining waste that has stagnated in the drainpipe, this experiment contributes to discussing time intervals for automatic flushing.

Table 4 Flushing patterns used in the experiment

(1) Single flushing

Flushing pattern No.			Flushing position				
			(Ⅰ)	(Ⅱ)	(Ⅲ)	(Ⅳ)	(Ⅴ)
Single flushing	1 position	No.1	○				
		No.2		○			
		No.3			○		
		No.4				○	
		No.5					○

(2) Combined flushing

Flushing pattern No.			Flushing position				
			(Ⅰ)	(Ⅱ)	(Ⅲ)	(Ⅳ)	(Ⅴ)
Combined flushing	2 position	No.6	○	○			
		No.7	○		○		
		No.8	○			○	
		No.9	○				○
	3 position	No.10	○	○	○		
		No.11	○	○			○
		No.12	○		○		○
		No.13	○			○	○
	4 position	No.14	○		○	○	○
		No.15	○	○		○	○
		No.16	○	○	○		○
	5 position	No.17	○	○	○	○	○

2.4 Items to measure and measuring methods

Table 5 shows the items to measure and the methods for measuring them. As shown in Fig. 3, supersonic water level sensors are placed at positions H1 to H4, respectively, to measure the water level, H[mm], of wastewater in the horizontal fixture drain branch. Meanwhile, pressure sensors are placed at positions P1 to P3, respectively, to measure the pressure in the horizontal fixture drain branch, and seal losses of the traps of the experimental toilets are also measured upon completion of each experiment. In the catch basin, a water pressure sensor is placed to measure a variation in the water pressure, and the measured value is converted to a volume of wastewater, W[L], to calculate a flow rate of wastewater, Q[L/s], in accordance with SHASE-S 220 ‘Testing Method of Discharge Characteristics for Plumbing Fixtures’. The interval for data sampling is 0.01 second, and a 100Hz low-pass filter is used for filtering sampled data.

Table 5 Items to measure and measuring methods

Items to measure	Measuring position	Measuring method
Backflow in the horizontal fixture drain branch	Water level variation in the horizontal fixture drain branch H_1～H_5	Supersonic water level sensor
Induced syphon action in the trap	Pressure variation in the horizontal fixture drain branch P_1～P_3	Small semiconductor pressure sensor
	Trap seal loss	Visual measurement
Fixture drainage characteristics	Water pressure variation in the catch basin	A variation in the water pressure is measured with a water pressure sensor, and is then converted to a volume of wastewater to identify the flow rate of the wastewater

※ Data sampling interval: 0.01(s), through a low-pass filter (100Hz)

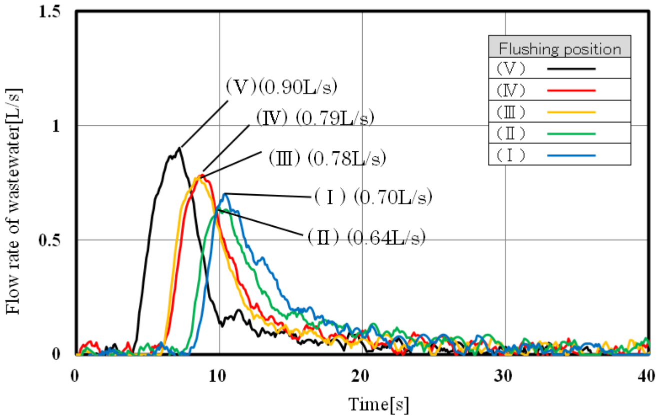
3. Results and Discussion

3.1 Fixture drainage characteristics experiment

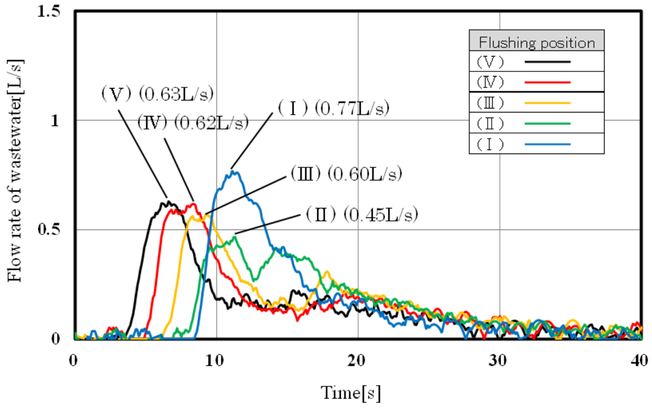
Fig. 6 shows the toilets which were flushed and the waveforms obtained subsequently of the corresponding wastewater flow rates in the single-flush experiment. Fig. 6 (1) shows the results of using 4.8L of flush water while Fig. 6 (2) shows the results of using 6.0L of flush water. In the case of using 4.8L of flush water, the maximum flow rate from the uppermost stream toilet (I) is the smallest of all the maximum flow rates, which increase downstream, from one to another, and the highest maximum flow rate is from toilet (V) at the lowermost stream position. In the case of using 6.0L of flush water, however, the maximum flow rate from toilet (I) is the highest and the maximum flow rates from the other toilets are all smaller than that from toilet (I) although they increase downstream, from one to another, in the same manner as in the case of using 4.8L of flush water.

These results are attributed to the backflow of wastewater in the horizontal drain branch, which varies depending on the configuration of the fitting in the inflow section. Fig. 7 shows the variation of the water level in the horizontal drain branch, which was measured at H1 in Fig. 3. Fig. 7 compares the water level values which were measured at H1 when toilets (III), (IV) and (V) were flushed downstream from H1. In the case of flushing 4.8L of water, the maximum water level was approx.15mm by toilet (III), and approx. 10mm by toilet (IV), and in the case of toilet (V), the backflow did not reach H1. In contrast, when 6.0L of water was flushed, the maximum water level was approx. 24mm by toilet (III), approx. 17mm by toilet (IV) and approx. 12mm by toilet (V). The backflow caused by the dispersion of wastewater was confirmed in all the cases.

Accordingly, in the case of flushing 4.8L of water, not much difference was found among the maximum water levels of wastewater that flowed back because of the fitting configuration that facilitated the wastewater to flow smoothly, whereas in the case of flushing 6.0L of water, the water level of wastewater caused by the backflow was found to be higher in the upper stream than in the lower stream due to significant inflow resistance in the fitting section. The state of the backflow is shown in Fig. 8. It is inferred that the backflow behavior affects the carrying performance of the horizontal drain branch for better or worse.

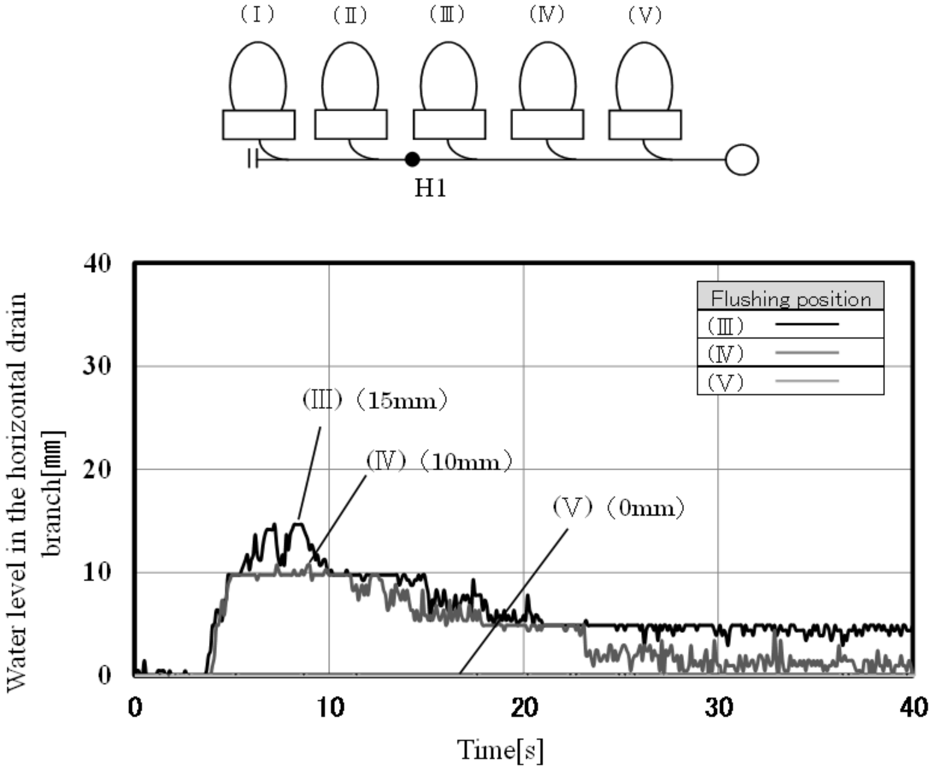


(1) 4.8L toilet

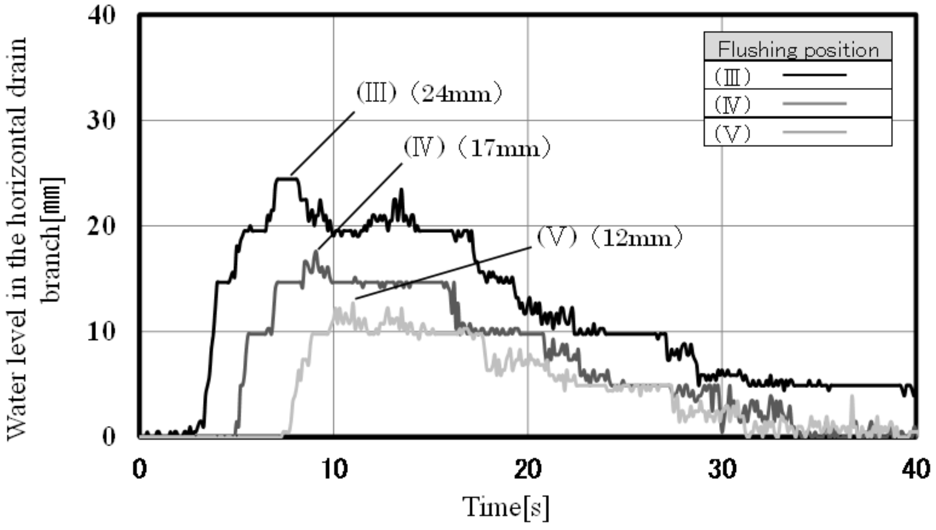


(2) 6.0Ltoilet

Fig. 6 Variations in wastewater flow rates measured during the single-flush experiment

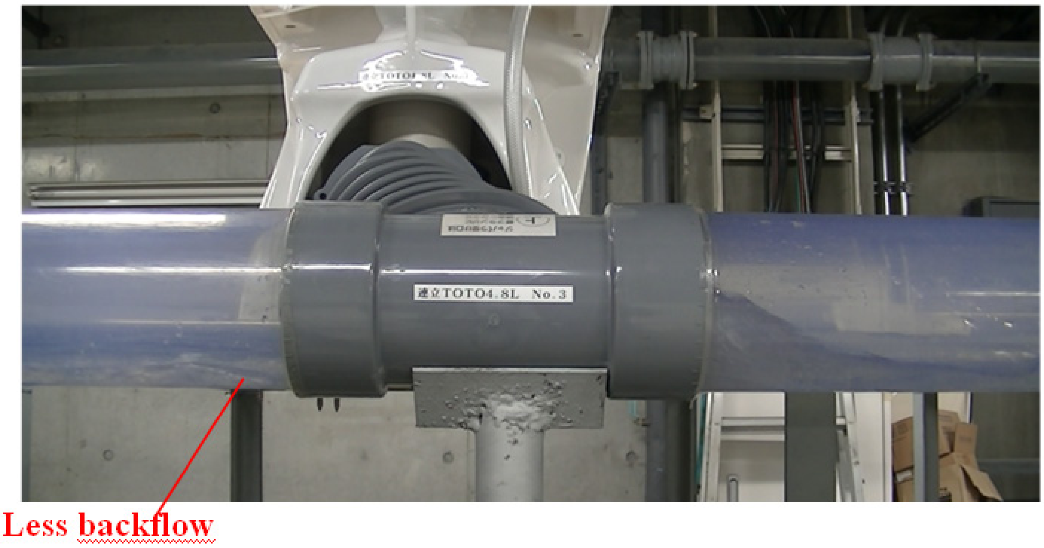


(1) 4.8L toilet

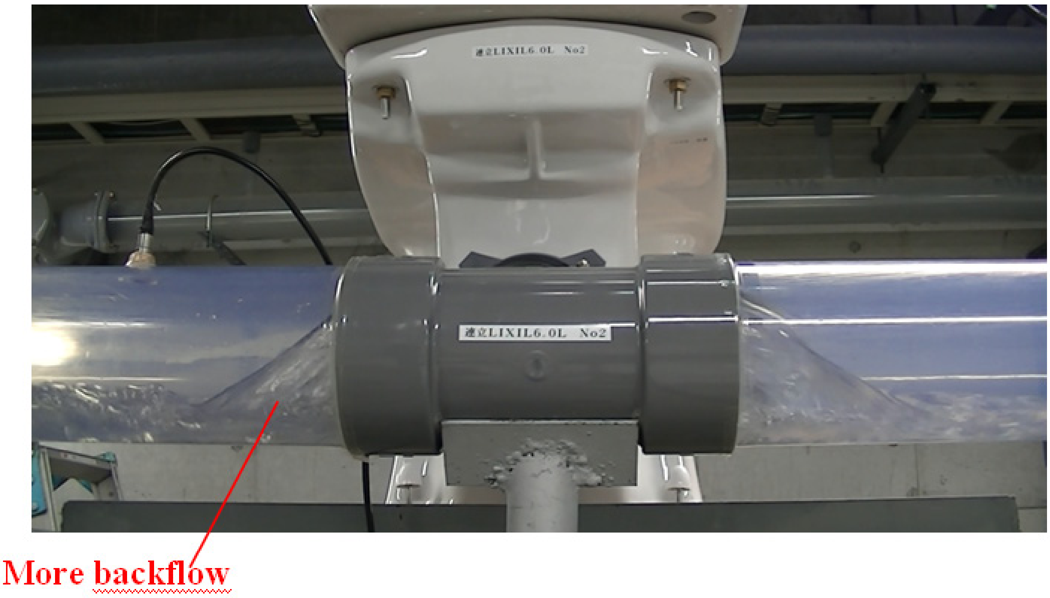


(2) 6.0L toilet

Fig. 7 Comparison of backflow levels by different flushing positions (water level sensor position H_1)



(1) 4.8L toilet



(2) 6.0L toilet

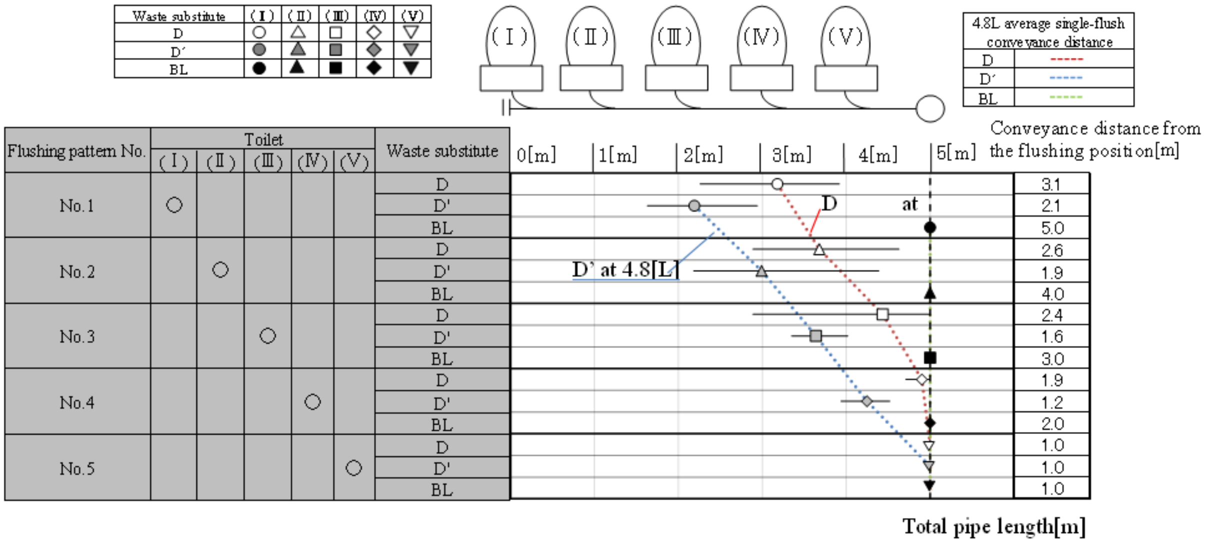
Fig. 8 Backflow in the inflow section

3.2 Carrying performance experiment

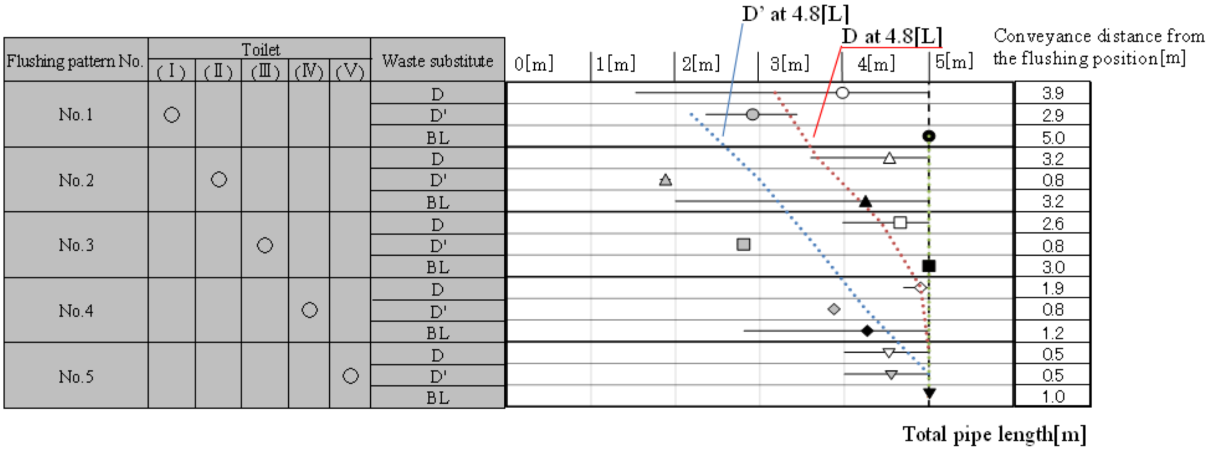
(1) Single-flush conveyance experiment

Fig. 9 shows various conveyance distances obtained by flushing toilets (I)-(V), once individually, using different types of waste substitutes. Waste substitute BL was carried 5m into the drainage stack from the uppermost stream of the horizontal drain branch when flushed with 4.8L of water from all of the toilets. However, waste substitute D, which is harder to drain than BL, was carried approx. 2-3m and came to a halt, and waste substitute D’, which is the hardest to drain, was carried approx. 1-2m and came to a halt, when flushed from the toilets, with the exception of toilet (V), from which both D and D’ were carried

5m into the drainage stack. When flushed with 6.0L of water, even BL became stagnant in the horizontal drain branch, and when flushed from toilets (II), (III) and (IV), the performance to carry D' turned out to be inferior to the carrying performance with 4.8L of water. It is inferred that the configuration of the fitting used for flushing 6.0L of water (Fig. 5) allows wastewater to disperse in the inflow section of the horizontal drain branch, into the upper and lower streams thus, reducing the carrying performance.



(1) 4.8L toilet

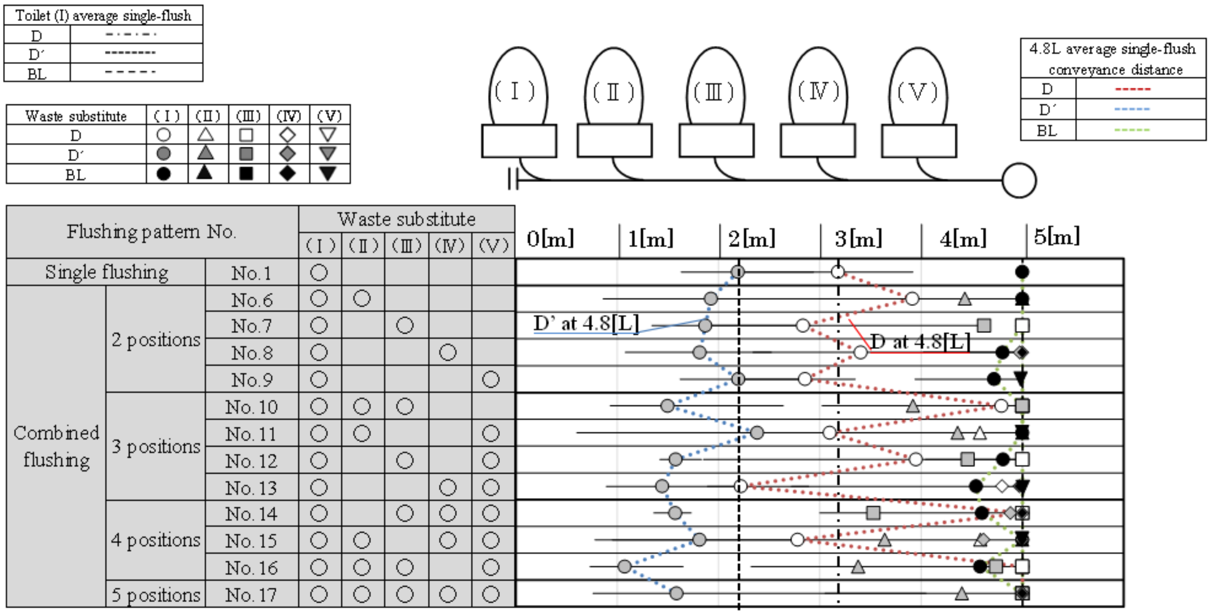


(2) 6.0L toilet

Fig. 9 Conveyance distances and stop positions of waste by single flushing

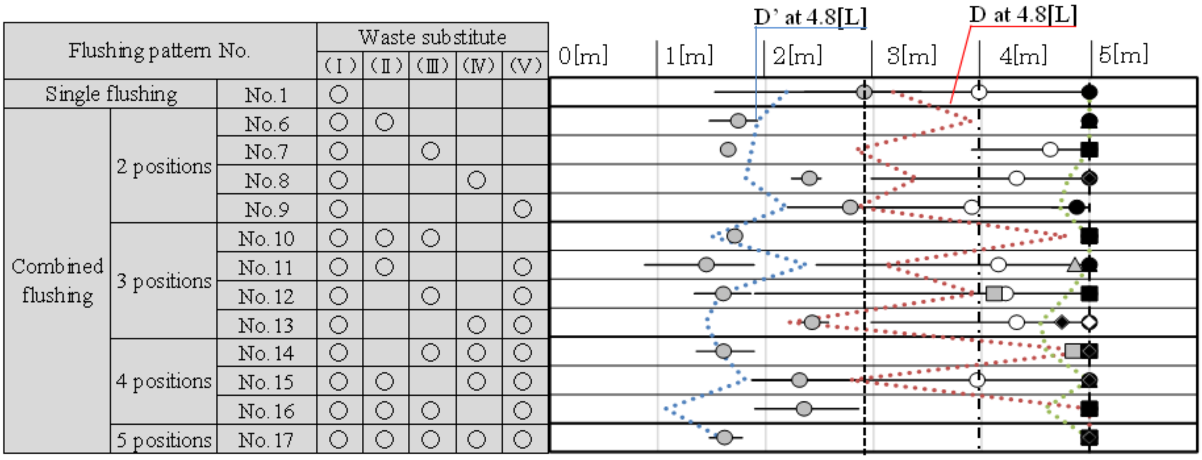
(2) Combined-flush conveyance experiment

Fig. 10 shows various conveyance distances obtained by flushing toilets (I)-(V) in a successive manner to create merged drainage, using different types of waste substitutes. Fig. 10 also includes the average conveyance distance of each waste substitute which was obtained from the single-flush conveyance experiment. Considering that combined-flush wastewater has a larger volume than single-flush wastewater, the conveyance distances of the waste substitutes from the uppermost stream toilet (I) were not necessarily increased by merged drainage in comparison with the conveyance distances of the waste substitutes from the uppermost stream toilet (I), which were measured in the single-flush conveyance experiment. This likelihood was noticeable particularly in the case of the flush with 6.0L of water. This is considered to be because blockage was caused in the horizontal drain branch, as shown in Fig. 11, by each waste substitute which was drained from the upper stream and then stopped by the resistance in the merging section as well as by the backflow from the lower stream.



Flushing pattern No.			Waste substitute				
			(I)	(II)	(III)	(IV)	(V)
Single flushing		No.1	○				
Combined flushing	2 positions	No.6	○	○			
		No.7	○		○		
		No.8	○			○	
		No.9	○				○
	3 positions	No.10	○	○	○		
		No.11	○	○			○
		No.12	○		○		○
		No.13	○			○	○
	4 positions	No.14	○		○	○	○
		No.15	○	○		○	○
		No.16	○	○	○		○
	5 positions	No.17	○	○	○	○	○

(1) 4.8L toilet



Flushing pattern No.			Waste substitute				
			(I)	(II)	(III)	(IV)	(V)
Single flushing		No.1	○				
Combined flushing	2 positions	No.6	○	○			
		No.7	○		○		
		No.8	○			○	
		No.9	○				○
	3 positions	No.10	○	○	○		
		No.11	○	○			○
		No.12	○		○		○
		No.13	○			○	○
	4 positions	No.14	○		○	○	○
		No.15	○	○		○	○
		No.16	○	○	○		○
	5 positions	No.17	○	○	○	○	○

(2) 6.0L toilet

Fig. 10 Conveyance distances and stop positions of waste by combined flushing

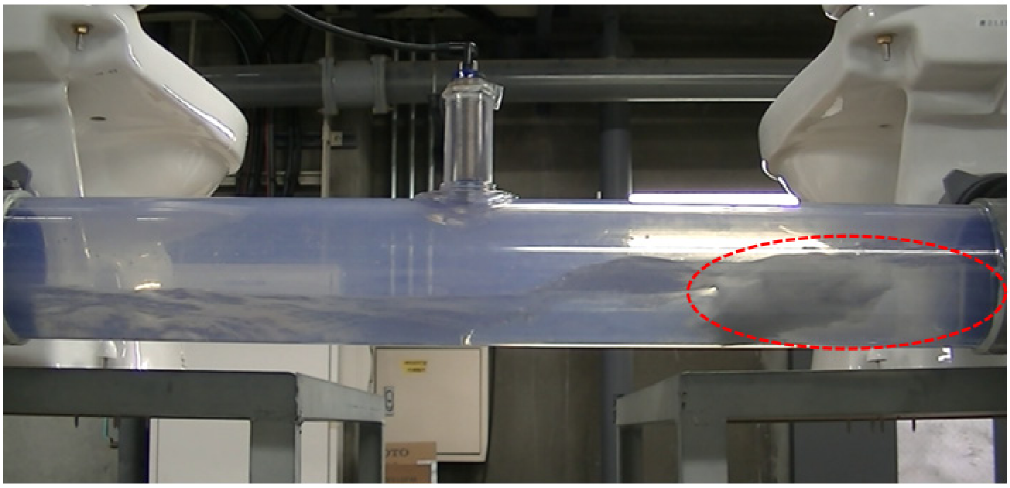
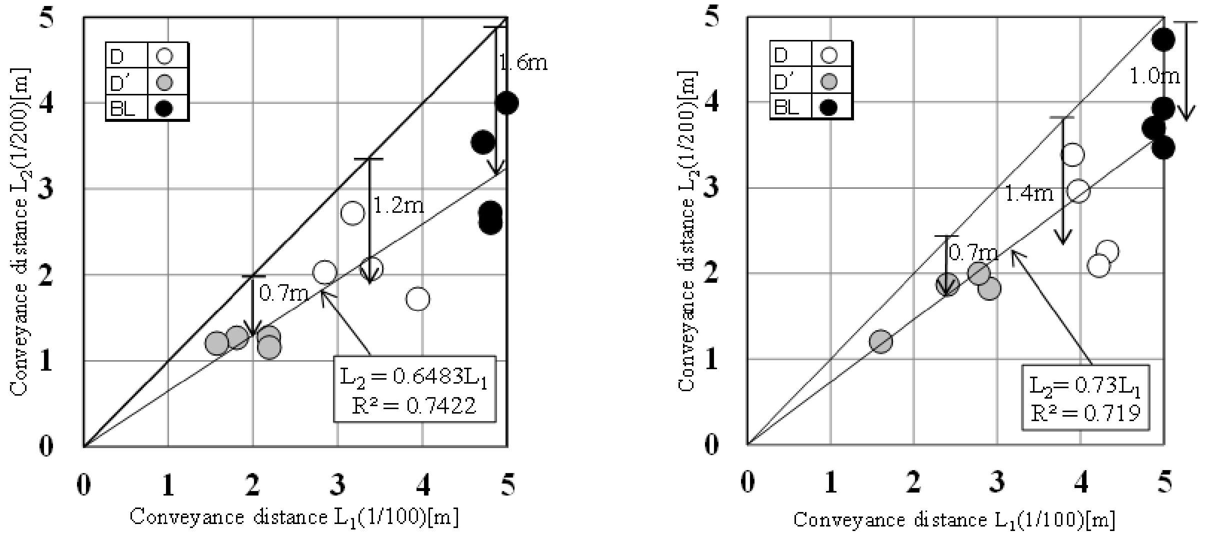


Fig. 11 Blockage by the waste substitute in combined drainage

(3) The influence of the pipe pitch

Fig. 12 compares the conveyance distances which were measured when pipe pitches of 1/200 and 1/100 were used for single flushing. In terms of construction, 1/200 provides a harsher condition than 1/100. In the case of flushing each of the waste substitutes from the uppermost stream toilet (I) with 4.8L of water and at the pipe pitch of 1/200, the conveyance distance of waste substitute D was approx. 1.2m, waste substitute D’ approx. 0.7m, and waste substitute BL approx. 1.6m. On the whole, these conveyance distances were measured to be shorter by approx. 35% than those measured at the pipe pitch of 1/100. In the case of using 6.0L of flush water and the pipe pitch of 1/200, the conveyance distance of D was approx. 1.4m, D’ approx. 0.7m, and BL approx. 1.0m. On the whole, these conveyance distances were measured to be shorter by approx. 30% than those measured at the pipe pitch of 1/100. This suggests that the pipe pitch of 1/200 has an adverse effect on the carrying performance of the horizontal drain branch, and therefore, it is necessary to pay careful attention to pipe pitches when constructing pipework.



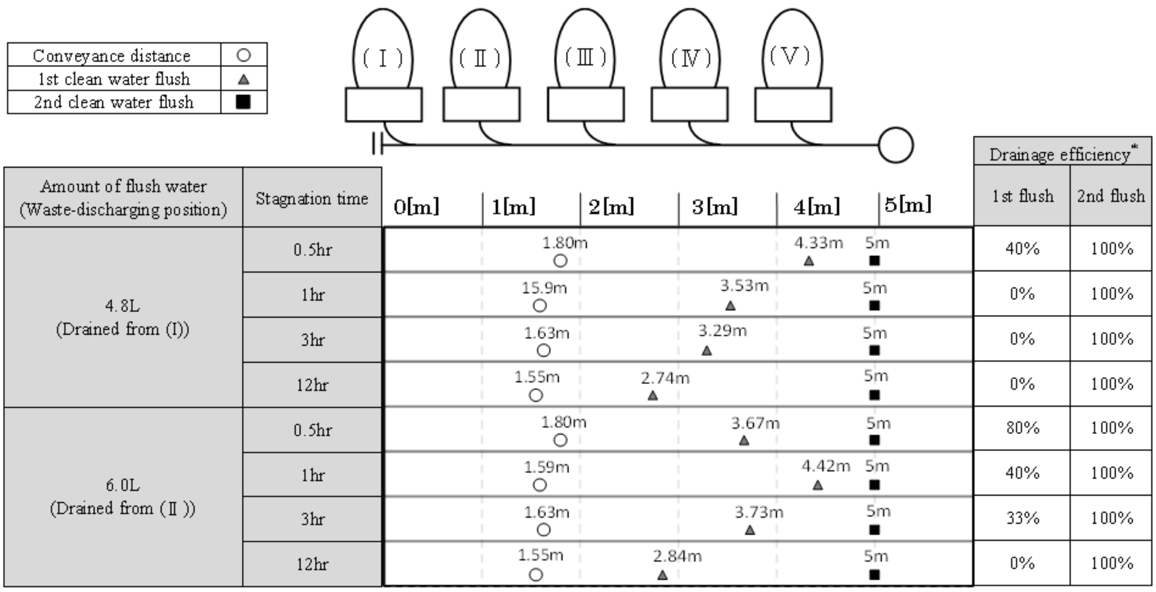
(1) 4.8L (2) 6.0L

Fig. 12 Comparison of conveyance distances by different pipe pitches

(4) The influence of scheduled follow-up flushing

Fig. 13 shows the conveyance distances of the respective waste substitutes, which were measured subsequent to follow-up flushing, with clean water only, from the uppermost stream toilet (I) at different scheduled times. As for the initial flushing, the waste substitutes, which were stopped in the horizontal drain branch by the harshest conditions, using both 4.8L and 6.0L of water, were used. That is, D’ was flushed from the uppermost stream toilet (I) with 4.8L of water, and D’ was also flushed from toilet (II) with 6.0L of water. Follow-up flushing was then performed, using clean water only, from toilet (I). The results are as follows:

Using 4.8L of water, after D’ was flushed and became stagnant for more than one hour, clean water was flushed from toilet (I) once, but failed to carry D’ into the drainage stack. However, when clean water was flushed twice in a row within 12 hours of the stagnant state of D’, D’ was carried 5m into the drainage stack from the uppermost stream of the horizontal drain branch. Using 4.8L of water, when one follow-up flush was applied 0.5 hours or more after D’ became stagnant, the drainage efficiency was 0%, whereas using 6.0L of water, when one follow-up flush was applied even one hour after D’ became stagnant, the drainage efficiency was 40%. Moreover, similar to the case of using 4.8L of water, two consecutive follow-up flushes with 6.0L of clean water from toilet (I) enabled complete draining into the drainage stack from the uppermost stream of the horizontal drain branch, provided that the follow-up flushes were applied within 12 hours of the stagnant state of D’. These results confirm that even when waste stagnates in the horizontal drain branch, two flushes of 4.8L water, i.e., 9.6L, or two flushes of 6.0L water, i.e., 12L, will enable complete draining, provided that the flushes are applied from the uppermost stream toilet within 12 hours after the waste has become stagnant. Consequently, it has become clear that the complete draining of waste in the horizontal drain branch is enabled by scheduled follow-up flushing from the uppermost stream, with approx. 12L of water per day, or by providing the uppermost stream toilet with a large capacity.



Conveyance distance	○
1st clean water flush	▲
2nd clean water flush	■

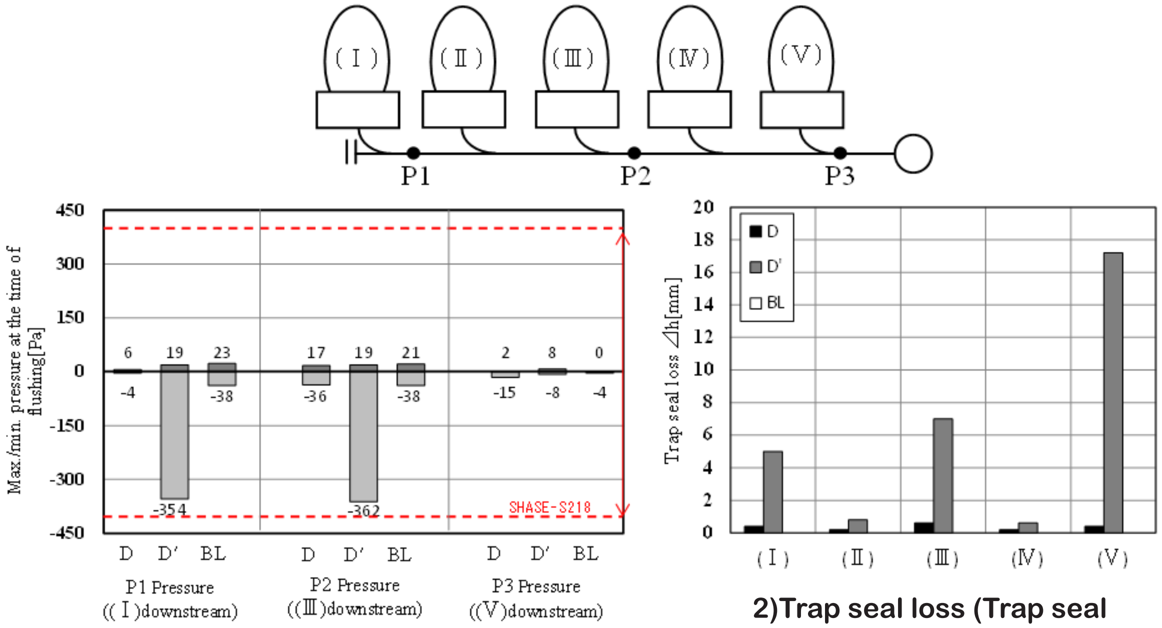
Amount of flush water (Waste-discharging position)	Stagnation time	0[m]	1[m]	2[m]	3[m]	4[m]	5[m]	Drainage efficiency* 1st flush	2nd flush
4.8L (Drained from (I))	0.5hr		1.80m ○			4.33m ▲	5m ■	40%	100%
	1hr		15.9m ○		3.53m ▲		5m ■	0%	100%
	3hr		1.63m ○		3.29m ▲		5m ■	0%	100%
	12hr		1.55m ○	2.74m ▲			5m ■	0%	100%
6.0L (Drained from (Ⅱ))	0.5hr		1.80m ○		3.67m ▲		5m ■	80%	100%
	1hr		1.59m ○			4.42m ▲	5m ■	40%	100%
	3hr		1.63m ○		3.73m ▲		5m ■	33%	100%
	12hr		1.55m ○	2.84m ▲			5m ■	0%	100%

* Drainage efficiency: (No. of conveyances to the stack/No. of flushes) × 100%

Fig. 13 Conveyance results by scheduled follow-up flushing

3.3 The effects of the loop vent pipe

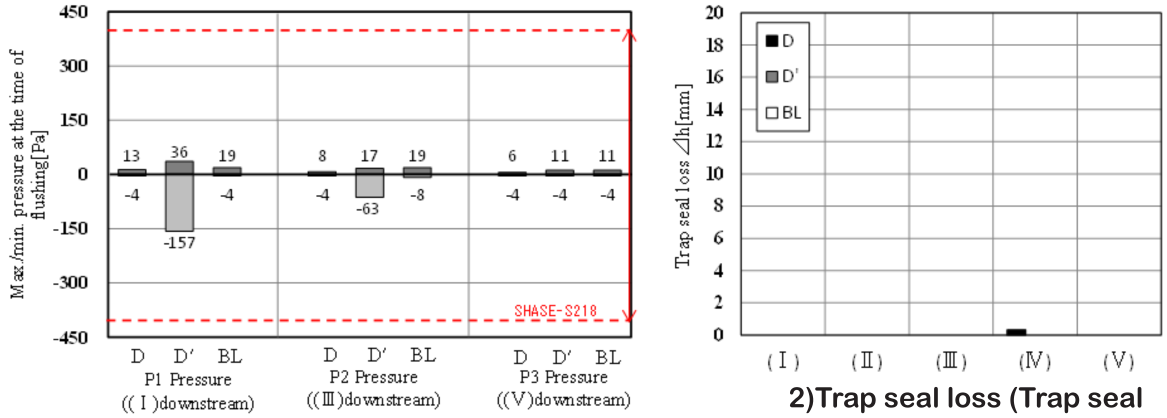
Fig. 14 shows the maximum and minimum values of the pressure in the horizontal drain branch, which were measured at positions P1-P3, and trap seal losses when the five toilets (each containing a waste substitute) were flushed simultaneously (Table 4, No. 17) and the connecting valves between the loop vent pipe and the horizontal drain branch were closed. The maximum negative pressure value was measured to be −362Pa when the connecting valves between the loop vent pipe and the horizontal drain branch were closed, and the value was within the reference range of ±400Pa which is defined by SHASE-S 218. Meanwhile, the maximum trap seal loss value was measured to be 17mm, and there was no breakage. According to the findings from the experiment, there is virtually no need for installing a loop vent pipe in the case of installing five toilets in series, and no trouble will be caused by not having one.



1)Pressure variations in the horizontal drain branch

2)Trap seal loss (Trap seal depth:66mm)

(1) 4.8L



1)Pressure variations in the horizontal drain branch

2)Trap seal loss (Trap seal depth:68mm)

(2) 6.0L

Fig. 14 Pressure variations in the horizontal drain branch and trap seal losses (with the loop vent pipe closed) by successive flushing of five toilets (I)-(V)

4. Conclusion

In this study, the fixture drainage characteristics experiment and the carrying performance experiment were carried out on the serial-type water-saving toilet system using 4.8L and 6.0L of flush water. The following knowledge has been obtained as a result.

(1) Backflows may be caused in the horizontal drain branch, depending on the configuration of the fitting in the inflow section, and therefore, it is necessary to configure and select appropriate fittings that can suppress backflows. Fittings, the configurations of which are problematic to the flow of wastewater, contribute to inferior carrying performance regardless of a large volume of flush water.

(2)Conveyance distances are reduced by 30-35% by changing the pitch of the horizontal drain branch from 1/100 to 1/200.

(3)It is considered that even if waste stagnates in the horizontal drain branch after a single flush, further flushing with 10-12L of water within 12 hours, as a benchmark, will enable the complete draining of the waste. Therefore, scheduled follow-up flushing would be effective.

(4)It is not necessary to install a loop vent pipe for the prevention of induced syphon action in the trap, provided that a water-saving toilet system comprises approx. five toilets which are connected to a horizontal drain branch having a total length of 5m.

5. References

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6. Presentations of Authors

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A Study for Waste Transportability Regarding to Less than 1–liter Toilet

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Abstract

With the further increase of the world population, water becomes increasingly valuable resource. In the world, while the precious lives of about 1.8 million people are lost each year, people are using lots of water to flush toilets as usual. In addition, due to a big amount of waste water drain, the sewage treatment tank can not correspond. Then that leads to further drinking water pollution. We’d like to introduce an example of a saving water toilet system without sacrificing the comfort of using a conventional toilet. Then it also can contribute to both the suppression of water pollution and securing water resources. Since we introduced the toilet system for apartments at 40th CIB W062, we have studied to reduce constraints of the piping for adjusting it to similar normal plumbing conditions. This time, we will inform you the system outline and the system evaluation results in the waste transportability in the gravity piping for detached houses and apartments. We have confirmed that the gradient of 1/30 is ideal for the fixture drain pipe of diameter of 100mm. The twice repetition of urinal flush can push the waste up to 9.5m. The total bends can be installed up to 8 in the fixture drain pipe. The gradient of 1/100 is ideal for the horizontal drain pipe of diameter of 100mm. The shower gray water can push the stuck waste up to 24m in the horizontal drain pipe. The total bends can be installed up to 5 in the horizontal drain pipe.

Keywords

1-liter toilet, Fixture drain, Horizontal main pipe, Gray water, Transportability

1. Introduction

With the further increase of the world population, the world water consumption is increasing, even though the world water resource is limited. According to one report, as a result the amount of water consumption in 1950-1995 has increased by 2.74 times, it is higher than the population growth (about 2.25% per a year) over the same period of time. The usage of domestic water in particular has been rapidly increasing 6.76 times. It has been reported (Reference 1) that the predicted water usage in 2025 will be 1.37 times that of 1995, and will be 1.83-fold for domestic water. In developing countries cities, while some people are using lots of water to flush toilets as usual, water can not be supplied to all who need. People have to prepare for water outage which occurs frequently. Hereafter, with the explosive cities population growth, absolute water scarcity is predicted easily. In addition, although septic tanks are major as waste water treatment, most of the tanks can not correspond due to a big amount of waste water drain as a result of the short hydraulic retention time. Thus that leads to further pollution of rivers, ponds, lakes, including available freshwater sources.

We introduced the toilet system for apartments as shown in Figure 1 that can contribute to both the suppression of water pollution and securing water resource at 40th CIB W062 (Reference 2). The piping constraints for fixture drain and horizontal pipe are unusual gradient and would be barriers to system installation. So we have studied to reduce constraints of the piping for adjusting it to similar normal plumbing conditions. This time, we will inform you the system outline and the system evaluation results in the waste transportability in the gravity piping for detached houses and apartments.

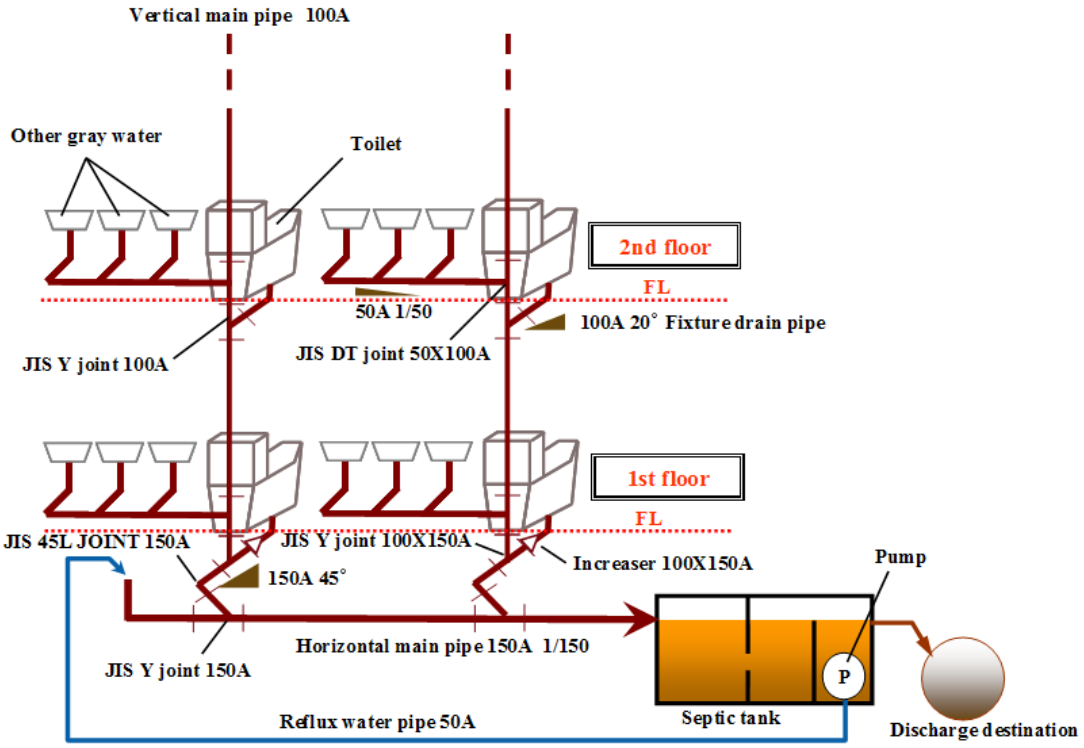
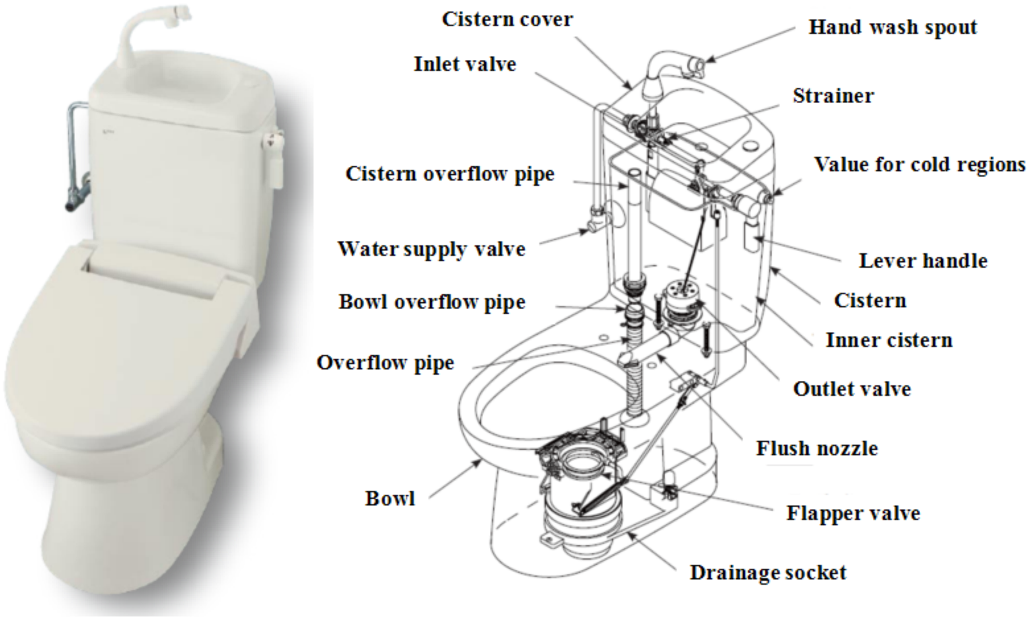


Figure 1 - Structure of the toilet system

2. Structure of the Less than 1–liter Toilet System

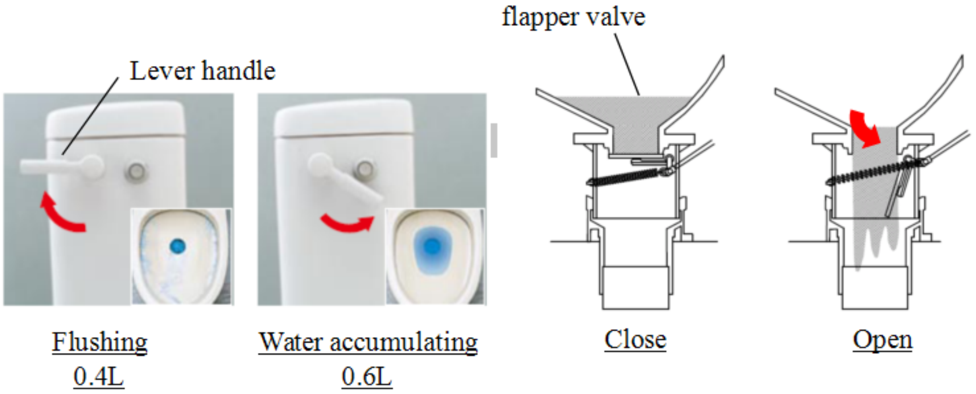
2.1 Less than 1–liter toilet

This toilet is conventional on the rural area in Japan and similar in outer appearance to the conventional Gravity Feed toilet. However, it doesn’t have a trap water seal but a flapper valve under the bowl. Figure 2 shows the toilet structure. For having a much bigger cistern than the flushing water volume, several toilet flushing can be done during the water outage.



(1) Appearance

(2) Internal structure



(3) Lever handle operation mode

(4) Flapper valve operation

Figure 2- Structure of the toilet

Flushing progresses as follows:

1) The outlet valve in the cistern opens to accumulate the bowl water by operating lever handle in the opposite direction to flushing before using toilet. (0.6L)

2) The outlet valve in the cistern and the flapper valve under the bowl open to discharge the waste by operating lever handle to flush. (0.4L)

3) The flush water stocked in the nozzle falls into the bowl and turns to the shallow water seal on the flapper valve.

Average drainage flow rate qd and maximum flow late of the toilet was much lower than the conventional toilet because its flushing water is extremely small. Drainage time was equivalent to the conventional toilet. Figure 3 shows a result in drainage flow rate and a discharged volume of the toilet. Table 1 shows its property. (Reference 3)

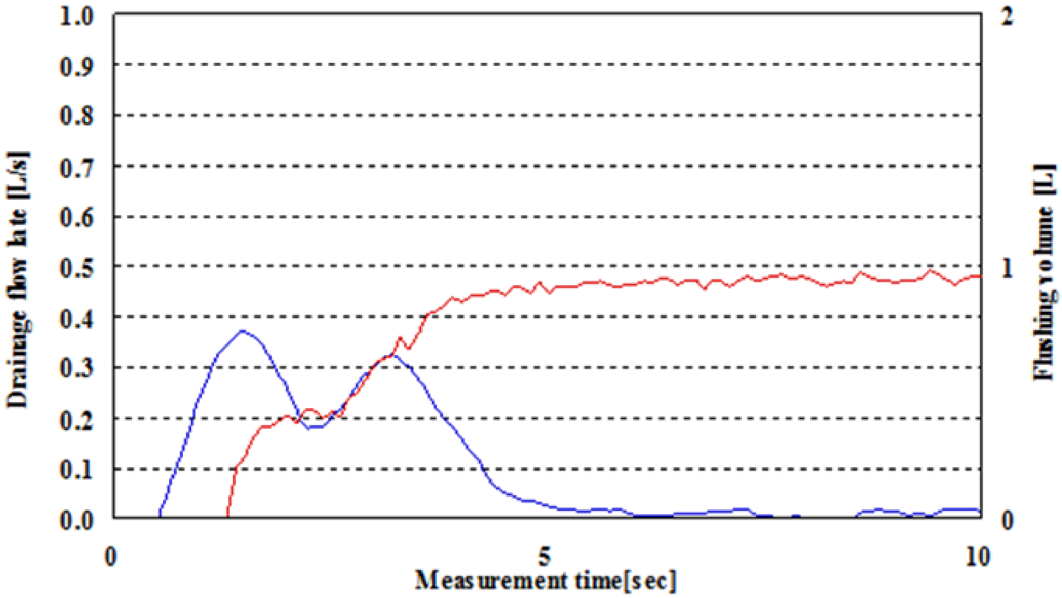
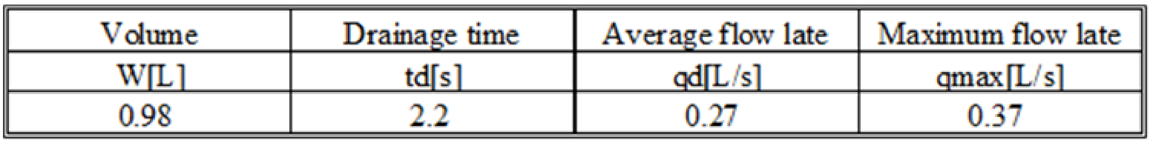


Figure 3 - Diagram of the drainage flow rate and the flushing volume

Table 1 - Property of the toilet



Volume	Drainage time	Average flow late	Maximum flow late
W[L]	td[s]	qd[L/s]	qmax[L/s]
0.98	2.2	0.27	0.37

2.2 System outline

In case of bungalow, toilet connects to the horizontal pipe through the fixture drain pipe that has 1/30 in gradient. The horizontal pipe connects to the septic tank or the sewage line. (Figure 4) In case of maisonette, ground floor toilet connects to the horizontal pipe through the fixture drain pipe that has 1/30 in gradient. 1st floor toilet connects to the vertical pipe directly through the fixture drain pipe that has 1/30 in gradient. The vertical pipe connects to the horizontal pipe. The horizontal pipe connects to the septic tank or the sewage line. (Figure 5) In case of apartment, ground floor toilet connects to the horizontal pipe through the fixture drain pipe that has 1/30 in gradient. Each toilet above the ground floor connects to the vertical pipe through the fixture drain pipe that has 1/30 in gradient. The vertical pipe connects to the horizontal pipe. The horizontal pipe connects to the horizontal main pipe that connects to the septic tank. The reflux water pipe connects to the most upstream of the horizontal main pipe and the pump that is installed in the septic tank. The waste discharged from the each floor toilet flows into the vertical main pipe through the fixture drain pipe. Then, it falls through the vertical main pipe and horizontal pipe and stays in the horizontal main pipe.

Next, the treated water (reflux water) in the septic tank is transferred to the most upstream of the horizontal main pipe by the pump. Finally, the waste can be transported to the septic tank through the horizontal main pipe. The reflux water flows at a frequency of once every 15 minutes. Figure 6 shows the system structure.

The verification method and results of the appropriateness of this specification is shown in the next chapter.

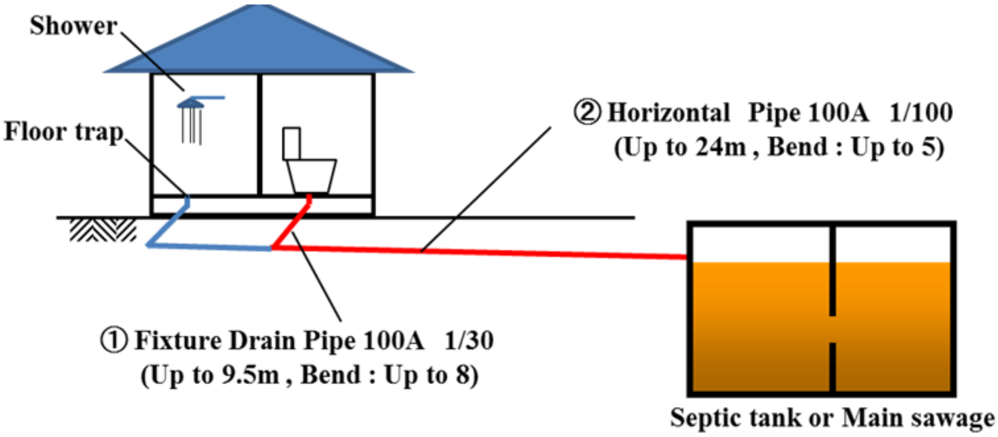


Figure 4 - System outline for bungalow

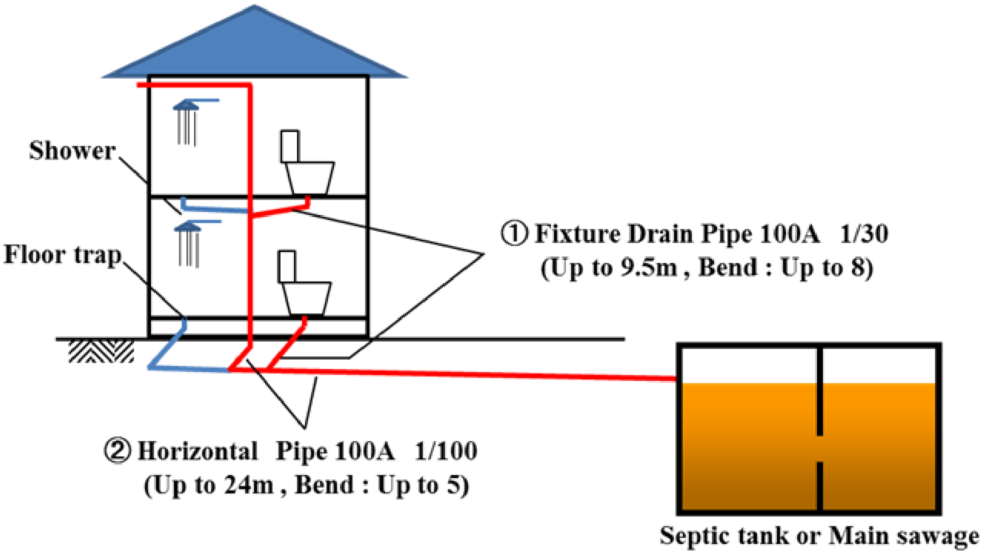


Figure 5- System outline for maisonnette

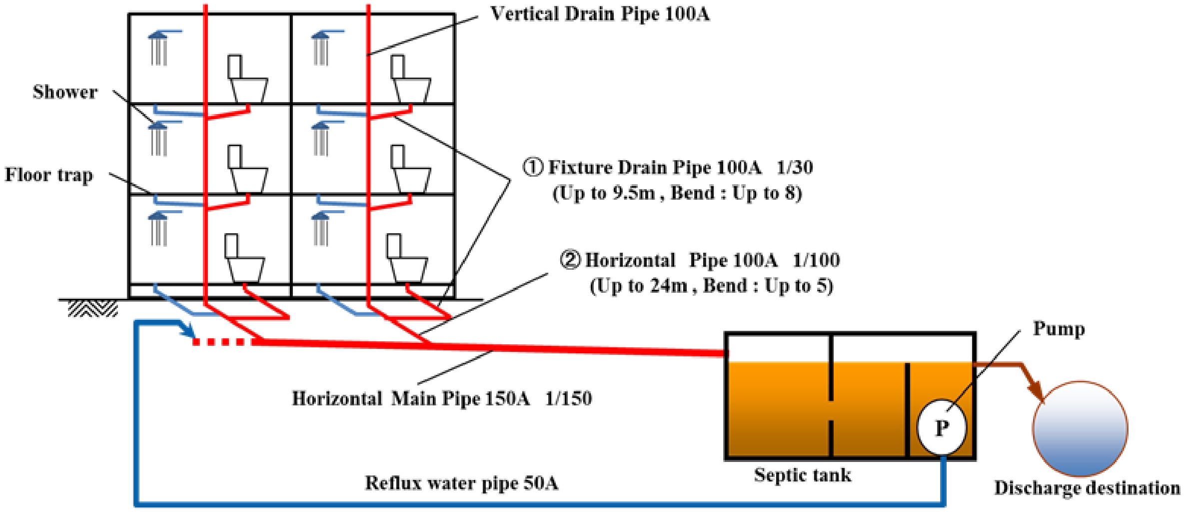


Figure 6 - System outline for apartment

3. Summary of the Methods of Experimentation

We confirmed the waste transportability in the fixture drain and the horizontal pipe. In order to clarify that this system has sufficient waste discharging performance, we tried to evaluate for the following items.

1. The waste transportability in the fixture drain.
2. The influence of gray water for the waste transportability in the horizontal pipe.

First, the temporary premise of those tests are shown as follows.
We have been concerned about the importance of the transportability of water saving toilets since 2005. In this process, it has become clear what is about more actual transportation of the solid waste, and we will explain about that below.
The first flush transports the solid waste for a certain distance, and then it stops. The following second flush transports the next one in the same way, and then it stops too. However, the second flush water pushes the stagnant water which remains after the first solid waste, then the first solid waste begins to move again before overlapping into each other. This behavior is reproduced every consecutive flush. It is a kind of chain-reaction, or figuratively speaking, it looks like the clash of billiard-balls, as shown in Figure 7. What is important here is that all solid wastes are neither clashed nor overlapped each other.
This attitude is based on the results of numerous repeated experiments, and suggests the more actual index of the transportability than the conventional one which evaluates only single full flush transportation. It brings us a change of perspective.
This attitude shows that it is not a problem even if the first flush could not transport the solid waste completely. The next flush could transport it enough.

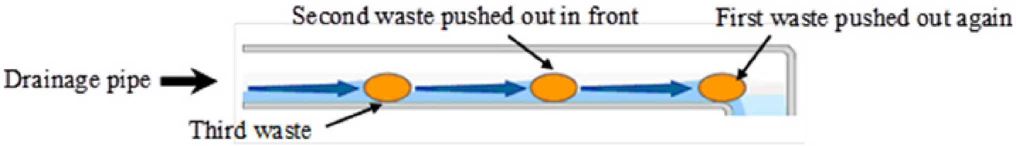


Figure 7 - The behavior of the consecutive flushes with solid wastes

On the other hand, the toilet use patterns based on usual lifestyle patterns of standard families are also concerned. For example, the full flush with solid waste is used at least 4 times a day and the urinal flush with only liquid waste is used at least 12 times a day, per family. Assuming there is no concern about the solid waste transportability in repetition as described above, we think it is important to confirm how long the following urinal flush, which is done frequently like above-mentioned example, can transport the resting billiard-ball, the stucked solid waste of the previous full flush. If the following urinal flush transports the previous solid waste by sufficient distance, we will not have to worry about pipe clogging. In addition, we have assumed that other gray water that has merged transports the solid waste in the horizontal pipe.
As test media of transportation experiment, we used 6-ply of JIS P 4501 (Reference 4)standard toilet paper (single type). Each ply is 1 meter's worth which was folded 4 times into a sheet of paper with a total length of 125[mm]. The paper was laid on the water surface in a stacked flat as shown in Figure 8 - 9. After soaked in water for 15 seconds, drainage was performed. As shown in Figure 10, we have measured the distance between the core of the vertical pipe and the tail of the stagnant test media as the transportation distance. The interval of time between full flush and following urinal flush was 700 seconds which is average interval of drainage equipment in housing by SHASE-S206. (Reference 5)

Figure 8 - Papers laid in a stacked flat

Figure 9 - Papers laid in a stacked flat

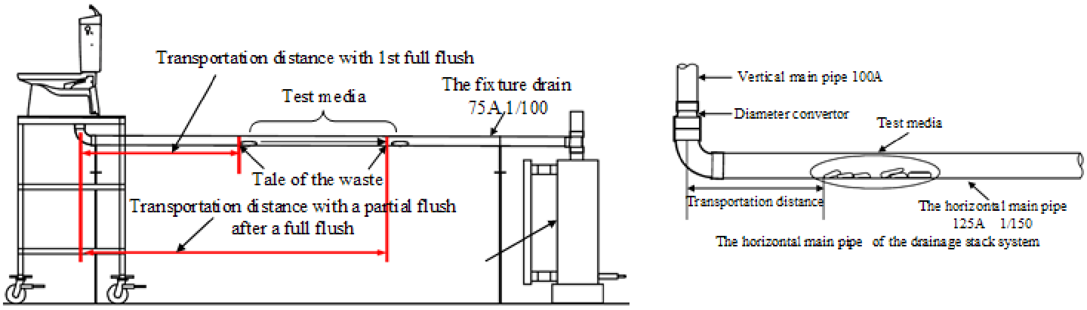


Figure 10 - Method for measuring the transportation distance

3-1) Measurements of waste transportability in the fixture drain
In order to confirm the transportability, we conducted drainage experiments by using an experiment building in Kanto-Gakuin University. The experimental equipment of the fixture drain pipe constructed from rigid PVC pipe which is 100 [mm] in diameters and options of 1/30, 1/50, 1/100 in gradient, the 1m pipes connected each other were placed straight up to 9.5m in length (system 1). And the pipes connected by 90 ° L at intervals of 1m, were placed horizontally in a zigzag up to 11.75m in length (system 2). Three pieces of T-joints (① ～ ③) were put in the each systems as shown in Figure 11-12. We evaluated the drainage transportability of single full flush and the effect of urinal flush after full flush for transportability. The transport evaluation was repeated two times for each.

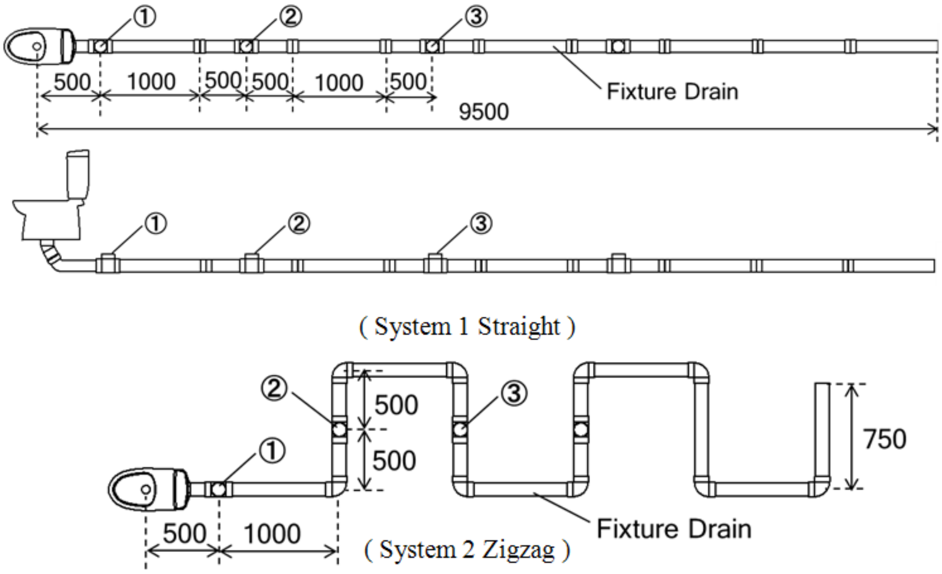


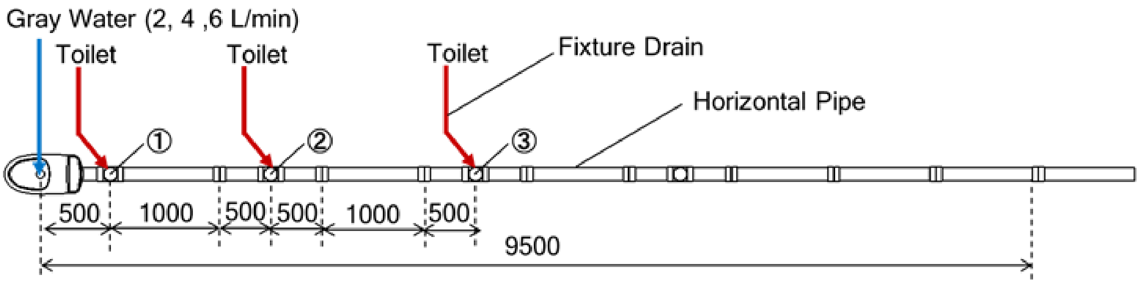
Figure 11 - Equipment to measure the drainage transportability

(System 1 Straight) (System 2 Zigzag)

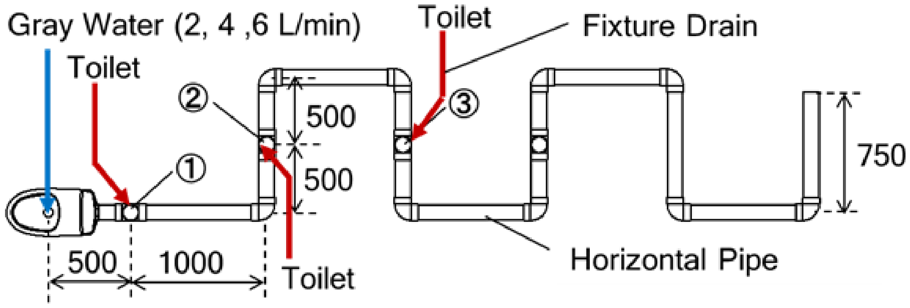
Figure 12 - Picture of equipment to measure the drainage transportability

3-2) Measurements of the influence of gray water for the waste transportability in the horizontal main pipe

In order to confirm how the gray water effects the waste transportability in the horizontal pipe. We conducted drainage experiments by using the same equipment shown in Figure 11-12 and assumed that each toilet fixture drain connects to horizontal pipe at each T-joint (①~③) and the waste stays there, the gray water from the most upstream toilet kept the flapper valve opened can push the stuck waste in the T-joint. The experimental equipment of the horizontal pipe constructed from rigid PVC pipe which is 100 [mm] in diameters and 1/100 of gradient. The test media was placed in a pair of T-joint (① + ② or ① + ③) in advance on each examination as shown in figure 13. We evaluated the drainage transportability in case of each flow rate of gray water (2, 4, 6L/min). The transport evaluation was repeated two times each.



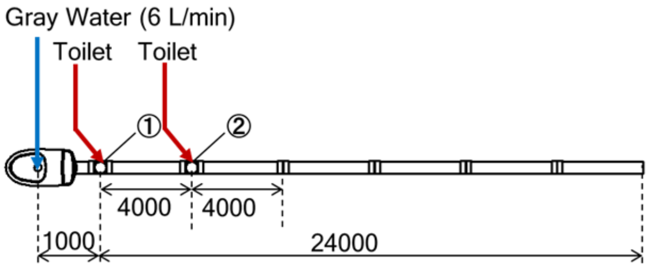
(System 1 Straight Gradient 1/100)



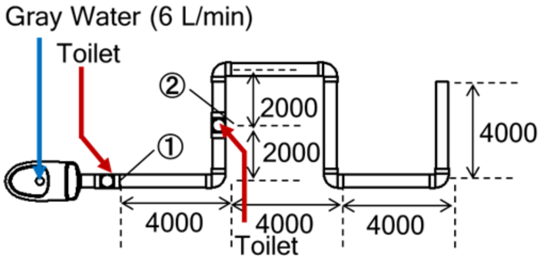
(System 2 Zigzag Gradient 1/100)

Figure 13 - Equipment to measure the transportability in the horizontal pipe

In optimal gradient (1/100) and flow rate of gray water (6L/min) obtained in the above test equipment, an extra experiment was performed to extended piping length as shown Figure 14-15. The 4m pipes connecting each other were placed straight up to 24m in length (system 3). And the pipes connected by 90 ° L at intervals of 4m, were placed horizontally in a zigzag up to 24m in length (system 4). The test media was placed in a T-joint (①) and a pair of T-joints (① + ②) in advance on each examination.



(System 3 Straight 1/100)



(System 4 Zigzag 1/100)

Figure 14 - Extra equipment to measure the transportability in the horizontal pipe

Figure 15 - Picture of extra equipment to measure the drainage transportability

4. Results and Consideration

4-1) The waste transportability in the fixture drain

Figure 16 and 17 shows the distance with urinal repeat flush after a full flush. It was confirmed that urinal repeat flush after a full flush extremely encouraged the transportation distance in the gradient of 1/30. In case of the gradient of 1/30, the repetition of twice urinal flush can push the waste up to 9.5m (system 1), 11.75m (system 2). So gradient of 1/30 and bends of up to 8 were chosen in the fixture drain pipe.

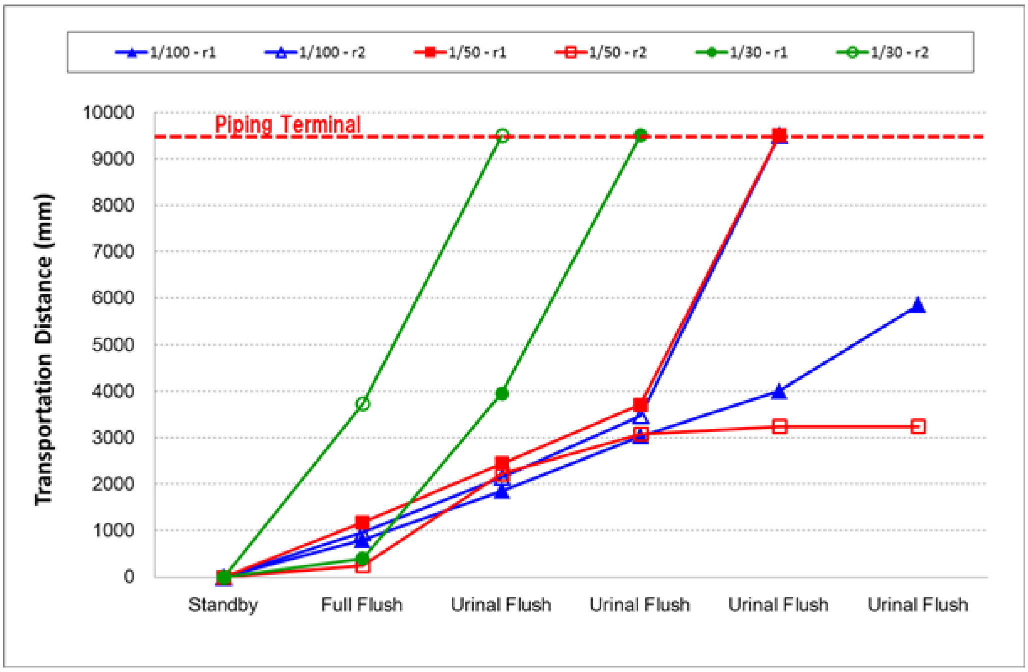


Figure 16 - Transported distance with an urinal flush after a full flush (Sys 1)

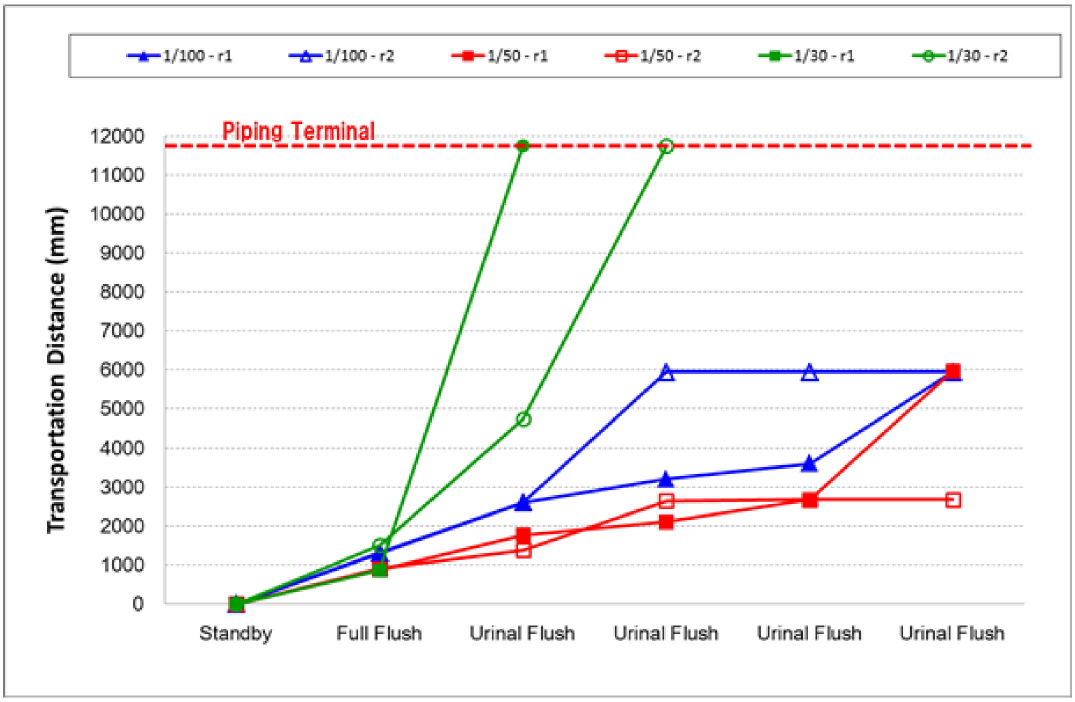


Figure 17 - Transported distance with an urinal flush after a full flush (Sys 2)

4-2) The influence of gray water for the waste transportability in the horizontal main pipe
Figure 18 - 21 shows the distance at which other gray water can push the stuck waste. It was confirmed that 6L/min of gray water extremely encouraged the transportation distance. In case of the flow rate of 6L/min , the gray water can push the waste up to 9.5m within 300sec (system 1: ① + ② , ① + ③), to 11.75m within 120sec (system 2 : ① + ② , ① + ③).

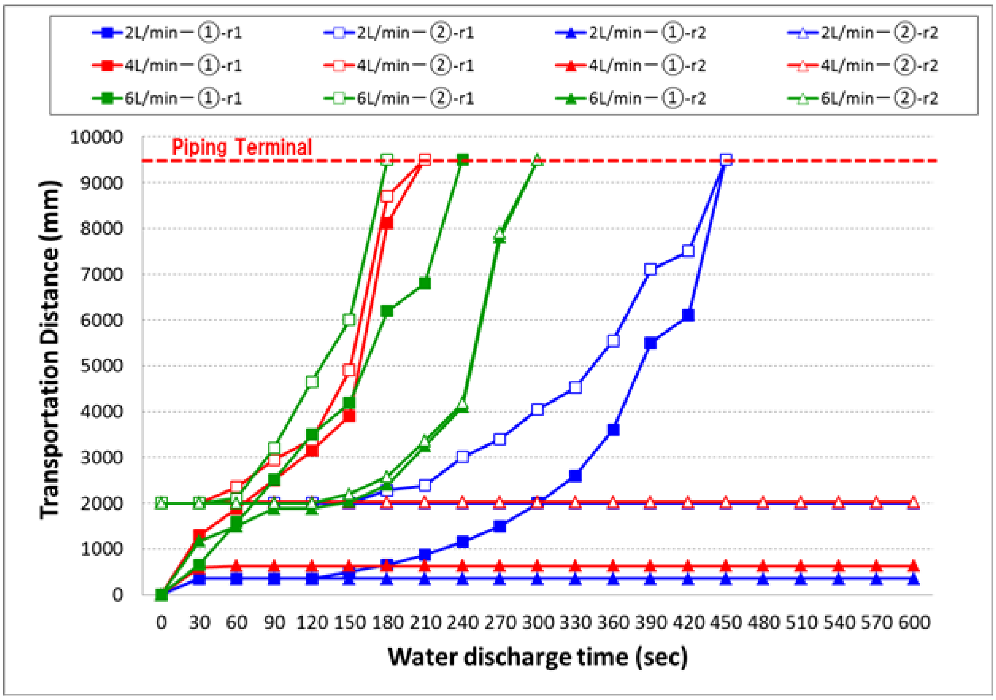


Figure 18 - Transported distance with gray water (Sys 1, ① + ②)

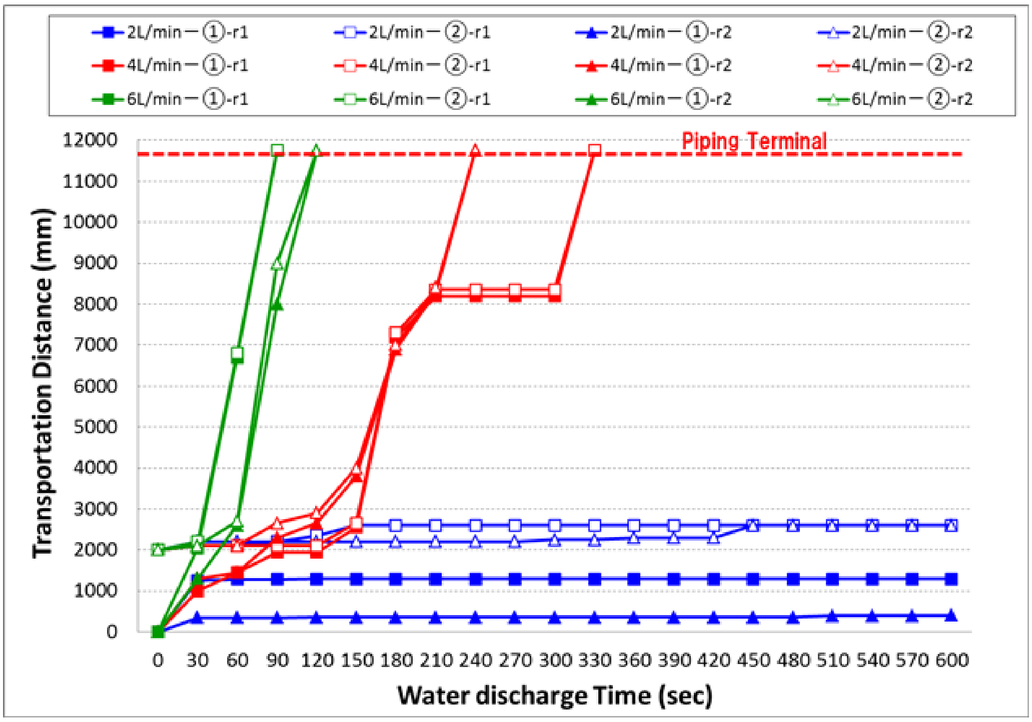


Figure 19 - Transported distance with gray water (Sys 2, ① + ②)

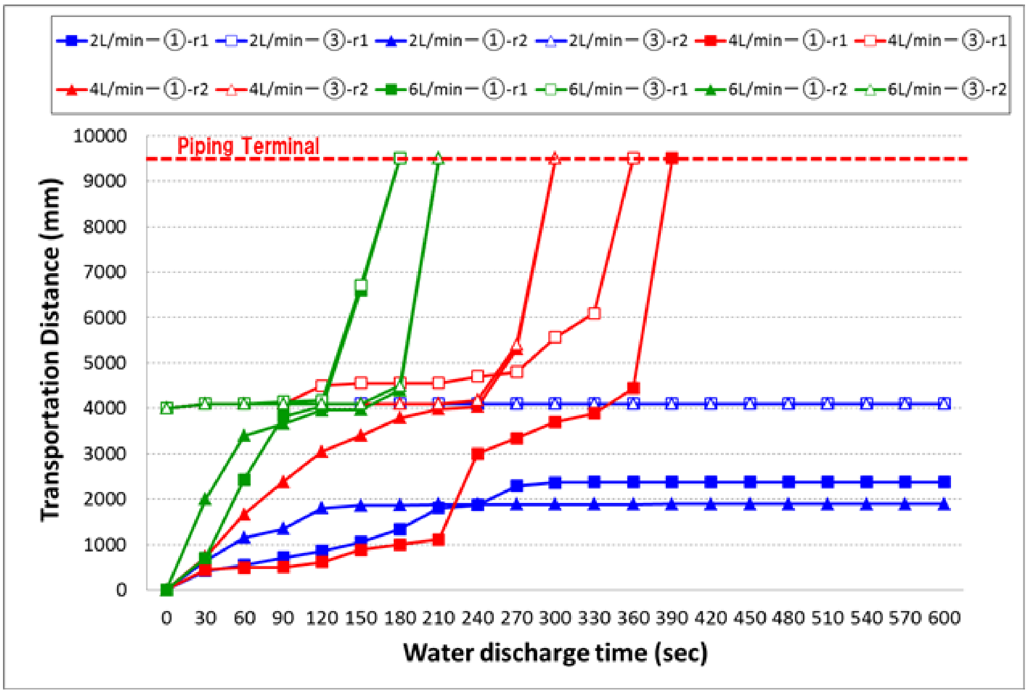


Figure 20 - Transported distance with gray water (Sys 1, ① + ③)

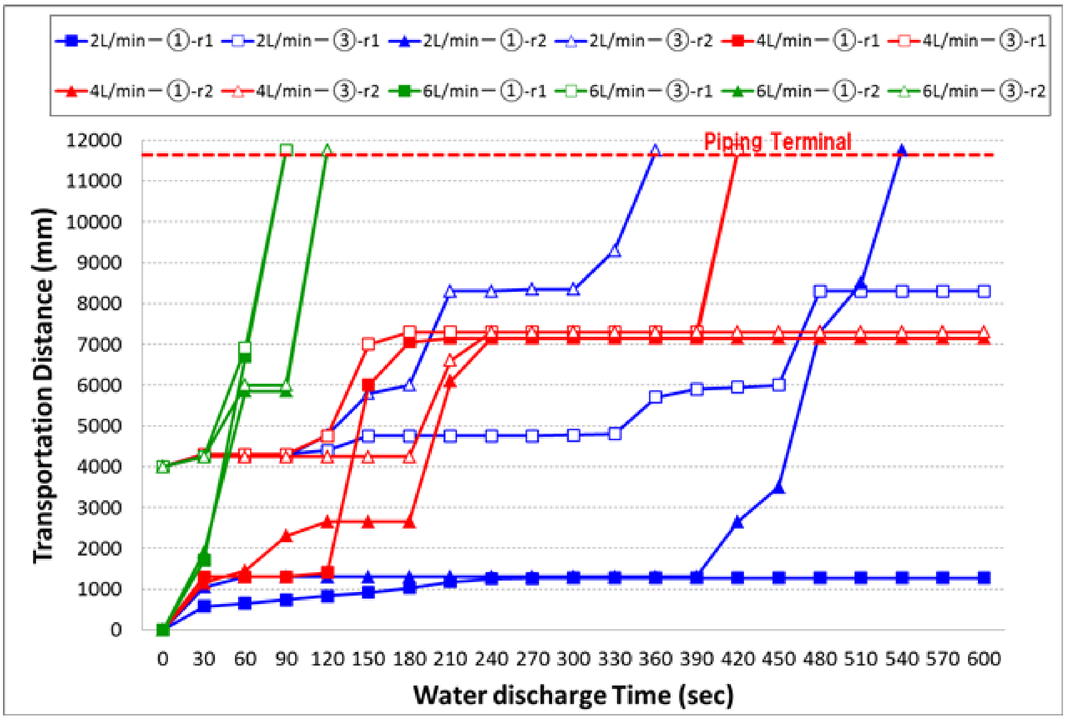


Figure 21 - Transported distance with gray water (Sys 2, ① + ③)

While water-saving of the shower is progressing worldwide, the minimum flow rate has been reported (References 6,7) to be approximately 6L / min. In addition, shower time of use has been reported (Reference 8) to be an average of 6-7 minutes. So it was confirmed that the confluence of the shower drainage of flow rate of 6L/min encourages the waste transportability.

In case of extra equipment, Figure 22 - 25 shows the distance at which other gray water can push the stuck waste. It was confirmed that 6L/min of gray water extremely encouraged the transportation distance. In case of the single waste at the point of ① , the gray water (6L/min) can push the waste up to 24m within 150sec (system 3), 240sec (system 4).

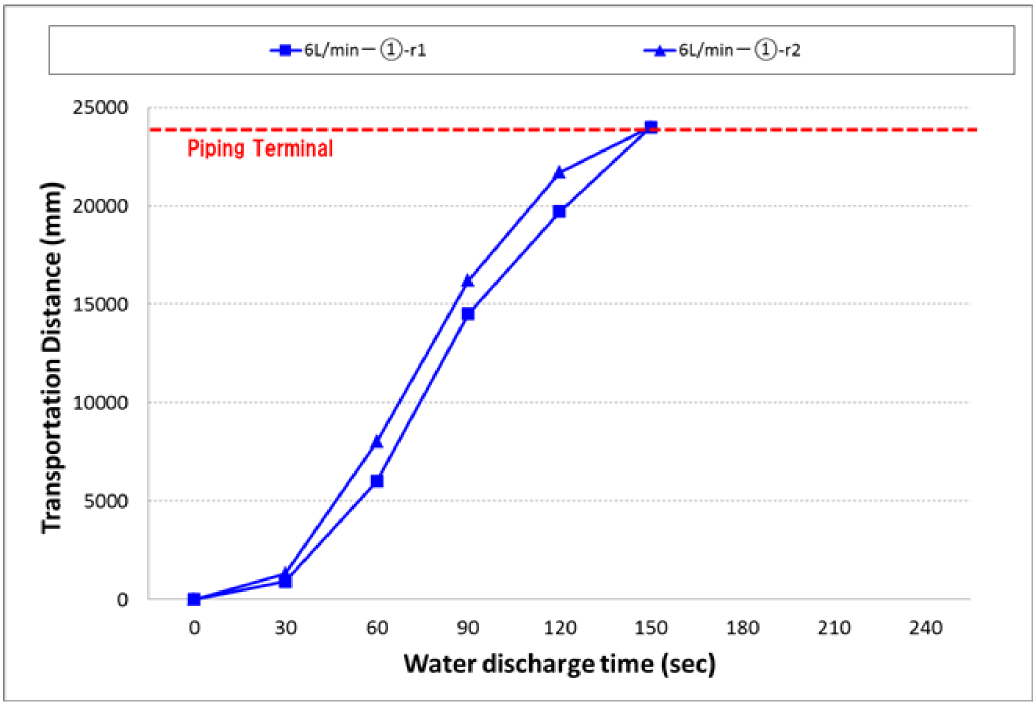


Figure 22 - Transported distance with gray water (Sys 3, ①)

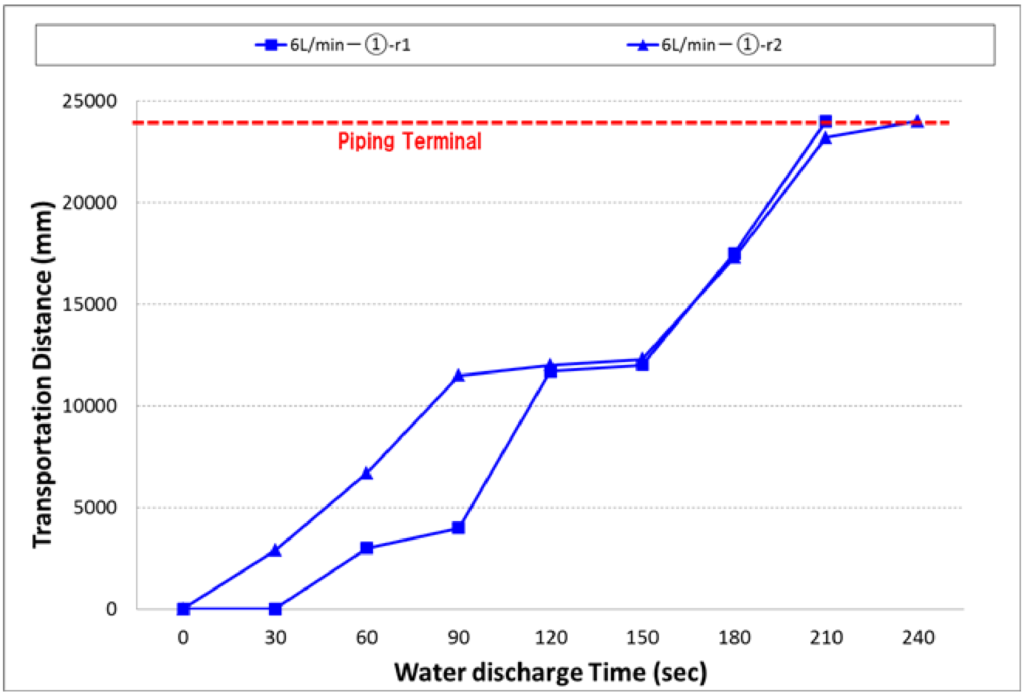


Figure 23 -Transported distance with gray water (Sys 4, ①)

In case of the dual waste at the point of ① + ② , the gray water (6L/min) can push the waste up to 24m within 210sec (system 3), 240sec (system 4). In case of Zigzag piping, same results were found between single and dual waste. The waste transportability on the downstream side is controlled to the movement of the waste on the upstream side. When the waste on the upstream side reaches the waste on the downstream side, those can move together to the downstream in the pipe.

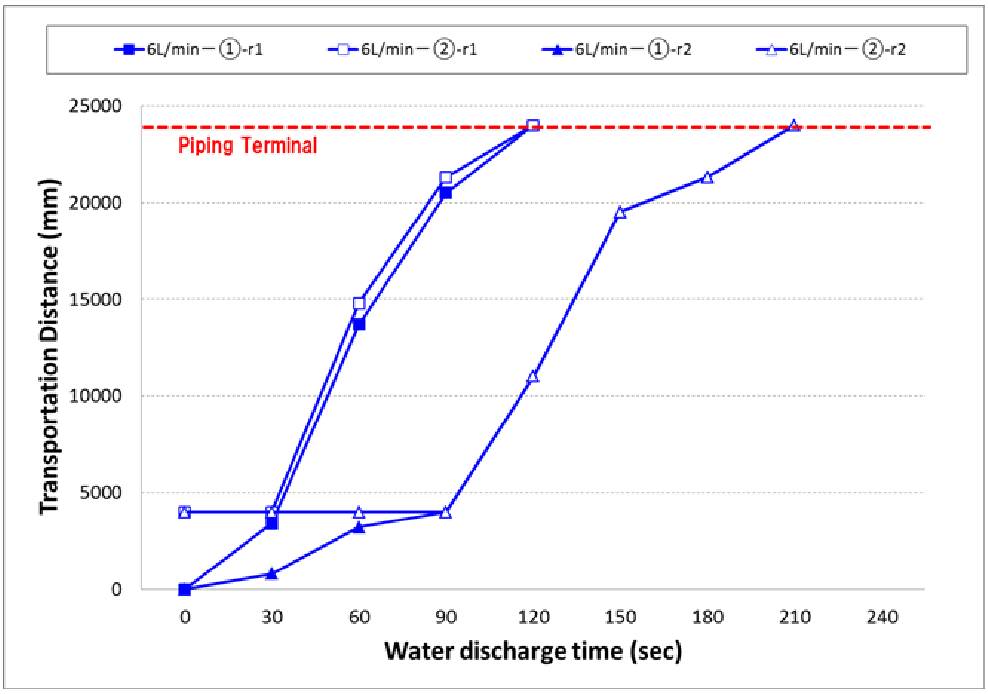


Figure 24 - Transported distance with gray water (Sys 3, ① + ②)

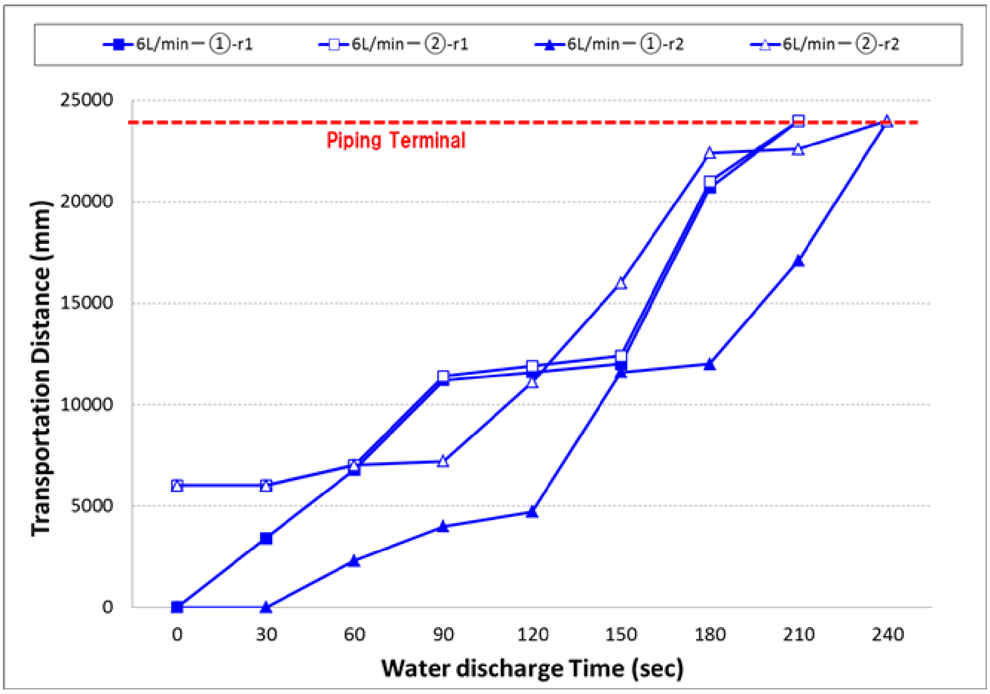


Figure 25- Transported distance with gray water (Sys 4, ① + ②)

Figure 26 – 27 shows summarized results of dual waste transportation. In the straight piping, the large variation was found. It was considered that the unstable water overtaking of the waste in the pipe causes the variation. On the other hand, the trend of transportation performance was stable in the Zigzag piping. It was also considered that the waste stuck at the bend disturbs the overtaking of water, the reservoir water behind the waste can push the waste enough.

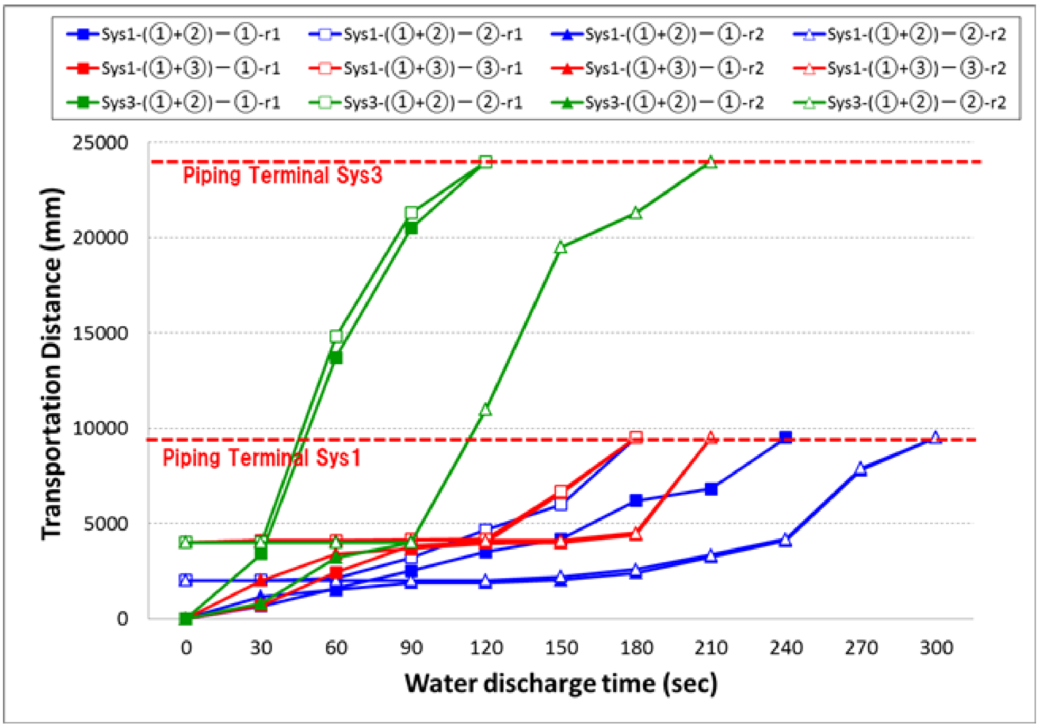


Figure 26 - Comparison of transported distance with gray water (Straight)

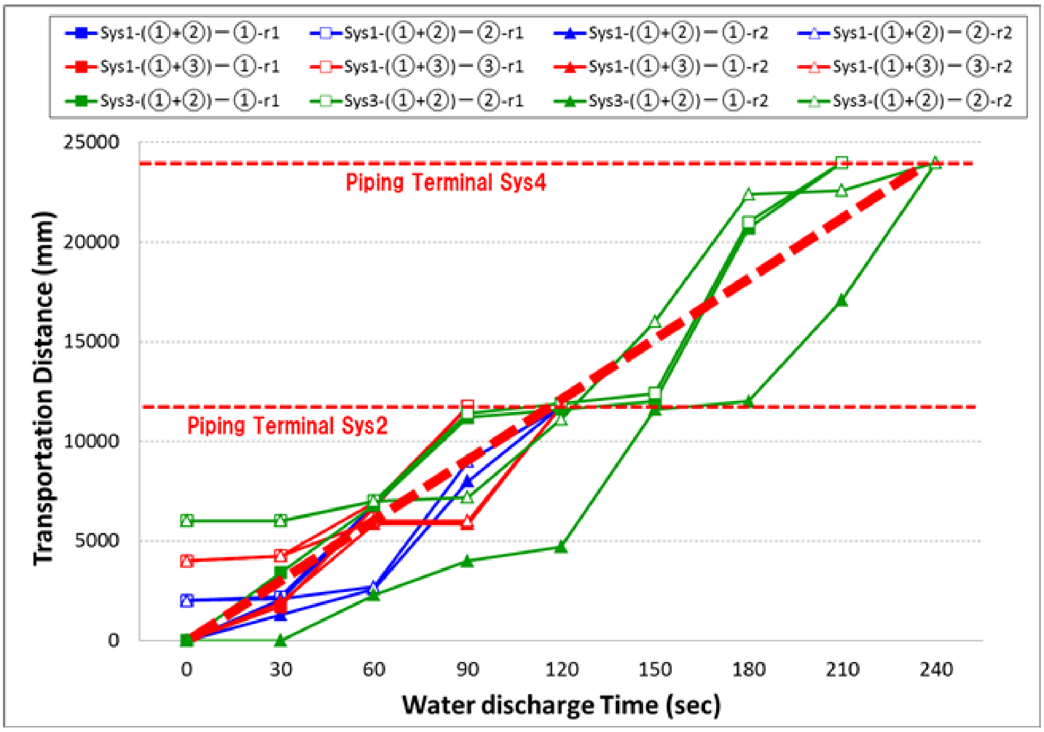


Figure 27 - Comparison of transported distance with gray water (Zigzag)

Considering the above results and safety, while comparing to the table 2, we have selected the specification of the equipment 3 and 4.

Table 2 - Comparison for Equipment of 1/100 gradient

Equipment	Pipe Length	Bends	System	Diameter	Gradient	Gray Water Flow Rate
	m	pieces		mm		L/min
1	9.5	0	1 Straght	100	1/100	6
2	11.75	9	2 Zigzag	100	1/100	6
3	24	0	1 Straght	100	1/100	6
4	24	5	2 Zigzag	100	1/100	6

5. Conclusions

We confirmed the following results about the waste transportability regarding to less than 1-liter toilet in the gravity piping.

1) It was confirmed that urinal repeat flush after a full flush extremely encouraged the transportation distance.
The gradient of 1/30 is ideal for the fixture drain pipe of diameter of 100mm. The twice repetition of urinal flush can push the waste up to 9.5m. The total bends can be installed up to 8 in the fixture drain pipe.

2) It was confirmed that 6L/min of gray water extremely encouraged the transportation distance.
The gradient of 1/100 is ideal for the horizontal drain pipe of diameter of 100mm. The shower gray water can push the stuck waste up to 24m in the horizontal drain pipe. The total bends can be installed up to 5 in the horizontal drain pipe.

According to those results, the parts of the availabilities of the system have been verified. Hereafter, we will verify the backflow of the sewage odor through the toilet flapper valve because the toilet doesn’t have continual water seal trap.

6. References

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Temperature Fluctuations in Shower Mixing Valves

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Abstract

Temperature fluctuation of mixing water is a well-known phenomenon in large commercial buildings and residential buildings. Rapidly fluctuating temperatures in a shower often result in frustration and confusion. This study tries to identify the temperature fluctuations in the shower head and the cause of temperature fluctuations are generated in water systems. The final goal is to determine some guidelines for technicians to avoid the temperature fluctuations. The building used for the investigation is equipped with a cold water supply and pressure system located in the basement. The hot water production contains a storage vessel located on top of the building and the hot water is distributed by a circulation pipe system. The shower mixing valve is connected to both the cold and hot water systems. Although the fluctuations have a small difference in water temperature and the exposure time is very short the sudden fluctuating temperatures are very inconvenient for the users because they fear for thermal shock and scald burns. In many cases people complain about the temperature fluctuations, but the technician is unfamiliar with the phenomenon and doesn’t know how to solve and prevent this problem.

Keywords

Shower mixing valves, Thermostatic shower mixing valves, Temperature fluctuations

1. Introduction

Motivated by the demand for hygienic water systems there is an increasing trend to design water systems with smaller pipe diameters. This is the result of a new, more realistic method to determine the water demand for hot and cold water. Moreover, water saving showers are widely used in buildings and they also contribute to the trend of smaller pipe diameters.

In large and more complicated buildings, for instance in hotels, hospitals and retirement homes, the water supply system is applied with many faucets. These faucets vary in design flow rates. The cold water used elsewhere in the building causes a pressure drop in the cold water system. The hot water system pressure remains relatively constant resulting in a change of the hot to cold water ratio and thus the temperature of the shower changes and becomes hot. The opposite happens when the usage of hot water is increased – the hot water pressure drops and there is a corresponding change in the mixed water ratio causing a burst of cold water. This sudden change in temperature at the showerhead is referred as thermal shock. One risk of thermal shock is that it may cause the affected user to react suddenly, resulting in a slip-and-fall incident. When persons using the shower fall as a result of a thermal shock, it is common for them to hit or grab the shower controls on their way down possibly turning the controls to hot and causing a scalding injury. In some extreme cases the person is seriously injured by the fall and cannot get out of the flow of hot water.

During the investigations it appeared that the cause for the temperature fluctuations is a complex problem, influenced by many parameters. This paper is a preliminary report. The study will be continued.

2. Complaints about Temperature Fluctuations are Well−known

Complaints about temperature fluctuations are well-known. For many years users of shower mixing valves have complained about wildly fluctuating temperatures. This phenomenon is associated with the application of water saving shower heads. This effect was reported mainly in large collective hot and cold water systems as used in hotels, health care [hospitals] and multi-storey dwellings, especially when the traditional shower head was replaced by a water saving shower head. Based on measurements in 1997 in buildings serviced by the Waterworks Company in Amsterdam it has been determined that if the pressure loss in the shower mixing valve, shower hose and shower head is lower than the pressure loss in the hot and cold water supply there is no remarkable problem. But if the pressure loss caused by the shower mixing valve, shower hose and water saving shower head is higher an undesirable temperature fluctuation of the mixing water occurs. On request of Uneto-VNI in 1999 KIWA made some small scale investigations on three traditional shower heads and three water saving shower heads [1]. One model was tested with a traditional shower head and with a water saving shower head provided with an in-line flow restrictor supplied by the manufacturer. During the test the pressure in the cold water supply changed while the pressure in the hot water supply was almost constant. Figures 1 and 2 show the fluctuations of the mixing water temperature caused by the changes in the pressure of the cold water supply. The shower head without in-line flow restrictor shows a pressure change of 35 to 50 kPa and a temperature fluctuation of approximately 5 ℃ . With an inline flow restrictor in the shower head the temperature fluctuation varies between 10 ℃ to 25 ℃ at a pressure change of 40 to 60 kPa. The measurement results of the other shower heads show similar significantly large differences, both the traditional shower head and the water saving shower head. The fluctuation in temperature of the water saving shower heads is significantly higher than that of the traditional shower heads.

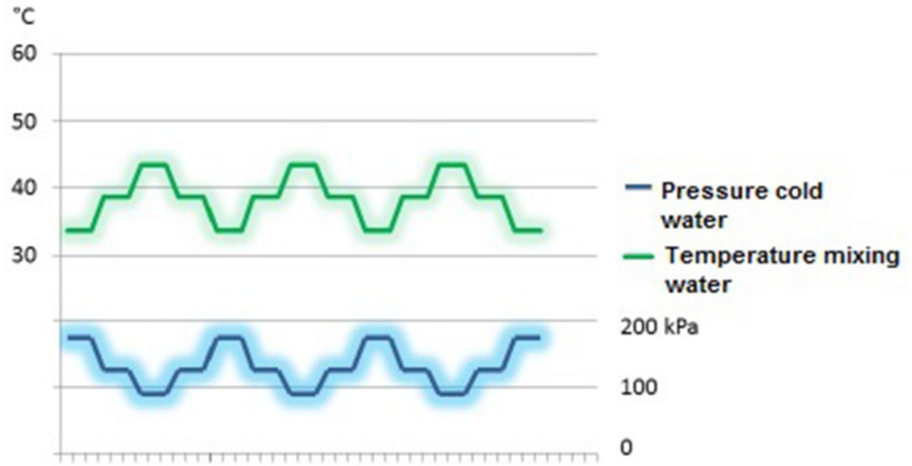


Figure 1. Pressure on the cold water supply (blue) and the temperature of the mixing water (green). Traditional shower head.

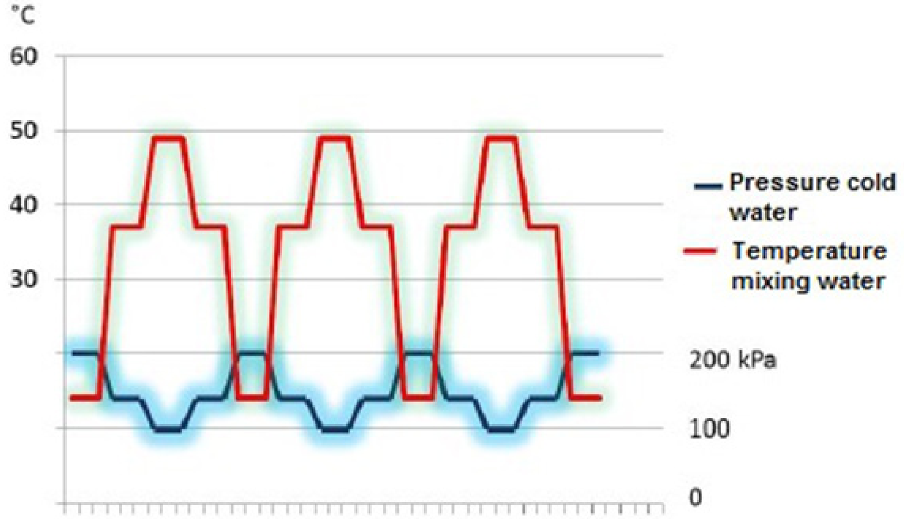


Figure 2. Pressure on the cold water supply (blue) and the temperature of the mixing water (green). Water saving shower head.

Also in Switzerland temperature fluctuation problems have been recognized when water saving shower heads are being applied in combination with a shower mixing valve. Also in Switzerland the question arises what causes the increase of the temperature fluctuation of the mixing water when water saving shower heads are being applied. Students of the University of Luzern [2] did research on this topic. They found that there is a lack of knowledge on the topic of temperature fluctuations in water supply systems. The students focused on water supply systems in dwellings. Measurements in a laboratory test facility confirmed that the application of water saving shower heads leads to significantly higher temperature fluctuations than with conventional shower heads.

At the same pressure drop in the cold water system caused by filling a toilet cistern while the shower is running, the mixing water temperature increases at a maximum of 8 ℃ with a water saving shower head while only 2,5℃ with a traditional shower head. As major contributor they indicated the in-line flow restrictor in the shower head. In the mixing chamber of the mixing valve both cold and hot water are mixed and determine the mixing water temperature. The pressure imbalance in the water supply leads immediately to significant temperature fluctuations on the outlet of a shower head equipped with an in-line flow restrictor.

Measurements in the test facility show that when the water flow is restricted at the inlet of hot and cold water of the mixing chamber instead of an in-line flow restrictor in the shower head there is a significant improvement in the mixed water temperature.

With a relocation of the in-line flow restrictor from the shower head – at the outlet of the mixing valve – to the inlet of cold and hot water of the mixing valve the influence of the pressure fluctuations in the water system is reduced significantly. But to limit the influence of the pressure fluctuations in the water system the sizing of the water supply pipes has to be adapted.

Undersized water supply pipes –hot and cold – lead to a reduction of the pressure in the pipe system in case of simultaneous discharges. The higher the pressure loss in the cold water supply pipe during the use of the shower head the higher the mixing water temperature of the water in the shower head. To prevent fluctuations of the pressure in the water supply the bore of the pipe should be sized larger to reduce the pressure loss, and the pipes connected to the inlet of the mixing valve should be sized as small as possible without exceeding the maximum flow velocity. So the pressure loss in the latter pipes should be relatively high.

The students of the school in Luzern concluded: “The higher the ratio of the pressure losses in the pipes with hot and cold water connected to the mixing valve to the pressure loss in the combined water supply the lower the temperature fluctuation of the mixing water”.

Figure 3 shows the ratio as mentioned above and the temperature fluctuation of the mixing water.

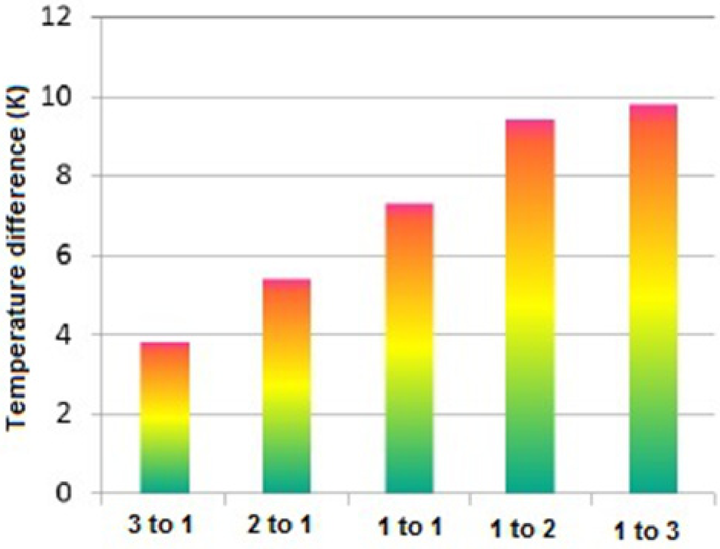


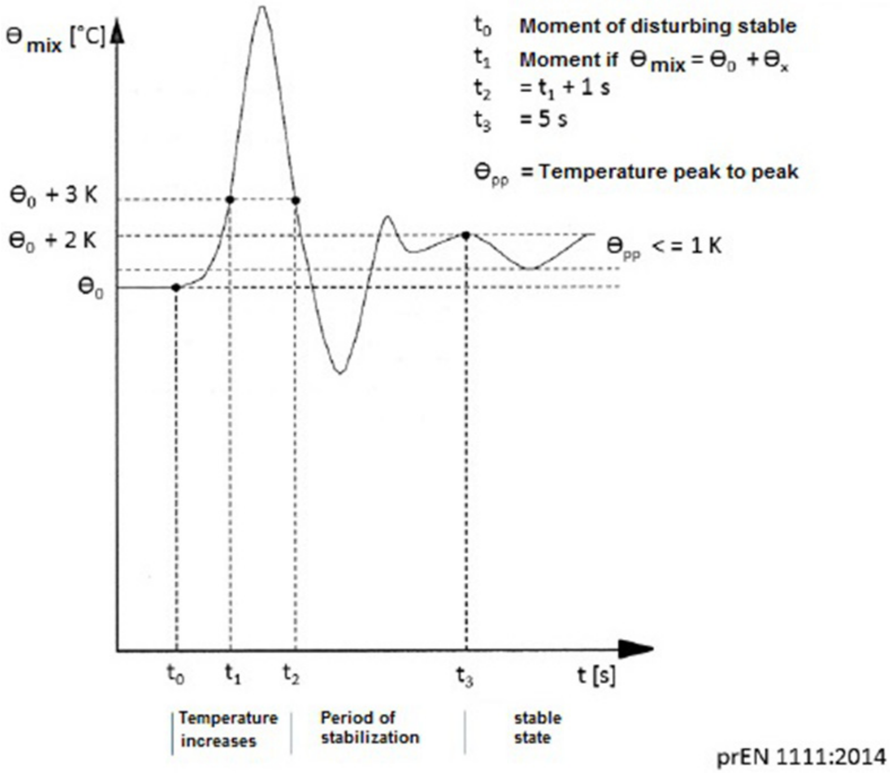
Figure 3 Temperature fluctuations in the shower depends on the ratio of the pressure loss in the inlet pipes connected to the mixing valve and the pressure loss in the combined pipe system.

3. Available Standard EN 1111 for Thermostatic Mixing Valves

Thermostatic mixing valves used in buildings, like the building used for the investigation, have to meet the standard EN 1111 [3]. The EN 1111 emphasizes the comfort: keep the water temperature as steady as possible. The EN 1111 describes a testing method how to test if a thermostatic mixing valve performs well with respect to the risk of scalding. The testing method measures the leakage of hot water in case of a sudden interruption of the cold water. Within 5 s after the interruption of the cold water supply the leakage has to be less than 200 ml and within 30 s less than 300 ml. This requirement applies for thermostatic mixing valves for a shower, bidet, kitchen and a central thermostatic mixing valve for a bathroom.

A revised EN 1111 is under construction. The most recent concept version includes requirements for the mixed water temperature caused by fluctuations of the pressure and temperature on the inlet of cold and hot water. These requirements are mentioned in prEN 1111:2014, annex C, shown by curves. See figure 4 and 5.

These curves are applicable for thermostatic mixing valves for the shower, washbasin and bidet. The deviation of the adjusted mixing water temperature Θ mix has to be less than Θ x = 3 K within a period of 1 s (t2-t1) for a flow rate of 12 L/min. For lower flow rates (< 9 L/min for a washbasin and bidet and < 12 L/min for a shower) the maximum temperature and minimum temperature drop in the curves will be smaller, for larger flow rates the increase and drops are larger, as long as there is a correct pressure balance between the cold and hot water. Five seconds after the start of the pressure fluctuation (t3-t0) the deviation of the mixing water temperature must be less than 2 K compared to the adjusted water temperature Θ o and the temperature difference must be less than 1 K (Θ pp <= 1 K).



prEN 1111:2014

Figure 4 Increasing water temperature caused by pressure fluctuations in the cold or hot water supply. Application of thermostatic mixing valves for households.

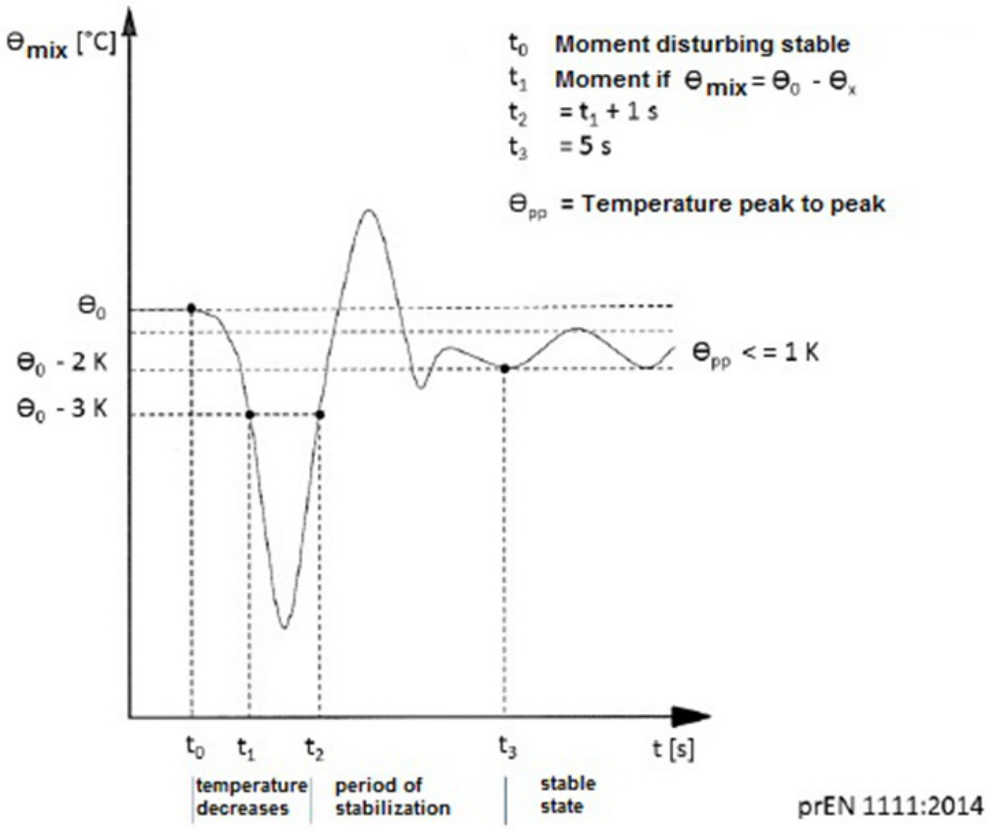


Figure 5 Decreasing water temperature caused by pressure fluctuations in the cold or hot water supply. Application of thermostatic mixing valves for households.

4. The Investigated Water System; Response of a Thermostatic Shower Mixing Valve in Practice

4.1 Hot and cold water system

For the practical investigation we selected a hot and cold water system regarding the next criteria:
(1) A collective hot water system
(2) Complaints about temperature fluctuations on the shower head
(3) Technical drawings available
(4) Prepared to cooperate

The investigation site contains a hot and cold water supply system for some houses linked to a care home. The water supply system consists of pressure booster pumps and the cold water supply pipe is located in an attic on the upper floor above the houses. This cold water supply pipe feeds the hot water tank also located on the in the attic on the upper floor. The hot water production provides two different groups. There is a continuous flow of water from the hot water tank around the distribution circuit and back to the hot water tank. This ensures that the hot water is quickly available at any of the taps, independent of their distance from the hot water tank. Copper pipes are applied for the distribution circuit. See figure 6.

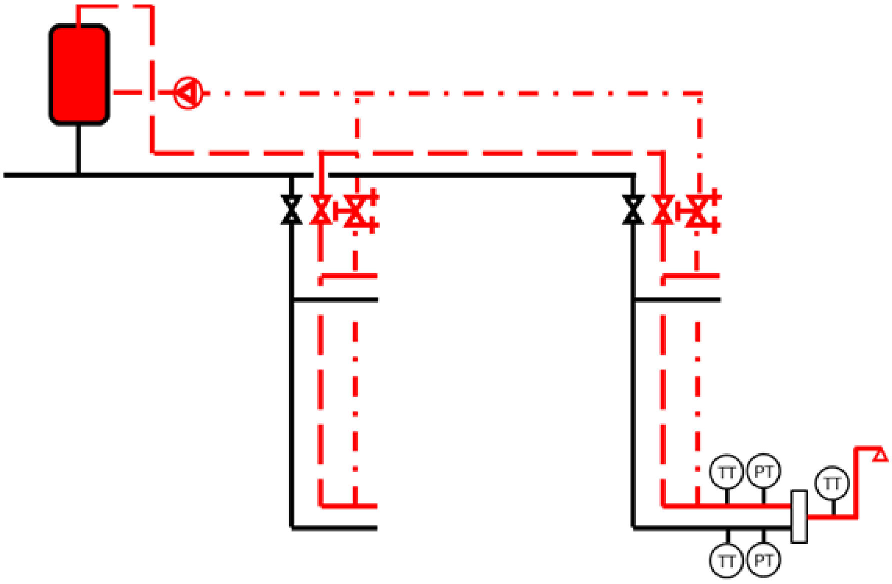


Figure 6 Scheme of the cold and hot water supply.

4.2 Temperature and pressure measurements

In order to investigate the influence of a change in pressure or temperature in the water supply on the mixed water temperature the pressures and temperatures at the inlet of the hot and cold water to the shower mixing valve were measured.

In order to measure the mixing water temperature a temperature transmitter was placed in the mixing water outlet of the shower mixing valve. The sample time was 1s. The pressure transmitters have a measure range between 0,1 and 1 MPa and the temperature transmitters are PT100 transmitters.

The data for the pressures and temperatures were monitored for one day. Figure 7 shows the measured values. It appears that the shower is used from 12,000 to 13,000 s. The curves also show some dips and peaks for the water pressure at the cold and hot inlet of the shower mixing valve. The pressure in the cold water inlet varies between about 300 and 700 kPa and in the hot water inlet between about 500 and 600 kPa. How will the shower mixing valve respond to these fluctuations?

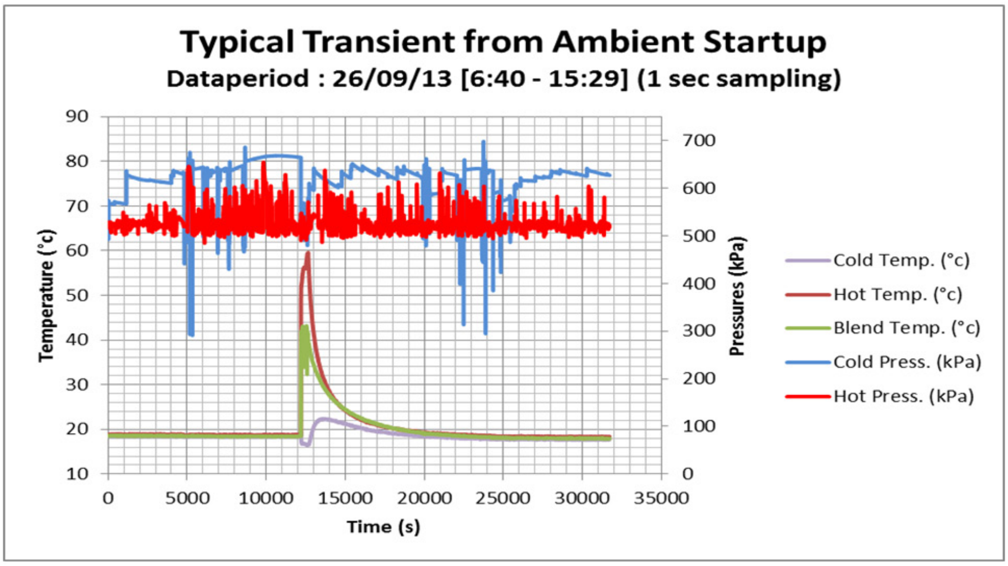
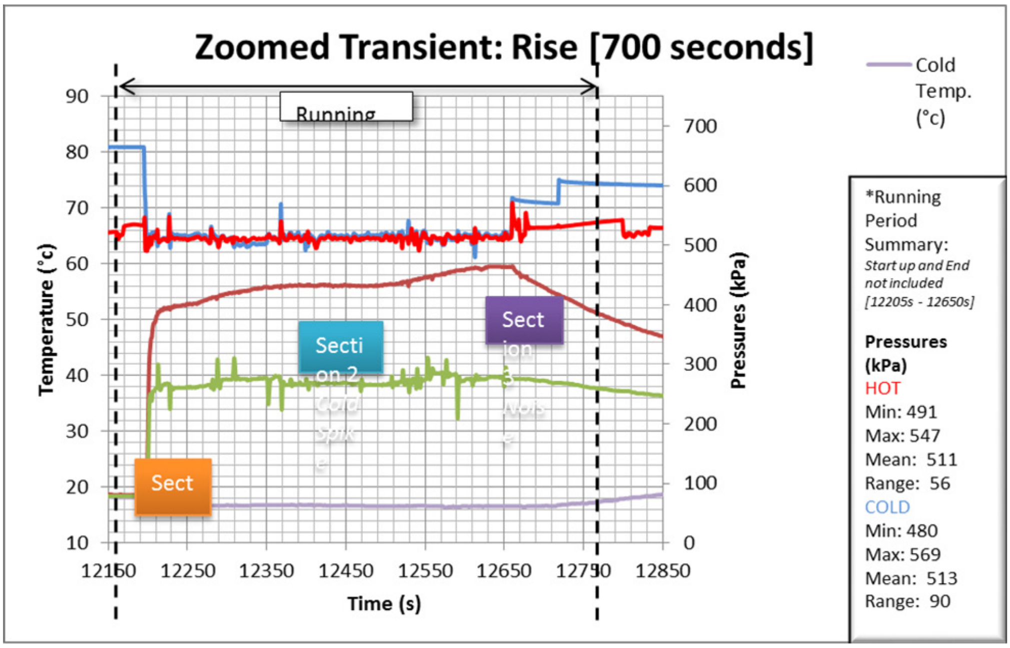


Figure 7 Measurement results at the inlet and outlet of the shower mixing valve. Date 26-09-2013.



*Running Period Summary:
Start up and End not included [12205s - 12650s]

Pressures (kPa)
HOT
Min: 491
Max: 547
Mean: 511
Range: 56
COLD
Min: 480
Max: 569
Mean: 513
Range: 90

Figure 8 Measurement results from 12,150 to 12,850 s

To determine what’s going on in the period the shower is used we zoomed in on the period from 12,150 to 12,850 s (See figure 8). During the use of the shower the cold water temperature is steady at 18 ℃ . The hot water temperature is immediately 52 ℃ and increases slowly to 60℃ . No short term fluctuations are noticed.

At the start the pressure of the cold water is rather high (660 kPa). Just after the start the pressure at the cold water inlet decreases to and stabilizes at about 500 kPa and in the hot water inlet to about 510 kPa. During the shower period there are short terms pressure fluctuations; for the cold water 50 kPa and for the hot water

70 kPa. In addition the green curve for the mixing water temperature shows a dip of about 6 K. To study the response of the thermostatic shower valve on rather small pressure fluctuations (37 and 45 kPa) we zoomed in for the period of 100 s from 12,550 to 12,650 s. See figure 9.

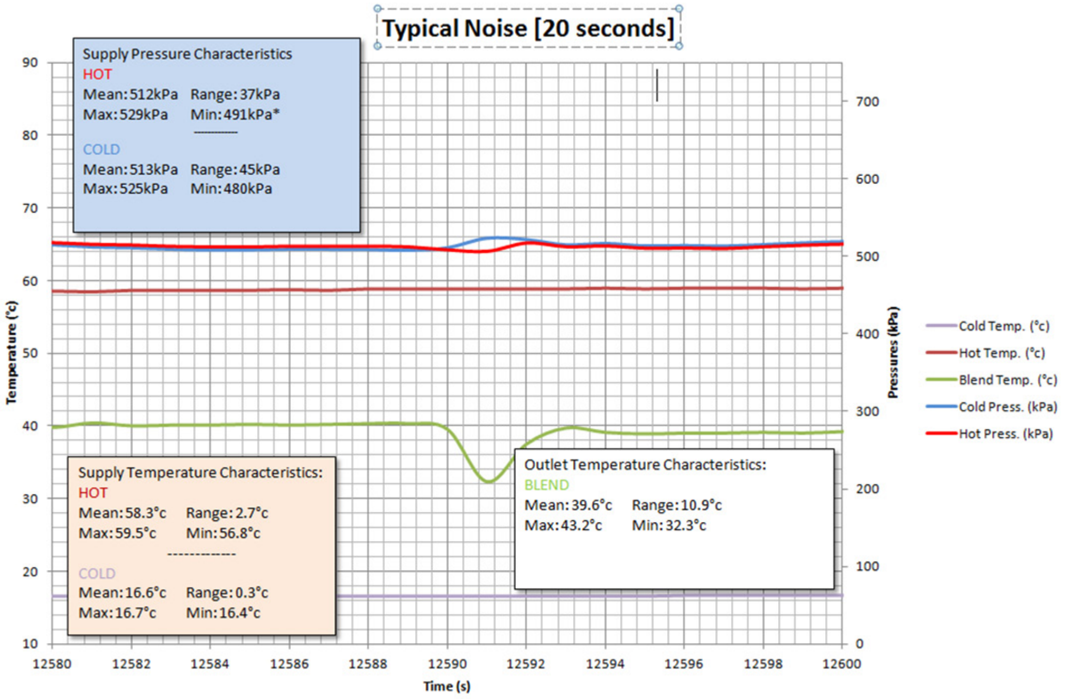


Figure 9 Measurement results between 12,550 and 12,650 s

It strikes that a pressure peak of just 20 kPa in the cold water inlet results in a 8 K dip of the mixing water temperature during a period of 1s. That is rather a large difference in mixing water temperature in relation to the change in pressure at the cold water inlet. For the user such fluctuations in the mixing water temperature are very inconvenient, or worse may be the user is startled [4].

5. Thermostatic Shower Mixing Valve in a Test

5.1 Temperature fluctuation mixing water depends on the water flow

It appears that the response to larger and smaller pressure fluctuations of a thermostatic shower mixing valve (TSV) in practice does not comply with the pressure fluctuations as described and shown in prEN 1111:2014 annex C. Small and slow pressure fluctuations in the hot and cold water supply at a small water flow rate leads to a large temperature fluctuation of the mixing water [See figure 9]. The Dutch certification organization KIWA recognizes this response but states that there are no requirements for this type of fluctuations. Regarding the lack of knowledge with respect to the temperature deviation at TSV's in practice a test has been executed with three TSV's corresponding with the type as used in the investigation in the house. At a mixed water flow rate twice as large as mentioned in the standard prEN 1111:2014, the cold water pressure on the inlet is reduced from 300 kPa to 200 kPa and then increased back to 300 kPa. After the response period the overshoot of the mixing water temperature is 2 K. See table 1. With a mixed water flow rate of 11.8L/min (100%) the temperature overshoot is 3.6 K and at a mixed water flow rate of 6.1L/min (50%) the temperature overshoot is 4.7 K.

If the pressure at the hot water inlet decreases from 300 to 200 kPa and then increases back to 300 kPa, the negative mixing water overshoot temperature is 0.6 K at a water flow rate of 23.6L/min (200%), 0.7 K at a 100% water flow rate and 2 K at a 25% water flow rate. It turns out that the water flow has a significant influence on the mixing water temperature after the stabilization period. The smaller the water flow, the higher the influence on the mixing water temperature.

Table 1. Test results with three TSV's in practice

Mixing water flow (L/min)	Pressure cold and hot water 300 kPa	
	After pressure dip cold water from 300 to 200 and back to 300 kPa; Positive temperature overshoot (K)	After pressure dip hot water from 300 to 200 and back to 300 kPa; Negative temperature overshoot (K)
23.6 (200%)	2.0	0.6
11.8 (100%)	3.6	0.7
6.1 (50%)	4.7	2.0

The overshoots in the increased mixing water temperature are larger in case of a pressure drop at the cold water inlet than a pressure drop at the hot water inlet. After a pressure drop at the cold water inlet in combination with a small flow rate, the temperature increase does not meet the requirements as described in prEN 1111:2014, annex C.

5.2 Improvements of the TSV's

Unexpected changes of the water temperature could lead to a thermal shock and scalding. Users could be startled while having a shower on a wet floor surface. In addition to the risk for scalding, reacting abruptly by moving away from the flowing water can cause a serious injury as a result of a slip or fall. Moreover there is a risk for scald burn when people are exposed to hot water. Table 2 shows the relation between the risk of scalding, exposure time and water temperature. The manufacturers of TSV's recognize the risk of scald burn and they work on accurate control systems to improve the security of the use of TSV's.

Table 2. Relation between the risk of scalding, exposure time and water temperature

Exposure time(s)	Temperature(°C)
300	49
120	52
30	54
10	57
5	60
1	68

6. Conclusions

Although a TSV meets the EN 1111 it does not provide sufficient protection against thermal shock caused by small pressure fluctuations at the hot and cold water inlet of the TSV.

The water flow rate has a big influence on the mixing water temperature. The test water flow is 12L/min. Usually the flow rate in a water saving shower head is 6L/min. When theoretically a TSV meets the EN 1111 in practice a TSV works with a smaller water flow. So the response isn’t correct.

The overshoot in the mixing water temperature is larger in case of a pressure drop at the cold water inlet than a pressure drop at the hot water inlet. We have no explication for this difference. Perhaps it has to do with the construction of the TSV.

The standard EN 1111 has to address temperature fluctuations caused by small pressure fluctuations at the cold and hot water inlet of the TSV.

To determine if in-line flow restrictors at the cold and hot water inlet provide a more steady mixing water temperature additional measurements are necessary.

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8. Presentation of authors

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Research on the Law of Domestic and Reclaimed Water in Hotel Buildings

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Abstract

Online monitoring is conducted on the water supply system and the reclaimed water system in hotel buildings. And we can get the instantaneous flow whose time interval between one and the neighboring data collection is one minute. By arranging and analyzing the data, we can achieve daily law of water consumption, the law of water consumption in its highly-consumed day and average day. Through analyzing the law of water consumption, we can provide reference materials for the design and operation of the water supply system and the reclaimed water system in hotel buildings.

Keywords

Hotel Buildings, Reclaimed Water System, Water Supply System, Law of Water Consumption

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1. Introduction

The law of water consumption is not only the important basis on the design and operation of secondary water supply system, but also playing a guiding role when determining the parameters of series of designs and operations. In this paper, we monitor two hotels, A and B, and summarize their laws of water consumption. The use of ultrasonic flowmeter will not affect the original water supply system. The flowmeter is set to read and stored an instantaneous flow every minute. Hotel A is a four-star hotel, which is designed in 2009 and then built and put into use in 2010. The hotel has 198 guest-rooms, each room has a toilet, and the domestic water apparatus includes a hand basin with mixed water mouth and a bath tub with mixed water mouth (including shower converter). Hotel B is a five-star hotel, which is built and put into use in 2009. It has 388 guest-rooms, the toilet and the domestic water apparatus of each guest-room are the same as Hotel A. The apparatus of reclaimed water of both hotels is a water closet with flushing cistern and float valve in every guest-room. The domestic water of these two hotels is mainly used to wash, so the domestic water is just cold water, it doesn’t contain hot water, and the reclaimed water is mainly used for toilet-flushing.

2. Analysis of the Law of Water Consumption in Water Supply System

We monitor the water supply system of Hotel A from June 14, 2014 to October 12, 2014, excluding the number of days that the data loss caused by outage of flowmeter, so we gain the monitoring data of domestic water in 80 days of Hotel A. In addition, we monitor the water supply system of Hotel B from November 15, 2014 to December 30, 2014, and finally gain the monitoring data of domestic water in 46 days. After analyzing and arranging the monitoring data, we can get the daily water consumption. In order to get the general law of the water supply system of both hotels, we choose the data of domestic water for any seven consecutive days, drawing as shown in Figure 1.

From Figure 1, you can see a dramatic gap of domestic water consumption between the two hotels, due to the differences between the scale of the hotel and the number of check-in. While the law of water consumption of two hotels is similar, the cycle is one day, and the instantaneous flow of domestic water changes periodic. The peak and the valley occur at the same time of the day respectively. In order to know the exactly time of the peak and the valley of two hotels, we average the instantaneous flow of the same time. Then according to drawing the average of 24 hours on the same day, we can get the law of average daily domestic water of the two hotels, as shown in figure 2.

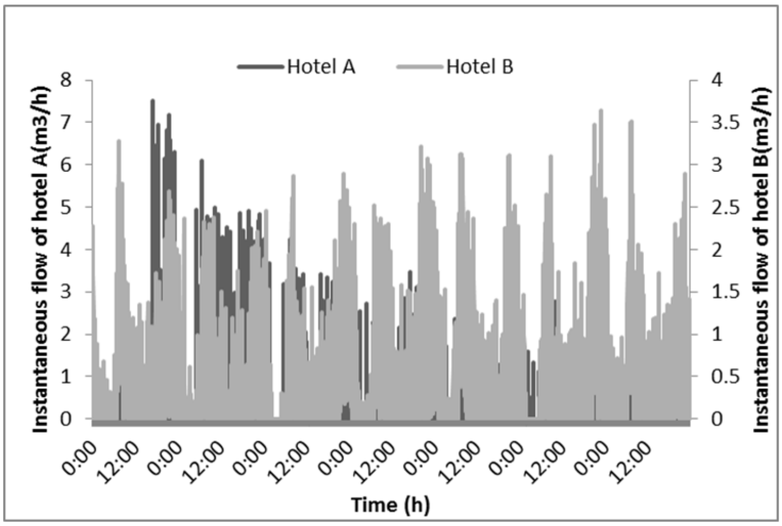

Figure1 The law of domestic water for any seven consecutive days of the two hotels

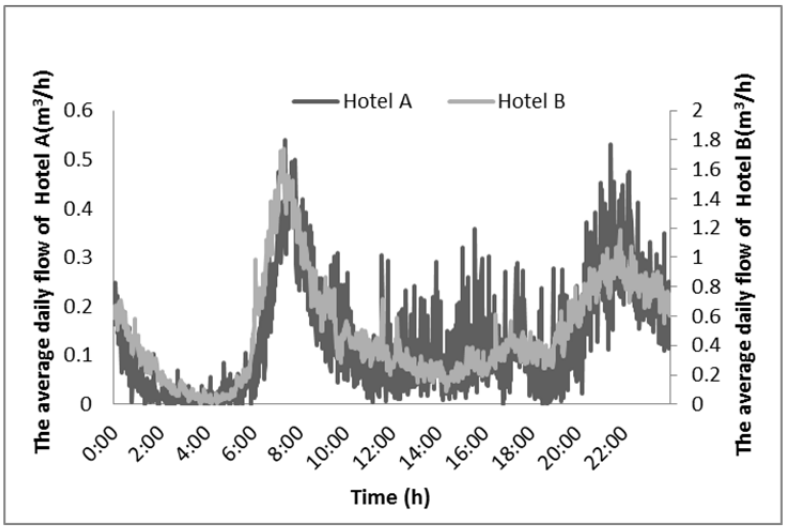

Figure 2 The law of average daily domestic water of the two hotels

It shows that the law of average daily domestic water of the two hotels is similar. Two large peaks, one sub-peak and one valley occur at the same time. One of the peak flows occurs from 6:00 to 11:00 while the other is from 21:00 to 1:00. The little peak flow occurs from 12:00 to 20:00, and the valley appears from 2:00 to 5:00. It is compared to the routine of people's lives. In order to deeply understand the average daily water consumption, we can gain the ratio of average daily domestic water in each of the time period after arranging and analyzing the instantaneous flow, the results are shown in Table 1.

Table 1 The ratio of average daily domestic water of the two hotels in each time period

time period	the ratio of water consumption	
	Hotel A	Hotel B
2:00~5:00	2.38%	3.43%
6:00~11:00	36.76%	39.03%
12:00~20:00	29.98%	28.65%
21:00~1:00	30.88%	28.89%

From Table 1, it can be seen that the early peak has the maximum flow, and then followed the later peak, and the valley has the minimum flow. The water consumption of two large peaks accounts for 70% of the average daily water consumption.

2.1 Analysis of the law of maximum daily water consumption

After contrasting and analyzing all the data of water consumption that have been monitored, it is concluded that the maximum daily water consumption of Hotel A appears on the July 28, 2014, which is 8.52 m3. And the maximum daily water consumption of Hotel B appears on December 15, 2014, which is 21.30m3. Comparing the maximum daily water consumption with its average daily water consumption of the two hotels, the results are shown in Figure 3, Figure 4.

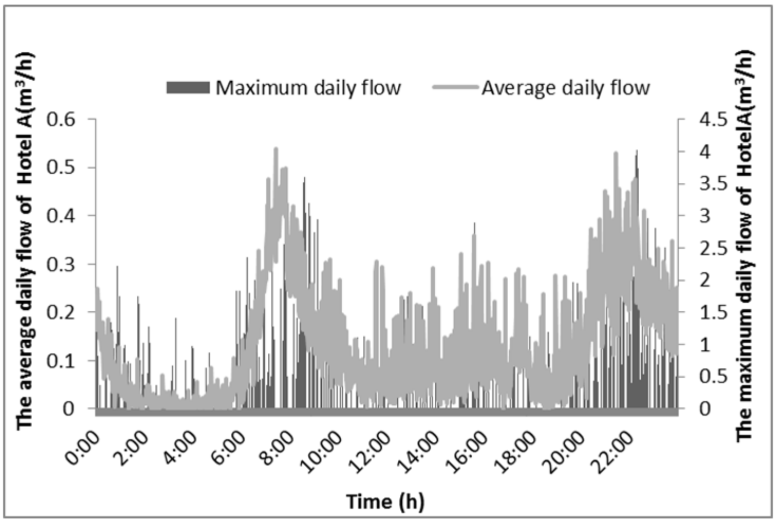

Figure 3 Comparing the maximum daily water consumption with its average daily water consumption of Hotel A

It can be observed that there are many similarities between the law of maximum daily water consumption and the law of average daily water consumption by Figure 3, Figure 4. Both frequency and duration of peak and valley are the same, and the fitting degree of the curve is very high. While the difference between them lies primarily in the total consumption of water. Through analyzing the data, we can see that the average daily water consumption of Hotel A which is 3.04m3 accounts for 35.68% of its maximum daily water consumption. And the average daily water consumption of Hotel B is 11.64m3 accounts for 54.66% of its maximum daily water consumption. According to *Code for Design of Building Water Supply and Drainage* (GB50015-2003 2009), the hourly variation coefficient of Hotel A is Kh=Qh/ Qp=1.73/0.35=4.94 (Qh is the maximum hourly water consumption, Qp is the maximum daily water consumption), and the hourly variation coefficient of Hotel B is Kh=Qh/ Qp=4.99/0.88=5.67. Both of them are out of the range of specified hourly variation coefficient (from 2.0 to 2.5) [1]. The maximum hourly water consumption in all days and the maximum hourly water consumption in its highly-consumed day of the two hotels are coincident during the period of monitoring.

As the average day, we can get the water consumption in each time period, through calculating the maximum daily instantaneous flow that is monitored, and the results are shown in Table 2. It’ s also the same as average day, for it can be seen that the early peak has the maximum flow, and then followed the later peak, and the valley has the minimum flow from Table 2. Besides, we will see the ratio water consumption of Hotel B is much higher than Hotel A during two large peaks, which proves that the hourly variation coefficient of Hotel B is larger than Hotel A.

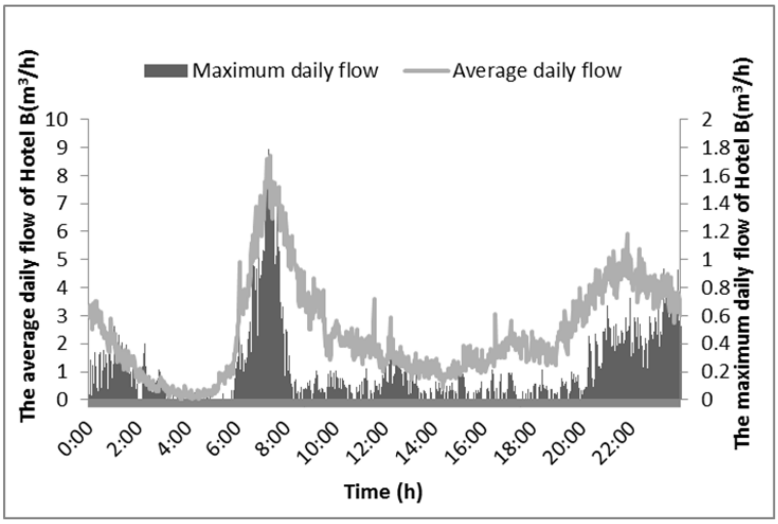

Figure 4 Comparing the maximum daily water consumption with its average daily water consumption of Hotel B

Table 2 The ratio of maximum daily domestic water of the two hotels in each time period

time period	the ratio of water consumption	
	Hotel A	Hotel B
2:00~5:00	3.82%	3.34%
6:00~11:00	34.31%	41.46%
12:00~20:00	23.19%	16.96%
21:00~1:00	38.68%	38.24%

2.2 Analysis of the time period of maximum hourly and maximum instantaneous flow

Table 3 The ratio of maximum hourly and maximum instantaneous flow of Hotel A and B in each time period

time period	maximum hourly flow		maximum instantaneous flow	
	Hotel A	Hotel B	Hotel A	Hotel B
2:00~5:00	0%	0%	1%	0%
6:00~11:00	51%	74%	58%	68%
12:00~20:00	10%	4%	11%	4%
21:00~1:00	39%	22%	30%	28%

The time period of maximum hourly and maximum instantaneous flow is an important content of the law of water consumption. The time of occurrence and the flow of maximum instantaneous water consumption can be gained by contracting and analyzing the instantaneous flow of per minute. Through the calculation and analysis, we can achieve the water consumption of any hours during the monitoring period, and obtain the maximum hourly water consumption after comparing. Finally, we made a count on the time of occurrence and the ratio of maximum hourly and maximum instantaneous flow during the monitoring period, and the results are shown in Table 3.

From Table 3, it’s evinced that the maximum instantaneous flow of the two hotels is most likely to appear in its early peak period, it is almost impossible to appear in the valley time. The rate of occurrence of the maximum hourly flow in each period is almost the same with the maximum instantaneous flow. Compared to Hotel A, the maximum hourly and maximum instantaneous flow of Hotel B are more likely to occur from 6:00 to 11:00.

2.3 Analysis of maximum instantaneous flow of the water supply system

The occupancy rate of two hotels has not reached 100% in the monitoring period, therefore, the comparison between the maximum instantaneous flow in monitoring period and the design second flow that calculated based on the total bed number is largely meaningless. Design second flow was calculated based on daily occupancy in this study, and then it was compared with maximum daily instantaneous flow.

For the Hotel A, only the occupancy rate in September was obtained, so only the monitoring days in September were analyzed, totaling 19 days. By processing the data, we found that the maximum instantaneous flow is 6%~21% of the design second flow, while the average percentage is 12.96%. Among them, there are 11 days’ value between 10% and 15%.

For the Hotel B, a total of 45 days’ occupancy data was obtained from November 15, 2014 to December 29, 2014. The maximum instantaneous flow of Hotel B is 5%~21% of the design second flow, while the average percentage is 12.32%. Among them, there are 28 days’ value between 10% and 15%.

3. Analysis of the Law of Reclaimed Water Supply System

Due to limited conditions, only the reclaimed water supply system of Hotel A was on-line monitored, so only the reclaimed water supply system of Hotel A was analyzed. In order to get the overall variation of reclaimed water consumption, we made a continuous seven days’ water consumption trend figure, just like what we did with the domestic water supply systems, as is shown in figure 5. The law of reclaimed water consumption was changing at a period of one day, which was the same as the law of domestic water supply system.

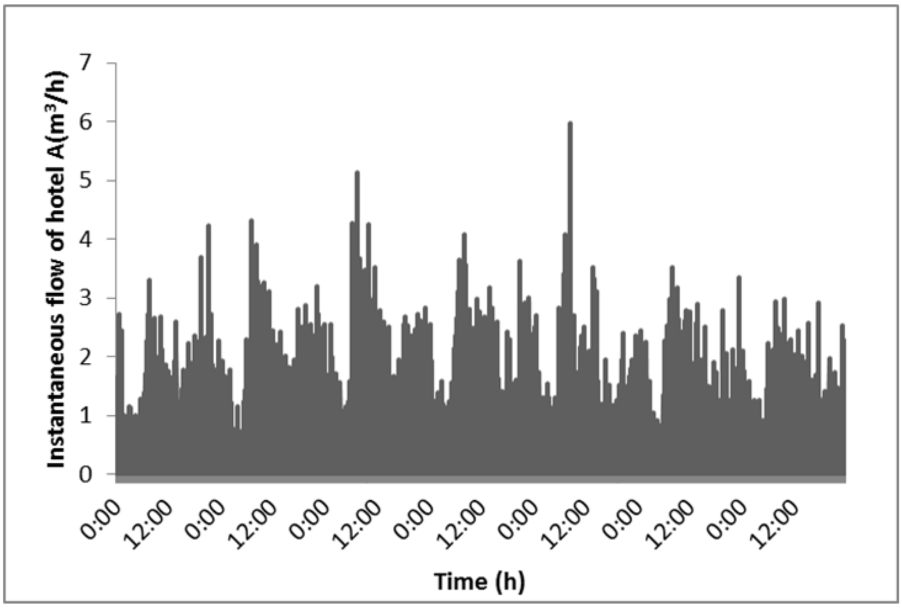

Figure 5 The law of reclaimed water consumption of Hotel A in continuous seven days

Similarly, we compared the law of the maximum daily with the average daily of reclaimed water supply system of Hotel A, as is shown in Figure 6. By analyzing the average daily variation curve in Figure 6, we drew a conclusion that the law of reclaimed water consumption consists of a large peak, two sub-peaks and two valleys, large peak was from 6:00 to 11:00, two sub-peaks were from 12:00 to 15:00 and 22:00 to 1:00, two valleys were from 2:00 to 5:00 and 16:00 to 21:00. Compared with the law of domestic water consumption, the valley period of 16:00~21:00 is something new in the law of reclaimed water supply system, mainly for the reason that the mainly use of reclaimed water is flushing and toilets are used less frequently during this period. By collecting and analyzing the data, we draw a conclusion that the maximum daily water consumption of Hotel A occurs on 2014 July 29, which is 27.17m^3, and the average daily reclaimed water consumption of Hotel A is 9.74m3, which is 35.85% of maximum daily. Reclaimed water consumption hourly variation coefficient is Kh=Qh/ Qp=2.30/1.13=2.04 (Qh is the maximum hourly water consumption, Qp is the average hourly water consumption)[1], it doesn’ t exceed the code of hourly variation coefficient. The maximum hourly water consumption is at 7:00 in June 18, 2014 during the monitoring period, which is 2.37m^3, and the water consumption of that day is 15.61 m^3.

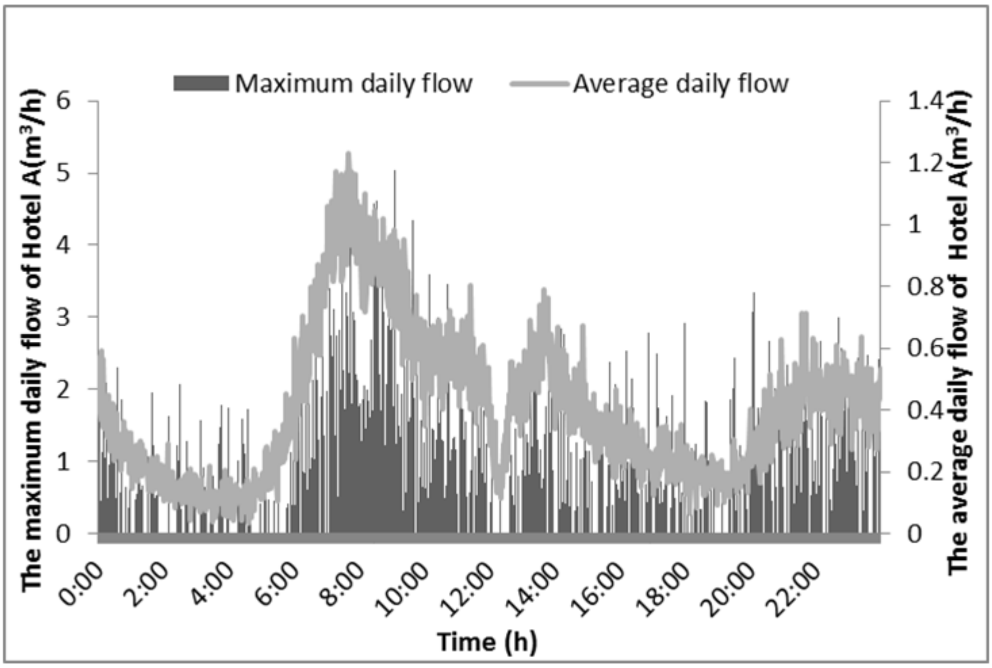

Figure 6 Comparison between the law of average and maximum daily water consumption in reclaimed water supply system in Hotel A

The ratio of average and maximum daily water consumption in each time periods is showing in Table 4. It can be seen that the most value of reclaimed water consumption occurs in the period of 6:00~11:00, it is the same as domestic water consumption. It is worth noting that the reclaimed water consumption of valley period from16:00 to 21:00 is relatively large, the reason is that although it is the valley period of reclaimed water consumption, the time span is relatively long, so the water consumption is relatively large.

Table 4 the proportion of reclaimed water consumption in Hotel A

time period	the ratio of water consumption	
	The maximum day	The average day
2:00~5:00	6.15%	6.54%
6:00~11:00	45.40%	44.23%
12:00~15:00	12.08%	17.07%
16:00~21:00	21.59%	17.19%
22:00~1:00	14.78%	14.98%

3.1 Analysis of the time period of maximum hourly and instantaneous flow in the reclaimed water supply system

By analyzing all the data, we obtained the frequency of maximum hourly and instantaneous flow of Hotel A in each time period, and the results are showing in Table 5. From Table 5 we can see that compared with the domestic water system, the maximum instantaneous flow in reclaimed water supply system is more likely to occur in the morning from 6:00 to 11:00, and the probability of its occurrence is about 90%, this is because people use the toilet more frequently during this period, especially for the stool.

Table 5 the frequency of maximum and instantaneous flow in the Hotel A in different time periods

Time period	Maximum instantaneous flow	Maximum hourly flow
2:00~5:00	0%	0%
6:00~11:00	85%	92%
12:00~15:00	1%	3%
16:00~21:00	8%	4%
22:00~1:00	6%	1%

3.2 Analysis of maximum instantaneous flow in reclaimed water supply system

In this study we calculate the design flow based on the daily occupancy, and contrast it with the maximum instantaneous flow obtained during the daily monitoring.

For the Hotel A, due to we only obtained the occupancy rate in September, so only the monitoring days in September are analyzed, totaling 25 days. By processing the data we find that the maximum instantaneous flow is 27%~53% of the design second flow, and the average percentage is 35.82%. Among them, there are 16 days’ value between 30% and 40%.

4. Analysis of Per Capita and the Ratio of Water Consumption

We just obtain the occupancy rate of Hotel A and Hotel B in partial days, so only the per capita water consumption in monitoring days can be analyzed.

For the Hotel A, the domestic water consumption per bed is between 16 and 54L/(d•bed) during the monitoring period, with an average value of 34.2L/(d•bed). The reclaimed water consumption per bed is between 60 and 170L/(d•bed), with an average value of 103.4L/(d•bed).

And for the Hotel B, the domestic water consumption per bed was between 25 and 110L/(d•bed) during the monitoring period, with an average value of 63.1L/(d•bed).

By comparing the domestic water consumption with reclaimed water consumption in Hotel A, we find that the proportion of domestic and reclaimed water consumption changes between 1:1 and 1:17, and the average ratio is 1:4.7, which is approach to the ratio of 1:5[2] from the Code of Design for Building Reclaimed Water System.

5. Conclusion

Continuous online monitoring is conducted on the water supply system and the reclaimed water system in hotel buildings by ultrasonic flow meter. And we can get the instantaneous flow whose time interval between one and the neighboring data collection is one minute. By arranging and analyzing the data, we can get the changing law of the water supply system and the reclaimed water system, find and analyze the law of maximum daily water consumption, drawing the picture of the changing average daily water consumption. And then we analyze the ratio of average daily and maximum daily water consumption in each time period, and the occurrence and rate of maximum instantaneous and hourly flow as well.

Considering occupancy rate, the study researches on per capita domestic water consumption and per capita reclaimed water consumption, and analyzes the ratio of measured water as well.

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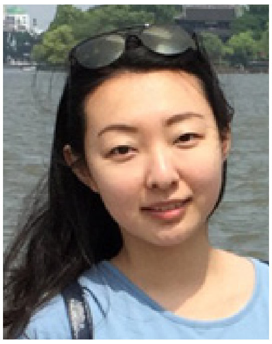

A Cost–benefit Analysis of Water Supply Pump Replacement in Buildings of Hong Kong

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Abstract

Energy efficiency of water supply systems in buildings becomes a concern for sustainable development nowadays. Aged, poor maintained and mismatched water pumps operating at low efficiency are highly undesired situations that can cause energy loss in water supply systems. This paper investigates in-use water pump efficiency and the associated energy cost for water supply systems in high-rise buildings of Hong Kong. Energy consumptions of water supply pumps are measured with the pump efficiencies determined from the water consumptions in 20 water supply systems in buildings. This paper presents expressions of in-use pump efficiency as a function of pump age and the associated energy cost is predicted against the pump installation cost. Pump replacement schedule is proposed with justification by the installation cost against the energy cost saving. The results show that a larger system could be benefited by a more frequent pump replacement schedule as compared with the ones of smaller pumps. The cost benefit is also observed for the worst scenarios of pump efficiency drops. The benefit isobvious as pump energy cost is high as compared with the installation.

Keywords

Water supply pump; replacement schedule; energy cost; buildings.

1 Introduction

Energy efficiency improvement of water supply systems in buildings is a way to address the issue of carbon reduction nowadays [1]. It was reported that the water supply system consumes 1-4% of electricity and was the largest single consumer over a city.Energy consumption in water distribution systems takes an important part of energy use in urban water supply cycle [2,3]. In Australia,the specific energy use excluding the end use part is 4.69kWh/m3. The specific energy use is 4.44kWh/m3 in California, 1.77kWh/m3 in Canada, and the water supply consumes from 1.1 to 1.4 kWh/m3 in some Asia cities [4,5]. As the energy consumption is proportional to building height, the in-use pump efficiency is therefore a matter of concern. Hong Kong is a dense, high-rise environment and water supply systems in buildings account for 1.6% of the total city electricity use. About half of the energy loss in water supply is due to pump [5,6].Aged, poor maintained and mismatched water pumpsoperating at low efficiency are highly undesired.This paper evaluates the cost-benefit of pump replacement against the pump efficiency drops in typical system life cycle for buildings in Hong Kong. Pumpsof deteriorated performance would be replaced and justifications were made by energy cost saving.

2 Pump Efficiency of Water Supply Systems

Water supply pumps in 20 Hong Kong buildings reported by Wong, Mui, Lau & Zhou [7] are shown in Table 1.The surveyed buildings included 11 commercial buildings, 4 residential buildings, 3 school buildings and 2 of elderly care buildings.As the water pressure headat the government water mains is insufficient to reach the topmost appliances in these high-rise buildings, water supply pumps are designedto feed gravity storage tanks on buildingrooftops for distributingwater through downfeed pipes. Total water consumptions were metered for at least one week. During the investigation, pump installation records were accessed including operation and maintenance manual, installation years, installation cost, pump motor ratings, flow rate and pressure, water supply system schematic drawings. All pumps were driven by 3-phase motors and the line current and voltage during pump motor operation were measured. The measurements lasted for one week. The number of pump operations, start-and-stop operation times were recorded for the measurement period.

In Table 1, the overall transmission efficiency of a motor pump set for water supply system η_c is calculated by the energy of water delivery from ground floor to the roof tank divided by the power input to the water pump motor and given below, where total pumped volume Σv (m^3), line current I_L (A), line voltage V_L(V) of the electric pump motor over a period of operating time period τ (s) and can be measured on site,

$$\eta_c = \frac{\Delta P \sum v}{\sqrt{3} V_L I_L \tau} \quad \ldots (1)$$

The pump total pressure ΔP (Pa) is determined by an expression below, where Hois the desired minimum water pressure head available at the tank inlet, Hfis thefriction head required in the up-feed water pipe which is taken as a portionof the pipe length, hl is the water lift height which is the sum of the height measured from thetank base to the roof tank inlet,

$$\Delta P = \rho g \left(H_o + H_f + h_l \right) \quad \ldots (2)$$

Table 1 Pump efficiency of 20 Hong Kong water supply systems

No.	^{a}Type	Floor Area (m^2)	Storey	Population (head)	Pump age Y_s (year)	Height h_l (m)	Average demand height $(h_l+h_h)/2$ (m)	^{b}Pumped volume (m^3)	Pumped energy E_{pump} (kWh)	Pump efficiency η_c
1	C	1250	21	600	20	142	76	87	183	0.18
2	C	1250	1	600	10	142	140	105	104	0.39
3	C	750	24	1200	12	120	57.5	95	67	0.46
4	C	400	31	1378	5	138	76	132	81	0.62
5	C	300	30	1000	12	142	71	100	86	0.45
6	C	150	20	333	10	55	27	19	7	0.42
7	C	100	20	222	5	82	41	68	27	0.55
8	C	600	20	1333	11	90	45	60	39	0.38
9	C	200	16	356	15	68	34	35	18	0.36
10	C	300	12	400	16	53	26	40	16	0.36
11	C	800	20	1778	18	92	46	44	24	0.46
12	R	625	31	1085	20	114	54	685	434	0.49
13	R	625	31	1085	20	114	54	851	505	0.52
14	R	1080	35	2940	20	130	65	2084	1409	0.52
15	R	1080	35	2940	1	130	65	1851	882	0.74
16	S	400	6	1050	10	34	15	49	7	0.66
17	S	600	5	1000	18	42	19	68	14	0.55
18	S	500	2	300	8	18	7.5	53	6	0.46
19	N	600	4	400	10	20	8	390	40	0.53
20	N	600	4	400	4	21	9	^{c}328	31	0.61

[a] Type: C=commercial; R=residential; S=school; N=Nursery; b7-day water consumption; c10-day water consumption.

Table 1 showed that the pump efficiency η_c ranged from 0.18 to 0.74 and found correlated with the year of pump service Y_s(year). It was reported that, where η'_c,0 is the efficiency of the new pump and is yearly drop of pump efficiency.

$$\eta_c = \eta_{c,0} - \eta'_c Y_s ; \quad Y_s \le 20 \qquad \dots (3)$$

A general trend of efficiency drop against installation time of a water pump was reported. In average, pump efficiency at the first year of installation is η_c,0 = 68% and the efficiency drop was η'_c=1.5% per year of installation. The performance drop probably was due to corrosion, scaling of impeller, casing and other parts of pumps. It was also reported for the best and the worst scenarios the pump efficiency drops were η'_c=1.18% and η'_c=2.84%, respectively.

3 Energy Cost and Pump Replacement

The total expenditure θ in a pump life cycle is given by an expression below,

$$\theta = \theta_m + \theta_e \qquad \dots (4)$$

Replacement cost θm (HKD$) of pump set is given by an expression belowfor budgeting purposes [7]. It was calculated from the basic installation cost plus a cost proportional to the pump motor ratings W_m (kW).

$$\theta_m = 3700 + 1780 W_m \quad \ldots (5)$$

Assumed the energy cost is HKD$1 per kWh, the yearly energy cost θe (HKD$) for the water system is given by,

$$\theta_e = 365 E_{pump} \quad \ldots (6)$$

Wong, Mui, Lau & Zhou [7] reported that larger motor-pump sets were generally installed for buildings of larger floor area, higher delivery demand locations and larger population. The surveyed motor ratings were found correlated to the total floor area (*R*=0.72, *p*<t-test), the delivery height (*R*=0.64, *p*<t-test), and the population (*R*=0.71, *p*<t-test). The average daily energy consumption Epump(kWh) was found correlated with the pump motor ratingsWm(kW) (*R*=0.91, *p*<t-test) and an expression is given below,

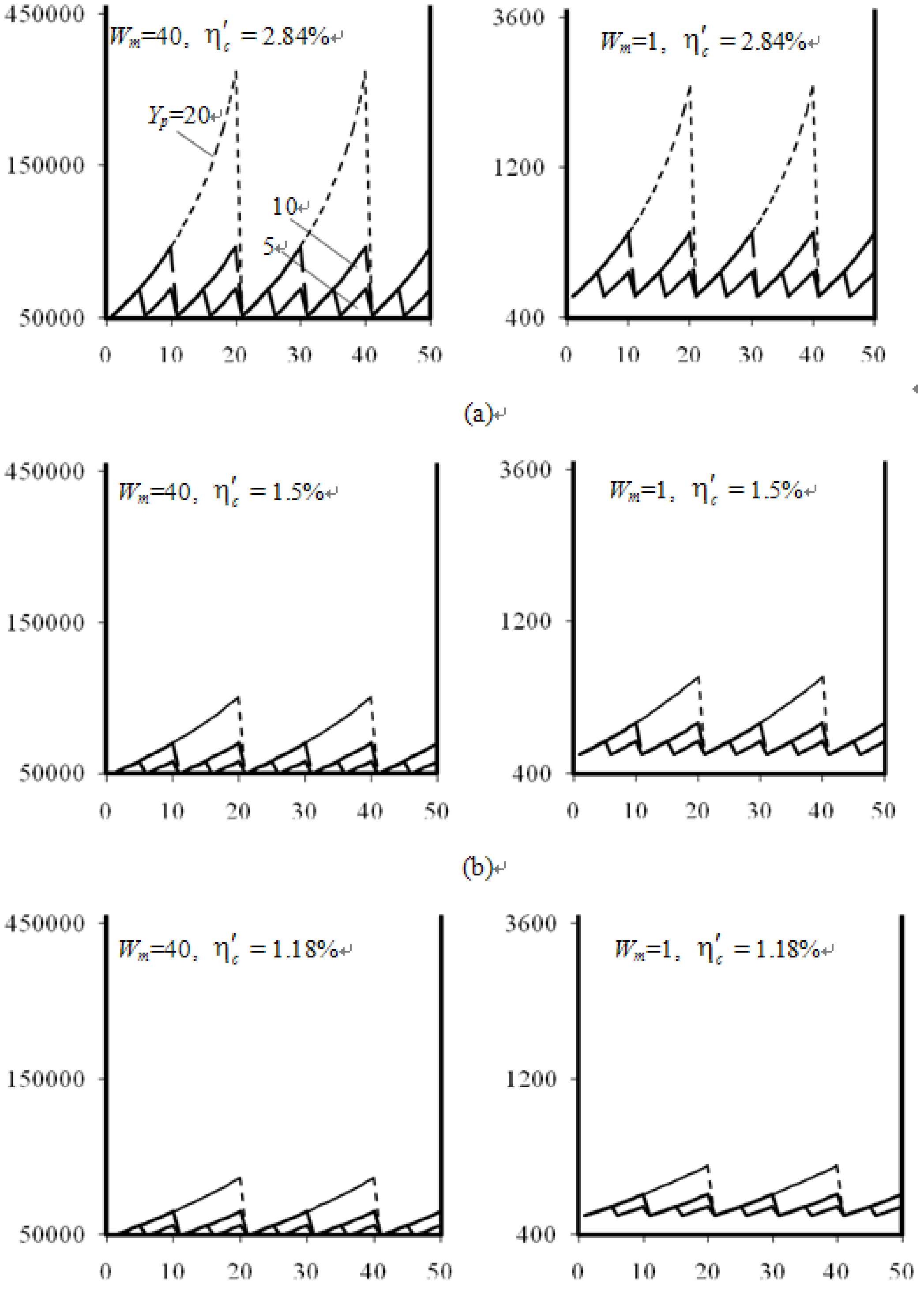
$$E_{pump} = 1.232\, W_m^{1.27} \quad \ldots (7)$$

Deterioration of pump performance was reflected by increasing pumping energy consumption. The energy cost is then determined by combining equations 6 & 7 and taking account the efficiency drop as shown by an expression below,

$$\theta_e = 450\, W_m^{1.27} \left(\frac{\eta_{c,0}}{\eta_{c,Y_s}} \right) \quad \ldots (8)$$

Figure 1 shows for a life cycle of 50 years, the energy cost of water supply systems with the pump motor ratings of 1 kW and 40kW, indicating for the smallest and largest water supply systems in buildings of Hong Kong. The best, the average and the worst scenarios of pump efficiency deterioration in 3 example pump replacement periods of Yp=5, 10 and 20 years are indicated in the figure. It is noted that the first energy costs of the two installations are about HKD$460 & HKD$50000, corresponding to 8% & 67% of the installation costs.The energy cost is increasing against the pump installation life and is justified for pump replacement in some cases.

Figure 2 shows the total expenditure of the water supply systems. The results show for a larger system (e.g. the 40 kW ones) could be benefited by a more frequent pump replacement schedule as compared with the ones of smaller pumps. The cost-benefit is also observed for the worst scenarios of pump efficiency drops. The results are obvious as pump energy cost is high as compared with the installation.



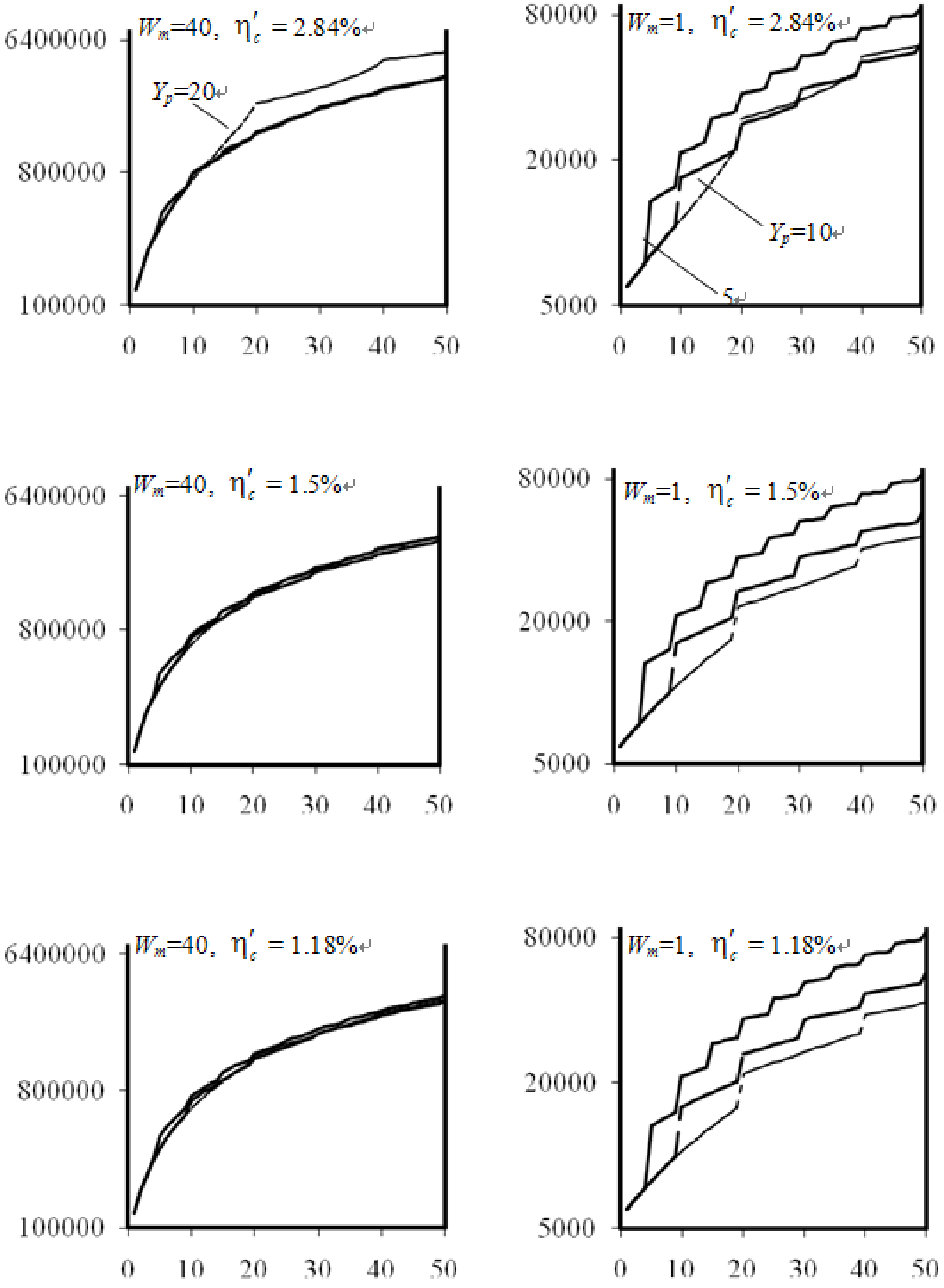
(a)

(b)

(c)

x-axis: Year of installation Y_s(year); y-axis: Energy cost θ_e (HKD$)

Figure 1 - Energy cost θ_e



x-axis: Year of installation Y_s(year); y-axis: Total expenditureθ (HKD$)

Figure 2 - Total expenditure θ

4 Conclusion

Energy efficiency improvement in buildings is a sustainable development strategy in Hong Kong. It is necessary to develop a systematic approach to address energy efficiency justified to the expenditure for high-rise water supply systems. This paper recognized pumping efficiencies as a function of installation time and proposed pump replacement schedule justified by the installation cost against the energy cost saving. In typical ranges of pump motor ratings, pump efficiencies and replacement periods, more frequent replacement is reported for larger pumps at greater efficiency drops.

Acknowledgment

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Water Resources Planning Of Wuhan International Garden Expo

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Abstract

This is a water resources planning of the park natural water, artificial lake and natural rainfall according to Wuhan International Garden Expo theme principles and objectives. Garden Expo combines exhibition grounds, vegetation distribution characteristics , makes full use of natural precipitation as an artificial lake and green water sources and natural water bodies for reserve water. It's using various water treatments ,such as ecological grass ditch, creek, wetlands, rain gardens, traditional water , for the realization of rainwater infiltration , storage and reuse. this project of water saving rate is more than 40%, meanwhile, water resources utilization mode enhances the effect of landscape ecology, significantly reduces rainwater runoff efflux load.

Keywords

Water Resources，Rainwater reuse，Rainwater Storage，Annual runoff volume capture ratio , Ecological grass ditch，Artificial Wetland，Green area irrigation，Water Saving rate

1. Project profile

The 10th China International Garden Exposition (Wuhan) is located in the junction of main city area and the new city area the Qiaokou district, East West Lake district and Jianghan district . The total planning area covers 231 Ha , of which green land area covers 168ha, water area covers 8ha， pavement area of road or square covers 40ha, building area covers 11ha, the other land covers 4ha. As shown in Figure 1.

The main site of Garden Expo is located in Jingkou landfill, which has been stopped running。The Zhang Gong Embankment and the Three Loop Road across the park. northeast corner of the site is joined the Jingyin Lake. Perimeter adjacent municipal road, municipal roads has improve water supply and drainage network. There is urban rainwater culvert in the south of the Three Loop Road， there is urban rainwater culvert and sewage culvert in the north of the Three Loop Road。

The main function of this project is landscape architecture, and the green land area is 72.7% of the total land area, which has obvious positive effect on the improvement of the regional ecological environment. The landfills which the project located is being carried out in an ongoing process of ecological restoration.

Figure 1: General Plan of Garden Expo

2. Purpose and Basis

2.1 Purpose

Garden Expo integrated water resources planning is based on national requirements on the construction of the sponge city, green building requirements, water-saving city construction requirements, according to Garden Expo green and ecological exhibition concept, combining the water resources relationship of the inside and outside park ,developed a deployment and using embodiment of integrated water resources, in order to achieve the rational use of water resources, construction of low impact development of rainwater system, realize the maximization of comprehensive benefit of water resources.

First of all，integrated water resources planning should achieve the balance of the park's internal and external water resource consumption and supplement . Water consumption of Garden Expo is mainly building domestic water, green sprinkling ， car washing and Waterscape (including evaporation, infiltration), etc. Water resources supplement of Garden Expo is mainly natural precipitation, municipal water supply and natural lakes nearby. After the analysis and calculation of water consumption, we can achieve the park water balance by the use of a variety of technical means.

Secondly ，integrated water resources planning will build a low impact development rainwater system in the Garden Expo . Construction of low impact development rainwater system is based on the park natural and geographical conditions, hydro-geological characteristics, water resource endowments, rainfall patterns, water protection and waterlogging prevention requirements, using natural drainage system, and a variety of ecological sanitation facilities and technology, gives full play to the green space, roads, water systems of rainwater absorption, infiltration and slow-release, mitigation site waterlogging, reduction of urban runoff pollution load, saving water resources, protecting and improving the park and improve urban ecological environment.

Thirdly， integrated water resources planning is also achieved the maximum benefit of water resources through a series of technical means. Comprehensive benefit of water resources is reflected in: make full use of rainwater and other non conventional water for landscaping, car washing and flushing, reduce consumption of municipal tap water; for rainwater infiltration, storage, groundwater conservation, reduce shock loads to the municipal pipe network; use ecological technology to maintain the stability of the artificial lake water quality; ecological measures taken to intercept and reduce the non-point source pollution; water resources using facilities are matched and combined with landscape facilities, foiled the green atmosphere of Garden Expo.

2.2 Basis

The theme of the Garden Expo is " Garden Expo connect you and me, green blend into the life", its target is "ecology, science and livelihood", the Garden Expo planning fully integrated Wuhan landscape of the natural ecological features, with the help of advanced scientific and technological means, technology and materials, attract people to participate and experience, benefit the people's livelihood. One important function of the Garden Expo is to turn the original garbage field waste into ecological value of land, which naturally blend ecological restoration, waste disposal, water resources and so on into the Garden Expo construction.

According to the《Sponge City Construction Technology Guide》 for the area of China to the Annual Runoff Total Control Rate（ARTCR）, Wuhan city belongs to the District Ⅳ , ARTCR should be between 70%~85%. In accordance with the requirements of 《 Assessment Standard for Green Building》three star standard, the non-traditional water source use rate is no less than 80% when that is use for green sprinkling ，roads cleaning, car washing purpose, the non-traditional water source use rate is no less than 50%when that is use for toilet flushing purpose. The Water Quality of raw water which be treated as greening, road, car washing, flushing a toilet water flushing should meet the water quality standard for urban miscellaneous water, when used in waterscape, should also meet the landscape waterscape quality standard. Sewage should meet the requirements of urban sewage discharge standards when discharging into the municipal pipe.

3. Integrated Water Resources Planning

3.1 Water Supply System

3.1.1 Source of wate

The road around this project has improved municipal water supply. With the Three Loop Road as the boundary, the south area and north area respectively provide water as a looped ring network. Every buildings of the park use municipal water as domestic water.

3.1.2 Water Consumption

The water supply standard of design is 3L/m^2•d for garden pavilion,40 l/person•time for employees and visitors,50l/ vehicle • day for washing car , 5L/m^2•d for commercial portion, 1L/m^2•d for service building, 1L/m^2•d for green water and 2L/m^2•d for road irrigation sprinkling

The highest total daily water consumption of the Garden Expo is 3187 m3/d, the water consumption of green sprinkling， roads cleaning, car washing is 2264 m3/d.

3.1.3 Water Supply Network

The south area of the Garden Expo are laying of DN250 main pipelines from east and north, the pipelines are becoming a ring within the scope of the land, to ensure the safety of water supply; the north area of Garden Expo are laying of DN250 main pipelines from west to north, the pipelines are becoming a ring within the scope of the land, to ensure the safety of water supply, the south and the north area water supply networks format a whole ring through connection bridge on the Three Loop Road, As shown in Figure 2.
North and south area are laying DN200 green pipeline respectively along the first grade road for the pavilion and green washing , flushing. Irrigation source of water is from rainwater collected in the park. The rainwater is discharged into artificial lake in the south area after initial process. Artificial lake water is used for irrigation and other purposes after water treatment process, the lack of green water is supplying from artificial lake.

3.2 Drainage System

3.2.1 Sewage water:

The maximum daily displacement is 2809m^3/d.

3.2.2 Sewage drainage system:

According to the terrain, the sewage of the Garden Expo is discharged into the municipal pipe network in the light of principle nearby. The drainage style of south area is gravity and south area is divided into three regional according to the construction monomer. The drainage style of north area is scattered point type gravity.. each monomer dispersed sets the septic tank, the treated sewage is discharged into the surrounding municipal road sewage pipe network. As shown in Figure 3.

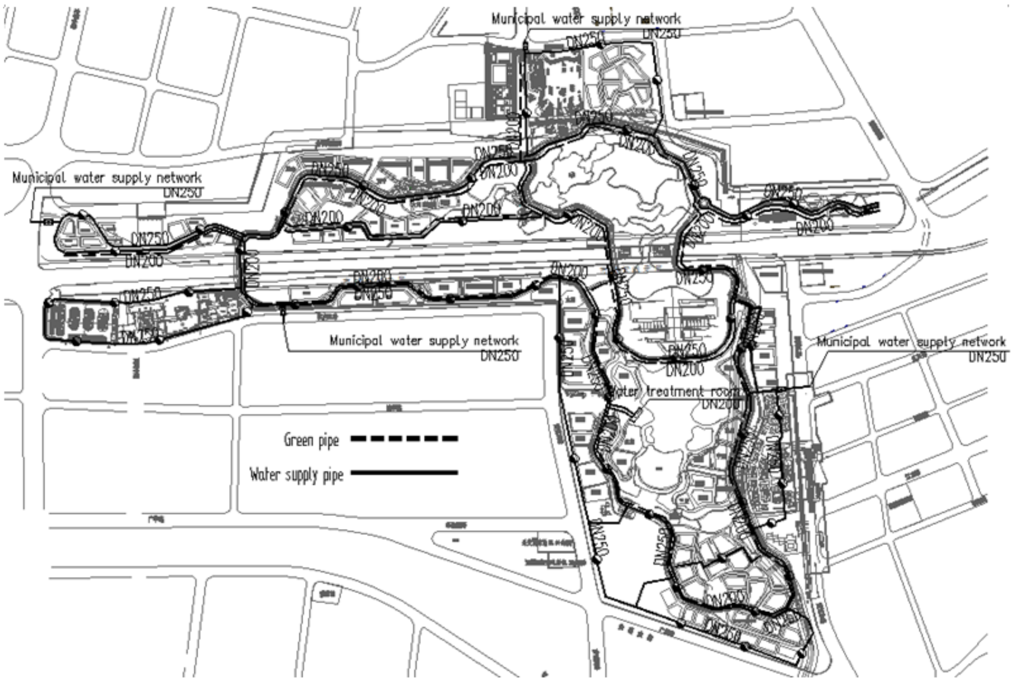


Figure 2: water supply system planning

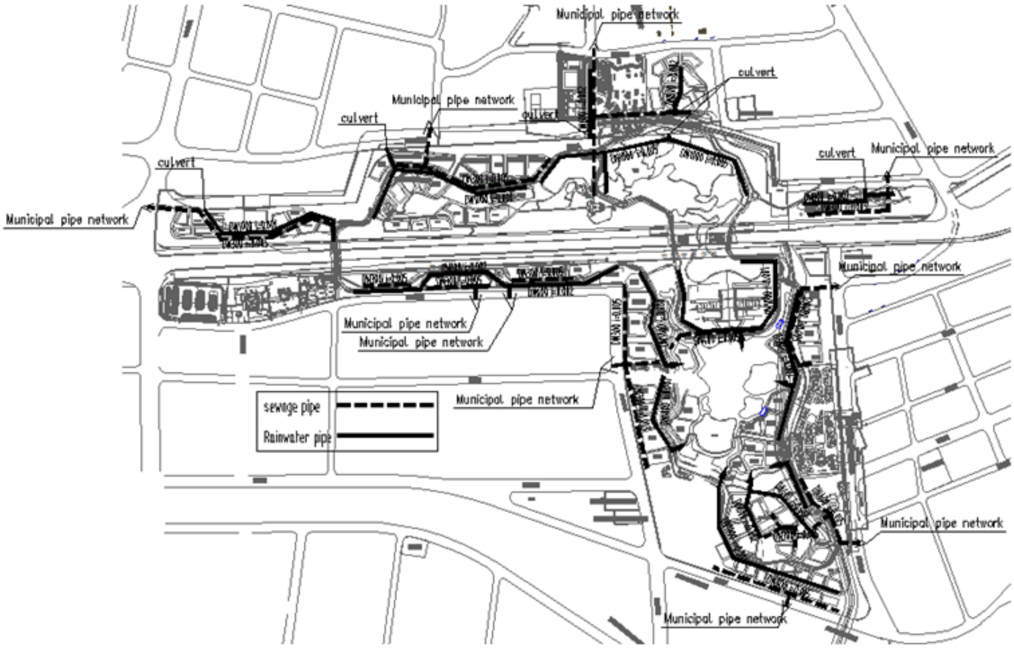


Figure 3: Sewage, rainwater collection and utilization system plannin

3.3 Rainwater collection and drainage system

3.3.1 Calculation Parameters

Storm intensity is using formula of Hankou area

Rainfall duration is different according to each block, and the return period is 5 year.

Runoff coefficient: Landscape land is 0.3, water is 1.0, exhibition park is 0.6, building block is 0.8.

3.3.2 Rainwater quantity

Each block is divided by the catchment area ,the runoff coefficient is determined according to the nature of the use of different plots ,South area rainwater drainage volume is 16451L/s, and North area is14122L/s.

3.3.3 Rainwater Storage

Annual runoff control rate is 70% of this project , the design control rainfall in Wuhan is 24mm, and the effective rainfall storage volume is $55440m^3$。

The low impact development of rainwater system is mainly embodied in the infiltration, storage, collection and reuse of rainwater. Because the green land area is more than 70% area of the garden, the underlying surface is planted soil, permeability is good.

rainwater permeation $Ws=aKJAsTs=41688m^3$。

In the above formula:

Ws—Permeation amount, m3；

a—Comprehensive safety factor，a=0.6；

K—Soil permeability coefficient，K=5.79×10-5m/s；

J—Hydraulic gradient，J=1.0；

As—Effective penetration area，$As=200\times104m^2$；

ts—Penetration time，ts=600s；

The artificial lake water storage volume $V1=Fh=11400\times0.8=9120m^3$。

In the above formula:

V1—Regulating volume，m^3；

F—water surface area，$F=11400m^2$；

h—Regulating water level，h=0.8m；

Other volume of rainwater storage facilities $V2=V-Ws-V1=4632m^3$;

Rain uses gardens manner is to be used. In total there will construct 24 rainwater garden. the regulation and storage capacity of each rainwater garden is not less than V3，$V3=V2/24=193m^3$。

Through rainwater infiltration, artificial lake accumulation, regulation and storage of rainwater garden, the Garden Expo can reach 70% of the total annual rainfall runoff control rate requirements.

3.3.4 rainwater pipe network

The south area is rich in vegetation, and the terrain is surrounded by high and middle low， forming an artificial lake. The rainwater system of south area collects rainwater from the ground, and is discharged into the artificial lake by the ecological barrier. The rain water , which can't gravity directly into the artificial lake, is discharged into the south urban rainwater culvert. Collected rainwater into artificial lake, is not only used for the water landscape ecology ,and also as a source of water after treatment reached urban miscellaneous water quality standards for the park greening, car washing and flushing.

North area is located on landfills, which is contaminated areas, landfills final settlement has not been stable, and it is not conducive to set up rainwater collection facilities , so rainwater system in the north area organization discharges into the city rainwater culvert. Ecological grass ditch is set on part of the northern mountain, it collect s rainwater from mountain and is discharged into artificial lake of south area by third ring connection bridge , used as green water.

3.3.5 water balance

Through water balance analysis which is used contrast for green and washing of collected rainwater. rainfall of south area can be used to meet the requirements of a non-winter season, the actual amount of rainwater available throughout the year, six months can be able to meet the green and syringing. the rainfall reaches the maximum profit value in June, which is 67074m^3, the daily average is about 2236m^3; in December, the rainfall reaches the maximum loss value, for 14865m^3, the daily average is about 496m^3. When the rainwater system at the maximum surplus value , the artificial lake overflow discharges excess rainwater, overflow is designed for 1.5m^3/s; when the rain system at the maximum loss value, rainwater system complements emergency water from the nearby natural lake, the design flow is 100m^3/ h. Artificial lake volume is only about 0.011% of the total volume of natural lakes, and the water abstraction of the artificial lake will not cause significant impact.

3.4 Water ecological purification system

Table 1

Month	Rainfall（mm）	Available precipitation（m^3）	Evaporation（mm）	Waterscape evaporation volume（m^3）	Green, flushing（m^3）	Profit and loss（m^3）	The actual utilization of rainwater（m^3）
1	45	22247	30	1800	28885	-8438	16452
2	50	24719	41	2460	28885	-6626	18280
3	90	44494	67	4020	28885	11589	32903
4	150	74157	91	5460	28885	39812	54839
5	170	84044	114	6840	28885	48319	62151
6	210	103820	131	7860	28885	67074	76775
7	170	84044	136	8160	28885	46999	62151
8	115	56854	123	7380	28885	20588	42043
9	78	38562	99	5940	28885	3736	28516
10	76	37573	74	4440	28885	4248	27785
11	52	25708	41	2460	28885	-5637	19011
12	32	15820	30	1800	28885	-14865	11699
Annual	1238	612041	977	58620	346622	206799	452604
per month	103	51003	81	4885	28885	17233	37717

The Garden Expo function of landscape and green area is accounts for 72.7% of total land area, Non-point source pollution is mainly composed of solid particles, and heavy metals, organic compounds, pesticides and other ingredients is relatively small compared to urban areas. rainwater in the park is relatively clean, after initial rainwater purification and improving the oxygen content of the rain, it can be used as a good source of water for artificial lake. In order to ensure the water quality of the artificial lake, besides above non dynamic ecological measures, some water treatment structures are also be put to use.

The main measures of non-point source pollution control is : ① rainwater garden, ecological stream (Figure

4), ecological grass ditch etc. it can reduce particulate matter content of rain and BOD load by plants, soil interception, adsorption, absorption; ② set ecological trash pool (Figure 5) in the rain estuary, it can further remove solid particles in rain water and contaminants, by the way of precipitation, filtration and absorption of filler graded aquatic plants.

Figure 4: Ecological stream

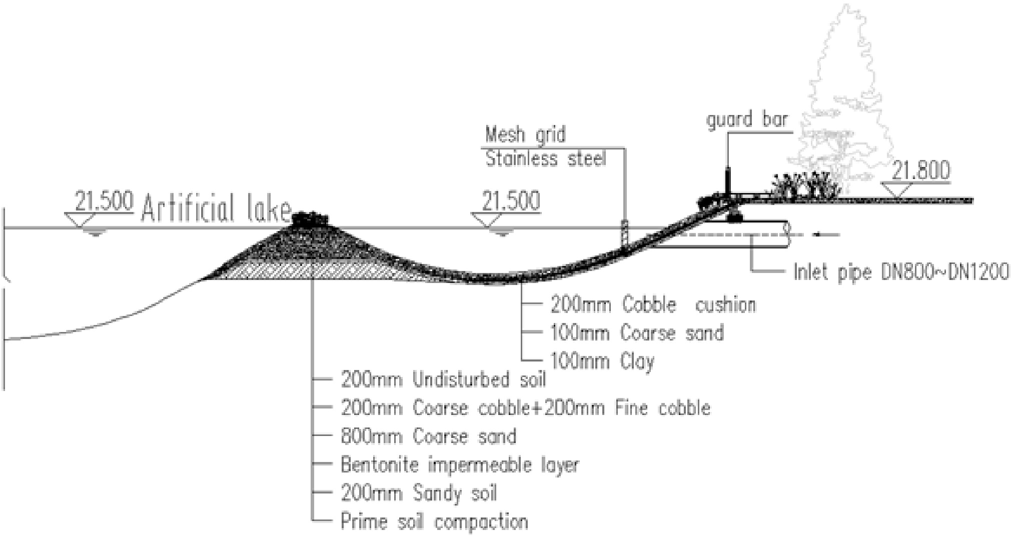


Figure 5: ecological trash pool

According to the natural shape of the landscape of the lake and terrain, it builds artificial dams, which is broad-crested weir, broad crested weir stream state is mainly concerned with the flow, the flow drips under the weir wall at low volume , when the flow reaches throwing flow, stream of water detached from the weir wall was thrown into the air, forming landscape with a waterfall and stream ecology. In order to the requirements of watching, the lights adorn is used in the center of the lake. Waterfalls and fountains in the artificial Lake is not only improved the environment, also increased dissolved oxygen (DO) content in the water activated, and reduced the role of water temperature.

As a proactive measure, STCC sewage treatment and deep purification technology is used to keep the artificial lake water quality. This process is a variety of media aeration biological filter technology, which is using natural materials and waste materials as filler, composite packed bed, through special aeration system in packed bed form alternating aerobic and anoxic and anaerobic environment, to remove nitrogen and phosphorus removal. The process is a natural flow type, full use of submerged retrace BAF structure, the device uses a closed buried, has a smaller footprint, less sludge, low odor and noise pollution and other secondary pollution, is better to handle the relationship with the surrounding environment and water treatment structures.

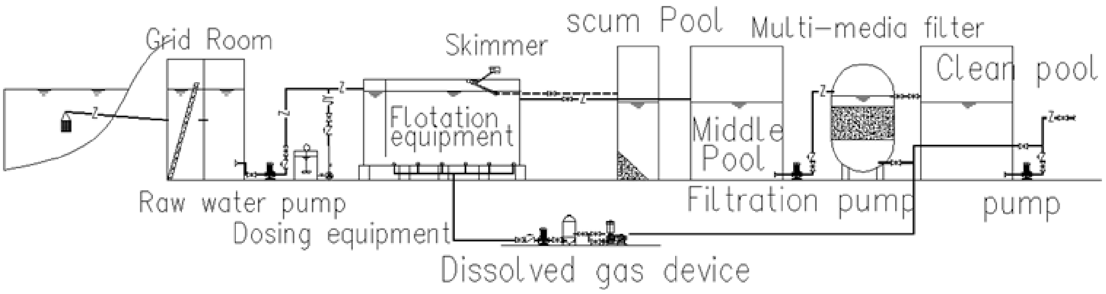
3.5 The artificial lake water system

Artificial lake in south area of Garden Expo uses nearby natural lakes as a supplementary source. Depending on the circumstances of the site, the intake point on the shore is steep, and muddy waterfront, no rocks, the depth of water, there are plants in the coast range 3m, Water abstraction conditions is better out of 3m,becouse of less plants.

According to the amount of water flow and water filling at the first supply to water shortage of artificial lake, water abstraction flow is 2000m^3/d.

Lake Water abstraction process is: natural lake → water abstraction head → Diversion pipe → grid → suction well → pump

Treatment Process is : raw water → raw water pump → flotation device → middle pool → filter pump → filter → disinfection → clear pool



Picture 6: Water treatment process flow chart

Raw water is lifted by the pump up to a flotation device, while adding PAC, PAM agent through the dosing device, the gas is dissolved and released from water, the suspension in raw water was flocculated and rising quickly , then the residue scraping machine remove scum, flotation effluent is flowing into middle pool and the filter pump lifting it into the filter, further removal of suspended solids and other impurities. Raw water quality is Ⅴ class, the treated water quality index reaches 《 The Urban Sewage Regeneration Use of Landscape and Environmental Water Quality 》(GB / T 1981-2002) of ornamental landscape environmental water lake or lake water quality standard.

4. Conclusion

4.1 Through integrated water resources planning, rainwater is used as non traditional water, for the garden green, flushing, washing and other purposes. the total water consumption of Garden Expo is 5451 m3/d, of which the non-traditional water sources are used as landscaping, car washing machine road irrigation sprinkling water ,which is 2264 m3/d, water-saving rate is 41.5%, this project has obvious economic benefit; the utilization rate of non-traditional water such as greening, flushing, car washing, toilet flushing and other can reach 100%, it makes full use of rainwater resources.

4.2 By the way of green rainwater infiltration, artificial lake water admission, rain gardens accumulation, etc, the annual total runoff control rate is more than 70%. this planning has achieved a low-impact development rainwater, reduced rainwater runoff pollution load , mitigating the impact of rainwater discharging to the municipal rainwater network.

4.3 Garden Expo has built a variety of ecological water treatment measures and facilities like rain garden, waterfall, ecological grass ditch, and ecological Trash pool. it will combine with reducing non-point source pollution, controlling artificial lake water quality and landscape design , all this methods are not only full using of water resources, but also supporting the Expo theme.

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Systematic Mapping Study on the Feasibility of Rainwater Harvesting Systems

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Abstract

Introduction and aims: With water scarcity, rainwater harvesting systems are increasingly used as an alternative source of water supply. However, its implantation often is not financially feasible. The feasibility analysis of such investments is made by traditional techniques based on discounted cash flow methods but these methods do not consider the managerial flexibility and have limitations on the uncertainties arising from variation in rainfall and in the readjustment of the water rates. Thus the objective of this study is to investigate the methods used to establish the feasibility of rainwater harvesting systems, identifying the trends of current researches. Method: It was performed a Systematic Mapping Study, an evidence-based paradigm tool. Initially the research strings have been defined, then it was made a search of articles in databases Engineering Village, Scielo, Scopus and Web of Science. The relevant articles were selected and, finally, an analysis of bibliometric datas was conducted. Results and conclusion: The majority of the studies was performed in the last ten years and it was verified that to determinate the rainwater harvesting systems feasibility, frequently it was used discounted cash flow methods such as net present value, internal rate of return and payback. Some articles seek to incorporate uncertainties with an analysis of sensitivity and only one study uses the real options analysis to define the investment feasibility. Contributions: The Systematic Mapping Study provided a viewing of current literature and contributed to the identification of areas for future studies.

Keywords

Rainwater Harvesting; Feasibility; Systematic Mapping study.

1. Introduction

Water conservation is an important issue towards sustainable buildings and the basic strategy to face the current shortage of water involves the use of alternative sources, demand management and an efficient use of water (SAUTCHUK et al., 2006). Among these several options for water conservation in buildings the rainwater harvesting (RWH) systems are very attractive (VARGAS-PARRA et al., 2013). This fact is due to the low energy consumption during the operating phase, the simplicity of construction with common materials, the use of simplified treatment and the different possible uses of this resource. This technique is also valuable for urban planning because it mitigates flooding by reducing the volume of rainwater that is intended for storm sewers and the demand for potable water.

Even if the environmental benefits are considered more valuable than the savings generated by these systems, the financial feasibility remains the main item for decision making in deployment of a RWH system, especially in developing country where resources are scarce. The financial feasibility of the implementation of a system should precede the construction, and this is the main obstacle to the use of RWH systems (ISLAM et al, 2010; KIM et al, 2014; MATOS, 2010), as construction, maintenance and operation costs are normally uncertain.

To determine the economic feasibility of a RWH system, it must be established the demand for non-potable water, the supply of rainwater, the volume of the reservoir, system efficiency, the costs involved, the water tariff and some economic variables such as required rate of return, inflation and the adjustment of the water tariff. Then, it is selected some economic evaluation method of investment that seeks to maximize the value of a project through decision making processes (COPELAND; ANTIKAROV, 2001).

Economical evaluations of RWH systems are usually based on traditional methods of Discounted Cash Flow as payback, Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit-Cost Ratio (BCR) (Campos, 2004; FARRENY et al, 2011; Gomes et al, 2010; MARINOSKI et al, 2008; MOREIRA NETO et al, 2012; ZHANG et al, 2009).

Often,these techniques do not lead to better strategic decisions (YOSHIMURA, 2008) since it evaluates the uncertainty by a discount rate that is set arbitrarily, and it does not consider administrative flexibility.

Investments in RWH systems are characterized by uncertainties that comes from changes in the rainfall volume, in the demand for rainwater and also in the readjustment of water rates, values that become more unpredictable with climate change. Thus, some studies began to perform a sensitivity analysis in order to determine the impact of different variables that can intervene on the viability of an investment in RWH systems (CAMPOS et al, 2007; GOMES et al, 2010; ISLAM et al, 2010; SACADURA, 2011).

However, by evaluating the sensitivity to different design parameters still does not consider the managerial flexibility that can transform the uncertainties in strategic opportunities from the introduction of the decision-making process during construction. The flexibility, according to Minardi (2000), maximizes the opportunity of a worthwhile investment as it increases the potential gains and limit losses from the management of initial expectations.

In an attempt to correct these flaws present in traditional methods of economic evaluation, it began to be used an alternative approach, the Real Options Analysis (ROA). According to Dias (2014) this is a modern method of investment analysis applied to real or tangible assets under technical uncertainty and market conditions.

This technique makes the option pricing by establishing a value for managerial flexibility, thus enabling an adjustment of future actions of a company according to the changes that it may occurs during its lifetime. Then an investment that had no economic return when assessed by traditional methods can become viable.

It can observed many applications of this method in various fields, especially in those with high volatility. General water supply systems shows considerable volatility due to the unpredictability of rainfall pattern and water tariff, ROA is already used to determine the feasibility of large supply systems. This method can also be applied for smaller systems such as RWH systems, Kim et al. (2014) conducted an economic evaluation of a system through the ROA and there was a reduction in the value of the NPV although it has remained negative.

Thus, this paper seeks to identify which methods are usually used to calculate the economic feasibility of RWH systems and the results of these analyzes. Because, as mentioned, the use of traditional methods can make an investment that should be considered viable to be discarded.

2. Methodology

One Systematic Mapping Study (SMS) was performed based on the economic evaluation methods used for a better understanding of how the analysis of the viability of RWH systems are performed. SMS is a process of searching for literature that provides an overview of a specific area of knowledge from the identification and description of the amount of studies, the frequency of publications, distribution of research in databases, the methods used and the available results. With this categorization, it is possible to verify the existence of studies on a given topic, as well to detect gaps in knowledge and areas for future studies. (BRERETON et al, 2007; LOPEZ-HERREJON et al, 2015; RUIZ; GRANJA, 2013)

It was adopted a procedure to perform the SMS already used by Ruiz and Granja (2013) and Costa et al. (2014), that consists of the stages shown in Figure 1. First, it was set the subject of research that would answer the following questions:

- What methods were used to analyze the feasibility of RWH systems?
- What considerations were adopted in these analysis?
- The RWH systems are considered economically feasible?

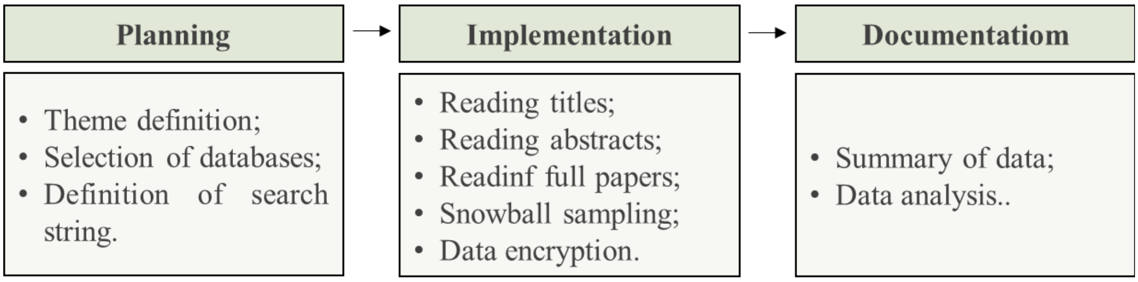

Figure 1 Stages of Systematic Mapping Study (COSTA et al., 2014; RUIZ; GRANJA, 2013)

The search for publications was conducted in the following databases: Engineerig Village (Compendex), Science Direct, Scopus and Web of Science. So it was determined keywords to find publications related to the topic under study. From the initial analysis of some relevant articles it was found that the majority uses the term “rainwater harvesting” in relation to rainwater utilization systems. However, some articles used the term “rainwater use” or only “rainwater”, so this latest term was defined as one of the strings once it includes the others ones. It was also found that there are numerous terms related to economic evaluation as: “economic feasibility”, “financial analysis”, “investment feasibility”, “payback period”, “net present value” and “sensitive analysis”.

Once “feasibility” was the word found most frequently after some testing, it was adopted the following search string: (Rainwater) AND (Feasibility). It should be noted that these terms were searched for in the title, abstract and keywords of existing publications in databases. It was not made any limitation in relation to the area of knowledge since it was observed that some papers were in multidisciplinary studies category. There was also no restriction on the publication year, it was considered articles of all years available in databases.

After exclusion of double texts, the total number of items was found. Reading the titles and subsequently the abstract and complete texts has been done to discard the irrelevant items to defined issues. The articles in another language and those who were not possible to have free access to full text through Capes Journal Portal also were excluded.

Thus, articles whose theme was the feasibility of rainwater utilization for agriculture, studies on the influence of water quality in sustainable systems, works related to the benefits of implementation of systems for infiltration of rainwater and socio economic analysis of RWH systems deploying were excluded from the analysis.

The relevant articles for this study published in CIBW062 from 2006 until 2014 also were included, the selection of these publications was conducted from reading the titles and subsequently abstracts and full papers. A snowball sampling has been made, with the inclusion of new items to the set of publications adherent to the theme from the analysis of the references of selected articles.

After reading all articles an evaluation of bibliometric data was developed and year of publication, research strategy, place of study and more frequent journals were evaluated. Furthermore, characteristics of the studies as the viability calculation methods used and considerations adopted in studies also were anlyzed.

3. Results

From the indicated selection criteria, 28 adherent publications to the research were selected, as illustrated in Table 1.

Table 1 Papers criteria selection

Papers previously selected	463
Papers with duplicity	-215
Reading titles	-112
Reading abstracts	-92
Full papers not available	-12
Reading full papers	-11
Papers published in CIBW062	+3
Snowballing sampling	+7
Total adherent articles	30

At Science Direct database was found the smallest number of items in the initial search, however most of them proved to be adherent to the subject of this study. While most of the articles obtained from the search string in other databases were excluded during the procedures for withdrawal of non-relevant articles, according to the results shown in Figure 2.

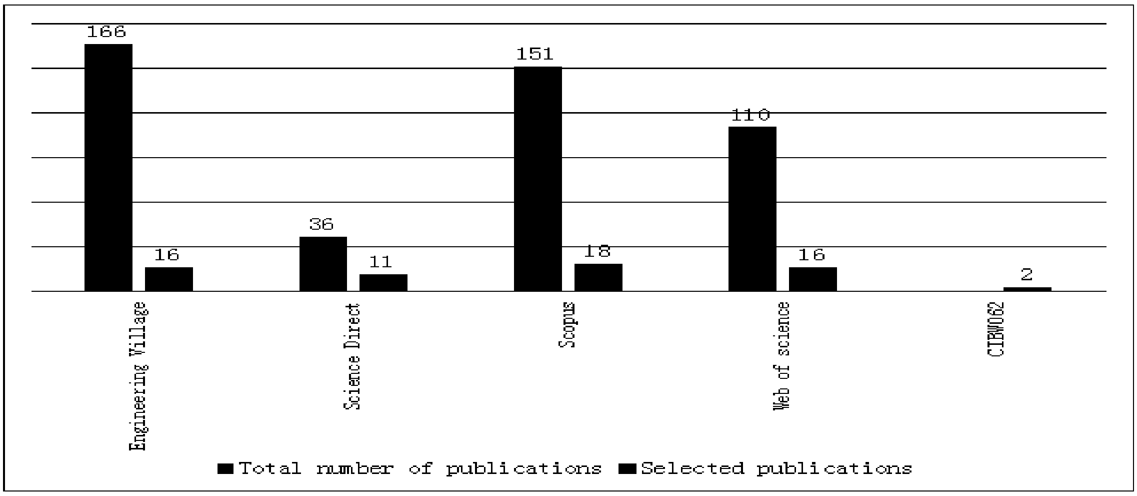

Figure 2 - Number of publications in each database

Figure 3 shows the distribution of publications in each year. It is possible to see that the issue studied is recent since despite it doesn´t have been made no restriction on the period of analysis, the first relevant article was published in 2000. In recent years there has been an increase in the concern about the viability of RWH systems which was probably caused by water scarcity in many areas of the globe.

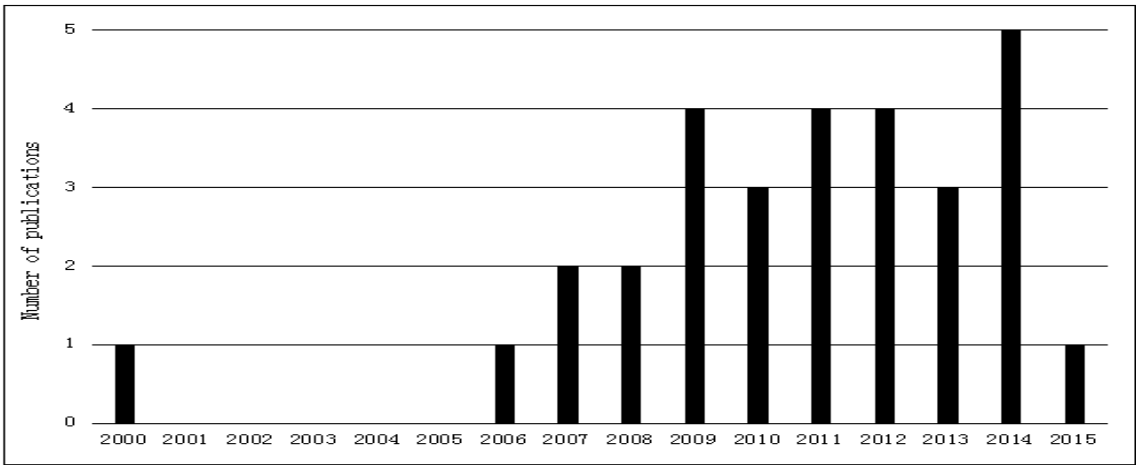

Figure 3 - Distribution of publications per year

From the distribution of the countries where each search were performed (Figure 4) it was found that Brazil is the country with more studies related to the feasibility of RWH systems deployment, followed by Australia, England and Portugal.

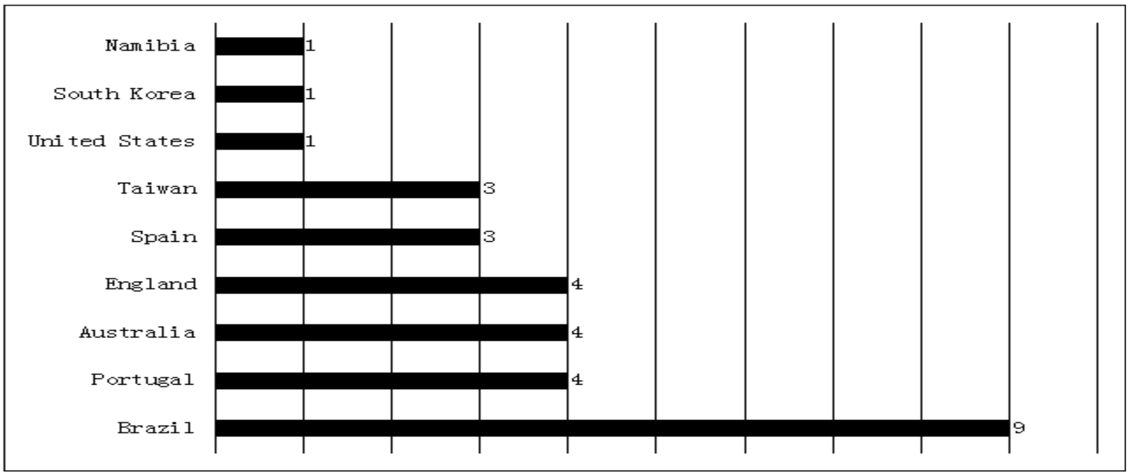

Figure 4 - Distribution of publications per country

A classification of publications regarding the economic viability approach was performed, as identified in Table 2. The most relevant articles for this research were case studies that verified the feasibility of RWH S deployment in a specific building, in several buildings with different locations or in different buildings from a single location. One case studied assesses the feasibility of a system in use comparing with the value set in design, and other determines the feasibility based on the construction of a rainwater harvesting prototype.

Publications that compare the sizing methods reservoir by calculating the viability of each system were also selected. Some studies checked which water conservation technique is the most viable. Others propose a procedure for determination of viability from the evaluation methods already mentioned.

Table 2 Approach of publications

RWH systems viability	21
Case study of a single building	9
Case study of several buildings	10
Case study of an existing system	1
Use of prototypes	1
Economic feasibility to aid in decision-making	**6**
Comparison of sizing methods	1
Comparison of water conservation techniques	5
Technical proposal to assess the feasibility os RWH systems	**3**

The method used in each study to conduct an economic evaluation RWH systems was analyzed, as identified in Figure 5. It can be noticed that the number of times that the methods were employed does not match the total of items considered relevant because many studies use more than one technique.

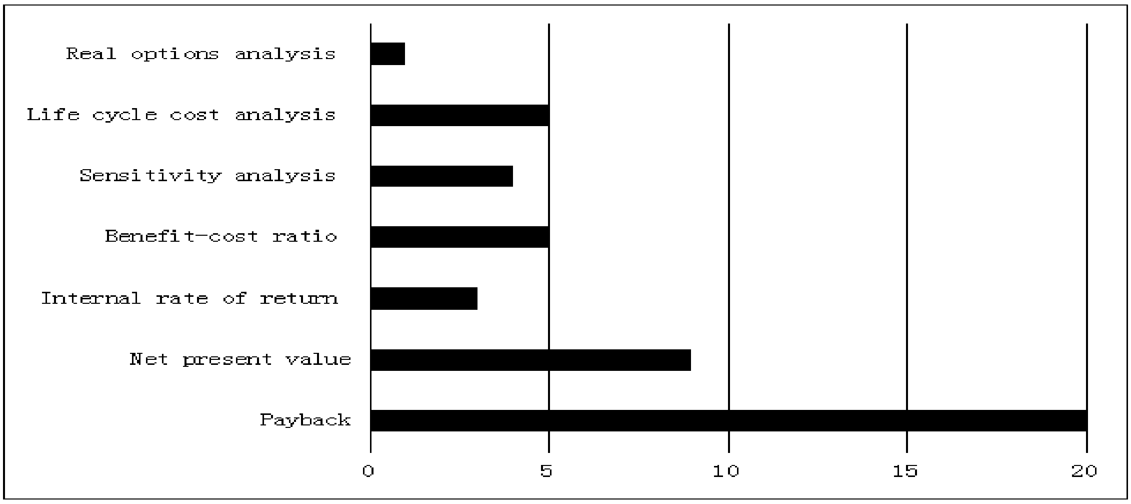

Figure 5 - Economic evaluation methods

It confirmed that the feasibility of RWH systems is usually defined by the use of traditional methods and the payback is the technique most used and the IRR is the one that is the least used. This is due to the simplicity application of payback; however, this indicator shows some flaws once it doesn´t consider the period after the recovery of the initial investment and certain difficulty in defining until how many years the investment is regarded feasible. Moreover, it is not considered an appropriate technique to compare more than one investment option and this is the analysis made by many articles.

Only the study by Kim et al. (2014) in South Korea used real options analysis as economic evaluation method for RWH systems, what indicates a potential topic for future studies. As this is the only method that assesses the uncertainties and the administrative flexibility, ROA would be the most appropriate technique for such assessments.

Table 3 Review of the papers about economic feasibility of RWH systems

Reference	Location	Method	Results	Water savings (%)	Uses	Rate of return	Lifetime (years)	Price of water	Increase of water price
Chilton et al. (2000)	Greenwich,	Payback	4 to 12 years	18,5 to 23,7	Toilet flushing				
	England								
Ghisi et al. (2009)	Brasília,	NPV	-4155,45 to 24744,64 R$	9,2 to 57,2	Car wash	0,01	15		
	Brazil	Payback	31 to 165 months						
Zhang et al. (2009)	4 cities,	Payback	8,6 to 21,9 years	7 to 32,3	Buildings	0,065		0,81$AU/ m³	
	Austrália								
Farreny et al. (2011)	Granollers,	NPV	-868304 to 447599 €	35,7 o 43,9	Laundry	0 e 3%	60	1,12 e 4 €/m³	0,05% per year
	Spain	Payback	27 to 51 years						
Morales-Pinzón et al. (2012)	16 cities,	NPV	-12839 to 38424 €		Laundry	0,05	50	0,85 a 2,65 €/m³	
	Spain	IRR	-21 to 15%						
Moreira Neto et al. (2012)	Confins,	NPV	-1057200,24 to 1022141,17 US$	66 to 100	Toilet flushing, cleaning and irrigation	0,01	30	2,36US$/ m³	6,00% per year
	Brazil	Payback	1,4 to >30 years						
Ghisi; Schondermark (2013)	5 cities,	Payback	1,5 to >30 years			0,005			
	Brazil								
Yoshino et al. (2013)	Belém,	NPV	-36526,13 to -39096,14 R$	16,53 and 30,88	Toilet flushing	13,28% per year	20		
	Brazil	Payback	more than 20 years						
Morales-Pinzón et al. (2014)	16 cities,	NPV	612,1 to -2236,9 €	8 to 96	Laundry	0,05	50	0,85 a 2,65 €/m³	3,00% per year
	Spain	Payback	5,5 to 204 years						
Kim et al. (2014)	Jeonju	ROA	Option value: US$9980,00		Toilet flushing, cleaning and irrigation	0,0514	35	$ 1,26	5,09% per year
	South Korea								
Silva et al. (2015)	Porto and Almada,	Payback	2,271 to 27,035 years		Toilet flushing, cleaning and irrigation		50		
	Portugal								

According to Table 3 it can be confirmed that most of the selected publications apply more than one method of economic analysis in their studies. Through an observation of the results, it can verify the more than one scenario is used to determinate the feasibility, thus, variations of economic indicators are obtained instead of a single value. This happens due to the attempt to clarify how the different variables can change the economic viability of a system in the same way that happens in a sensitivity analysis. In all the articles that happen this, it was not mentioned that would be performed this analysis.

Despite the flaws already commented, payback method is still used. Some studies accomplished in recent years verify the feasibility using only this technique (GOIS et al, 2014; SHAH et al, 2013; SILVA et al, 2015.). However, part of recent work uses the payback period associated with another economic evaluation method (GHISI et al, 2014; MORALES-PINZÓN et al, 2014; YOSHINO et al, 2013)

The economy of drinking water generated by the system implementation in the studies analyzed variations of lower values than 10% to 100%, as shown in Table 3. However, the largest percentage reduction in consumption does not necessarily indicate greater viability of systems. An increase in the volume of rainwater tank causes a greater increase in the cost of installations that in savings generated by the reduction of drinking water consumption (SANTOS; TAVEIRA, 2013).

Articles included different uses of rainwater and consider public buildings, residential and commercial. So it is ascertained there is not an application that is supposed to be more viable than others. Only in domestic and small systems, which normally has low demand, it is expected that the economic benefits are insignificant (GHISI; SCHONDERMARK, 2013; SANTOS; TAVEIRA, 2013). Therefore, in buildings with low demand the RWH systems must be constructed seeking only the environmental benefits.

The rate of return as well as the lifetime of the system show a great variability, as shown in Table 3. According to Khastagir and Jayasuriya (2011), the higher the rate of return used is, more viable is the system. The lifetime values established in Brazil are lower than in others countries, while in another countries this parameter varies from 25 to 60, in Brazilian studies are adopted values from 15 with a maximum of 30 years.

Water tariffs can not be compared since they are in different currency but it can be ensured from the low values that water is subsidized in the countries where the studies were conducted. The value of the water tariff tends to increase in a higher rate than inflation (SILVA et al., 2015) and the consideration of these changes in the publications is very variable. Some articles assume a single inflation rate for water, energy and other costs, others consider that the rate of return already incorporates this inflation in water supply systems and adjustments are also adopted in other jobs. The selection of such values can influence the results of the feasibility due to value of water interferes in the economic evaluation, the higher the cost of water the most viable is the system (KHASTAGIR; Jayasuriya, 2011).

4. Conclusions

According to the analysis of data obtained in SMS it is checked that the economic evaluation of RWH systems is done through traditional methods, primarily by payback period. A gap in the use of real options analysis has been identified, and this is the only technique that evaluates the uncertainties and flexibility, indicating a need of the development of research on the applicability of this technique to RWH systems.

However, a tendency in the increase of the amount researches reflects the current concern about water conservation and demonstrates an effort in trying to show that beyond the environmental gain the rainwater harvesting can generate economic benefits.

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Developing a Whole–systems Approach to the Simulation of Connected Flow–routing within a Property

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Abstract

There has always been a requirement to better understand, through modelling, the flow conditions of the property-level water supply and drainage system. In many situations, the conventional approach has been to review the different components of the system, mainly categorized as water supply, rainwater discharge and wastewater discharge systems, in isolation. But due to the increasing pressure on water conservation, decentralized water saving options such as rainwater and greywater recycling, which can be seen to interconnect system components, are being integrated at the domestic scale. Little attention has been given to the assessment of the overall impact of this interconnectivity, which if properly understood, can illustrate how different water-saving options perform in terms of attenuation and ‘residence time’.

This paper illustrates the modelling approach developed for a complete flow route within a property-based system. The significance of using a whole-systems modelling approach, which then allows the simulation of flow attenuation and identification of changes that can assist in estimating the residence time of water, either from rainfall or mains water, has been highlighted.

Keywords

Rainwater, drainage, recycling, residence time

1. Introduction

There has always been a requirement to better understand the flow conditions in a property level water supply and drainage system. Such understanding of property level water flow conditions is necessary for specifying system design guidelines and integrating innovative solutions for sustainable water consumption while managing the resulting system performances. Hence simulation methods have been developed to analyse and design water supply and drainage systems for properties. In many situations, the conventional approach has been to review the different components of the system, mainly categorized as water supply, rainwater discharge and wastewater discharge systems, in isolation.

With the increasing pressure on water conservation, decentralized water saving options such as rainwater and greywater recycling, which can be seen to interconnect the system components, are being integrated at the domestic scale. Hence integrating timely management practices of using and reusing water at the property level is a necessity. Reviewing the system components and selecting water saving options based on a holistic approach that represents the impact of interconnected system components creates a platform to achieve the maximum benefits and identify potential limitations of these options. Therefore integrated modelling approaches are increasingly being developed, particularly for evaluating efficiency of water saving options, by computing the water balance between system components, often in daily time steps, not only confined to the property level but also in the wider urban scale [1].

In the same way, understanding the property level flow conditions will need to be revised to represent the modifications initiated through the use of water saving options, and based on flow routing principles adequately detailed for reviewing flow conditions and system performance. Furthermore, such an approach needs to reflect the dynamic behaviour of water inflows to the property and the dynamic pattern of water usage inside different components of the system. It can then assist in understanding the dynamic response of the total system due to the individual modifications added to system components usually perceived as performing remotely.

Flow attenuation and the resulting residence time of flows in the property is a key feature of this dynamic response. A whole system simulation approach that enables connected flow routing through the property can illustrate how individual design modifications, sited at different locations of a property, attenuate water flows and impact residence time of water volumes routed through different flow paths of the property. Hence this approach will facilitate the understanding to exploit different water-saving options to best achieve water efficiency while balancing dynamic flows to enhance system performance in terms of attenuation and residence time.

Thus, two stages of this approach have been identified; developing a whole system simulation approach for connected flow routing through a property and understanding how different water saving options can impact flow attenuation and hence residence time of water. In this paper, an inflow to the system, routed through a selected single pathway of the system and conveying rainwater to the downstream end of a property has been illustrated.

2.Property Level Water Usage

It is necessary to understand interconnectivity of system components to facilitate complete flow routing through the property. A frame work was proposed illustrating possible interconnections for flow transition within a domestic property taking into consideration the importance of holistically viewing a property-based water management approach, Figure 1: Framework illustrating component connectivity (adapted from Jack 2008).

Rainwater and potable water supplied through a mains connection have been identified as the common inflows to the system. It is worth noting that neither of them can be represented using steady flow profiles. Even though steady rainfall intensities are recommended and used for some design purposes, rainwater inflow to the property has event based dynamic flow intensities, that are becoming increasingly unpredictable due to the impacts of climate change. Conversely, mains water supply depends on water demand within the property which can be altered due to the implementation of water saving options and efficient water consumption. The nature of outflows of a property will depend on its specific drainage arrangement and mainly comprise one of the options shown in Figure 1; ie combined or separate (foul and rainwater drainage separately) sewer systems. In addition, absorption through pervious areas and evaporation provide alternative ‘pathways’. The links joining these inflows and outflows illustrate the possible flow routes through a property along which water inflows may be stored, attenuated or transformed to the relevant outflows as a result of the water usage pattern in the property.

This framework is based on the system being bounded by a property curtilage and includes internal and external building pipe arrangements and a local underground drainage network. As it represents only the basic system components and their interconnections, all potential pipe work arrangements are not included. A more in-depth discussion of this framework, on the interactions between components and conceptual flow routing along different flow paths is provided elsewhere [2].

3. Approach for Whole System Flow Routing

The two main stages of this study are;

1.Development of the simulation of flow routing through different flow paths of the system, reflecting the dynamic interactions, transformations and attenuation of flow conditions.

2.Development of a method that enables the ‘tracking’ of water volumes along their respective flow paths to quantify the impact of flow attenuation of different water saving options on residence time.

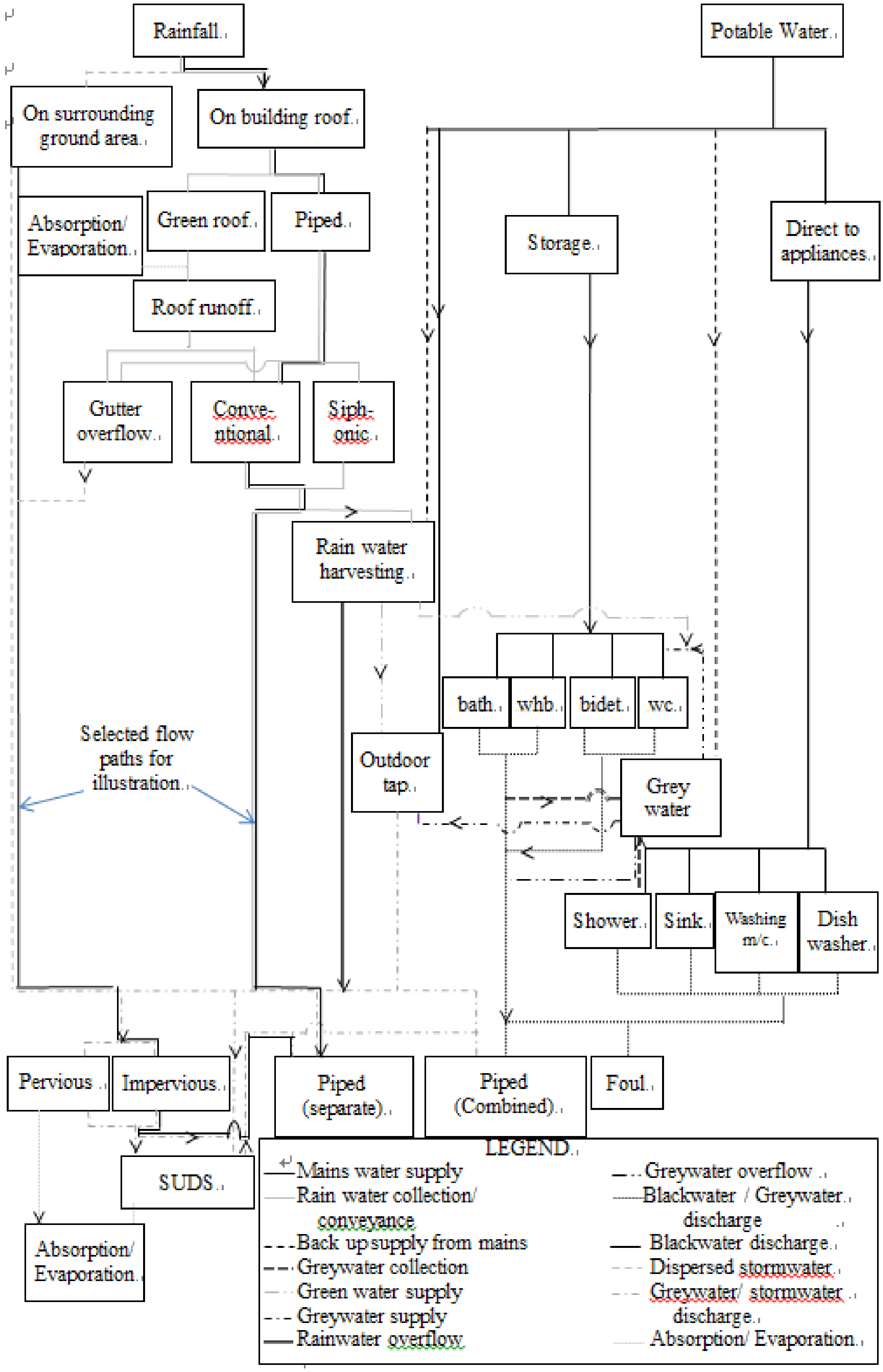


Figure 1: Framework illustrating component connectivity (adapted from Jack 2008)

This approach can then be used to identify components/locations in the system with potential flow retention capacities that enable the most effective modifications to the system for efficient water consumption and system performance. The framework illustrated in Figure 1 is referred to as the basis for identifying potential system components and flow routes.

Numerical models developed at Heriot-Watt, for simulating the dynamic response of different system components - rainwater discharge and wastewater discharge components, referred to in this text as ROOFNET and DRAINET respectively, are used in developing the whole system flow simulation approach. Both of them are based on the Method of Characteristics technique and have been successfully used to understand and improve system performance. However, these models lack the provision for integrating water saving options, encompassing their impact on the dynamic response of the system and operating together to represent flow interactions. For example, the recycling of rainwater through a rainwater harvesting system has so far, not ben presented. The first stage of the proposed approach will address this restriction. Furthermore, though the models can simulate the time-dependent response of a system and the user can obtain flow conditions as location-specific output results, a methodology is required to enable information on the time dependent flow along the respective flow routes, for the purpose of quantifying the impact of flow attenuation on residence time. This purpose is the objective of the second stage of the approach.

4. Developing the Simulation of Flow Routing

The development of the simulation approach for connected flow routing through the whole system is discussed in this text by illustrating a flow path extracted from the developed framework Figure 1, indicative of a complete route for the discharge of rainwater captured at the roof surface and from the surrounding area.

All the basic elements of a rainwater drainage system are included in this straightforward example. The discussion herein presents the development of the simulation approach by modifying the previous version of the ROOFNET model.

4.1 Simulation of flow routing through the property

At the first stage, the ROOFNET model was modified to allocate provision for integrating water saving options, although not all are included in this example; particularly for merging a rainwater harvesting system which is directly related to the rainwater drainage system. It is worth noting at this point that the structure of the ROOFNET model performs as two components.

The roof and area drainage component simulates flow conditions from the rainfall catchment surface of the property, either from the roof surface and/or surrounding areas through to the point of entrance to the property level local underground drain system. It can account for unsteady flow conditions within gutters and both free and full-bore flow conditions related to conventional (gravity driven) and siphonic roof drainage systems, based on Method of Characteristics technique. A comprehensive discussion of this calculation is provided elsewhere [3]. A simple volumetric approach is used to calculate runoff from the surrounding areas. The local drainage component is run as the second module. It can simulate the flows collected from the rainwater downpipes and gullies of the surrounding areas to the boundary of the property level local underground drainage system. Hence the only inflows to this component of the model are outflows from the downpipe network and the surface area runoff via gullies. For these, complete flow hydrographs for the total simulation period for both are known from the results of the simulation in the roof and area drainage component of the model. During the calculation of the flow routing within this local drainage network, starting from the inflow pipes connected to the exit of the downpipe network and/or to the gullies of the surface area, the flow inflow hydrograph related to the total simulation period is translated from the upstream of the each pipe to its downstream, and this procedure is repeated up to the last pipe of the local drainage network at the property boundary [4].

Property level rainwater harvesting systems commonly comprise the underground rainwater storage tanks with tank overflows connected back to the local drainage system. In such scenarios, the local drainage system has to incorporate overflows from the storage tanks where this flow depends on the inflow to the storage tank and the available storage volume. Hence the storage tank overflow acts as an additional inflow to the local drainage system, for which the flow hydrograph can only be established during the flow routing through the local drainage system. The previous version of the local drainage component of the ROOFNET model is unable to simulate the flow conditions in such scenarios due to its sequence of calculation. Hence only the local drainage component of the model was modified as presented in the following text to enable flow routing through the local drainage component whilst integrating a rainwater storage tank. Modifications to the previous version of the ROOFNET model were done on its FORTRAN software platform.

With reference to the same pipe layout illustrated by Wright and Jack 2012 in Figure 2, the sequence of calculation for simulating flow conditions within the local drainage system was modified relative to the previous version as follows:

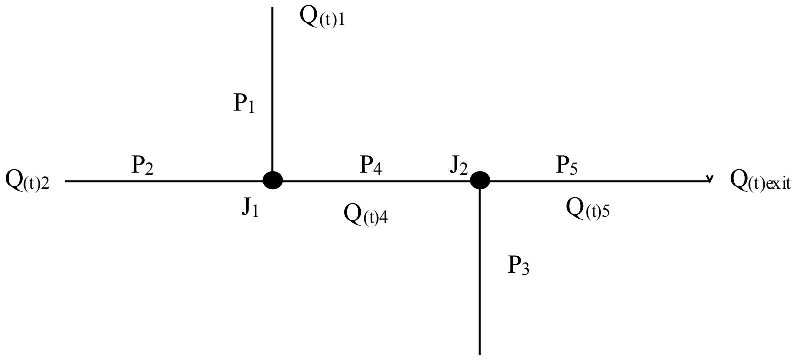
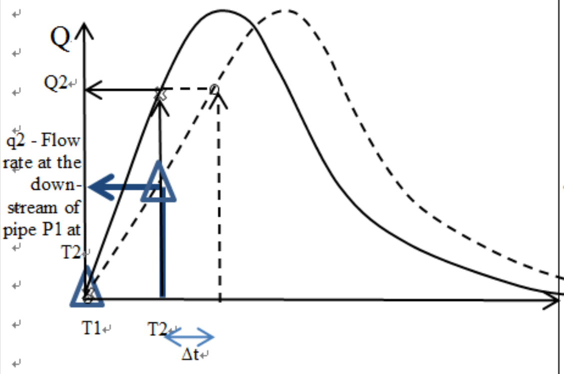
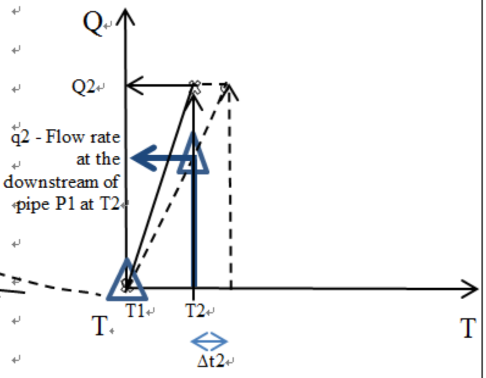


Figure 2- Pipe layout (adapted from Wright and Jack 2012)

Previous version of local drainage component [4]	**Modified local drainage component**
-The hydrograph of each inflow pipe (for P1- $Q(t)_1$) is analysed and modified accounting for full-bore capacity calculated from the Manning equation. -From the modified hydrograph, modified-mean discharge is calculated from the total hydrograph for each inflow pipe. -Assuming steady flow conditions, relevant modified-mean flow depth is obtained from the modified-mean discharge. -Modified-mean flow depth is used in the Manning equation to calculate mean flow velocity of the inflow hydrograph for the total period of simulation. -Using mean flow velocity, mean travel time (Δt) of the inflow hydrograph, to route from upstream of the pipe to the next downstream junction is calculated. -The inflow hydrograph is translated to the junction J1 (end of the pipe P1) adding Δt to the time base of the hydrograph. *Ex: Q1 flow rate at the upstream of pipe P1 at T1, is assigned to the downstream end of the pipe P1 at a time T1+Δt, Q2 flow rate at T2 is assigned to the downstream at a time T1+Δt.* -For the purpose of maintaining uniformity in presenting output results of all pipes and continuing the flow routing for the subsequent pipes, flow rate at the required time steps (at T1,T2), are interpolated between known points. *Ex: At T2- flow rate q_2 at the downstream of P1 is interpolated between (Q1, T1+Δt) and (Q2, T2+Δt)* -Inflow hydrograph for P4 is the combined translated hydrographs of P1 and P2. Then the same procedure is repeated for P4 and all successive local drainage pipes.	-For P1, the inflow rate at the initial time step (Q_1 at T_1), is checked for its full-bore condition and if exceeded, the flow rate is modified to the full-bore flow rate. -Using the modified flow rate at the time step (at T_1), the modified flow depth and modified flow velocity (V_1) is calculated using the Manning equation. -From the modified flow velocity (V_1), travel time to the end of pipe (Δt_1) is calculated. -The modified flow rate Q_1 is translated to the junction J1 (end of the pipe P1) adding the Δt_1 to the time base. *Ex: Q1 flow rate at the upstream of pipe P1 at T1, is assigned to the downstream end of the pipe P1 at a time T1+Δt₁.* -For the purpose of maintaining uniformity in presenting output results for all pipes and continuing the flow routing for the subsequent pipes, the flow rate at the required time steps (at T1), are interpolated between known points. -This procedure is repeated for all inflow pipes. -The inflow rate for P4 is calculated as the combined translated flow rates of P1 and P2 and the same procedure is repeated to translate its upstream flow rate to the downstream of P4 and it is repeated for all subsequent pipes. -The whole procedure is repeated for the next time step T2 starting from the first inflow pipe P1 and repeated for

Hydrograph points at the upstream of pipe- ⊗ Translated hydrograph points at the downstream of pipe- ○ Hydrograph points at the downstream of pipe (at required time steps)- △  Hence in one step, the *total flow hydrograph* at the upstream of a pipe is translated to the downstream of the pipe by a time shift (for one hydrograph, same Δt at each point) necessary for the travel time and this is repeated for all the pipes.	all pipes. *Ex: For P1, Q_2 flow rate at the upstream of P2 at time T2 is assigned to the downstream at a time T1+Δt_2.*  Hence, the *flow rate* at the upstream of a pipe is translated to the downstream of the pipe by a time shift (in one hydrograph, Δt_i at i^{th} point), this is repeated for all the pipes at one time step, and then repeated for the successive time steps.

Although mean flow parameters have been used in this approach to simulate flow conditions in the local drainage system, translating flow conditions to account for the travel time along each pipe can be considered as a reasonable approximation for representing the flow interactions that take place in the local drainage network [4]. Modifying the calculation sequence of the flow simulation in the local drainage component in order to 'translate flow conditions from upstream to downstream at every time step', has enabled the integration of rainwater storage tanks in the system and combine its function and overflow interaction during the simulation of flow routing back into the local drainage system.

4.2 Quantifying the impact of flow attenuation

During the second stage of developing the whole system simulation approach, it was necessary to process the location specific output results of the numerical simulation models in order to quantify the impact of time dependent flow interactions and attenuation on the residence time of inflow water, relative to their flow paths.

In relation to the example used in this text for the simulation of the discharge of rainwater flow through a property, the ROOFNET model provides output results of flow conditions at different locations in the property (ie at the end of roof, along the gutter, and at the downstream end of each downpipe and local drainage pipe) as flow-time (Q-T) profiles. But in order to understand the continuous time dependent progression of the inflow along their respective flow routes, output Q-T files at different locations have to be merged and with reference to a unit flow volume, each flow volume entering the property is identified at every location where flow conditions are known, to record their arrival time. As the simulation of flow routing has been carried out by numerical models that account for the dynamic response of the system, the output results will represent the impact of flow attenuation through the system. This procedure assumes that the flow along the each route through the property is continuous and any loss of flow during flow conveyance through the pipe system is insignificant.

This is achieved by calculating the cumulative flow volume passing each location from the available Q-T files and then referring back to the flow time of each unit volume. In the scenario of merging of flow routes at a pipe junction, flow rates are not directly assumed to be in steady flow conditions. The flow hydrographs are translated from the upstream to downstream end of the pipe by a time shift, to account for the travel time through it. Hence the total flow from the upstream of the junction at one time step is not represented at the downstream of that particular pipe, at the same time step, in the output Q-T files (Figure 3- Schematic of inflow at pipe junction and hydrograph translation). To process results from the Q-T files for establishing the information on the flow time of each flow volume from the upstream of the pipe through to the downstream, the downstream flow is considered to be proportionate to the upstream flows. It is assumed that the average flow at the downstream pipe-end of a junction share the same ratio of the upstream flows of the junction, at one time step, which is often in the range of few seconds.

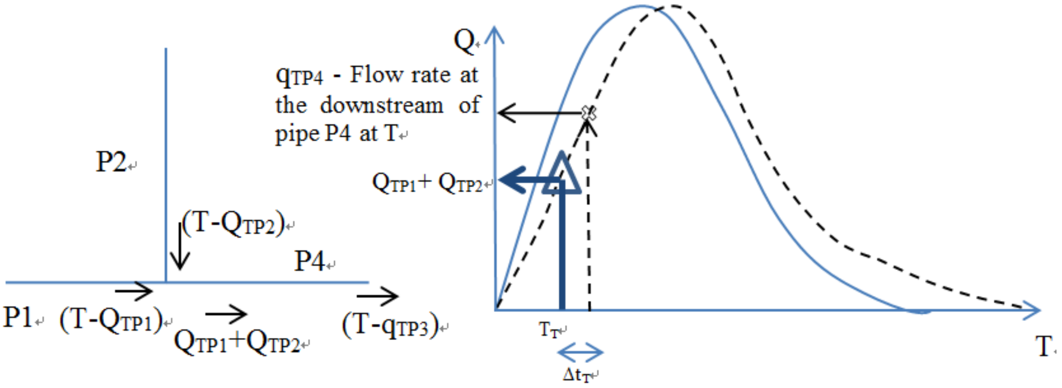


Figure 3- Schematic of inflow at pipe junction and hydrograph translation

Hence for calculation, a proportionate flow profile (sub- hydrograph, Q-T file) for each upstream flow continuing to the downstream end is obtained at the downstream junction. Then the same procedure is iterated at every location, and repeated by calculating the cumulative flow volume from the Q-T files and then referring to the flow time of each unit volume.

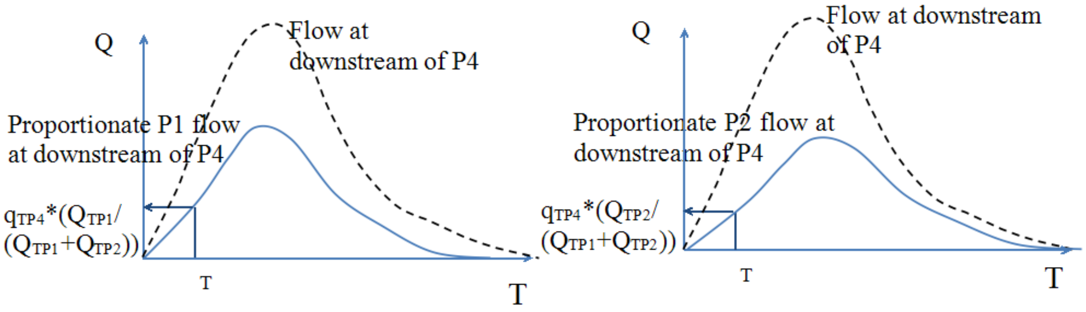


Figure 4: Schematic of proportionate upstream flows at downstream pipe end of junction

4.3 Application of approach

The same flow path used for the illustration of the approach was adapted to simulate flows through a straightforward example where a single roof of 50m^2 is drained through a conventional drainage system of a 100mm diameter downpipe. This system is connected to the local drainage system of 225mm diameter pipes which also collects the runoff from a surrounding 100m^2 impervious area.

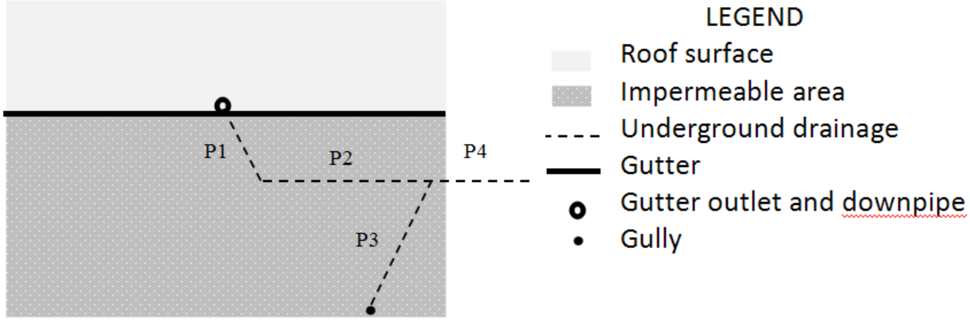


Figure 5: Schematic of local drainage system

The selected flow path encompasses both the roof drainage system and underground drain and sewer system. Different design rainfall intensities are recommended for these two systems according to design standards BS EN 12056-3:2000 and BS EN 752:2008 respectively. Also design rainfall intensity depends on the location of the property, duration and return period of the event. As discussed by D. A. Kelly and L. B. Jack (2011), it is necessary to establish a unified design solution especially for assessing the future impacts of climate change on the whole property level and to apply modifications in system design and water usage, as highlighted in this text. For an assumed location in Edinburgh, a steady-state rainfall intensity of 100mm/h is derived for the roof drainage system from BS EN 12056-3:2000 for a 2 minute storm event with a return period of 50 years[6]. However a similar steady-state rainfall intensity of 57.6 mm/h for a 5 minute storm event with a return period of 5 years is recommended in [7] for the underground drain and sewer system (for areas less than 4000m2 in a city centre location). As the derived storm events display similar event profile shapes, the higher intensity rainfall event (100mm/h) was used to study the system response.

The simulation results of the local drainage component, of which the calculation sequence was modified are illustrated in Figure 6- Pipe flows in local drainage system. The results indicate that, although the calculation sequence was modified relative to the previous version of ROOFNET, a reasonably approximate flow translation from the upstream to the downstream section has been achieved by routing the inflow from the downpipe (in Pipe1) with the surface runoff from the surrounding area (in Pipe3) to the last pipe in the local drainage system (Pipe4).

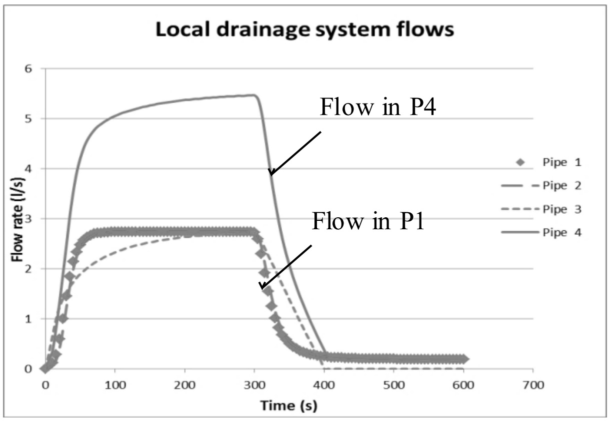


Figure 6- Pipe flows in local drainage system

5. Conclusions and Future Work

Flow attenuation and resulting residence time of flows in the property is a key feature of the dynamic response of the system performance. These have to be better understood, particularly in order to enhance onsite flow attenuation to mitigate the impacts of changes in water availability due to climate change. Residence time of inflow water, either rainfall or potable water supply from water mains, depends on its complete flow route through the property and it will further be enhanced by individual design modifications integrated to the system in terms of water saving options which interconnect different system components. Better understanding of connected flow routing through the system using numerical modelling techniques is necessary to identify potential locations of flow attenuation along different flow routes through the property to enhance the residence time and obtain best efficiency of water consumption.

A brief overview of the proposed approach for simulation of the connected flow routing through the whole system is presented in this paper. Its application is demonstrated with an example. A component of the numerical simulation model ROOFNET has been modified to enable the simulation along the complete flow route - for rainwater discharge through the system. The approach has to be further applied to quantify the residence time through the flow route. Furthermore, it will be applied to property level rainwater harvesting and greywater recycling options by combining both ROOFNET and DRAINET, to assess the dynamic response of the system and to understand potential locations for improving property level water retention.

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Further Consideration on the Prediction Method of Carrying Performance of Horizontal Drain Pipes for Water–saving Toilets

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Abstract

The study intends to identify changes in the drainage characteristics of a water-saving toilet when wastewater is flushed into a horizontal drainpipe, as well as aiming to develop a prediction method of carrying performance, by means of simulation and on the basis of the conveyance distance of waste which serves as an index. Last year, the carrying performance of a straight pipe was identified through simulations in which substitute 'sponge' waste was used, and results with high accuracy were produced.

The study furthers the knowledge that was gained from the previous study, and implements simulations using a variety of piping arrangements with elbows so as to provide configurations that are very similar to the actual designs. A model is also proposed, which enables relatively easy calculations of carrying performance, and the effectiveness of the model is discussed.

Keywords

Conveyance simulation, waste-carrying performance, water-saving toilet, fixture drain

1 Background of the Study

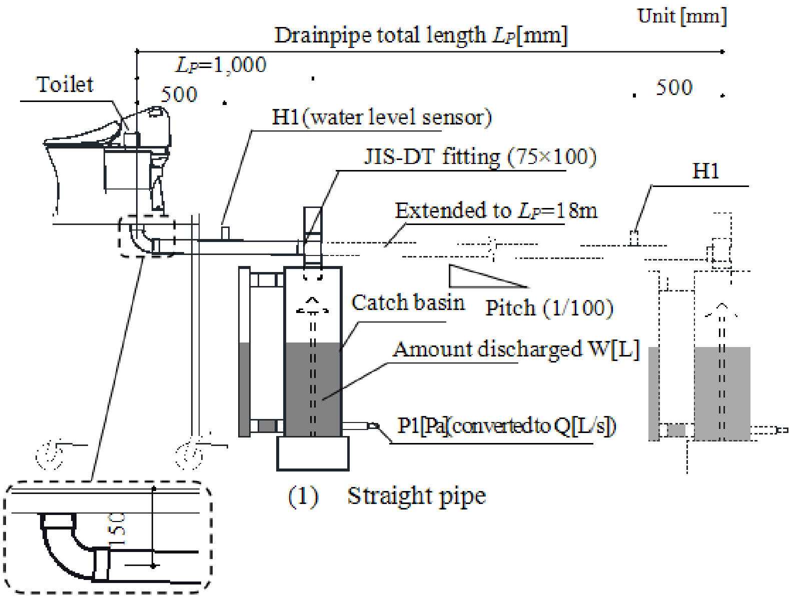
As part of the measures to tackle global warming and secure water resources, the development and promotion of water-saving toilets is ever more vigorous on a global scale. However, there is a lack of data of fixture drainage characteristics which would contribute to designing pipework for connecting water-saving toilets. In particular, blockages in horizontal drainpipes, which are caused by a decrease in the carrying performance, are raising concerns. In response, numerous surveys involving actual measurements have been carried out on wastewater flows and carrying performance of toilets1)2), and methods for predicting waste-carrying performance have also been discussed. However, a prediction method in consideration of the actual pipe conditions with elbows is yet to be established3)4) .

At the International Symposium of CIB W062 in 2014, a method for predicting the waste-carrying performance in a straight pipe was proposed5), the method using a simulation model in which a straight pipe was connected to a water-saving toilet, and the distance waste was carried in the pipe was obtained from the variations in the drainage characteristics of the water-saving toilet and was used as an index to calculate the waste-carrying performance. Developing further on last year’ s proposed method, this study aims to establish a way to calculate the waste-carrying performance in pipes with elbows in consideration of the actual plumbing conditions.

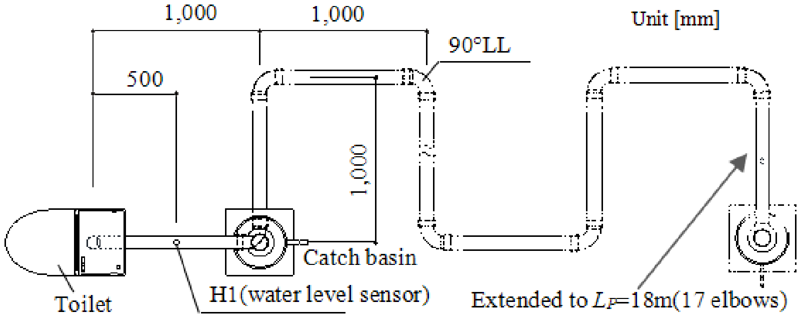
2 Experiment Overview

2.1 Experimental toilets and experimental piping layouts

The study involved three types of water-saving toilets having different nominal flush capacities; 8.0L, 6.0L and 4.8L. The toilets are respectively connected to three different piping layouts; the most basic layout using a straight pipe (total length LP=18m) (Fig. 1 (1)), a layout using a pipe provided with elbows at 1m intervals ((total length LP =18m, 17 elbows) (Fig. 1 (2)), and a layout based on an actual design using variations of pipes (Table 1)6). A fixture drainage characteristics experiment and a carrying performance experiment were carried out using these piping layouts. Incidentally, all the pipes used for the experiments had a pipe diameter of 75A (inside diameter 78mm), and a pipe pitch of 1/100 was applied in all the locations.



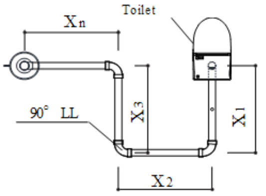
(1) Straight pipe



(2) Pipe with equally-spaced elbows

Fig. 1 Experimental piping layouts

Table 1 Variations of pipes

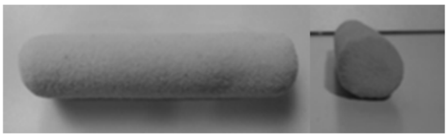
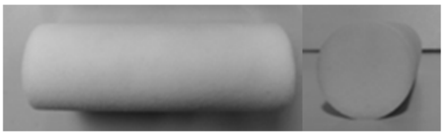
Pipe No.	Total length L_P[m]	No. of elbows N	X_1[m]	X_2[m]	X_3[m]	X_4[m]	X_5[m]	X_6[m]	Note
No.1	4.0	2	1.5	1.5	1.0				<Experimental piping system overview> 
No.2	4.0	2	1.0	1.0	2.0				
No.3	6.0	3	2.5	1.0	1.0	1.5			
No.4	8.0	4	1.0	1.0	1.0	1.0	4.0		
No.5	10.0	5	2.0	2.0	2.0	2.0	1.0	1.0	
No.6	10.0	3	1.0	1.0	1.0	7.0			
No.7	4.0	2	2.0	1.0	1.0				
No.8	8.0	4	4.0	1.0	1.0	1.0	1.0		
No.9	10.0	3	7.0	1.0	1.0	1.0			
No.10	12.3	1	0.3	12					

(Note) The elbows are all installed with 90°LL fittings.

2.2 Items to measure and measuring methods

The carrying performance experiment is divided further into two experiments; a single-flush conveyance experiment and a follow-up-flush conveyance experiment, and the items to measure were measured during the experiments. In the single-flush conveyance experiment, a waste substitute (see Table 2) was flushed down each of the experimental toilets, and when the waste substitute stopped in the drainpipe, the distance from the draining core of the toilet to the tail of the waste substitute was measured. In the follow-up-flush conveyance experiment, assuming that in the actual situation, the toilet is likely to be flushed again after the preceding waste stopped, clean water was flushed into the drainpipe after the water stagnating upstream from the stationary waste substitute was completely gone, and the position at which the waste substitute stopped was identified.

Table 2 Experimental waste substitutes

Type	Photo image	Waste substitute
①		PVA sponge Diameter：20mm Length：82mm Specific gravity：1.07* Kinetic friction coefficient μ'：0.22* Static friction coefficient μ：0.32*
②		PVA sponge Diameter：30mm Length：82mm Specific gravity：1.01* Kinetic friction coefficient μ'：0.26* Static friction coefficient μ：0.35*

*The specific gravity and μ’ and μ of each waste substitute were measured, in the state of being sufficiently soaked with water, in a preliminary experiment.

3 Simulation Overview

3.1 Waste conveyance models

In the prediction of waste-carrying performance, the flow of clean water discharged without any waste contained therein was estimated from the values obtained from formulae (1) to (6), and the water force to carry waste, Fw, and the friction caused by the pipe configuration, Fr1, were calculated from formulae (7) and (8) (see Fig. 2). Incidentally, Manning's coefficient of roughness, n, used in formula (1) was predetermined in a preliminary experiment.

In the case of using the straight pipe, the water level and the flow velocity in the pipe were calculated using continuity equation (2) and motion equation (3), and the water force to carry waste, Fw, and the friction, Fr1, were calculated using formulae (7) and (8) (see Fig. 2). The conveyance distance, L[m], was then measured according to the variation in the conveyance speed affected by the combined force of Fw and Fr1 at each measuring time. Incidentally, the kinetic friction coefficient, μ’, used in formula (8) was predetermined in the preliminary experiment. Furthermore, in said formula, variations in the submerged area, Asink, in which the water flow is affected by the submerged state of a waste substitute dependent on the water level in the pipe, and in the buoyancy of the waste substitute, f, were taken into consideration, and the position at which the waste substitute stopped was determined when the waste substitute speed, Vs, was calculated to be 0m/s.

In the case of using the pipe with equally-spaced elbows or the variations of pipes, which is an improved model from the model used in the previous report5), the behaviour of a waste substitute flowing along the inclination of the water surface in the bent and inclined parts of the pipework was taken into account (see Fig. 3), and the floating direction of the waste substitute affected by the water flow was used in calculation as the direction opposite to the acceleration in the normal direction, accn.

In the follow-up-flush conveyance experiment, calculations were carried out on the assumption that there was no water accumulating upstream from a waste substitute (see Fig. 4), which is consistent with what it is like in reality. The water force to carry waste was calculated from the water flow against a stationary waste substitute, and the position at which the waste substitute began to move and the position at which the waste substitute stopped were calculated in relation to the friction. More specifically, for calculating the position at which the waste substitute began to move, the kinetic friction coefficient, μ’, in formula (8) was replaced with the static friction coefficient, μ, as in formula (9), and the relationship between the friction, Fr2, obtained from the calculation and the water force to carry waste, Fw, at the initial stop position of the waste substitute was used for determining the start of the waste substitute’s movement. Once the waste substitute started moving, formula (8) was used to predict the conveyance distance of the waste substitute.

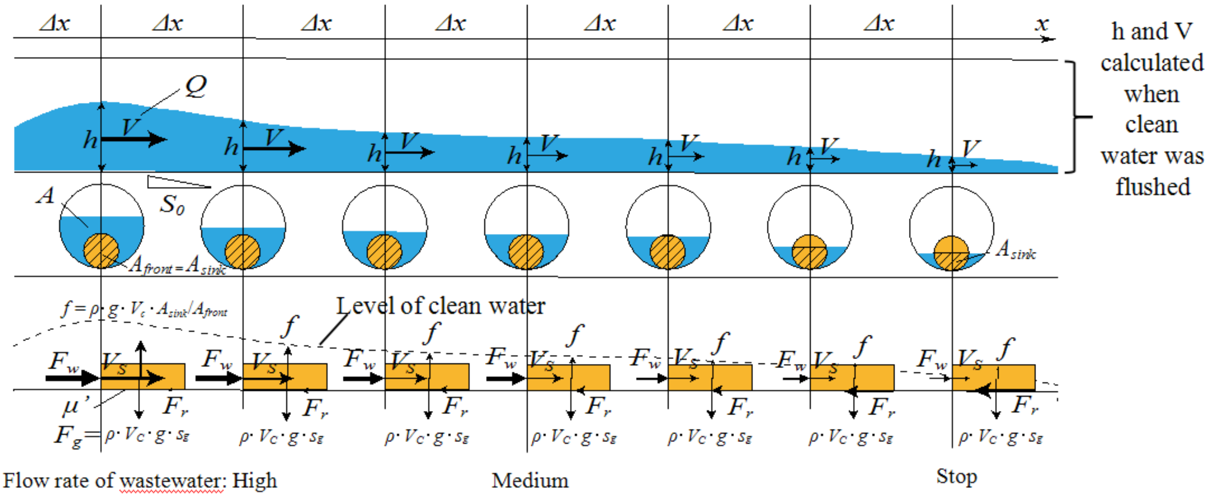


Fig. 2 Waste conveyance model (straight pipe)

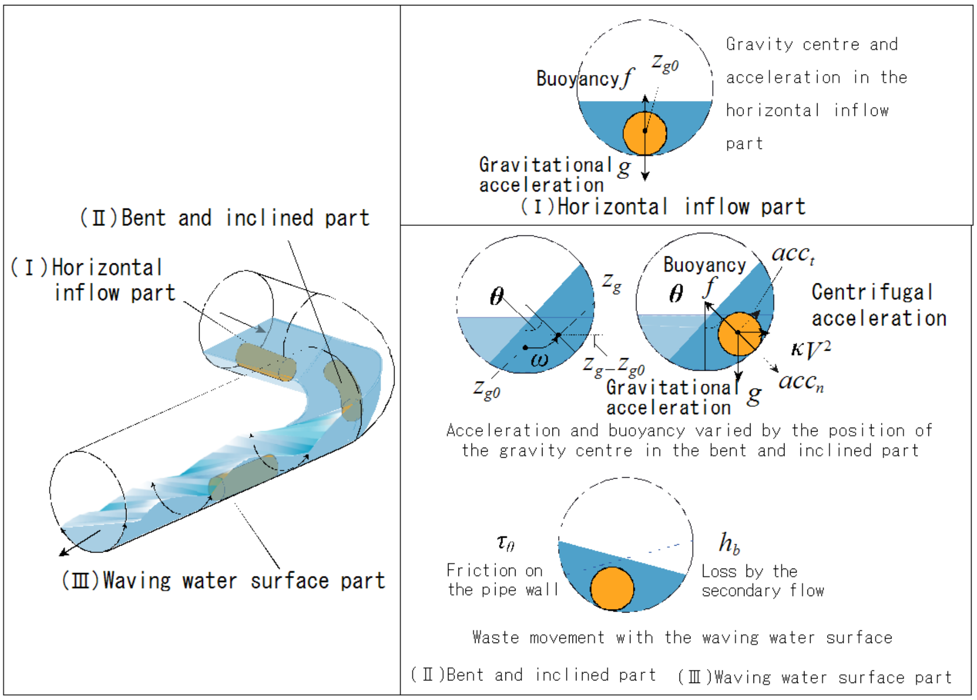


Fig. 3 Waste conveyance model (bent pipe)

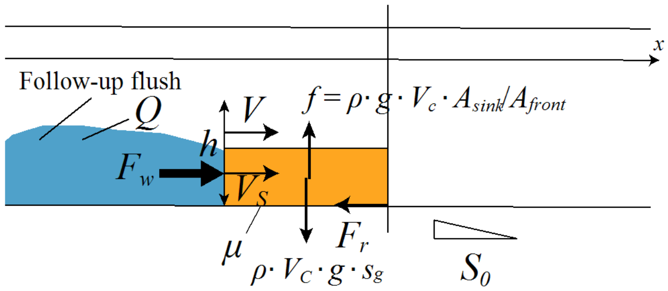


Fig. 4 Waste conveyance model using a follow-up flush

$$n=\frac{1}{V}\times R^{\frac{2}{3}}\times S_o^{\frac{1}{2}} \quad \cdots\cdots\cdots(1)$$

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \quad \cdots\cdots\cdots(2)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}+Agh\right)=gA\left(S_0-\frac{n^2V\,|V\,|}{R^{4/3}}\right) \quad \cdots\cdots\cdots(3)$$

$$\frac{\partial \theta}{\partial t}+\frac{\partial \theta V}{\partial x}=\omega \quad \cdots\cdots\cdots(4)$$

$$\frac{\partial L}{\partial t}+\frac{\partial LV}{\partial x}=r_g\cdot m\cdot acc_t-\underbrace{\frac{D}{2}\tau_\theta P}_{\text{Loss by the friction with the pipe wall}} \quad \cdots\cdots\cdots(5)$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\underbrace{+A\cdot acc_n\cdot h+A\cdot g\cdot(z_g-z_{g0})}_{\substack{\text{Variations of the acceleration in the normal}\\ \text{direction and the gravity centre}}}\right)+\underbrace{A\frac{\partial}{\partial x}\left(\frac{1}{2}\frac{I}{m}\omega^2\right)}_{\substack{\text{Variation in the angular}\\ \text{momentum}}}$$

$$=A\left(g\cdot s_0-acc_n\cdot\frac{n^2V|V|}{R^{4/3}}\right)\underbrace{-A\cdot g\cdot\frac{h_b}{L_p}}_{\text{Loss by the secondary flow}} \quad \cdots\cdots\cdots(6)$$

$$F_w=C_d\cdot\frac{1}{2}\cdot\rho(V-V_s)^2\cdot A_{sink} \quad \cdots\cdots\cdots(7)$$

$$F_{r1}=\mu'\cdot g\cdot\rho\cdot V_c\cdot(s_g-\frac{A_{sink}}{A_{front}}) \text{ ——— Kinetic friction } \cdots\cdots\cdots(8)$$

$$F_{r2}=\mu\cdot g\cdot\rho\cdot V_c\cdot(s_g-\frac{A_{sink}}{A_{front}}) \text{ ——— Static friction } \cdots\cdots\cdots(9)$$

[Reference symbols]

n:Manning's coefficient of roughness [s/m$^{1/3}$], Q:discharge flow rate [m^3/s], h:water depth [m], D: pipe diameter [m], A:running water cross section (($D^{2/8}$)×(θ-$sin\theta$)[m^2], V: average flow velocity (Q/A)[m/s], P:wetted perimeter [m], R:hydraulic radius (A/P)[m], S_0:pitch, x:pipe axial length [m], t:time [s], g:acceleration of gravity [m/s^2], acc_n: acceleration in the normal direction[m/s^2], acc_t: acceleration in the tangential direction [m/s^2], z_g,z_{g0}:gravity centre, I:moment of inertia [kg･m^2], ω:angular velocity[rad/s], m:mass [kg], h_b:loss in the bend, L_p: pipe length [m],θ: water surface angle [rad], L:angular momentum [kg･m^2/s], r_g: gravity centre radius [m], τ_θ: wall surface friction,F_w: conveyance force [N], F_r: friction [N], C_d:resistance coefficient =0.87, ρ:water density [kg/m^3], f: buoyancy [N], V_s:waste substitute speed [m/s], A_{sink}:submerged area [m^2], A_{front}:representative area [m^2],
μ': kinetic friction coefficient, μ:static friction coefficient, V_c:volume [m^3], s_g:specific gravity

3.2 Method for calculating the waste–carrying performance

In the calculation of the waste-carrying performance, a fixture drainpipe having a length of 1m was used, and the flow rate of wastewater, Q[L/s], and the water level in the drainpipe were actually measured (see Fig. 5). The measured values were used as initial conditions to calculate a characteristic point of the running water cross section, A[m2], and Q, A,and the time, t[s], were then measured at the characteristic point. The measured values were then used as input conditions, and sequential calculation was carried out by the Lax–Wendroff method. Incidentally, in the case of using pipe No. 10 (Table 1) having the first horizontal elbow located only 300mm away from the opening, for example, the values were measured with that pipe configuration in consideration and used as initial conditions.

The calculation conditions are: the diameter, length and specific gravity of each of the waste substitutes in Table 2, the friction coefficient and the speed measured by a high-speed camera, and on the basis of these conditions, the flow-in time and initial velocity of each waste substitute were set as shown in Table 3. The calculation interval was set to 0.01s in consistent with the case of actual measurement.

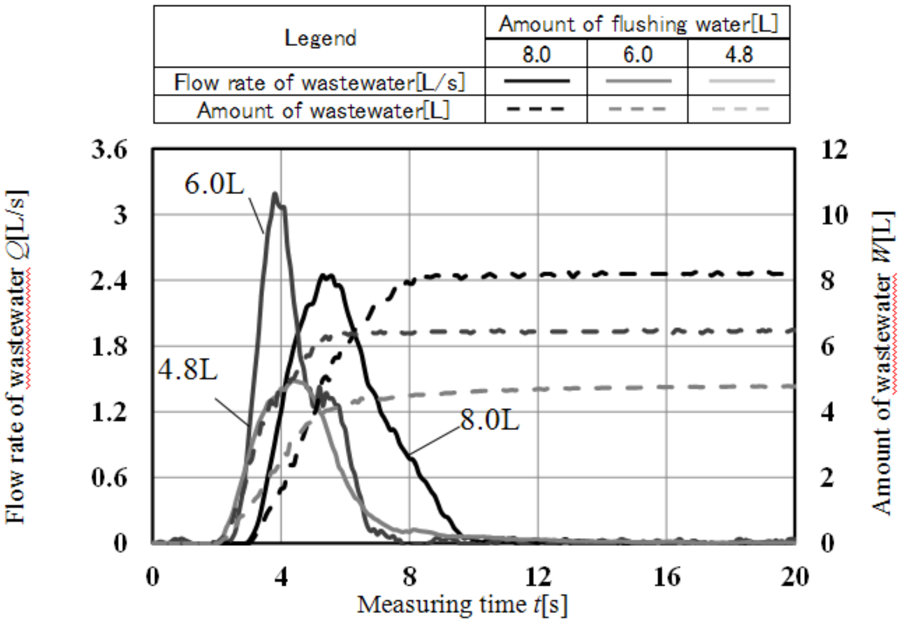


Fig.5 Flow rate and amount of wastewater from the experimental water-saving toilet (initial conditions)

Table 3 Initial input for waste-carrying performance prediction - example

Amount of flushing water[L]	4.8		6.0		8.0	
Type of waste substitute	①	②	①	②	①	②
Flow-in time[s]	1.83	2.21	1.46	1.52	1.23	0.98
Initial speed of waste[m/s]	1.58	1.41	1.71	1.91	1.86	1.86

4 Results and Discussion

4.1 The water level and flow velocity in relation to the position of the waste substitute in the drainpipe

The water level corresponding to the position of each of the waste substitutes in the drainpipe was calculated, as shown in Fig. 6, and the flow velocity in the drainpipe was also calculated, as shown in Fig. 7. The water level was approximately 14mm when waste substitute stopped after being flushed down the 4.8L and 6.0L toilets, respectively, and approximately 18mm using the 8.0L toilet. In the case of waste substitute , the water level was measured to be approximately 19mm at maximum. As for the flow velocity required for carrying waste, both waste substitutes stopped at approximately 0.5m/s, regardless of the amount of flushing water.

According to these results, in order to carry cylindrical waste, such as the waste substitutes used in the experiment, through the drainpipe, it is necessary to ensure that the ratio of the water level in the pipe is approximately 70% against the diameter of the waste and the flow velocity in the pipe is 0.6m/s or more.

4.2 Prediction of single–flush conveyance distances

Fig. 8 compares the actual measured and calculated conveyance distances of the waste substitutes. In the case of using the equally-spaced elbow pipe configuration, although the actual measured and calculated values vary therebetween, in the light of the average values, the actual measured distance of waste substitute ① is 7.5m and the calculated distance of same is 7.3m, when using the 4.8L toilet, creating a mere 0.2m error therebetween. In the case of waste substitute ② , there is also only a 0.3m error between the actual measured value and the calculated value; the values more or less correspond to each other. Similarly, when using the 6.0L and 8.0L toilets, the errors between the actual measured values and the calculated values are below 1m in both cases of waste substitutes ① and ② , and the accuracy of calculating these values in any combinations of the settings is within the range of $\pm 2\sigma$. Therefore, single-flush conveyance distances can be predicted within a very realistic range.

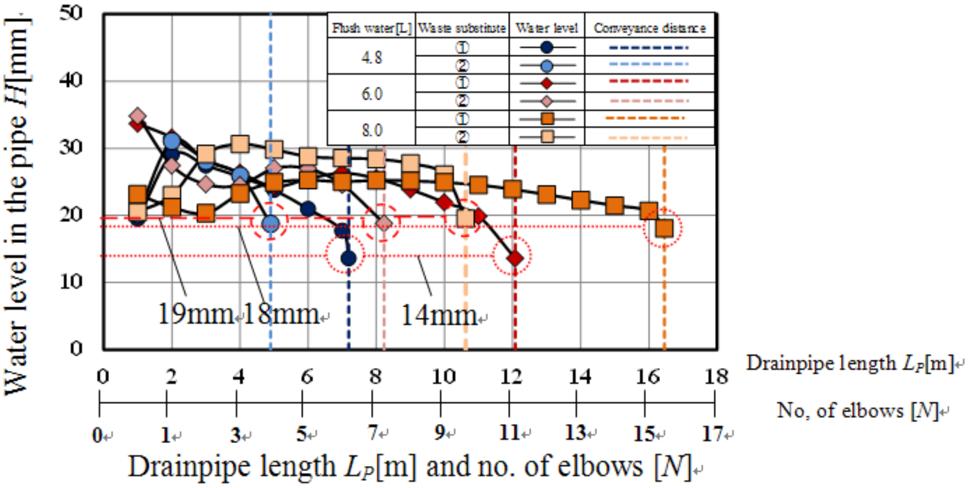


Fig. 6 Water level in the pipe at the position of the waste substitute (calculated values, pipe with equally-spaced elbows)

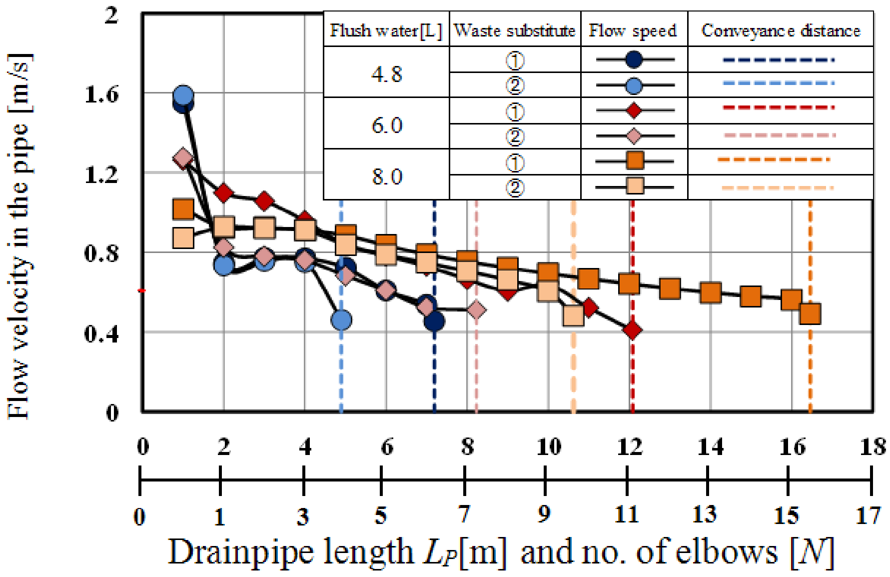
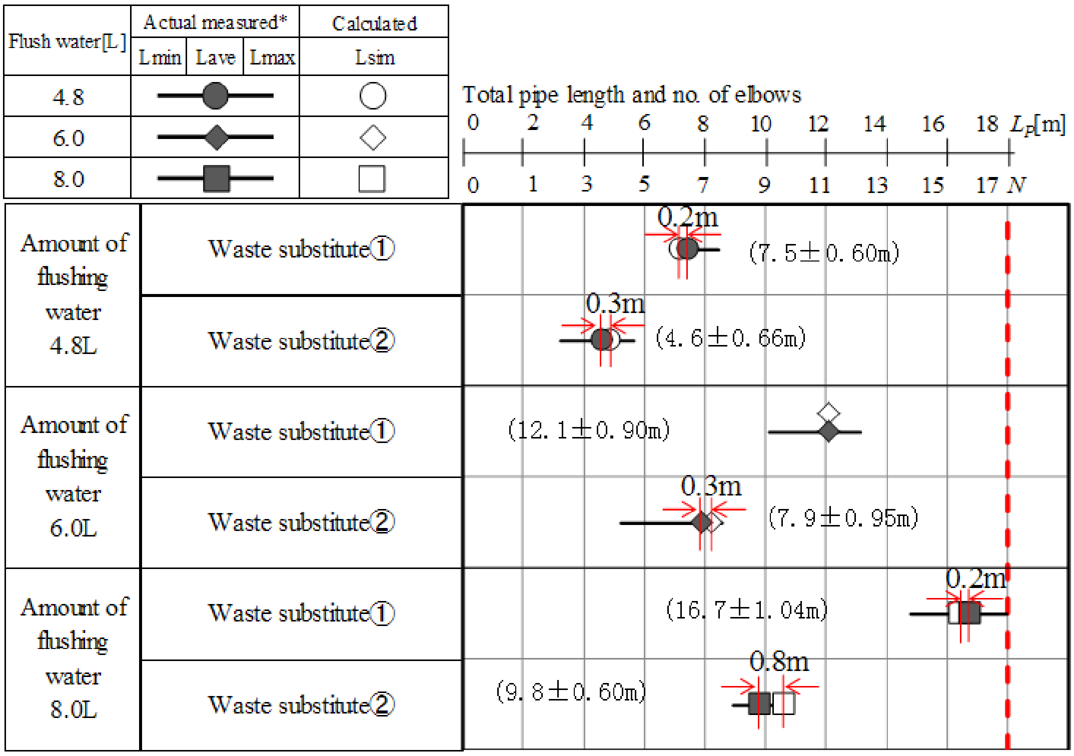


Fig. 7 Flow velocity in the pipe at the position of the waste substitute (calculated values, pipe with equally-spaced elbows)



※The conveyance distance was measured 10 times in each test to identify variations and obtain the average value.

Fig. 8 Comparison of the actual measured and calculated conveyance distances (equally-spaced elbow pipe)

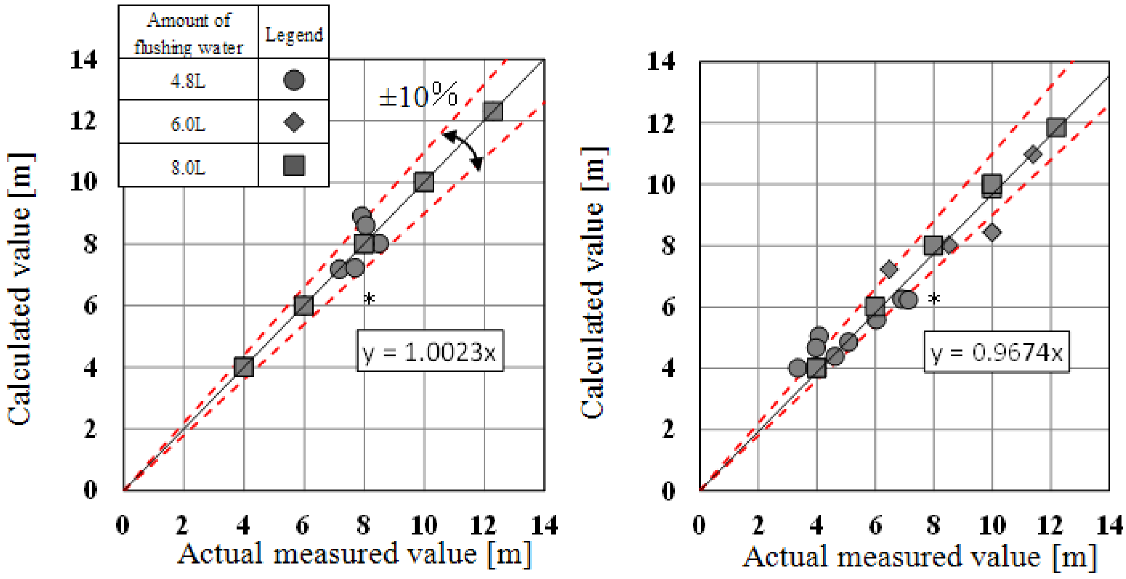
Fig. 9 compares the actual measured and calculated conveyance distances when using the variations of pipes which are shown in Table 1. The values obtained by using all the pipes are plotted in the graph. On the whole, the errors between the actual measured and calculated are all below 1% in the case of using waste substitute ① , and are 3% in the case of using waste substitute ② . Accordingly, it is considered to be possible to predict conveyance distances with high accuracy in the actual plumbing conditions. Meanwhile, as shown in Fig. 10, the qd' value measured at the stop position of each waste substitute was: 0.31L/s in the case of waste substitute ① , and 0.46L/s in the case of waste substitute ② .

4.3 Prediction of follow–up–flush conveyance distances

Fig. 11 compares the actual measured and calculated conveyance distances by follow-up flushing. Incidentally, in the calculations, the stop positions of the waste substitutes subsequent to the initial flushing refer to the conveyance distances shown in Fig. 8. The conveyance distances were actually measured and estimated by calculation three times, respectively, and Fig. 11 indicates the following results in the light of the errors between the actual measured and calculated values:

Fig. 11 (1): Waste substitute ① was flushed down the 4.8L toilet, using the straight pipe configuration, and the toilet was flushed again, with clean water only, after the water stagnating behind the tail of the stationary waste substitute was completely gone. The actual measured distance was 13.2m and the calculated distance was 12.2m, creating an error of approximately 8%. In the case of using the other amounts of flushing water and the other waste substitute, the errors between the actual measured and calculated distance values were in the range of 0-4%.

Fig. 11 (2): The follow-up-flush experiment was carried out in the same manner as (1), but using the equally-spaced elbow pipe configuration, and the errors between the actual measured and calculated distance values were in the range of 1-8%.
Accordingly, conveyance distances can be predicted with high accuracy even when the distances are extended by follow-up flushing.



(1) Waste substitute ① (2) Waste substitute ②

*x: actual measured value, y: calculated value

Fig. 9 Comparison of conveyance distances using the variations of pipes

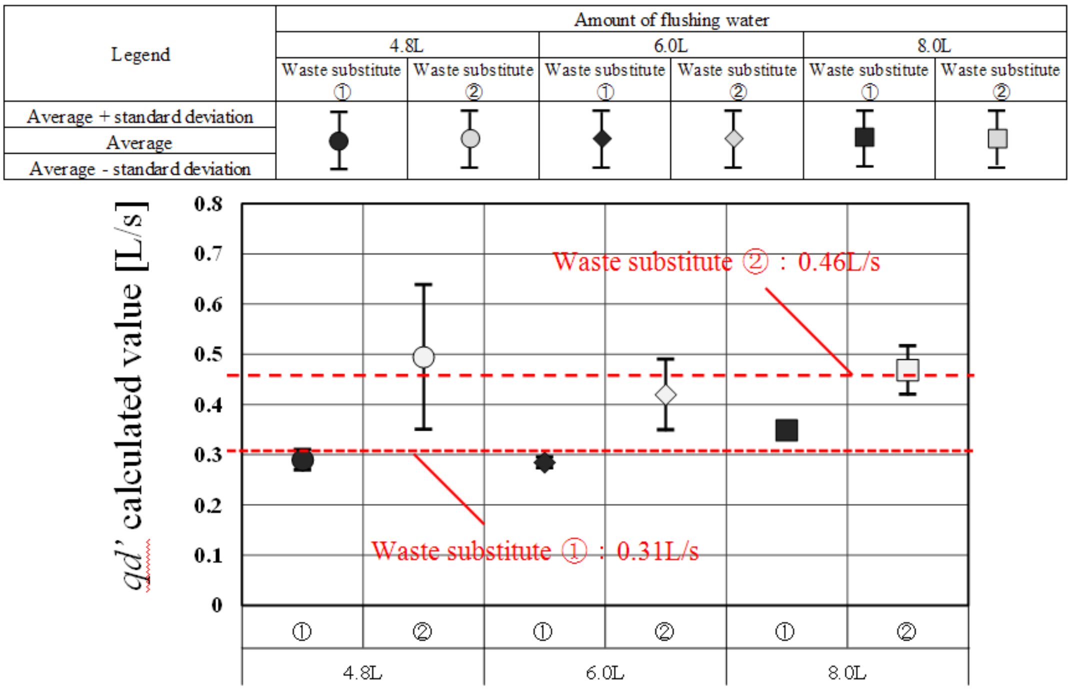
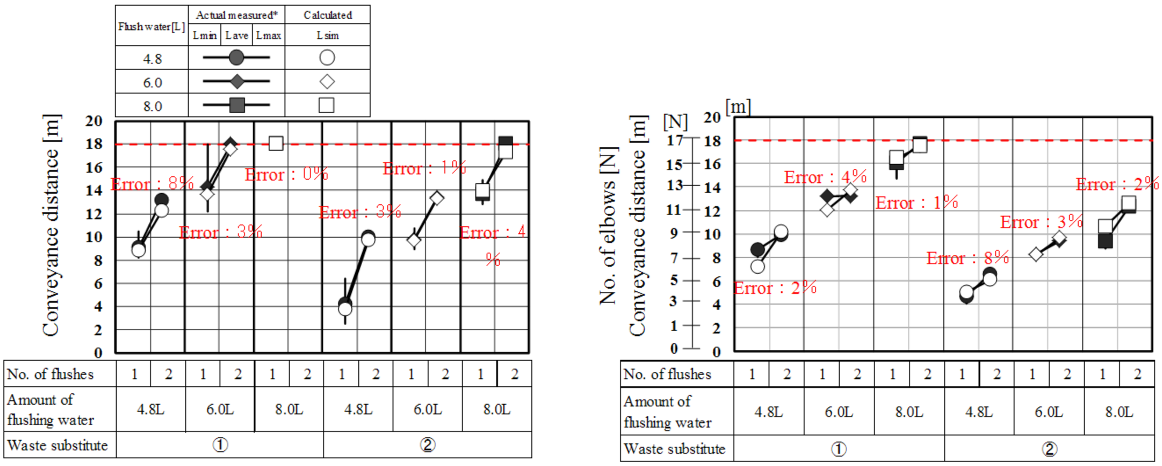


Fig. 10qd' values at the stop positions of the waste substitutes



(1) Straight pipe (2) Equally-spaced elbow pipe

＊The conveyance distance was measured 3 times in each test to identify variations and obtain the average value.

Fig. 11 Comparison of conveyance distances by follow-up flushing

5 Conclusions

A study was carried out to identify the drainage characteristics of different types of water-saving toilets when wastewater is drained into the horizontal drainpipe, and to develop a prediction method of carrying performance by means of simulation. The following knowledge has been acquired as a result.

(1) In order to carry the waste substitutes used in the study, it is necessary to ensure that the ratio of the water level in the drainpipe is approximately 70% against the diameters of the waste substitutes.
(2) In order to carry the waste substitutes used in the study, it is necessary to ensure that the flow velocity in the drainpipe is 0.6m/s or more.

(3)In the prediction of conveyance distances of the waste substitutes, using water-saving toilets, types I and II, all the predicted values were obtained with high accuracy in all plumbing conditions in consideration of the actual pipe structures with elbows.

(4) In the prediction of conveyance distances of the waste substitutes, which were extended by follow-up flushing with clean water after the waste substitutes stopped in the drainpipe, the errors between the actual measured values and the predicted values were 8% or less, and therefore, the carrying-performance prediction method provides further applicability in practice.

Acknowledgments

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Numerical Simulation on Hydraulic Regime of a Single−stack Drainage System for Super−high−rise Building

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Abstract

As the demand of the economic development and living environment, the height of the high-rise building becomes higher and higher, while the difficulty for drainage system design is encountered subsequently. There are two types of method to study the previous high-rise building drainage system: experiment and numerical analysis. After all, the experimental condition is limited to study the super-high-rise building drainage system. Recently, numerical method is drawn more and more attention to simulate the performance of hydraulic property of the drainage system for super-high-rise building. In this paper, the air pressure fluctuation in a single-stack drainage system is analyzed by multiphase flow numerical simulation method, and the relation between the dimensionless pressure and flow rate is obtained. It is shown that the numerical simulation results are basically consistent with that of the verification experiment in the single-stack drainage system, and the relation between air pressure and the square of water flow rate is approximately linear.

Keywords

Super-high-rise Building; Single-stack Drainage System; Hydraulic Regime; Multiphase Flow; Numerical Simulation

1 Introduction

With the development of social economy and the need of improvement for living environment, more and more super-high-rise buildings are erected. The so-called super-high-rise building refers to those whose height is more than 100 meters, which are denoted on an international conference in 1972. There are many differences between the super-high-rise and ordinary high-rise building drainage systems, for example, the design requirements, difficulties and cost for super-high-rise building drainage system are all far more than the ordinary high-rise building drainage system. And not only that, in the super-high-rise building drainage system, the drainage stack is longer, the discharge flow rate is larger and the flow regime is more complicated, thus the air pressure fluctuation in the drainage stack must be controlled in a reasonable range to avoid trap seal loss and thereby to prevent the foul gas leaking into and affecting our living environment. The flow regime is mainly triple phase flow incorporating solid, liquid and air in the super-high-rise building stack. The flow process in ordinary high-rise building stack was usually described as four stages [1,2]: 1) “dry stack” consisting only of airflow, located at the upstream part of the stack from the discharge entry; 2) a water annulus forms rapidly in the vertical stack as a result of the discharge from an appliance and water accelerates to the terminal velocity under the interaction of gravity, pipe wall friction force and air resistance; 3) water rushes to the bottom of the vertical stack at the terminal velocity and produces a negative pressure due to siphonage induced by downstream water flow; 4) hydraulic jump can make the air column suffered from stronger compression and produce a larger positive pressure when water gets to the bottom of the vertical stack.

However, during the down-flow process in the super-high-rise building stack, the interaction between water, pipe wall and air is quite severe because of the large height of the stack and the long time accelerating flow. During the discharge from an appliance accesses to the vertical stack, the flow regime may take on difference flow pattern with different flow rate, such as annular flow and rain-type flow. Physical changes may also happen for water morphology in the vertical stack, for example, dollops of water may stripe off from the pipe wall as a result of rotation in boundary layer or further break into fragmental sprays falling down like raindrop due to collision between water and the pipe wall. This leads to a new phenomenon of “discretization and atomization” which not only changes the air components and density in the vertical stack but also accelerates the entrained air and enlarges the negative siphon pressure and ventilation quantity. In fact, the phenomenon of “discretization and atomization” also exists in the ordinary high-rise building drainage system, but its performance is usually ignored because the changes of the air density and the resulting static pressure by gravity are not enough to give rise to sharp pressure fluctuation owing to the lower height of the stack. On the contrary, the phenomenon of “discretization and atomization” should be paid more attention in designing of super-high-rise building drainage systems in which the pressure fluctuation may increase multiply.

Lots of research works have been done on hydraulic performance for ordinary high-rise building drainage system. Most of the works are about experimental study while only a few numerical simulation methods are developed. The existing numerical simulation methods consist of two types: the characteristics method and direct solving of multiphase flow equations. The characteristics method has been widely applied to free surface drainage flow as well as water hammer and high-rise building drainage system [3-6]. J.A.Swaffield and D.P.Campbell analyzed the pressure level within complex pipe networks and demonstrate the relation between appliance discharge to a building drainage network, the resulting entrained air flow and the subsequent propagation of air pressure transients in the vertical stack as well as the trap seal oscillations as a result of pressure fluctuation [7]. C.L.Cheng investigated the air pressure fluctuation frequency, as well as the maximum and average air pressures with their respective standard deviations, in a 38 m high-rise drainage system under steady flow conditions [8]. E.S.W.Wong provided a mathematical model with which a step function is used to describe the effect of the air entrainment caused by the water discharged from branch pipes and an additional source term is introduced to reflect the gas-liquid inter-phase interaction and stack base effect to predict the performance of drainage system [9]. The method of direct solving multiphase flow equations which includes Volume of Fluid model (VOF), Mixture model and Euler model is also used in some building drainage system. Each of the models has both advantage and disadvantage: 1) VOF model is used to model immiscible fluids with clearly defined interface, so it cannot reflect phenomenon of "discretization and atomization"; 2) Mixture model allows the phases to interpenetrate and has relative velocity. For introducing the concept of mixture density, this model is more suitable to the case in which the difference between the densities of multiple phases is little. However, the density of water is 1000 times denser as compared to that of the air, thus super-high-rise building drainage system cannot be simulated exactly by Mixture model; 3) the governing equations are solved independently in Euler model, and the pressure is shared among phases. But its shortcoming is the poor convergency. Adopting the Mixture model, Liu Hui and Cheng Hao simulated the pressure fluctuation caused by variation in discharge for a 12-story single stack drainage system and obtained the consistent result with that of the verification experiment [10]. In reference [11], a 12-story single stack drainage system is transformed into a two-dimensional model and the air pressure fluctuation, the flow velocity as well as the volume fraction distribution are simulated under steady and unsteady flow rate by Chen Xia. One of the conclusions is the air pressure fluctuation will increase with the length of the drainage stack and the value of the flow rate.

Obviously, almost all of the simulation results are got for ordinary high-rise building drainage system but less super-high-rise building drainage system. Because of the lack of the proper constitutive model to describe the discretization law of water in computational fluid dynamics, it should be pay more attention to the selection of the available physical model and the division of mesh pattern which is closely related to whether the phenomenon of "discretization and atomization" can be distinguished in computing process. In this paper, the Euler model is adopted in solving multiphase flow equations to simulate the air pressure fluctuation in the stack under steady flow rate for a single stack drainage system of a super-high-rise building. To discuss the relation between the characteristic pressures (the maximum positive pressure at the stack base and the minimum negative pressure by siphon) and the influencing factors, the dimension analysis principle is hired. By fitting the computing result, the dimensionless relation between the characteristic air pressure and water flow rate is obtained. At last, the computing result is verified by experiment conducted in a 104-meter high super-high-rise building. It is shown that the computing result is basically consistent with that of experiment.

2 Numerical Simulation Configuration

2.1 Governing equations

The practical flow in the stack is a mixed flow with gas-liquid-solid three phases and the flow status is quite complicated in super-high-rise building drainage system. For convenience to demonstrate how the numerical simulation works, here a two-phase flow model is used, in which the fluid media just involves gas and liquid and the result can be easily verified by experiment.

1) Mass conservation equation

$$\frac{\partial}{\partial t}(\alpha_i \rho_i) + \nabla \cdot (\alpha_i \rho_i v_i) = 0 \quad i = 1, 2 \tag{1}$$

where ρ_i, α_i and v_i are the density, the volume fraction, and the velocity of the ith phase respectively.

2) Momentum equation

$$\frac{\partial}{\partial t}(\alpha_i \rho_i \vec{v}_i) + \nabla \cdot (\alpha_i \rho_i \vec{v}_i \vec{v}_i) = -\alpha_i \nabla \cdot p + \nabla \cdot \bar{\tau} + \sum_{i=1}^{n} \vec{R}_{ij} + \alpha_i \rho_i \vec{F}_i \quad i, j = 1, 2 \tag{2}$$

where $\bar{\tau} = -p\vec{I} + \vec{\tau}$, $\vec{I}$, is a unit tensor, p is pressure, $\vec{\tau}$ is the viscous stress tensor, $\vec{F}_i$ is body force, and $\vec{R}_{ij}$ is the inter-phase interaction force.

3) Turbulence model

Here the $k - \varepsilon$ equation of mixed turbulence model is adopted.

$$\frac{\partial}{\partial t}(\rho_m k) + \nabla \cdot (\rho_m \overrightarrow{v_m} k) = \nabla \cdot (\frac{\mu_{t,m}}{\sigma_k} \nabla k) + G_{k,m} - \rho_m \varepsilon \tag{3}$$

$$\frac{\partial}{\partial t}(\rho_m k) + \nabla \cdot (\rho_m \overrightarrow{v_m} \varepsilon) = \nabla \cdot (\frac{\mu_{t,m}}{\sigma_k} \nabla \varepsilon) + \frac{\varepsilon}{k}(C_{1\varepsilon} G_{k,m} - C_{2\varepsilon} \rho_m) \varepsilon \tag{4}$$

ρ_m is the mixed density, $\overrightarrow{v_m}$ is the mixed velocity, $\mu_{t,m}$ is the turbulence intensity, and $G_{k,m}$ is the turbulent kinetic energy.

2.2 Geometric model and mesh division

The geometric model of the drainage stack for numerical simulation should not be simplified as a two-dimensional model for the pipe is cylindrical and water is discharged from the unidirectional branch. Because the super-high-rise building drainage system is a very complicated unsteady-flow system and the lack of the discretization model, the mesh division pattern for numerical simulation is very important for whether the above-mentioned phenomenon of “discretization and atomization” can be recognized. Hence, more attention should be paid to mesh division, especially to the key parts of the stack where the geometric configuration changes and then influences the flow status. The divided meshes for water inlet and bottom of the stack are shown in Fig.1.

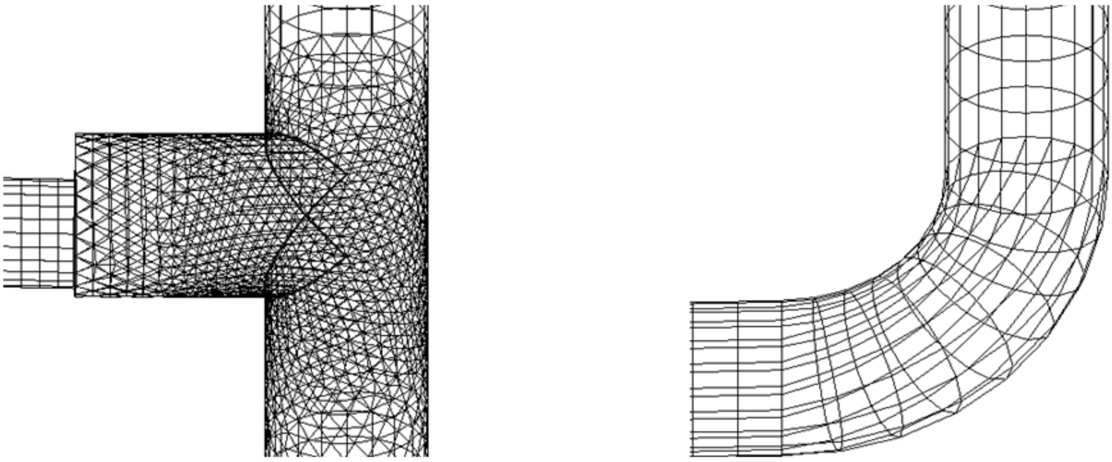
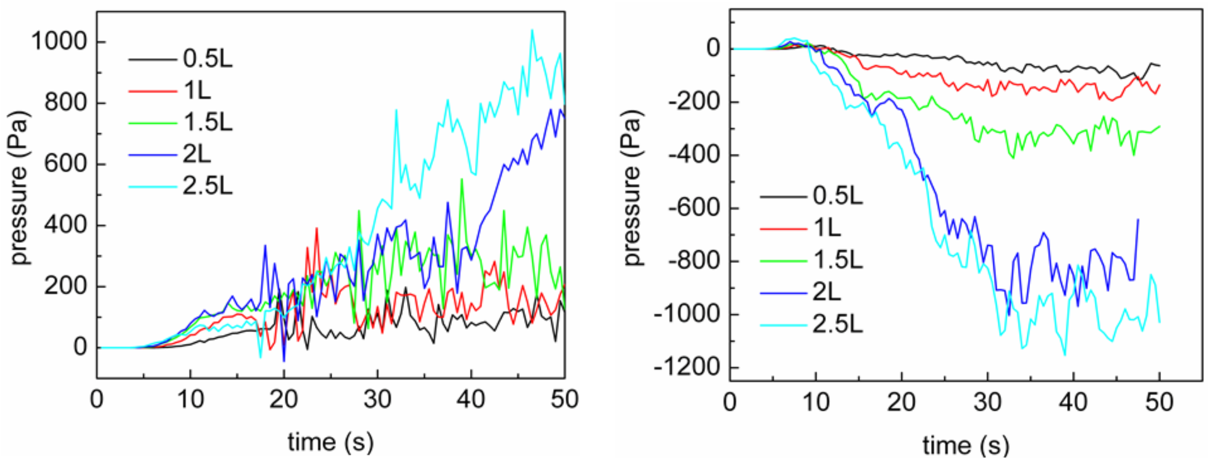


Fig.1 Divided meshes in the key parts of the stack

2.3 Simulation of typical cases

The hydraulic performance of a 34-storey super-high-rise building drainage system with the height 104 meters is taken as an example for numerical simulations, and water is discharged at 31-floor with the drainage height 94 meters . As the resulted air pressure is relatively low (less than 1000 Pa), the air is considered as incompressible. The air vent at the top of the vertical stack and the outlet of the main horizontal drainage pipe at the base of the stack are set as the pressure boundary conditions. The discharge inlet at 31-floor is set as velocity boundary condition. For each case, the numerical simulation is carried out at a steady water flow rate with which 0.5L/s, 1 L/s, 1.5 L/s, 2 L/s, 2.5 L/s is selected respectively. Fig.2~ Fig.5 illustrate the simulation results under different flow rates. The maximum positive pressure and the maximum negative pressure fluctuate with time are shown in Fig.2(a) and Fig.2(b) respectively. Fig.3 presents the law of pressure distribution after the flow rate reaches steady and the flow regime from water inlet to vertical stack is also shown in Figure.4. Furthermore, the ventilation quantities (calibrated with air velocity) at the top of the stack changes with time are given in Fig.5.



（a） （b）

Fig.2 the characteristic pressures fluctuate with time

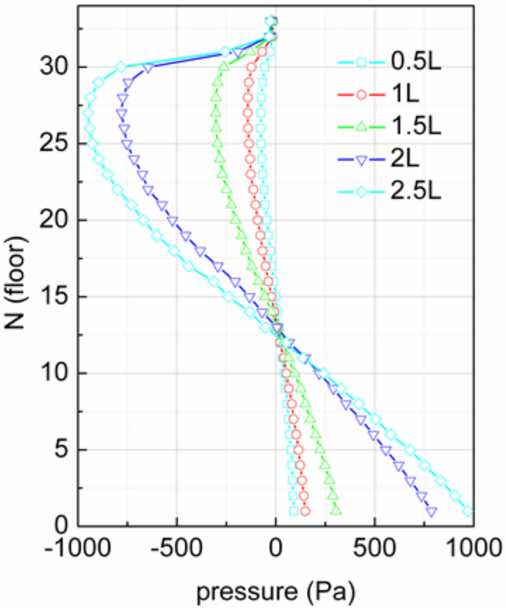


Fig.3 Pressure distribution in the stack with water flow rate 2.5L/s

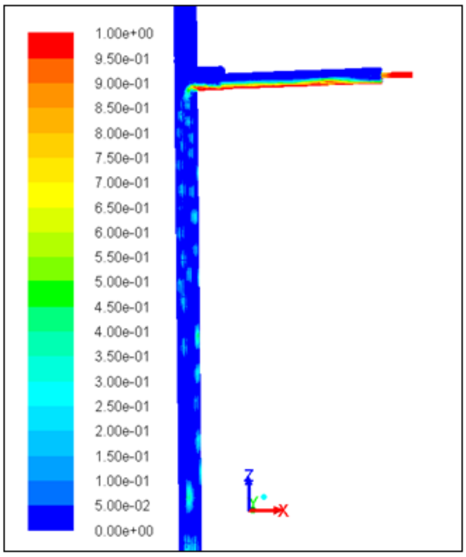


Fig.4 The flow status in the stack with water flow rate 2.5L/s with the flow rate 2.5L/s

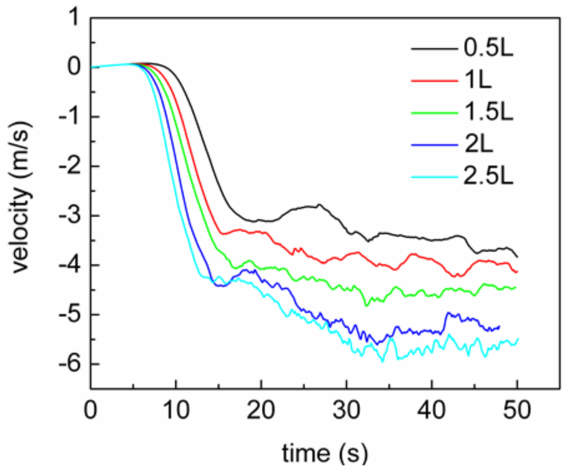


Fig. 5 Ventilation quantity over time(calibrated with air velocity)

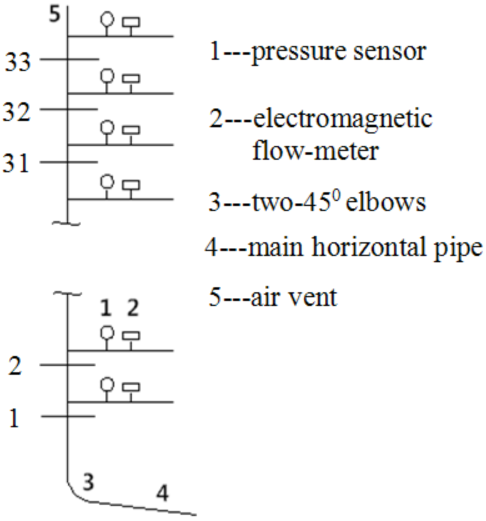


Fig. 6 The schematic diagram of experimental setup

3 Experiment Verification

3.1 The experimental system

To verify the validation of the numerical simulation, a series of experiments with on-line testing are carried out at the Base of National Engineering Research Center for Human Settlements. The experimental tower is 34-storey with the total height of the drainage stack 104 meters. The vertical drainage stack of the single-stack drainage system is made of PVC-U with the diameter DN150 mm and that of the horizontal drainage branch DN110 mm. The connection between the vertical stack and its branches is the type of straight tee. The length of the main horizontal drainage pipe at the base of the drainage system is 21 meters. The water discharge flow rate is controlled by electromagnetic flow-meters during the experiment process and the pressure sensors are installed on the branches nearby the vertical stack. The schematic diagram of experimental setup is illustrated in Fig.6. During the experiment, the flow rate is increasing gradually until reaches to the steady flow rate being set previously.

3.2 Comparison of the numerical simulation and experimental results

For clarity, only the results of numerical simulation with the flow rate 2.5 L/s and the corresponding results of experiment are illustrated below. Fig.7 and Fig.8 shows the characteristic pressures change with time at the characteristic positions of the stack. The pressure distributions by simulation and experiment are given in Fig.9. Besides, the ventilation velocities at the top of the stack change with time are also presented in Fig.10.

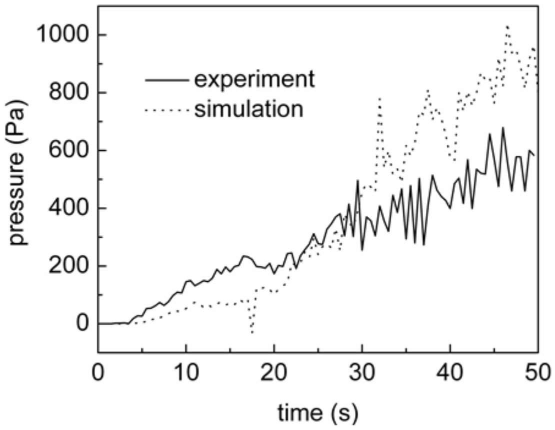


Fig. 7 Pressure fluctuation versus time at floor 1

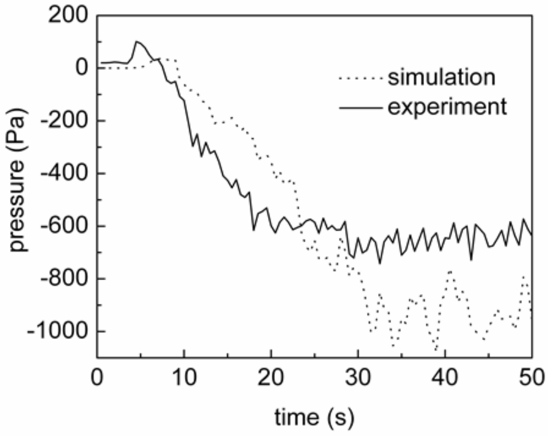


Fig. 8 Pressure fluctuation versus time at floor 27

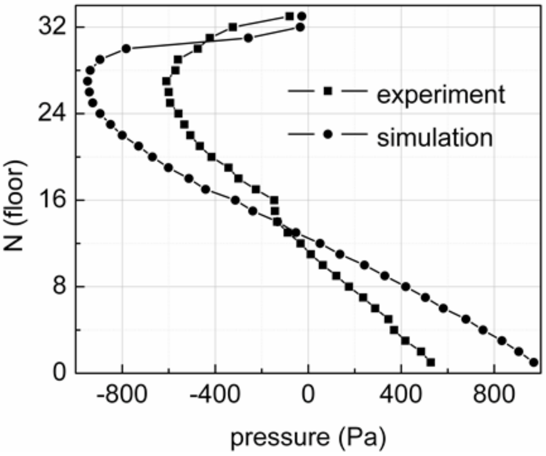


Fig. 9 Pressure distribution law in the stack

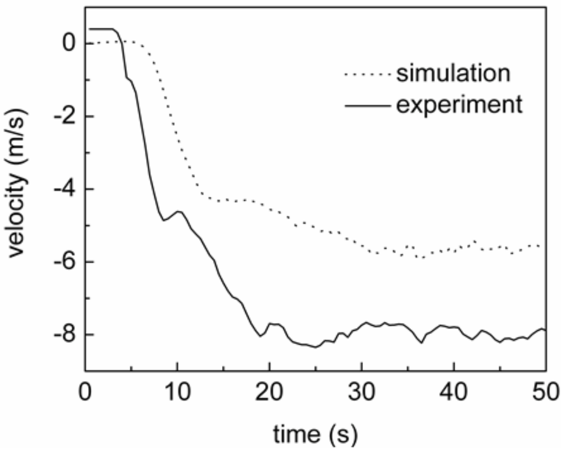


Fig. 10 Ventilation velocity over time

4 Relation between the Characteristic Pressure and the Flow Rate

1) From Fig.2 to Fig.5, it’s obvious that the absolute values of the characteristic pressures and the ventilation velocity at the top of the vertical stack increase with the discharge flow rate increasing. The maximum negative pressure happens at floor 27 for the case of flow rate 2.5 L/s and it may change with the discharge flow rate. The maximum positive pressure occurs at the bottom of the stack certainly. However, it is interesting that the position of the transitional zero-pressure from negative pressure to positive pressure for all cases appear approximately at floor 13 as shown in Fig.3 and Fig.9. This indicates that the position of transitional zero-pressure has no obvious relation with flow rate but may be relevant to the drainage height and pipe diameter.

2) Fig.7~ Fig.10 show that the numerical simulation results are basically consistent with that of the verification experiment in distribution feature and the order of magnitudes. The absolute values of both the maximum negative pressure and the maximum positive pressure by simulation are greater than those of the experiment, but the ventilation velocity at the top of the stack is less than that of experiment. The maximum

error can even reach 40 percent for it is just compared with once experiment result. It should be noted that the experimental results with different surrounding environment may manifest two-times difference and sometimes the negative pressure value may be greater than those of the simulation result. First, the super-high-rise building drainage system is complicated and the flow status is unsteady, the phenomenon of “discretization-atomization” influences the pressure fluctuation severely but not be involved in numerical simulation; Second, the pressure fluctuation can also be influenced by seasonal climate, the wind speed of the surrounding environment, and the humidity in the drainage stack. All of the environmental factors are not considered in the numerical simulation process. Last, the different form of the mesh pattern and the computational scheme adopted in numerical simulation can also introduce some error.

From the point of dimensional analysis, the main controlling factors influencing the pressure fluctuation in the drainage stack include the gravity acceleration *g*, discharge flow rate Q_w , diameter of the stack *D*, drainage height *H*(from the discharge inlet to bottom of the stack), the length of main horizontal drainage pipe *L*, the density of water ρ_w and viscosity μ_w as well as the density of air ρ_a and viscosity μ_a . There must be a functional relation between the characteristic pressure and these main controlling factors

$$P = f(\rho_a, \mu_a; \rho_w, \mu_w, Q_w, D, L, H, g) \qquad (5)$$

Taking ρ_a , Q_w and as independent variable, Eq (5) can be written as

$$\frac{P}{\rho_a gH} = f(\frac{\rho_a}{\rho_w}, \frac{\mu_a}{\mu_w}, \frac{\rho_w Q_w}{\mu_w D}, \frac{Q_w}{g^{\frac{1}{2}} D^{\frac{5}{2}}}, \frac{L}{H}, \frac{H}{D}) \qquad (6)$$

where $\rho_w Q_w / \mu_w D$ is Reynolds number, $Q_w / g^{\frac{1}{2}} D^{\frac{5}{2}}$ is Froude number. Froude number can be ignored in such a problem because there is no obvious interface between the air and water in the stack and the pressure gradient is small. In the above numerical simulation, the aim is focused on the relation between the pressure fluctuation and the discharge flow rate, and the only variable is the discharge flow rate while the other factors keep unchanged. Then, Eq.6 can be simplified as

$$P = \rho_a gH \cdot f(\frac{\rho_w Q_w}{\mu_w D}) \qquad (7)$$

Because ρ_w and μ_w is taken as constant in such cases, the relation between $P_{\max} / \rho_a gH$ 、 $P_{\min} / \rho_a gH$ and Q_w / D can be obtained from the dimensional analysis above. The dimensionless relations between the pressure and the discharge flow rate for both simulation result as well as the experimental result are demonstrated in Fig.11. The mathematical expression between $P_{\max} / \rho_a gH$ 、 $P_{\min} / \rho_a gH$ and Q_w / D can also be got by data fitting. Eq.8 and Eq.9 are the fitting mathematical expression for numerical simulation result and Eq.10 and Eq.11 for that of experiment.

$$\frac{P_{\max}^{(s)}}{\rho_a gD} = 2429 \left(\frac{Q_w}{D} \right)^{1.89} \qquad (8)$$

$$\frac{P_{\min}^{(s)}}{\rho_a gD} = -2256 \left(\frac{Q_w}{D} \right)^{1.88} \qquad (9)$$

$$\frac{P_{\max}^{(e)}}{\rho_a gD} = 1628 \left(\frac{Q_w}{D} \right)^{1.95} \qquad (10)$$

$$\frac{P_{\max}^{(e)}}{\rho_a gD} = -1659 \left(\frac{Q_w}{D} \right)^{1.92} \qquad (11)$$

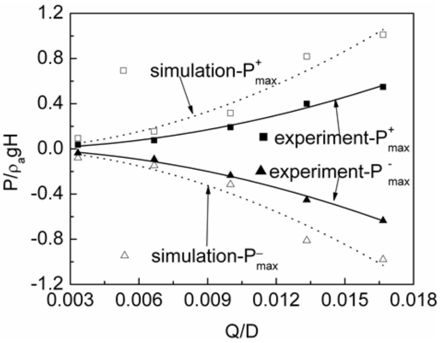


Figure.11 The dimensionless relation between pressure and flow rate

It is shown that the relation between the dimensionless characteristic pressure (and) ($P_{\max}/\rho_a gH$ and $P_{\min}/\rho_a gH$) and the square of the dimensionless discharge flow rate Q_w/D is approximately linear.

5 Conclusions

The physical mechanism of air pressure fluctuation in super-high-rise building drainage system is probed. The pressure distribution law is studied by numerical simulation and the result is basically consistent with that of the verification experiment in distribution feature and the order of magnitudes. However, there is still some error between the simulation and experiment results due to the lack of the rational mathematical model to describe the physical phenomenon happening in the drainage stack. The main conclusions are drawn as follows:

(1) The phenomenon of “discretization-atomization” is the essential difference between the super-high-rise drainage system and the ordinary high-rise building drainage system. The influence of water-discretization on air pressure can be ignored for ordinary high-rise building drainage system because the change in air density and static pressure caused by gravity are not enough to give rise to sharp pressure fluctuation owing to the lower height. However, the pressure fluctuation will increase multiply due to the phenomenon of “discretization-atomization” in super-high-rise building drainage system. Hence more attention is needed to pay on the mechanism of “discretization-atomization” and on the development of corresponding mathematical model to calibrate its influence on air pressure.

(2) With the increasing of the discharge flow rate, the air pressure fluctuates severely and the ventilation velocity at the top of the stack also increases gradually, but there is no obvious relevance between the characteristic position of zero-pressure and the discharge flow rate.

(3) The relation between the characteristic pressures and the square of the discharge flow rate is approximately linear in dimensionless form for both simulation and experimental results.

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Research on ZigBee Technology–based Monitoring System for Building Drainage System

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Abstract

In order to meet the demands of more measurement points and long spatial span of the building drainage monitoring system, and to deal with the complicated question of lying cable by traditional cable measurement scheme, this paper proposes the design and implementation scheme of a drainage monitoring system based on ZigBee wireless sensor network , gives a realization method of ZigBee protocol and ZigBee network topology structure, and then introduces hardware and software design scheme of various nodes in the network in detail. This system applies MSP430 as control chip of terminal acquisition nodes, and CC2530 chip to realize networking and wireless transmission. Finally, in order to facilitate observation and supervision, data are transferred to the upper computer monitoring platform written by Visual Basic 6.0. Compared with the traditional cable mode, this system greatly improves the convenience of communication and measurement.

Keywords

ZigBee; Wireless sensor networks; CC2530; Visual Basic 6.0

1. Introduction

Normal operation of building drainage system can directly affect the people's daily life, so it is necessary to have real-time monitoring on the opearting parameters of the drainage system, so as to find and handle the problem in time when the system is abnormal. In drainage system, the hydraulic pressure of pipe wall in different location of soil stack is the main concerned parameter, especially in high-rise buildings. It requires a lot of monitoring points, and the space distance span is very long, so the traditional data monitoring system based on wire communication cable needs to decorate a large number of measurements. High cost of wiring, complexity of installation and difficulty of expansion to expand make this paper proposed a data monitoring system based on ZigBee wireless sensor network. ZigBee technology is a kind of wireless communication technology low power consumption, and short distance, and it is developed based on the IEEE 802.15.4 wireless standards. After ZigBee equipment networking, we can realize long-distance data transmission through the network link, and the network structure is easy to expand. Using ZigBee protocol self-organizing network has great convenience, and it can satisfy the requirement of the measuring points' number and the spatial span of drainage monitoring system very well.

2. General Planning

2.1 Systematic Structure Design

In order to realize the data determination and management of the building drainage system, the system must have functions like automatic data acquisition, remote wireless transmission, data storage, data analysis and processing, etc. Be divided by the logical function the system will be divided into three parts: data acquisition unit, wireless sensor network, The general architecture of Monitoring System is shown in Figure 1.

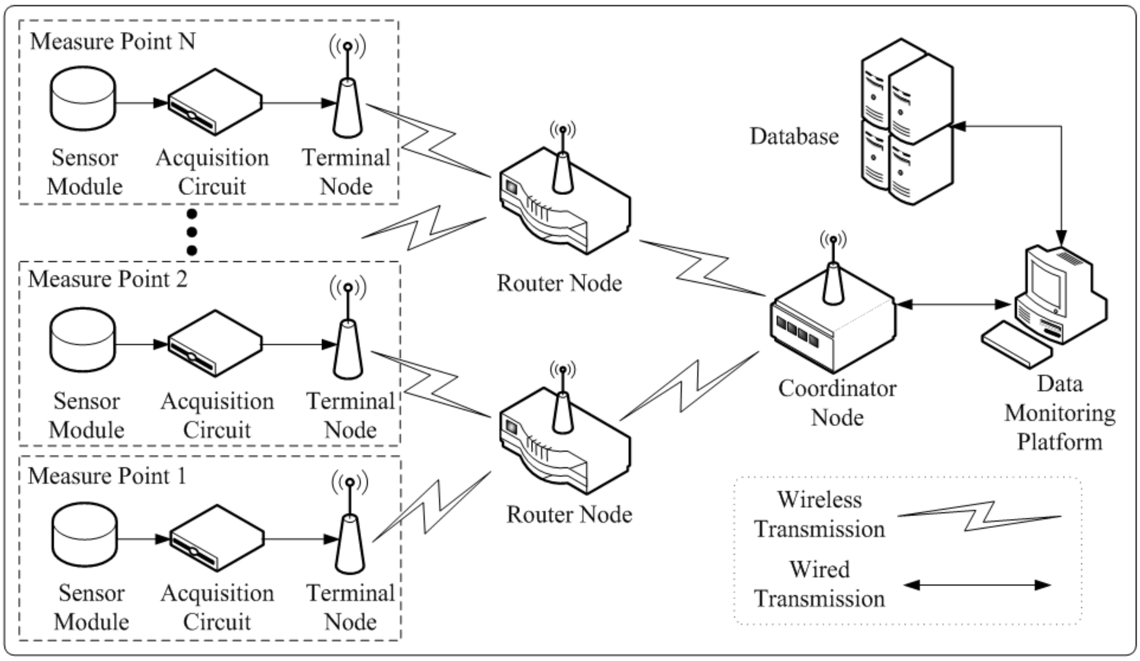

Figure 1 - The general architecture of Monitoring System

The sensor module and the corresponding sampling circuit make up the data acquisition unit. We set an acquisition unit at each measuring point of the floor for field data collection, and send out the collected data through ZigBee terminal node. ZigBee terminal nodes, ZigBee router nodes and ZigBee coordinator nodes constitute the wireless sensor network. The data from each terminal node transfer through the corresponding router nodes, and are summarized to the coordinator node, and then the data are transferred from the coordinator nodes to upper computer through wire communication. The upper computer monitoring platform is written by Visual Basic 6.0. It receives data from the coordinator nodes, accomplishes data processing and storage management, and has the function of the database interface and generate reports

2.2 Sensor Network Topology

Wireless sensor network (WSN) uses a tree topology structure as shown in Figure 2.

The fully functional device is used as the physical devices of the coordinator nodes. It has large storage capacity and strong computing power, and is responsible for establishing and initializing the ZigBee networks, and combining the information of each node. A ZigBee network can only exist in a coordinator. Router nodes also use fully functional equipment to transpond data, and to allow other nodes to join and leave networks within the scope of communication. Terminal node is generally the simplify function equipment. As the leaf node at the end of the tree structure branches, it can only communicate with its parent node. The tree topology has the advantage of the large network coverage area, which complies with the requirements of this system. Compared with other topological structures, the tree topology is easy to extend.

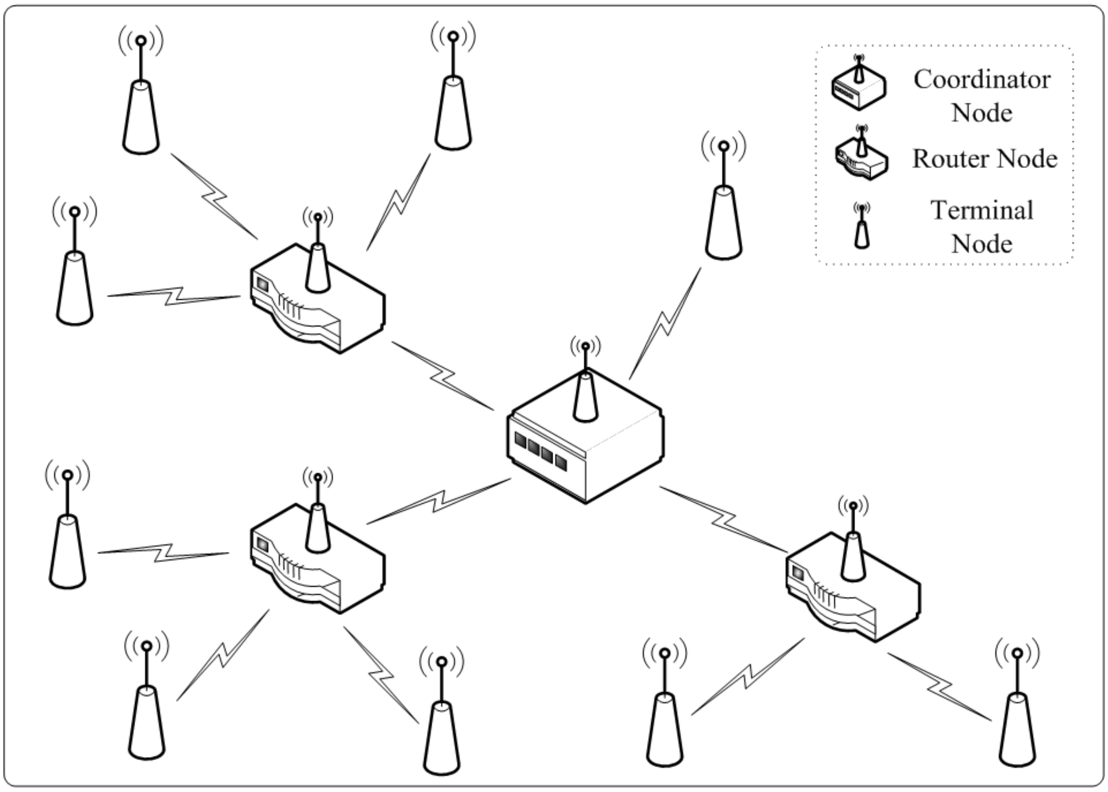

Figure 2 - Topology of sensor network

3 Hardware Design

3.1 Hardware Selection of ZigBee Node

Considering the complexity of ZigBee nodes’ working environment in the building drainage system, and the power dissipation requirements of the system, we need to choose the control core parts for node device with high anti-interference, low power dissipation and high processing performance, etc. So we selected TI 16bit low power and high performance consumption microprocessor MSP430, which is high performance and 16-bit, as the main control chip of the node equipment in this scheme. The chip can work as ultra-low power consumption state in ultra-low voltage. It also has rich peripherals, where 12 bit A/D converter and 2 channels serial communication interface (software selection is UART/SPI mode) make it convenient for data collection and transmission. In addition, the temperature range of MSP430 operating ambient is from -40℃ to +85℃ , and this chip can adapt to the harsh environment.

We choose TI company’s CC2530 as the core device of the wireless communication module to implement the ZigBee protocol. The chip contains a radio frequency transceiver which accords with IEEE802.15.4 standard, and works in the ISM public channel at 2.4 GHz, and a industry standard enhanced 8051 CPU, it has strong anti-interference ability and is especially adapted to ultra-low power requirements of the system especially. The communication distance between two nodes of the transceiver is 10~100m, and it can also transfer further after increasing the wireless transmission power, which meets the requirement of the communication distance between nodes in different floor drainage system.

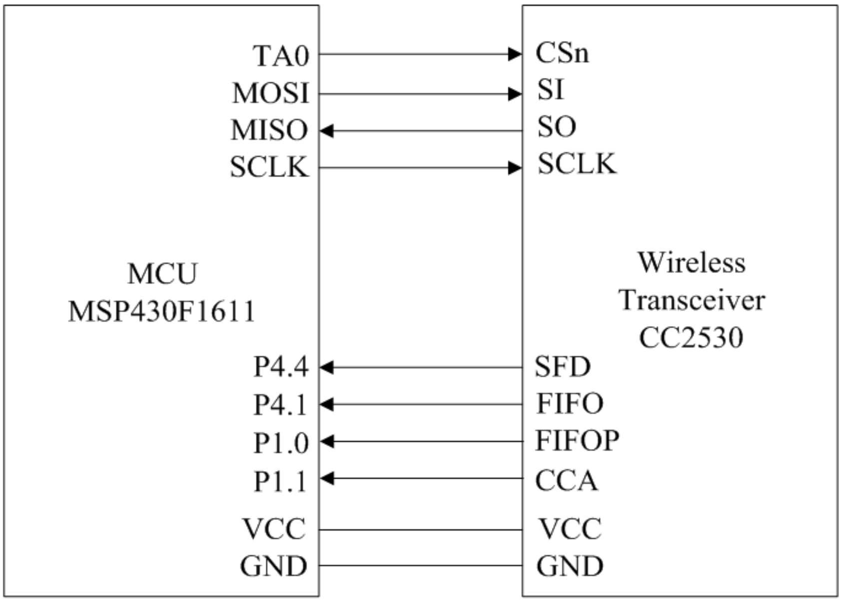

Figure 3 - Pins connection between MSP430 and CC2530

Processor MSP430 transmits data with CC2530 through SPI interface; CC2530 indicates the status of sending and receiving data by SFD, FIFO, FIFOP and CCA pin. MSP430 is the host of SPI communication, and CC2530 is the slave. The pin connection diagram of them is shown in Figure 3.

3.2 Hardware Design of Coordinator Node

Coordinator nodes receive the measured data from routes or terminal nodes, and transmit them to upper computer buffer for upper computer software load through the serial communication. Coordinator nodes are not directly involved in the field data acquisition of drainage system, so there is no need to use additional processor module in the coordinator nodes hardware structure. We directly use the UART serial port in CC2530 chip to connect to the upper computer COM interface directly, and the coordinator nodes hardware structure is shown in Figure 4.

As the center of the whole network, coordinator nodes need to communicate with more child nodes. Because of the large data throughput, coordinator nodes need to use the higher power antenna to enhance the ability of sending and receiving data.

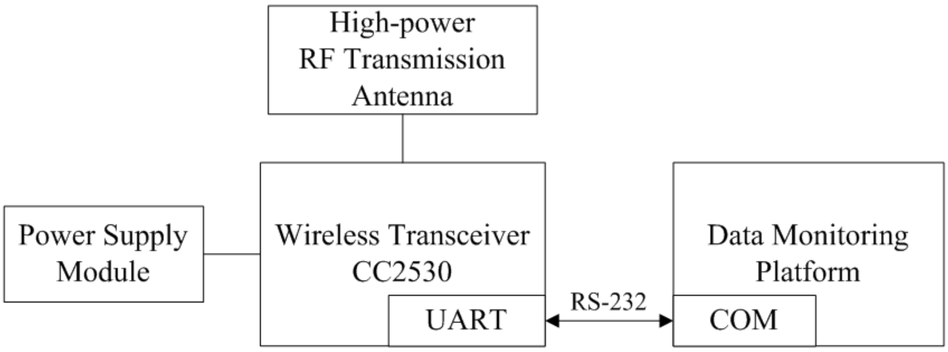

Figure 4 - Hardware architecture of coordinator node

3.3 Design of Terminal Node Acquisition Unit

Terminal node acquisition unit has functions of signal acquisition, preprocessing, conversion, temporary storage (TS) and sending, etc. Its function structure is shown in Figure 5.

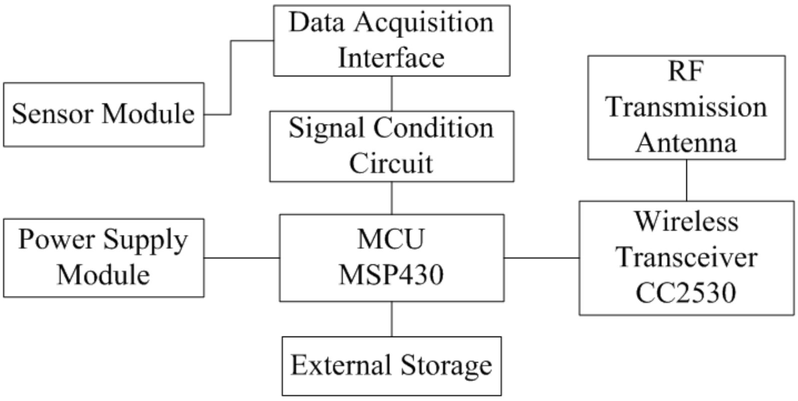

Figure 5 - Hardware architecture of terminal node

The sensor module includes pressure sensor and its connector wires, etc.; Every data acquisition interface of each node is set to 4 channels with obligates 1 ~ 2 channels; Signal processing circuit complete the signal isolation, amplification, filter and signal type conversion; Microprocessor part is responsible for the control operations of entire node, including A/D conversion of the collected data, conversion of data format, reading and writing to the external memory chips, and data interaction with CC2530, etc.; External memory chips are used for collected data temporary; Wireless transceiver chip CC2530 complete data transceiver with other nodes and transmission of the control signals; The antenna is used to increase the transmission power; Power supply module complete the corresponding AC/DC and DC/DC conversion to meet the needs of different acquisition unit parts on the power supply.

4 Software Development

4.1 ZigBee Protocol Implement

ZigBee protocol, developed by the ZigBee Alliance, is one of the criteria for short-distance wireless communication, in line with IEEE 802.15.4 specification. IEEE 802.15.4 meets the International Standards Organization (ISO) Open Systems Interconnection (OSI) model defined physical layer and media involved control layer, and the ZigBee Alliance provides the design of network layer and application layer. The layers under ZigBee protocol are connected via service access points, including data services and management services, and each layer provides services to its upper or lower through a set of service primitives. Taking into account the commonality and convenience of software development, the system uses Z-Stack, a TI provided industry-leading gold unit stack, to implement the ZigBee protocol.

Z-Stack makes the ZigBee protocol specific, which greatly reduces the workload and the difficulty of users' development. It can be compiled and developed by IAR Embedded Workbench. Z-Stack adopts the thought of operating system, and the entire program is set up on a polling mechanism. The program completes two things: system initialization and task polling. The program would keep in osal_start_system() loop after the system initialization is complete. The function keeps task rolling, and when a system task occurs, it calls the appropriate handler for processing. According to Z-Stack protocol, users add their own task in accordance with the Z-Stack given manner and these functions would be called for hardware initialization during system initialization.

4.2 Design of ZigBee Node Applications

Each ZigBee network must and only have one coordinator node. The coordinator node is the key to the whole network, and it is responsible for configuration of network parameters, start-up and maintenance of the network, reception of the collected data and transmission of data to the host computer monitoring platform. Application Process of coordinator node is shown in Figure 6.

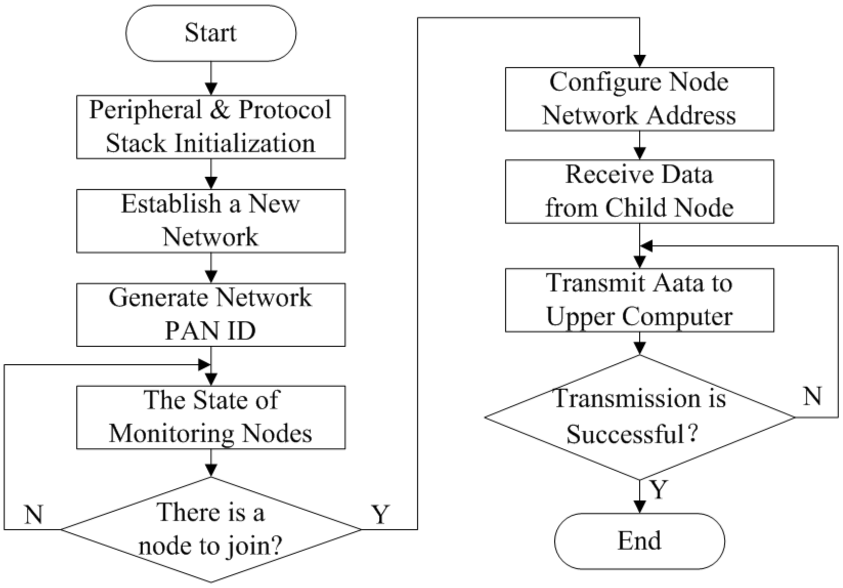

Figure 6 - Program flow of coordinator node

After powered on, first the coordinator node is initialized. In this process the coordinator will retrieve an available channel, and establish its own network in the channel. Only after successfully building a network the system will enter the normal start-up state, otherwise it re-enters the initialization state. After the network construction is completed, the coordinator node generates network PAN ID, and then enters the node listening state. If there is a request from routes or terminal nodes to join the network, the coordinator node will make judgments based on the request contents and then respond. After the confirmation signal receiving routes or terminal nodes join the network, the coordinator node will assign a unique network address to the routes or terminal nodes as the identity. Finally, the coordinator node enters a loop: sending related control signals to the child nodes on time, receiving child nodes transmitting data and transmitting the received data package to the host monitoring platform.

Terminal nodes need to complete the task of data collection and data transmission. Its application layer program is shown in Figure 7. Similar with coordinator node, terminal node would also first be completed the appropriate initialization operations after powered on, which includes hardware peripheral initialization and Z-Stack protocol stack initialization. After initialization, the terminal node does not need to establish a network, but queries the signals within its communication scope, selects the appropriate network, launches its request to join the network, and joins it after receiving confirmation from the coordinator node.

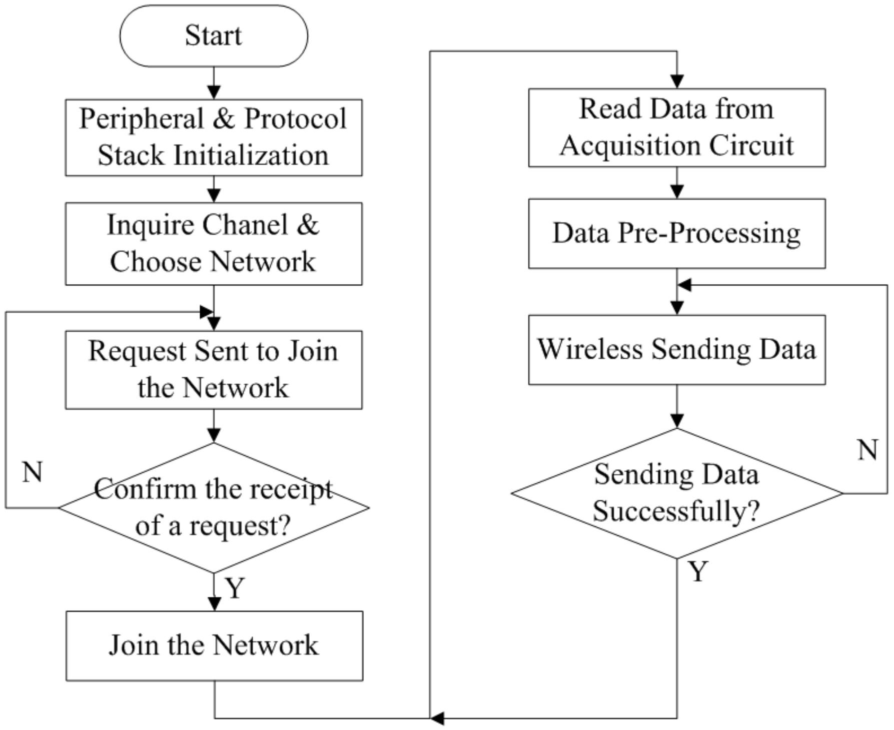

Figure 7 - Program flow of terminal node

After a successful network accession, the terminal node program also enters a loop: constantly receiving control command from parent node, reading the data from acquisition circuit on time, pre-processing, and sending the data to the parent node after format unified. It should be noted that the reading and pre-processing of data is done by the MSP430 microprocessor chip, and the wireless transceiver is chip CC2530. These two communicate via SPI.

4.3 Upper computer Monitoring Platform Development

In this paper, we adopt an object-oriented language Visual Basic and develop upper computer monitor platform in Microsoft Visual Basic 6.0 environment. VB 6.0 programming tool packs the system's various Windows API function into different controls for application of different software development. In addition, it also has a lot of objects libraries, and the program interface is quite artistic, friendly. Therefor VB 6.0 fully meets the upper computer software needs of the system.

The system requires host computer of the following functions: 1) real-time communication and data exchange with coordinator; 2) the ability of controlling the entire system' s start-stop process and setting the system acquisition parameters; 3) the analysis and processing of collected data and display of the key parameter values; 4) data storage and reports generation; and 5) friendly human-computer interaction interface for easy operation. upper computer monitoring platform program is shown in Figure 8.

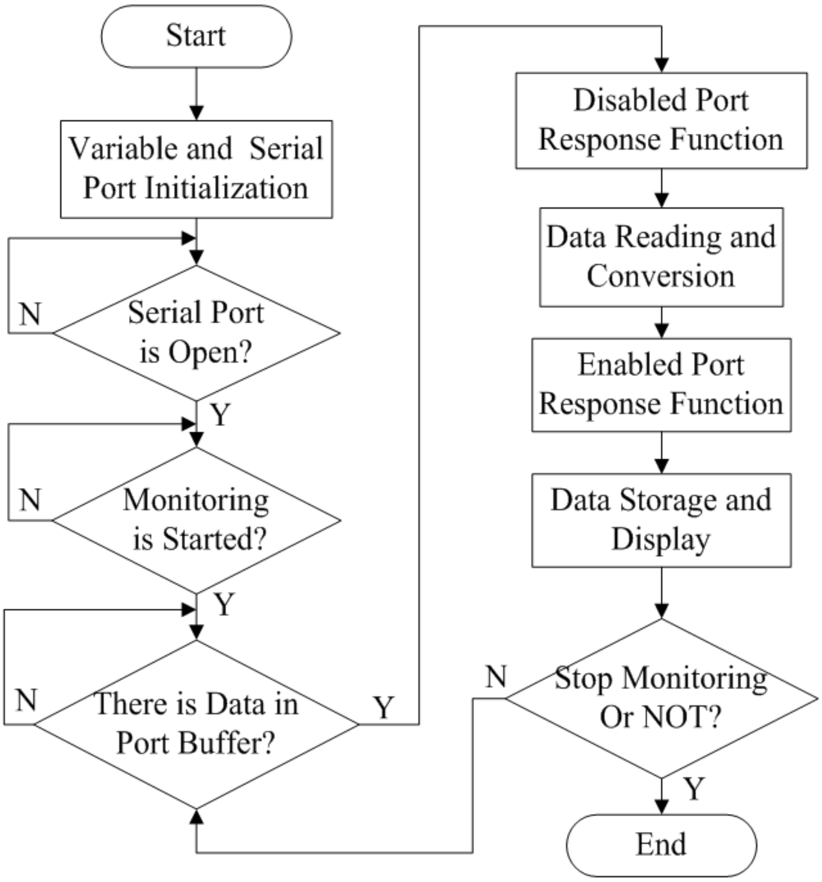

Figure 8 - Program flow of upper computer software

The mainly used controls and libraries are: 1) MSComm controls to achieve RS232 serial communication function; 2) Text control and the PictureBox control to draw the real-time data curve and dynamic curve; 3) Microsoft Excel 12.0 object library to generate Excel data tables and to store the collected data on time; 4) Microsoft Forms common control to improve the friendliness of human-computer interaction interface.

5 Conclusion

A building drainage monitoring system based on ZigBee wireless communication technology, is proposed in this paper. We use the MSP430 microprocessor finishing the control of data acquisition, while using CC2530 chip realizing wireless transceiver, and according to the monitoring characteristics of the drainage system, we establish a reasonable network topology structure to implement the data transmission in the ZigBee wireless network. The upper computer monitoring software based on Visual Basic 6.0 is connected with the coordinator through RS-232 serial ports, and this make the data interaction and display, storage function realized, the monitoring process visualization and operation convenient. This building drainage monitoring system based on ZigBee wireless sensor network effectively solves the problems of the traditional wired monitoring system, such as structure fixed and difficult to extend, wiring complex and high cost. It also can reduce the system power consumption, and monitor the drainage system effectively at the same time.

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7 Presentation of Authors

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Engineers Kill People –Don't They?

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Abstract

Quote: "We can't solve problems by using the same kind of thinking we used when we created them" Albert Einstein.
Managing urban areas throughout history, has always been challenging, and is no less so for these major developments in the 21st century
The challenges come with the need for an "adapt or die" approach to the news of, climate change and other influences, as much as a shift in economic and technological factors.
The paper is meant to be controversial, challenging and thought provoking.
This paper is an attempt to draw attention to some of the engineering design and installation practices and processes that need to be challenged. It will consider the influence of other external sources, with particular reference to Water and Drainage in Buildings, which need to change significantly to meet the challenges of the 21st Century.
Many present codes have not considered the recent changes made to construction processes, the research undertaken, economics, or the rate of urban development, concentrated communities/mega cities.
It sets out to identify and draw the attention of practicing engineers to some of the errors made, by blindly applying the codes and guidance documents, some of which were written 60++ years ago.
Presently many of the Codes by which we design, although updated, lack the foresight to include solutions offered by results of engineered/academic research, which has been peer reviewed and will impact on future generations.

Keywords

Urbanization, Design Codes, Hospital Acquired Infection, Water and Airborne Disease, Epidemiology,

1. Introduction

The Romans left a great legacy across most of Europe, in fact, next to the Emperor, was the “Plumber Senator” who ensured that Rome had plenty of supply of clean water (not bottled) by investing in huge aqueducts from uncontaminated sources. “Next to Godliness – Cleanliness” was the maxim of that day.

As Rome grew in size, he was the first, in later years to introduce a two tier system, this enabled a secondary quality of water to be used for sanitation, leaving the best quality for drinking as the population continued to grow,(very much like our needs for our Mega Cities today).

There were also heavy penalties for would be polluter’s, far heavier levy’s compared to what is awarded against our polluters’ at this present time.

Sanitary Engineering has been at the forefront of every major urban development and supported the strength of Empires. The purpose to enable larger communities to live together with limited disease, providing strength and safety in population numbers.

The health of a nation is always paramount to its economic development and survival.

With the many water related challenges already presented to us as an industry, we are hard pressed to respond. Too many decisions are “knee jerk” responses to a localized crisis. Then suddenly, that solution is the basis for common practice, with scant regard for local differences and cultures.

Normal responses to any kind of risk –epidemic-pandemic or other life risks, as mentioned earlier, are only characterized by the numbers of people that die or are at risk. Localized or globalized (Ebola more recent, SARS & MERS, LD -Legionnaires Disease, ongoing HAIs, MRSA, C.Diff, Noroviras etc).
1) Legionnaires Disease (where there is blame, there is a claim)!!
2) SARS South Asia Respiratory Syndrome
3) MERS Middle East Respiratory Syndrome
4) Waterborne diseases e.g. E Coli, Salmonella, Pseudomonas, etc
5) MRSA, C Diff and others, HAI’s, Hospital Acquired Infections (where there is blame, there is a claim)!!

Too little of the limited research, which is undertaken and peer reviewed gets acted upon in applying the results to benefit directly, the communities and processes those University and Research establishments serve.

Too little attention is also paid to the cultural differences, where generalized international codes are applied, in lieu of any locally developed code, of any merit.

Hence, highlighted in this paper are only a few areas that have made headlines, due to the larger numbers of people affected.

As can also be seen many of the codes are updated, according to political will and the amount of adverse publicity an event or occurrence attracts.

2. Here is the News — Driving the Need to Change

United Nations states: 54% of World's population live in urban areas. (1)
This is expected to increase to 66% by 2050. An additional 2.5 billion people predicted to live in urban areas.

This highlights the need for successful urban planning with greater attention to how we design for high density living conditions.

37% of the projected growth will be in India, which currently has the largest rural population, then secondly, China and Nigeria.

The world's largest city population is Tokyo with 37 million inhabitants, New Delhi second most populous city with 25 million but projected to grow to 36 million by 2030.

Shanghai, 23 million, Mexico City, Mumbai and San Paolo, with about 21 million, followed by Osaka with over 20 million and Manila lead the top population hot spots.

The future demography is expected to change with these "mega cities" falling in rank as smaller urban cities gain population. (So provinces will also see unprecedented growth).

The present most urbanised areas include North America where 82%, Latin America 80% and the Caribbean 73% of populations live in urban areas.

By contrast, Africa and Asia remain mostly rural, housing nearly 90% of the world's rural population. Their urban populations are on the rise 40% for Africa, 48% for Asia by 2050, this is projected to grow to 56% and 64% respectively.

Managing urban areas throughout history, has always been challenging, and is no less so for these developments in the 21st century.

This will bring challenges for housing, transportation, employment, infrastructure, energy, food and water security along with other basic services, such as education and healthcare.

3. The Codes –– Other Influences –– Your Thoughts

Your own thoughts on code contents and their applications would be welcome and appreciated.

From ongoing experience, I have found that many of the Codes by which we design, although updated, lack the foresight to include solutions offered by results of engineered research, which has been peer reviewed and will impact on future generations.

At best, revisions are decided by committee, many times influenced by a disproportionate ratio of manufacturers, practitioners and researchers, union representatives, lawyers and politicians et al. Also the length of time it takes to programme, such that progress can take many years, and who of us would want to change our comfort zone – or the status quo? (Happy to "have always done it this way")?

Nothing wrong with this, as some will say, we managed with them this far.

If that is so, why then do we have the continued challenges of hospital acquired infections, epidemic outbreaks, localised air and waterborne diseases, and in particular all their associated epidemiology?

We need to re-assess the limitations of many of the Institutions which are operated on a voluntary or part-time basis, as this only frustrates progress which in many cases will be slow and biased in favor of political will, (lobbyists) and those who can be supported or financed by vested interest parties.

3.1. Other influences impacting on application

There are also other external influences and pressures that have a greater or lesser impact on what has been designed to the codes, and that which is installed, in the actual.

3.1.2. Root cause, or contributor?

I am not sure, who of the following, influences the poorest of the outcomes the greatest. In no particular order of preference:-

(1) Accountants,
(2) Politicians
(3) Lawyers
(4) Union Representatives
(5) Quantity Surveyors
(6) Value Engineering (or Engineering with No Values)
(7) Architects
(8) Main Contractors/Developers
(9) Lack of Education/Training
(10) Just Ignorance of Basic Principle
(11) Regulations and Codes of Practice. Others (please list) …….

Over the many years of experience in the field of Sanitary Engineering and with the huge steps forward in IT, complete with advanced research and technological tools at our disposal, it is difficult to comprehend, how we have turned safe, simple principles and practices, into hazardous, many times, life threatening systems.

3.2. Hope I’m Making you think!

The following facts also continue to haunt us even to this day, and with projected urbanization, the situation will not improve without radical shift in thought processes.

Every 20 seconds a Child dies, from water related disease, in developing nations.

3.3 million People die each year from water related disease.

Worldwide, over 60% of hospital beds, occupied by People suffering from water related diseases.

3.4 Billion People still don’t have access to a safe potable water supply and sanitation.

Strange phenomenon, is that many of the health risks/problems associated with plumbing services are when emissions from the product or service enter into the air streams. So I feel the “building services engineers” need to practice joined up writing.

Somehow, do you get the impression that we just haven’t got it quite right yet??

So, how are we to address these and balance them against other pressing issues associated with the basic human requirement for safe water and sanitation, along with food and energy needs as urbanisation takes on a new emphasis?

If this doesn’t attract your attention, and that in any drought crisis you can still buy bottled water at 10 + times the price of tap water, then, I’m going home. Just joking, it’s far to an important message.

The number of scenarios where mistaken/misuse of an applied principle increases with the complexity of the project, time and budget constraints, and/or the limited amount of suitably trained personnel available, will increase wastage and the risks to health.

This critical situation also applies to many other professions as well.

Never before, has there been so much readily available technical information, right at our finger tips.

Yet basic understanding of the practical application of that information, in many cases, only just falls short of criminal negligence.

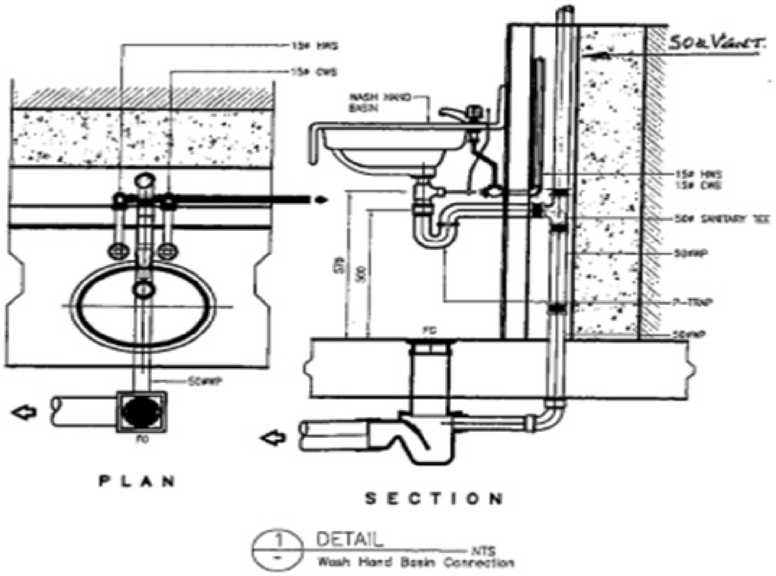
So even if challenged, a response from the un-enlightened is often, “show me where in the documentation, it says I can’t do this”

The ever changing social culture, certainly in many western societies, that acceptance, moves onto litigation, of where there is “blame” there will be a “claim”.

This should bring about a bit more emphasis of duty of care and safety in the design within the installation guides and procedures. But as with many situations the protective legislation is in most cases in the form of guidance documents or recommended codes of practice. And apart from a few instances, are voluntary.

4. Lack of Training or Ignorance of Basic Principle?

Some examples here are very domestic in their nature, but apply globally to demonstrate how limited some practitioners are in understanding the principles and their obligations.



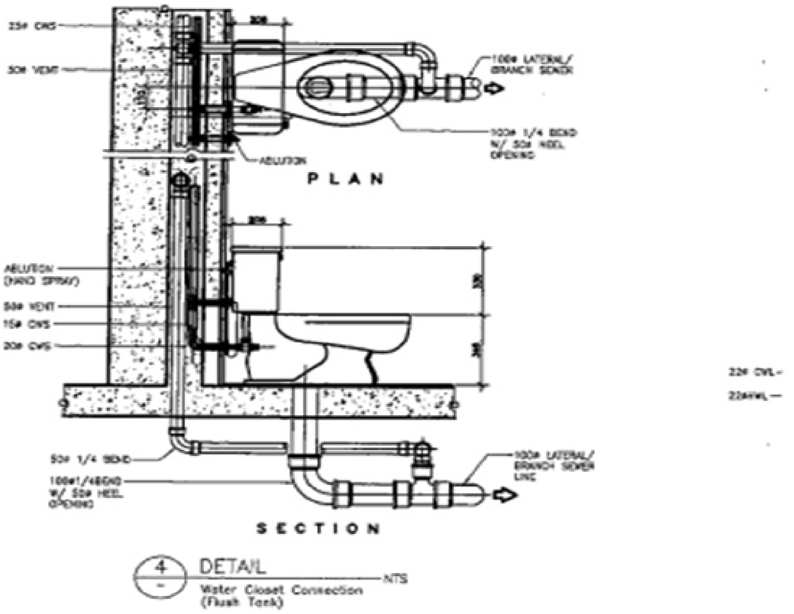


Fig.1 Lavatory and WC Venting

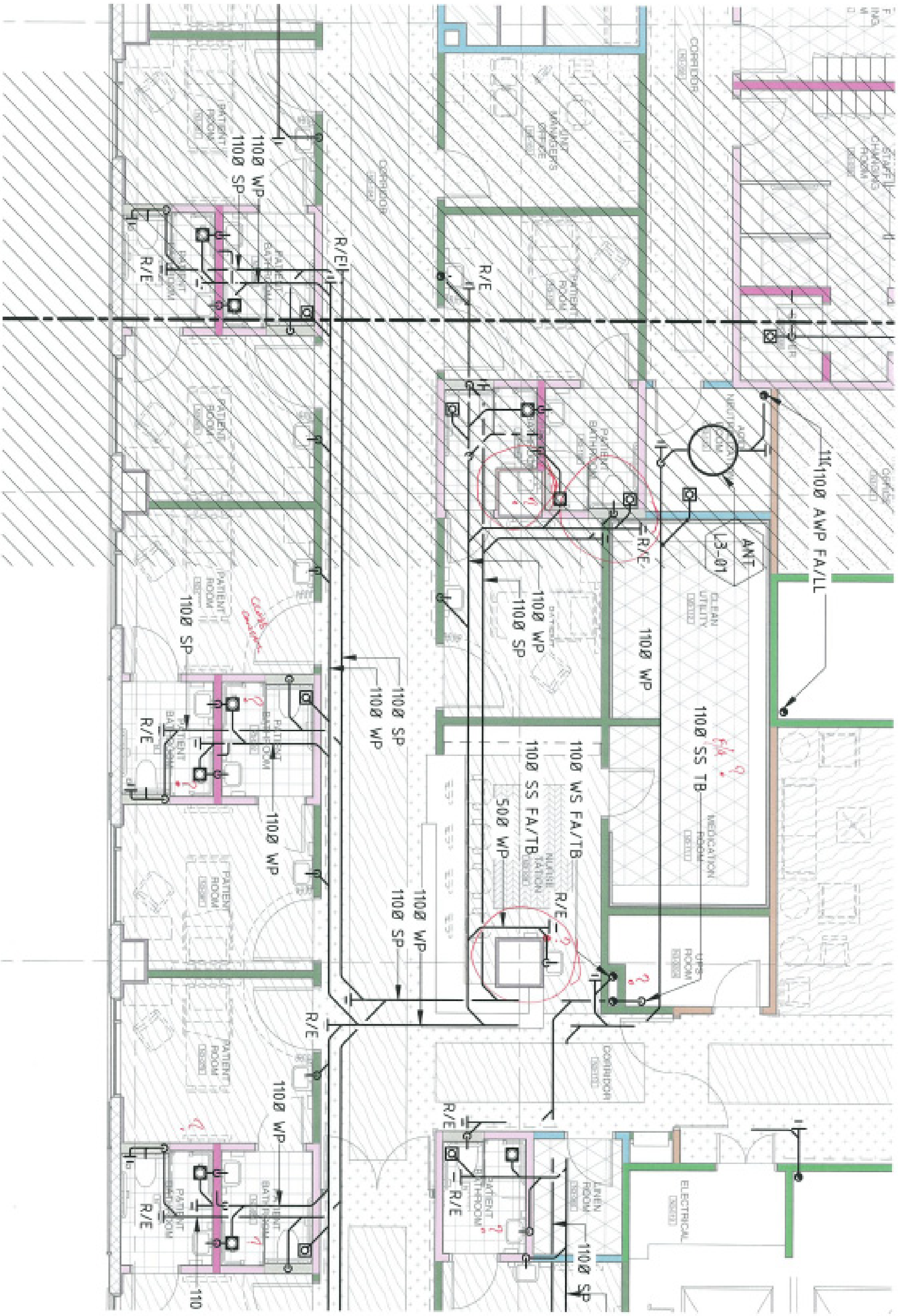


Fig.2 Cross Contamination

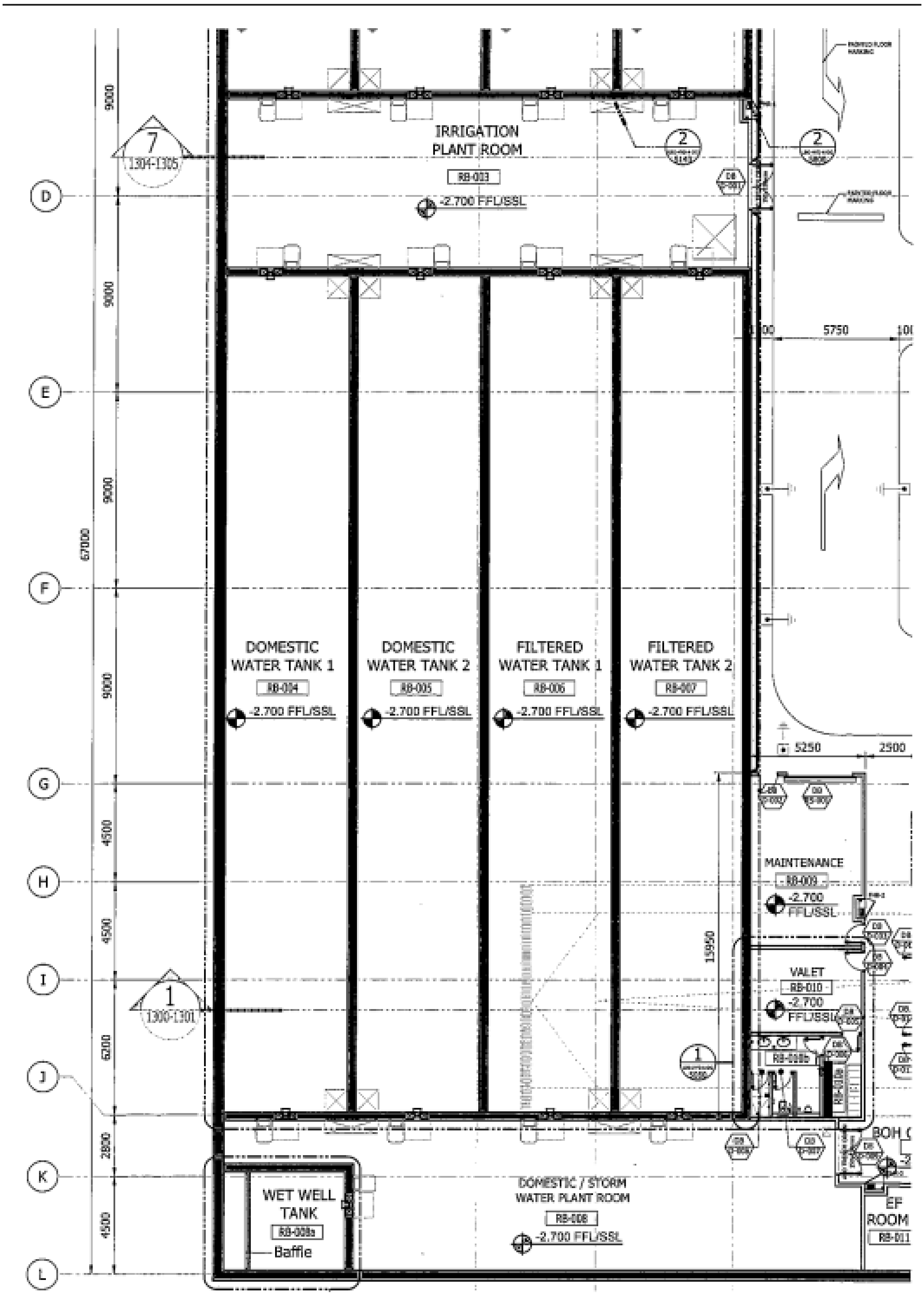


Fig.3 How many think about water stagnation in storage tanks and distribution systems?

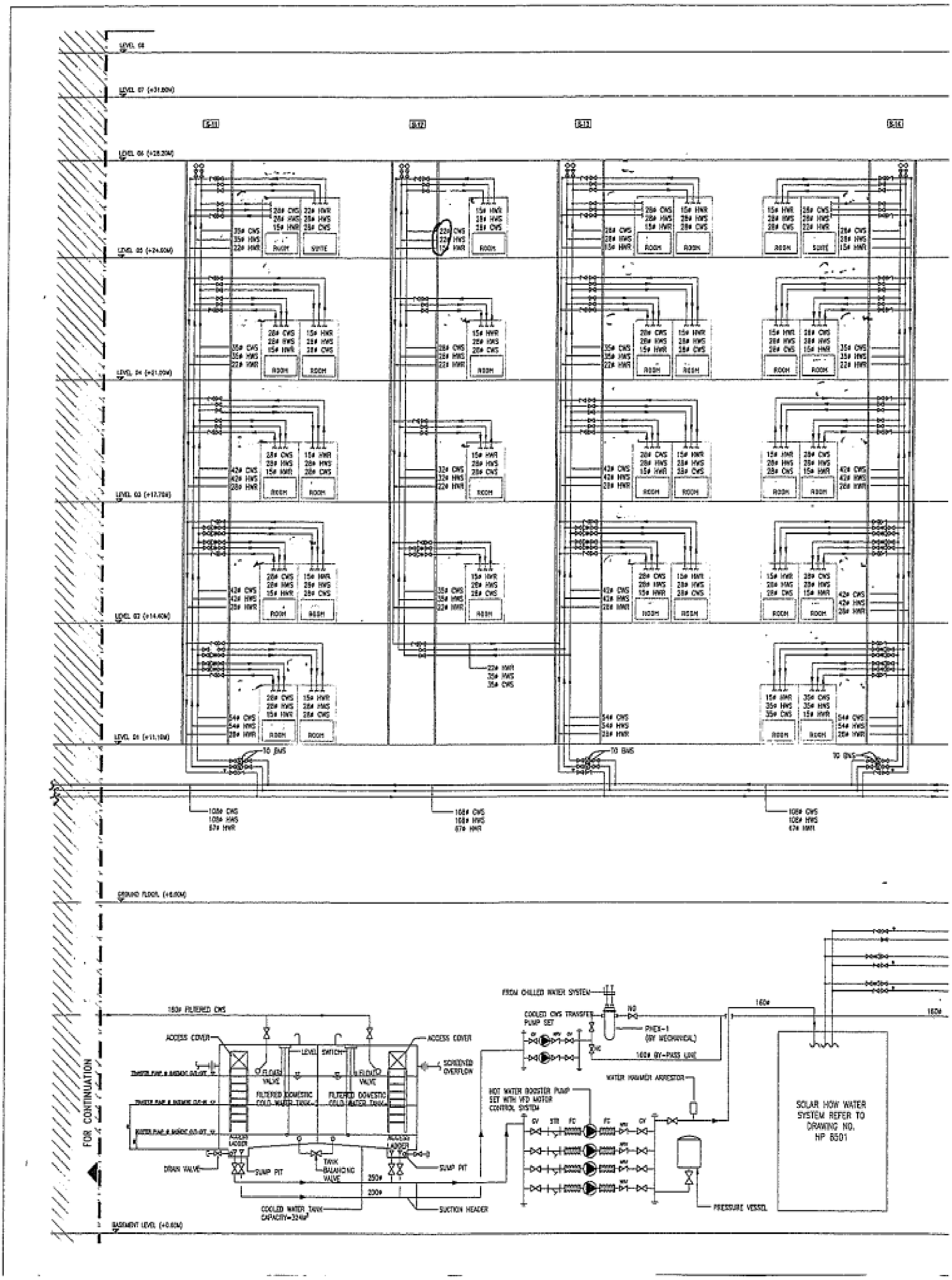


Fig.4 Do we all understand how a pressurized/boosted hot and cold system operates?

5. A Change of Mind Set

“Change, is not the enemy of security, it is the means of achieving it”.
Below, a selected sample of just some simple illustrations of research presented, although examples are quite recent, you can consider the many advantages of adopting some of the information into our codes. Much of the research is based on solving today’s problems, so surely we should be brave enough to incorporate it.

Why are we still designing/sizing all our pipe systems based on outdated information?

The reduced volume flow rates for most of the fittings both supply and discharge, the materials we use, should be giving us different pipe sizes, falls, as well as different velocities and performance curves.

If we take some of the papers presented over the past few years, just a snapshot of research from some innovative approaches presented at CIB WO62, 2009.

Fuzzy Logic “Applications of Fuzzy Logic to the Assessment of Design Flow Rates in Water Supply Systems of multifamily Buildings (2).

The Evaluation of Water Demand of the University of San Paolo, throughout Ten Years of the Water Conservation Programme(3).

Fixture Units at Choices of Reference Design Flow Rates for Simultaneous Demand problems of Large Water Supply Systems in Hong Kong.(4)

The effects of using water velocity as a technique to control biofilm development in water supply systems. (5).

The need to rethink the design criteria for water supply in buildings in light of the implementation of water efficiency measures. (6)

These, and so many others could assist in applying a more logical approach to compensate for the impact of concentrated communities, and demographic changes which have taken place, which could not have been envisaged 60++ years ago.

5.1 Further Challenges

With the many water related challenges already presented to us as an industry, we are hard pressed to respond. As mentioned earlier, many decisions are “knee jerk” responses to a localized crisis. Then suddenly, that solution is the basis for common practice, with scant regard for local differences and cultures.

Water recycling and re-use is one area where local needs and cultures can affect the outcomes within local/international codes.

Recycled water, TSE (treated sewage effluents) in particular, has had some bad publicity in recent times, with food being contaminated. Yet we probably have more quality control over that source, than supplies for irrigation from heavily polluted rivers of unknown contaminated levels. Which of these options are contributing to the ongoing emergence of new infectious disease, I wonder.

Source Control, is an appropriate approach for many communities. The rainfall, the water use, the wastewater discharges are used and wasted locally. Presently in many urban areas a centralized plant is used and then discharged to river or sea, lost from the system. If treated locally, this can contribute to a greater amount of sustainability. Recharge to stressed aquifer, or well, from where the water was drawn. Rainwater harvesting, providing seasonal benefit, allowing again recharge or reservoir top ups to reduce worst effects of droughts. In addition such actions can also contribute to reduce local flooding.

Guidance and Codes, hold major differences of approach, many not always considering the bacterial quality, and considering it safe, to re-introduce secondary quality water direct into our buildings. WC flushing!! Irrigation (spray in particular).

Strange phenomenon, is that many of the health risks/problems associated with plumbing services are when emissions from the product or service enter into the air streams. So I feel the “building services engineers” need to practice joined up writing.

6. Conclusion

Whilst there are still too few answers to the questions raised in this paper, I sincerely hope that it can open up minds for further debate, and actions.

Licensing, could be one way forward and can be a control mechanism for responsibility of the design, installation and performance of all things connected to the building/construction process. Licensing is already operational in many countries (except UK where anyone can call themselves anything, qualified or not)!

However, licensing, will also fail in its endeavors to protect the building owner/operator/public user from malpractice, if not properly supervised or policed.

I am always optimistic when leaving a conference like this, that we can cooperate in working together towards practical, economic and acceptable solutions.

In reality, we need to find a way of disseminating the information of the researcher, right down to the installer on the site.

“A Big Ask”

For as just a few examples from Codes to Designer has demonstrated, we have already failed in that communication exercise, through interpretation or misunderstanding.

Too few practitioners have any real “hands on” experiences, on-site, seeing their actual design being installed and commissioned. Too few installers in this “push fit” world have any real technical training to appreciate the – “Why or How”.

One more route is that the family of CIB WO62, can add to the platform of ideas already developing

through the World Plumbing Council (6), and bring about the changes so necessary to the way we think.
I look forward to seeing a task force of young Public Health conscious researchers and practitioners working on an open programme for the benefit of the societies we serve, and in which we all live and work.

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8. Presentation of Author

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CONFERENCE DELEGATES SURVEY

As part of this paper presentation it would be appreciated if you would comment and fill in the boxes in the list below, in order of the worst influencers. (1-12, 1 being the worst and 12 being the better involved in Code decision making)

The limitations of many of the Institutions which influence the design codes are operated on a voluntary or part-time basis, this only frustrates progress which in many cases will be slow and biased in favor of political will, (lobbyists) and those who can be supported or financed by vested interest parties. TRUE or FALSE

Over the many years of experience in the field of Sanitary Engineering and with the huge steps forward in IT, complimented with advanced research and technological tools at our disposal, it is difficult to comprehend, how we have turned safe, simple principles and practices, into hazardous, many times, life threatening systems. TRUE or FALSE.

Root cause, or contributor?

I am not sure, who of the following, influences the poorest of the outcomes the greatest. PLEASE Note your order of preference: - 1 -12

- Accountants
- Politicians
- Lawyers
- Union Representatives
- Quantity Surveyors
- Value Engineering (or Engineering with No Values)
- Architects
- Main Contractors/Developers
- Lack of Education/Training
- Just Ignorance of Basic Principle
- Regulations and Codes of Practice
- Others (please list) …….

Anonymous or add your details Thank you for presenting your views.

Name……………………………………………… e-mail…………………………………………………

Fire Plan of Beijing Jiaozhuanghu Warfare Site

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Abstract

Introduction and aims: Jiaozhuanghu historical and cultural protected areas Warfare Site is located during the war. For now Jiaozhuanghu Warfare Site fire hazard exists, in the full investigation of local natural conditions, combined with the local economic development, as well as reference to other ancient building fire in the advanced ideas proposed station sites Jiaozhuanghu authentic fire planning and formed for the protection of the region Warfare Site philosophy. Method: Fully meet the fire safety requirements, it reflects this particular tunnel warfare jiaozhuanghu monuments in the fire protection features, namely different protection modes from activities in the war underground tunnel warfare to villages on the ground. Results and conclusion: Firefighting system of Beijing jiaozhuanghu Historic District Tunnel Warfare Site is feasible and necessary. Contributions: Safe and secure fire water system is able to effectively respond to emergencies.

Keywords

Site protection, Fire plan, Warfare Site

Jiaozhuanghu tunnel Warfare Site demonstrated the Chinese nation created immortal performance against aggression, showing the great and magic of people's war. In 1964, Jiaozhuanghu former militia headquarters location build the memorial, known as the "History of the militia fight Jiaozhuanghu showrooms." In 1979,defined as a key cultural relics protection units by Beijing city, jointly be repaired Beijing Shunyi county governments in 1987, and in October 1987 set up a "Beijing Jiaozhuanghu Tunnel Warfare Site Memorial", in 1994 named "Beijing Youth Education Base", "national primary and secondary patriotism education base" in 1996. In 2001, identified as one of the top ten Propaganda patriotism education bases. September 2003 as one of the second batch of Beijing historical and cultural protection areas (suburbs 10), an integral part of the protection of historical and cultural city of Beijing. And became the first "red tourism House" listed units of Beijing in 2010.

In order to get the overall protection and reflect the spirit of respect for the historic sites and national culture, fire planning will protect the village pattern on the ground and tunnel activities underground in Tunnel Warfare War sites. To prevent the destruction of this historical and cultural heritage, the establishment of a comprehensive and effective fire fighting system is a priority. Because fire is a high-fat, wide-ranging, large losses, strong social impact of sudden disaster, it is necessary for the effective implementation of scientific sites, practical firefighting measures. In the implementation process, it should fully embody the "people-oriented" and the important thought of the scientific concept of development, in order to protect the historical and cultural heritage Jiaozhuanghu for the purpose of protection of people's safety as a precondition to develop fire planning.

1. Overview Jiaozhuanghu Village

Jiaozhuanghu village is located in southwestern mountain plain of Yanshan Mountains, full of ups and downs, the higher the northeast, southwest low. There are many low-lying areas and ponds naturally formed in the village. Mountains, hills and villages northeast southeast direction reflected, the village pond before (in recent years has been filled), northeast mountains, the main road at the south links with the outside world, the west rivers and reservoirs of Chaobai River tributary Rooster River. Jiaozhuanghu village is in good natural environment among the mountains, water, farmland, plains, mountain woodland integration.

According to the plan range delineation (ie core protected areas, protected areas, building control areas), the distribution of the population changes. Tunnel Warfare Site Memorial where core protected areas, the main population management personnel and visitors; protected areas for the resident population of the old village of Jiaozhuanghu; building control areas for the resident population Jiaozhuanghu Village.
According to statistics of the population of the status quo: total agricultural population of the village is 1490, 491 household, building control areas 898, 296 household, protected areas 900, 224 household.

2. Fire Features Jiaozhuanghu Village

Fully meet the fire safety requirements, it reflects this particular tunnel warfare Jiaozhuanghu monuments in the fire protection features, namely different protection modes from activities in the war underground tunnel warfare to villages on the ground.

2.1 Residential fire protection design

Residential mainly refers to villages with regard to the activity of the war, the building fire protection design ideas mainly prevent the ancient building brick or wood structures from fire or extinguish fire promptly. Set in the outdoor fire hydrant system design, the supply water through the pipe network or pressurized pipelines should transport to put out the fire within the building, which is the most basic fire-fighting facilities. Construction of outdoor fire hydrant in the spacious hall of the court, or a more open courtyard, ensuring protection within the radius of each residential neighborhood in the outdoor fire hydrant.

As is discovered after studying the local village water infrastructure, it can not be evaluated in accordance with the general transformation of the ancient town of the fire. According to the "architectural design code for fire protection" (GB50016-2006) in our country: "Ancient brick or wood frame construction focused national cultural relics protection units, should set fire hydrant."[1] The museum is not a national security unit, temporarily not set indoor fire hydrant. But the design of outdoor fire hydrant system should meet the indoor system requirements, the outdoor fire hydrant system adequate water supply and water pressure to meet fire safety requirements within residential.

Outdoor fire hydrant water supply system consists of an outdoor pipe network and fire hydrants, fire water and pumps, etc. to ensure the safety of water, so that the ancient architectural monuments get more protection. Fire water storage capacity should meet once water extinguishing in fire duration.

2.2 Tunnel inside fire protection design

The ruins inside the tunnel was mainly left after anti-Japanese War, so to focus on protection. Fire protection design inside uses a hydrant system outdoor to meet the fire safety requirements of the room. In rainfall season, the water inside the tunnel using a mobile pump discharge, mobile pumps for use by the vehicle load. In the dry season, after an authentic full estimate possible ignition point, where appropriate, such as offices and other relatively spacious aisles, configure the appropriate number of fire extinguishers to ensure that it will extinguish the fire in the shortest possible time. Without prejudice to the visitors and staff accepted the premise of the necessary arrangement of fire extinguishers to prepare for contingencies.

3. Fire Water Supply

3.1 The fire pool

In Jiaozhuanghu residential area, living water can not meet the needs of the fire water, so set the fire water reserves which store fire hydrant water for duration 2h. In case of fire, extinguish residential fires can ensure adequate water required. According to the actual situation, the region terrain relatively high build fire water and fire water tanks by collecting groundwater. Unable to set fire water tank, its function can be replaced by fire pool, fire water for the initial fire 10min in fire pool is used to ensure that the water pressure and water pipe network in the early fire.

3.2 Role of natural water supply

Jiaozhuanghu Sanctuary Museum in Beijing Shunyi district, covering about 17.23 hectares, can import penetration of rainwater catchment pond roofing and pavement area of about 1/4 of the total area, namely the catchment area of about 43000m2, rain collected mainly from stormwater infiltration pond north of aggregation, in addition to some to be a shallow trench into the ground or vegetation interception, most of which will import into penetration pond. Both play the role of regulation and storage of rainwater, but also largely improve the surrounding environment. there is groundwater recharge in dry season, so it is also another effective complement for fire protection water.

4. The Fire Water System (Temporary High Pressure)

Temporary high-pressure fire water supply system can meet the fire water and water pressure requirements as a supplement to the water distribution network. This system pressure in the water pipe is not usually high, whose pressure and flow can not meet the requirements of the most negative point of fire in the pump station. Equipped with fire pumps, when receiving fire alarm, temporary high-pressure fire water supply system startup, then the pressure inside the pipe soon reaches high-pressure piping requirements, and water cannons should be set at the highest point of any building layout within the scope of protection, but the water column should not be less than 10m, in order to ensure that firefighters rushed to access from the hydrant and a safe and effective fire fighting.

4.1 Fire Water

According to specifications, civil construction should have outdoor fire hydrant, it should be set when fire resistance rating less than two. The number of fires set at the same time a second, about a fire in an outdoor fire hydrant water, according to the characteristics of the museum building, the largest building by volume of less than 1500m^3, so take 10L/s. Civil fire duration by 2 hours meter, the water consumption is canceled anti-10L/s, fire water should be located 72m^3, water supply wells, according to the museum to provide data for 20m^3/h, can be completed within four hours supplement to meet the requirements.

4.2 Fire water pressure

Fire water pressure mainly refers to the hydraulic pump to provide the system, according to the outdoor water supply design specifications, ie pump head must meet the minimum effective:

$$H=H_{xh}+z+\Sigma h$$

H-the pump can provide water pressure to the system

H_{xh}-the most unfavorable hydrant pressure port

z-the elevation difference from the axis of pump to Water-intake

Σh-the sum of the head loss in the pipeline

4.3 Fixed fire pump

Taking many factors into account, such as residential water security, in the case of that the pipe network is not working properly, we should set in three fixed fire pumps, two dual-one devices, to protect for fire control.

In the event of a fire, in case of insufficient water pressure, if the fire may not reach, you can make use of fixed fire pump to pressurize the water through the pipe to guarantee the fire water. In the main fire pump and fire use fire pump surge tank, the system pressure and water control and regulation. This fire pump is simple, absorbent, easy to manage, in a residential area Jiaozhuanghu configuration such fire pump, help put out the initial fire, improve Jiaozhuanghu village security.

4.4 Pipeline network laying

On the basis of the existing network and the construction of water canals, the fire water piping system composed of key protected areas in Jiaozhuanghu village. Fire water is less than 15L/S, so the fire can be arranged branched piping and the pipeline depth 1.00 meter, while meeting the following requirements:

$$S_1 \leqslant 2\sqrt{R^2 - b^2}$$

$$R=C \bullet L_d+h$$

S_1-hydrant spacing，m；
R-hydrant protection radius，m；
C-bending reduction factor when hose unfolded，0.8~0.9；
L_d-hose length, each hose length should not exceed 25m，m；
h-the length of the horizontal projection when gun enrich the water column tilted 45° , m ，h=0.71Hm，h=3m；Hm- the length of the substantial water columns of the water guns，m；b-the maximum width of the fire hydrant protection，m.

Distance calculated from the above formula and the fire hydrant hydrant protection radius between , be arranged in accordance with its requirements.

The formation of both open channel have double protection of underground pipe network in the separate courtyard , a plurality of small branched pipe network. In laying the pipeline without damaging the original and authentic integrity premise , so that the original laying of the pipeline and the new pipeline to link up to provide a more secure water supply protection for Jiaozhuanghu site protection .

4.5 Other

The protection of cultural relics in Jiaozhuanghu village , it is necessary to take the measures firefighting , fire control facilities and devices that increase a certain amount . Such as fire extinguishers configuration , the rational allocation of fighting since the beginning of the fire extinguisher is guaranteed , in Jiaozhuanghu villages arranged a sufficient number of fire extinguishers in the tunnel warfare to strengthen the maintenance and management of the site is necessary for some environmental conditions, poor location can be taken posted notices warning in order to achieve results. The configuration should be based on the location and type of fire " building fire extinguisher configuration design specifications" to determine [ ] . And a dedicated department staff responsible for teaching skills to use a fire extinguisher , and regularly check the condition of fire extinguishers and configuring.

5. Conclusion

Firefighting system of Beijing Jiaozhuanghu Historic District Tunnel Warfare Site is feasible and necessary. Fire water system layout full consideration of local natural conditions, in ensuring the basis and cultural heritage without destroying the absolute protection of this non renewable, more of effective construction and optimization of fire protection system. Fixed pump has played an irreplaceable role in this system, which makes the fire water supply system more secure, can more effectively respond to emergencies. In addition, Jiaozhuanghu area belongs to semi arid area, in the dry season may consider the supply function of groundwater on fire water, increasing the types of fire water to ensure the fire safety of water supply.

6. Funding

This project is funded by Open Research Fund Program of Key Laboratory of Urban Stormwater System and Water Environment（Beijing University of Civil Engineering and Architecture）， Ministry of Education

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8. Presentation of Author

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Discussion on Building Drainage Systems Numerical Simulation Method

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Abstract

Describes the current rise and high-rise building domestic drainage systems and roof drainage system problems, take advantage of its mathematical and physical model simulation to theoretical analyze and research on building drainage system. In this paper use finite volume method to modeling analyze the domestic drainage system, and study the drainage system pipeline pressure, speed and other parameters of the case. Another argument finite element and finite volume method of combining the theoretical level in numerical simulation on the drainage system, using a variety of methods and paths to further improve the physical and mathematical models of numerical simulation of drainage systems in existing buildings, to explore combined finite element and finite volume method development and prospects in the field of building drainage.

Keywords

Building drainage; Roof drainage; Numerical simulation; Finite volume method; Finite element method

1. The Present Situation of Building Drainage System

1.1 Experimental study on the drainage of "Vanke tower"

The domestic drainage system design from set up a stack vent to a specific vent stack, or a special single riser drainage system, the capacity of domestic system has been greatly improved. In high-rise building, the time when each household use a sanitary apparatus is different, which makes pipe drainage is actually in a state of instantaneous interruption, complex and unstable situation, so sewage anti spill, unpleasant odor and noise problems have appeared in some projects , which leads to some bad effects on the living environment of and the health of residents. In order to create a health and comfortable residential environment for the residents, China's tallest residential performance test tower - 122 meters high of Vanke tower, currently is being carried on a variety of drainage Experimental analyze and summarize from based on a large amount of measured data, in order to build mathematical model to guide the application. Another drainage experimental test tower of 17.2 meters high of Xuanshi and Xuanshi building laboratory in Shanxi province, as National technology center of the building drainage pipeline system, they current has also carried out several drainage experimental research.

The establishment of drainage experimental tower need to consume a lot of manpower, material resources and financial resources, the numerical simulation is applied to the building drainage system to promote the further data analysis. There are many scholars who have made research on the related issues such as the water movement in the pipeline of the drainage system and the movement of the solid in the pipeline, and the optimization of the system.

1.2 Experimental study on the roof rainwater of super high−rise building

High-rise and super high-rise building roof rainwater usually use gravity drainage system. On the roof single bucket system or multi bucket share a Rainwater riser system, and design of overflow and overflow system to exhaust to the unscheduled roof rainwater. If building is too high, adopting the refuge floor setting tank to reduce energy and to prevent excessive pressure in the pipeline of impact force on the bottom of the pipe is too big, Outflow of discharge pipe is too big so that the influence of the outdoor inspection wells. In regard to the super high-rise building roof rainwater system in pipeline flow, the velocity and pressure, Shanghai Institute of architectural design and research have done experiments on super high-rise building rainwater drainage technology to explore and have prepared high-speed camera tracking on experiment, and to calculate the velocity of flow, then measure different flow impact on the pipe, and combined with the pipe settings etc to eliminate the effect of energy.

Due to there are no too much theory research of super high-rise roof rainwater, and there are some difficulties to study roof rainwater in super tall building by establishing full-scale experimental tower, So numerical simulation is a development direction in the field.

2. Numerical Simulation Methods

Numerical simulation methods include finite difference method (FDM)、finite volume method (FVM) and finite element method (FEM). The FDM solves the region of the nodes set which is constructed by the points of intersection of lines which parallel to the axis. On every point, the derivative of the equations is estimated by the difference expression and the algebraic equations can be established .By solving these equations, the numerical solution can be solved. The FVM divide the computational region into a series of control volume. Every volume has a point to establish the discrete equations. The constructions of the function and its first derivative should be assumed. The method of the construction is up to the FVM. The FEM divide the region to many elements arbitrarily and constructs interpolation function. The control equation can be transpose to the finite equation on every element by the extreme value principle.

Recently, the business software mostly is up to the FVM. Compared with other numerical methods, the FVM can keep the conservation, but the accuracy is only second order. As the widely application software, the fluent consider the fixed method and can not be modified and add for some special problems, so the business software perhaps has some difficulties to describe the accurate conditions. In additional the business software is difficult to defend the multi-scale problems and the solution is not stable.

The FEM is applied on solid mechanic firstly, and then applied on fluid filed. By combining the FEM and the FVM, the advantages of the FEM are that the method can be adjust to any irregular region and be easy to increase accuracy. While solving the flow and heat exchange problems, the FVM is better for lots of researches. The FVM is expert at solving the convection. Combining the FEM and FVM can solving the problems more accuracy than each of them. The convection part of the control equation uses the FVM solve and the others use the FEM to solve. The mesh is the FEM mesh and the stiffness matrix of the convection can be obtained by the duality of meshing. The method has been proved in theory and verified by some fluid problems.

In order to obtain the accuracy solution, the FEM is applied to the fluid fields by many researchers for its well theories and meshes. The program of the FEM is also easy to write and coupling. Thus the combining of the FEM and FVM is a trend in computational fluid dynamics.

3 The Application of Numerical Simulation

3.1 Finite difference method

The business software of the PFC, the FLAC and UDEC are up to the FDM and main to study the particles crack, the flow of particles and plastic flow problems. The applications in oil prospecting and earthquake fields are widely recently. The building drainage systems is related to solid, liquid and gas. The FDM can not be accuracy to solve the problem.

3.2 Finite volume method

Based on the application of FVM in fluid fields, the fluent is applied on simulate the building drainage systems on the conditions of Tongji university. The height of the building is 33.6 meters and the building is 12 floors. The height of every floor is 2.8 meters. There are drainage horizontal branch pipe, toilet and bathtub. The pipe is DN100. The drain of toilet and bathtub are DN100 and DN50. The connection of the horizontal branch pipe and vertical pipe is a 45 degree. By establishing the math model, the solution is realistic at different drainage conditions. For the third floor, the pressure distribution is figured in figure.2.1.

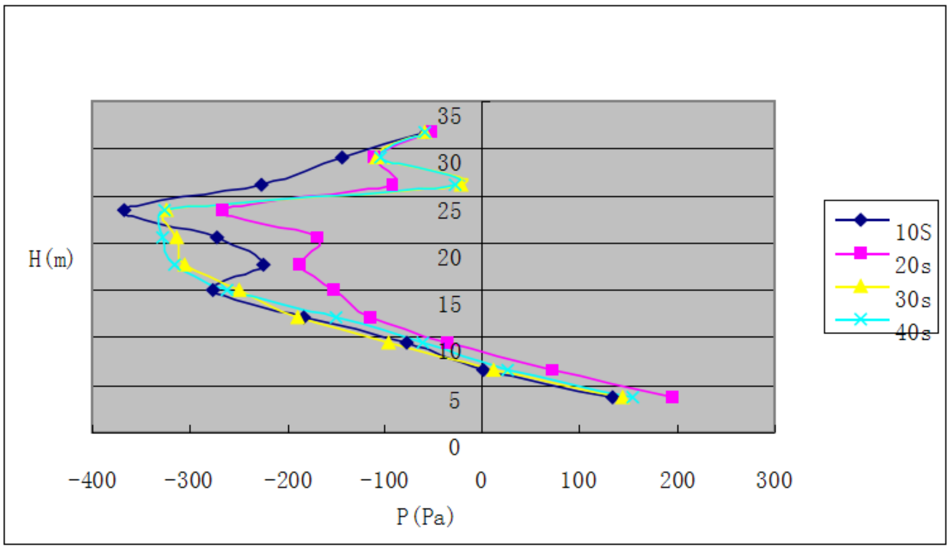

Figure 1-three layers toilet drainage pressure fluctuation diagram

For the drainages of toilet and bathtub at the same time, the result is discussed. By using the UDF, the flow curve is translated to the velocity condition.

```
#include "udf.h"
DEFINE_PROFILE(unsteady_velocity,thread,position)
{
  face_t f;
  begin_f_loop(f,thread)
  {real t=RP_Get_Real("flow-time");
   F_PROFILE(f,thread,position)=(0.00213+0.00873*t)/(1-   0.498*t+0.0749*t*t);}
  end_f_loop(f,thread)
}
```

The figure2, figure3 and figure4 are the distribution of the pressure, the velocity and the volume.

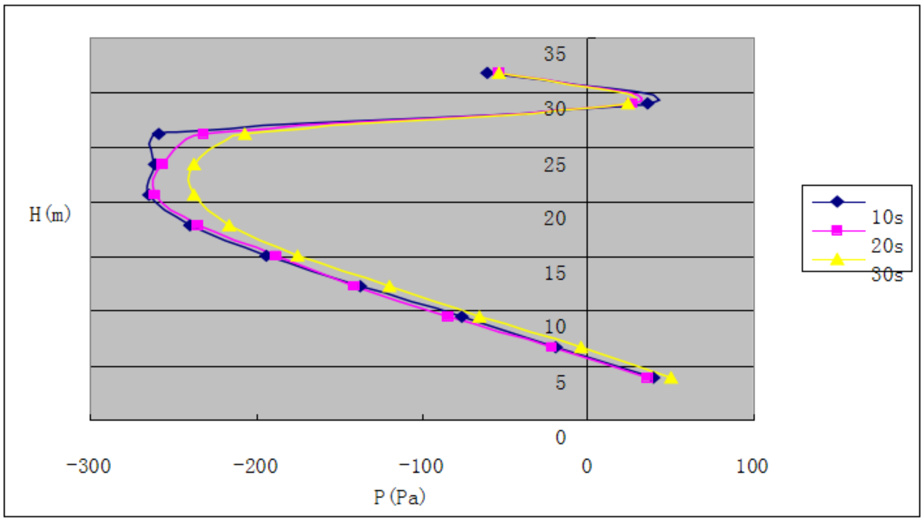

Figure 2-Two layers of toilet (curve) and bathtub drainage pressure fluctuation diagram

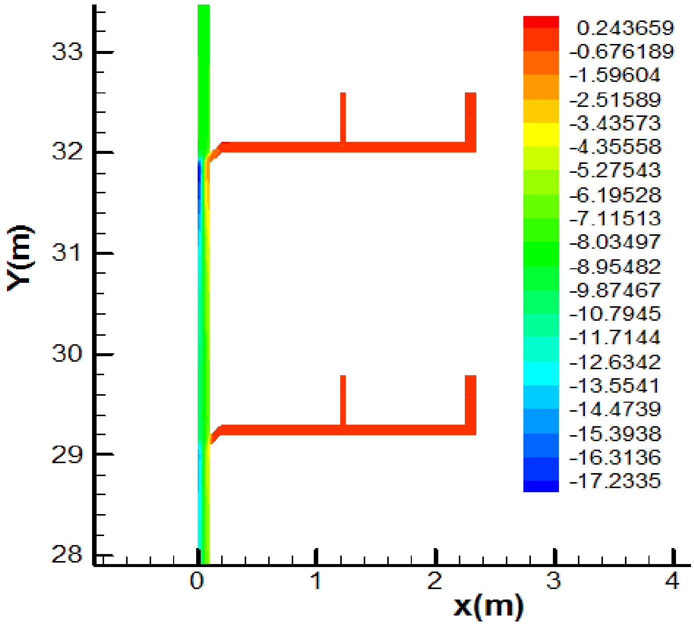

Figure 3-Two layers of toilet (curve) and bathtub drainage Velocity along Y direction

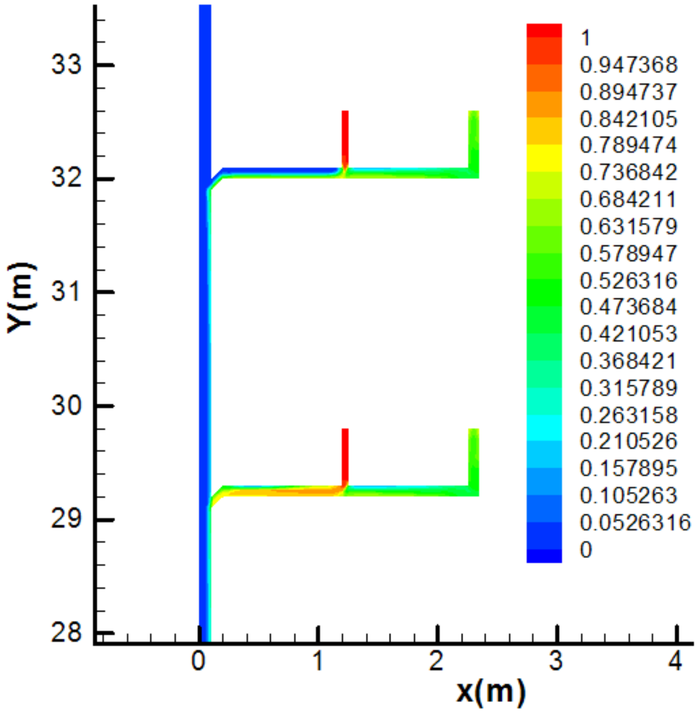

Figure 4-Two layers of toilet (curve) and bathtub drainage Volume fraction

The pressure distribution of the vertical pipe is a little deviation with the theory and experiment. The velocity is basically conform to reality.

3.3 Combining of the FEM and FVM

Based on the flow in the vertical pipe and experience, a larger amount of roof rainwater is different from the domestic drainage. At the beginning it is similar with the domestic drainage of two phase flow. As the increase of the rain, the pipe is full and there are gas and a little bubble. Rain speed up drop under gravity acceleration, the rainwater in the vertical pipe will reach the limit velocity which will bring strong attack force to the bottom. The pipe should have a large endure pressure.

At this stage the super high-rise roof rainwater system is being modeled and analyzed, taking into account the fixity of the commercial software, hence choosing a open source software of The Chinese Academy of Sciences (CAS) of independent research and development. the software provides matching expression language and the user subroutine and so on ,and different levels user interface program and allows the user to add their own special physical model, the software has been widely used in the field of solid and fluid, has completed a number of project and using the combination of finite element and finite volume method in the fluid project ,including the numerical simulation of two-dimensional incompressible flow around a Circular cylinder at different Reynolds. In this study the finite volume method is used to calculate the convection term in the N_S equation and other is calculated by the finite element method.

3.3.1 Finite element discretization

For incompressible flow, equation can be written as:

Continuity equation:

$$\frac{\partial u_j}{\partial x_j} = 0$$

Momentum equation:

$$\rho \frac{\partial u_i}{\partial t} - \frac{\partial}{\partial x_j}(\mu \frac{\partial u_i}{\partial x_j}) + \rho u_j \frac{\partial u_i}{\partial x_j} + \frac{\partial P}{\partial x_i} = \rho f_i$$

P is pressure,f_i is unit force in different direction of Ω, $\mu$is the coefficient of viscosity.

For the nonlinear factor $\rho u_j \frac{\partial u_i}{\partial x_j}$,use the finite volume method, now discrete the other term in equation by finite element method, the weak form is:

$$(\rho \frac{\partial u_i}{\partial t}, \delta \mathrm{u})_\Omega + (\mu \frac{\partial u_i}{\partial x_j}, \frac{\partial \delta u_i}{\partial x_j})_\Omega - (P, \frac{\partial u_i}{\partial x_i})_\Omega + (\frac{\partial u_j}{\partial x_j}, \delta P)_\Omega + (\frac{\partial P}{\partial x_j}, \frac{\partial \delta P}{\partial x_j}) * const = (\rho f, \delta u_i)_\Omega$$

The last term at left, which is be added to ensure the positive of matrix, and the const is a constant.

3.3.2 Finite volume discretization

For the nonlinear factor $\rho u_j \frac{\partial u_i}{\partial x_j}$, use the upwind method of finite volume method. For general cases$(b \cdot \nabla u, \delta u)$, first of all mesh the area by triangular or quadrilateral, and then to the dual subdivision.

$$c(u_h; u_h, v_h) = (u_h \cdot \nabla u_h, v_h) \approx \sum_i \int_{\Omega_i} u_h \cdot \nabla u_h v_{hi} dx$$

$$= \sum_i \int_{\Omega_i} v_{hi} (\nabla \cdot (u_h u_h) - u_h (\nabla \cdot u_h)) dx$$

Then using simple linearization to get the following expression

$$= \sum_{i} v_{hi}^{n} \sum_{j\in\Lambda_i} \int_{\Gamma_{ij}} \left(u_{h}^{n-1}\cdot n\right) ds \left[(u_{hj}^{n} - u_{hi}^{n})(1-r_{ij}) \right]$$

For the local mass conservation of element , it can natural meet when the pressure is piecewise constant ,if the pressure is piecewise linear or higher order, it can’t natural meet that the local mass is conservation ,but on the whole mass conservation is clearly established. For the stiffness matrix of convection term in this software, it can be done alone by a file. there are many choices in the upwind scheme, it guarantees the conservation of mass, and in a certain condition the maximum value principle is established. And the stiffness is M-matrix in a certain condition, so it is stable. Then adding the stiffness by finite volume method to the total stiffness matrix

Further research will continue to be carried on, the application of the combination of finite element and finite volume method in the field of building drainage will make the simulation data more reliable

4. Concluding Remarks

Through the application of numerical simulation and the simulation method, the numerical simulation technology can solve some engineering doubt and bring innovation in the field of building drainage. At the same time, we can increase the research efforts in the computer numerical simulation, in order to deal with the problem of building drainage in the super high rise buildings that to be built later. With the continuous development of computer technology, numerical simulation technology, visualization technology and virtual reality technology, numerical simulation has evolved as a common and important scientific research methods, through numerical simulation method can provide closest to the real status of guidance for engineering design and construction, and has great application prospect both in the cost of scientific research, engineering design and construction on.

5. Prospect

Water flow pattern of building domestic drainage belongs to gas, liquid and solid three-phase flow, compare with the roof rain water’s gas, liquid two-phase flow pattern is very complicated, hope can through the study on roof rainwater, the late there are reference point in the domestic drainage system will be researched.

Now China has been built "Tianhe No.1" "Tianhe No. II ", computing speed per second can be achieved on a petaflop, by 2020 there will be computing speed to reach trillion per second powerful E level computer system. To make full use of the existing computer parallel capability, the finite element technology is applied to the building drainage field, and to further improve the theory and engineering practice.

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7 Presentation of Author

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Analogy of Water Flow in Soil with the Heat Flow by Conduction Applied to the Sizing of Permeable Pavements

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Abstract

Strategies for rainwater infiltration play an important role in the sustainability of cities, contributing to the reduction of runoff due to increased sealing surfaces. The sizing of rainwater infiltration systems in the ground has been done considering the constant effluent flow over time due to the complexity of the flow, for which the study is partially based upon. Very often this leads to over-sizing of these systems. Therefore, this study proposes a method based on the analogy of the runoff into the soil with the heat flow by conduction in solid media for the sizing of permeable pavements.

Keywords

Water Infiltration; Lot Drainage; Permeable Paving; Hydraulic Modeling; Scientific Analogy

1 Introduction

Increasing urbanization brings as a consequence the increase in paved areas in cities. With the reduction of infiltration, the water flow drainage increases superficially, which has contributed to the largest occurrence of overflows and floods. The use of urban drainage strategies that allow the control of runoff infers that the establishment of design parameters that consider the characterization of local rainfall, the geometric characteristics and hydraulic properties of the soil where they will be installed.

The performance of strategies for water drainage in soil involves different variables and due to the complexity of the flow in this medium, the sizing of systems for this purpose has been done so empirically.

From a systematic mapping of the literature [2], [5], considering the indexed journals in the Web of Science, Scopus and Engineering Village databases (Compendex) with the search expression ["* water infiltration" AND model *], 90 articles were found, most of them based on mathematical modeling (Table 1).

Table 1: Number of articles related to modeling of water infiltration into the soil, indexed in the Web of Science, Scopus and Engineering Village databases (Compendex).

Category	Articles that address …	Number of Articles
Mathematic Modeling	The use of mathematical modeling, including partial differential equations (PDE), Stochastic theory, Fractal analysis, fuzzy logic, neural networks, finite differences, finite elements and finite volume degradation.	37
Resolution of partial differential equations (EDP)[1]	EDP resolution methods embedded in modeling, using mathematical transforms or dimensionless studies.	31
Physical Modeling theories	Using theories of physics and engineering which serve to support understanding phenomena, therefore, taking advantage of already established studies.	22

[1] Differs from mathematical modeling category, because it focuses on the use of tools for the resolution of the EDP, with less emphasis on modeling itself.

The models found in the literature, describe only part of the phenomenon under study, disregarding the interaction between the materials that make up the soil, which is considered usually homogeneous. The sizing of infiltration systems from this assumption often leads to over-sizing, resulting in anti-economical systems.

This study proposes to consider the heterogeneity of the soil in the design of permeable pavements by analogy of water flow through the soil with the heat flow into solid materials (conducting). Therefore, the concept of hysteresis in the soil [4] and scientific analogy between the variation of water in the soil and soil temperature variation was considered, and between the thermal conductivity and thermal capacity was applied in assays using Darcy's law.

2 Analogy Between the Water Flow and Heat Flow

Applying the principle of conservation of thermal energy of a solid medium for a defined volume of control, it follows that the variation of internal energy corresponds to the heat flow in the surrounding medium during a defined time interval (Δt), as such:

$$-c\rho V dT \quad = \quad \frac{kAs\,\Delta T}{\Delta t}$$

In which:
c = specific heat of the studied material [J/(kg.°C)]
ρ = specific mass of the studied material [kg/m^3]
V = volume of the studied material [m^3]
ΔT = temperature variation during the time period [s]
ks = thermal conductivity of surrounding material [W / (m.°C)]
As = surface area [m^2]
In turn, the variation of the hydraulic volume material being analyzed is equal to the hydraulic flow in the surrounding medium during a defined time interval (Δt), as such:

$$\frac{\Delta x * \Delta h_i * A_p}{\Delta t} = \frac{k * A_p * \Delta h_m}{\Delta x}$$

In which:
Δx = later thickness “x’ [m]
Δhi = humidity difference between layer “i” and layer “i+1” [%]
Ap = pavement [m^2]
Δt = analyzed time interval in the interaction “i” [s]
k = hydraulic conductivity of the analyzed element [m / s]
Δhm= humidity difference between the analyzed layers, in the period “m” [%]

This hydraulic equality was used to analyze the variation of internal moisture of the permeable paving and the ground layers immediately below. Therefore, the water flow in the "n" layers comprised of the permeable paving and by soil to a preset depth (es) was considered, which may be decomposed into:

a) runoff pavement thickness (Δxp) is equal to the thickness (H) of the empirically
pre-sized pavement from the imposed filling time, equal to the duration of the rain design;
b) flow in the first layer of soil immediately below the permeable paving;
c) flow in layer "i" (generic) with temporal influence in the "i-1" layer;
d) flow in the layer "n" with temporal influence of the "n-1" layer.

For setting the value of H, it was considered that the permeable paving must be able to absorb the intensity of precipitation, discounting the infiltration into the soil [1]. Therefore, the thickness of the pavement can be defined by:

$$H = \frac{\left(i_p + \frac{i_p}{A_p} * A_c - i_E\right)}{f} * t_p$$

In which:
H = paving thickness [mm];
ip = intensity of the rain project [mm/h];

iE = infiltration rate into the soil [mm/h];
tp = duration of rainfall [h];
Ac = contribution area for the permeable pavement [m^2];
Ac = area of the permeable pavement [m^2];
f = porosity of the permeable pavement [%].

For determining the depth of soil to be analyzed, one can match the hydraulic flow in the ground and the pavement by the same area and for the same time interval Δt. Thus:

$$\frac{A_s * e_p * f_p}{\Delta t} = \frac{A_s * e_s * f_s}{\Delta t}$$

Or, in other words:

$$e_s = \frac{f_p}{f_s} * e_p$$

In which:
es = equivalent thickness of the soil [m];
fp = porosity of the pavement [%]
fs = porosity of the ground [%]
ep = pavement thickness [m]

Figure 1. shows the control volume considered for the development of water flow modeling in the soil by analogy with heat flow in solid media. For each test situation, there is an iterative process that checks the moisture values in the initial state and the lower layers.

The first layer, which is the volume control on the pavement itself, receives the direct influence of Qp, the design flow, being that the temporal iteration rule (time step rule) is:

$$h_p^{m+1} = h_p + \left(\frac{2 * k_s * A_p * (h_1 - h_p)}{\Delta X}\right) * \frac{\Delta t}{(A_p * \eta_p * \Delta X_p)}$$

In which:
hp m+1 = humidity in the pavement in the period “m+1” [%];
hp = initial humidity of the pavement [%];
ks = hydraulic conductivity of the soil [m/s];
Ap = pavement area [m^2];
h1 = humidity in the first lower layer below the pavement [%];
Δ X = thickness of the first layer below the pavement [m];
Δ t = time increment for iterations [s];
hp = porosity of the pavement [%];
Δ Xp = pavement thickness [m].

The next layer to be modeled is the one immediately below the pavement, considering the moisture (hp) of the pavement and the humidity levels (h1 and h2) in their respective lower layers, being the corresponding time step rule:

$$h_1^{m+1} = h_1 + \left(\frac{2 * h_p - 3 * h_1 + h_2}{\Delta X}\right) * \frac{k_s * \Delta t}{\Delta X * \eta_s}$$

In which:

h_1^{m+1} = humidity in the first layer below the pavement in the period “m+1” [%];
h_2 = humidity in the second layer below the pavement [%].

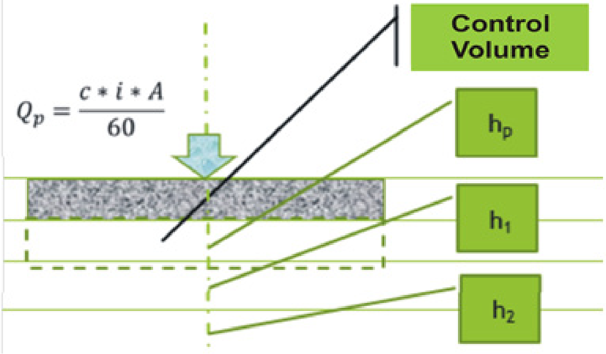


Figure 1: Control volume setting in the first layer under the permeable paving with initial values of moisture in the pavement (hp), the first lower layer (h_1) and the lower second layer (h_2).

Similarly, for a generic layer "i", using the moisture in the layer "i-1", in the layer itself "i" and "i + 1" layer, which is (Figure 2):

$$h_i^{m+1} = h_i + \left(\frac{h_{i+1} - 2 * h_i + h_{i-1}}{\Delta X}\right) * \frac{k_s * \Delta t}{\Delta X * \eta_s}$$

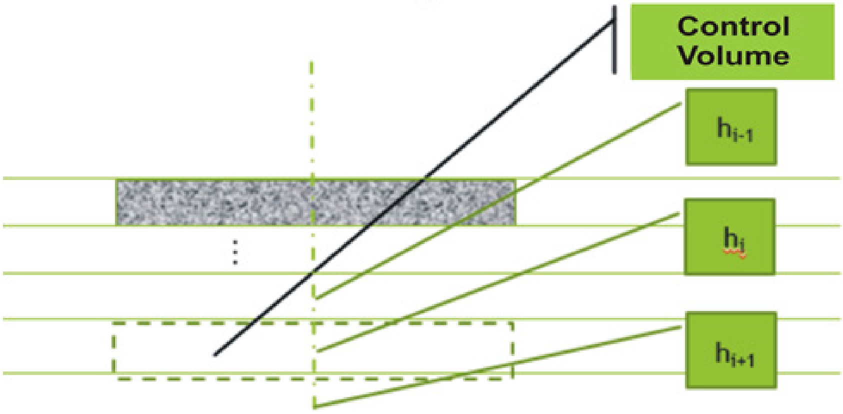


Figure 2: Volume control definition in the layer "i" above the permeable paving, with the initial humidity values in the layer itself "i" (hi) and in the first lower layer (hi+1) and the first upper layer (hi-1).

Finally, for the last layer ("n"), the following iteration rule (Figure 3):

$$h_n^{m+1} = h_{n-1} + \left(\frac{h_{in-1} - h_n}{\Delta X}\right) * \frac{k_s * \Delta t}{\Delta X * \eta_s}$$

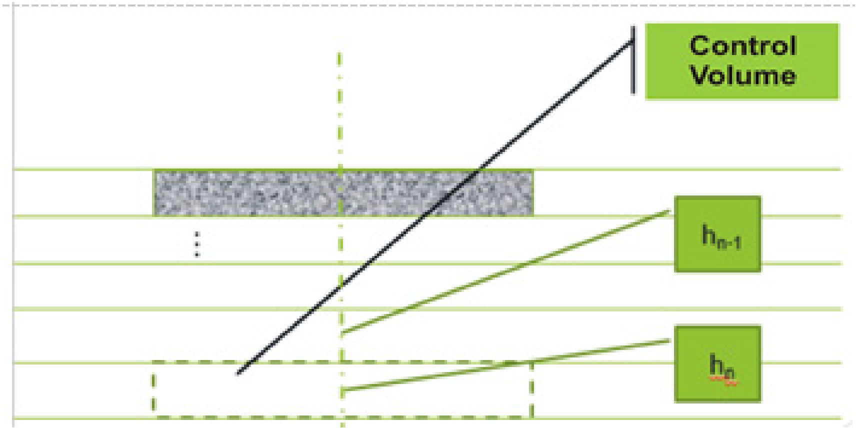


Figure 3: Volume control definition in the "n" under the permeable paving layer, with moisture values in the layer itself "n" (hn) and in the first immediately higher layer (hn-1).

3 Application of the Proposed Model and Discussions

To validate the proposed model, the results were obtained from measurements made in a permeable pavement without a stone reservoir (see execution steps in Figure 4) investigated by [3]. The project design flows correspond to 3.5 m^3/h for 16 min and 10.5 m^3/h for 6 min.

The moisture temporal variation over the soil layers was considered to be equal to 30 s, following the same criteria adopted by [1].

Thus, by determining the hydrogram cited by [3] and the difference in minutes between the start of the runoff without an infiltration system and the beginning of the runoff with permeable paving without evaluated compression in the study, you can determine the overflow system time, i.e., when it begins to overflow into the drainage system.

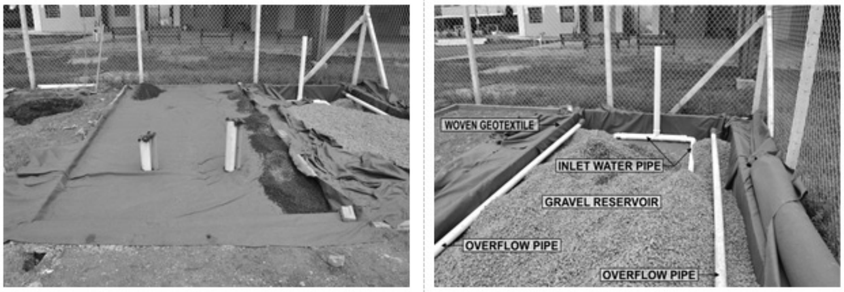
For the thickness of the permeable paving, the value of 0.065 m was considered, in view of the possibility to validate the results obtained experimentally in the study by [3].

Thus, considering the data obtained by [4], it follows that es ≈ 4*ep or in other words, four layers were analyzed under the permeable paving.

For the simulation period, the value [1] is considered, ie, 30 s. In addition, in order to verify system behavior in study 2, other periods were considered, 15s and 60s.

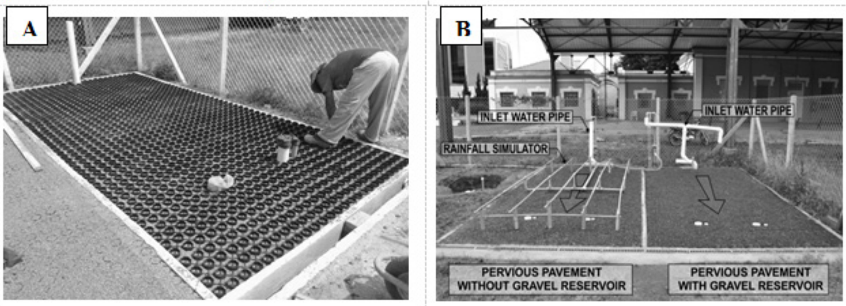
Table 2. shows the results obtained for the two flow rates studied, considering simulation periods of 60s, 30s and 15s and with 0.065 m. for the thickness.

Digging for the installation of the pervious pavements.



Geotextile and water pipes of the PPNR (pervious pavement without stone reservoir)

Geotextile, water pipes and stone reservoir of the PPWR.



Installation of plastic grid pavers sheets of pervious pavement

Final installation of two pervious pavements

Figure 4 Steps of the execution of the permeable pavements. [4]

Table 2: Elapsed Time interval between the time at the beginning of the pavement overflow (min) to the time that the pavement reaches the hydraulic thickness of 0.065m and design flow rates of 3.5 m^3/h and 10.5 m^3/h.

Design flow rates	Δt simulation (s)		
	60	30	15
3.5 m^3/h	4:00 – 5:00	4:00 – 4:30	4:00 – 4:15
10.5 m^3/h	1:00 – 2:00	1:00 – 1:30	1:00 – 1:15

Thus, for the flow rate of 3.5 m^3/h, the overflow would occur between 4:00 and 4:15 min after the onset of rain, close to that obtained experimentally by [3] was 7:00 min. Similarly, for the flow rate of 10.5 m^3/ h, the overflow would occur between 1:00 and 1:15 min, this value is also very close to that obtained in the referred study: 1:30 min.

Table 3 shows the results obtained with a thickness of the pavement immediately below the simulated value, 0.20 m, considering that a greater part of the infiltration would be absorbed by the soil. The thicknesses of the layers of soil considered in the simulations are also 0.05m.

Table 3: Elapsed Time interval elapsed between the beginning of the pavement overflow (min) to the pavement with hydraulic thickness of 0.05 m, for project flow rates of 3.5 and 10.5 m^3/h.

Design flow rates	Δt simulation (s)		
	60	30	15
3.5 m^3/h	2:00 – 3:00	3:00 –3:30	3:30 – 3:45
10.5 m^3/h	0:00 – 1:00	0:30 – 1:00	0:45 – 1:00

With a thickness just greater than 0.10 m, the interval before the overflowing would be between 5:45 and 6:00 min. for the flow of 3.5 m^3/h and between 1:45 and 2:00 min. for the flow of 10.5 m^3/h, contributing to the dampening of the hydraulic flow, and thus delaying and reducing the contribution of discharges into the drainage system.

From the realization of the simulations, the ideal thickness of permeable paving to be adopted must take into account the depth of the water table and the economic analysis, among others.

4 Conclusions

The analogy of the ground water flow with the heat flow by conduction in solid media for the transient modeling in the infiltration of water proposed in this study showed results consistent with those obtained experimentally by [3] indicating the adherence of the theoretical model.

The proposed model allows for a fast computational simulation, including hydraulic conductivity variables between layers or even impermeable layers (with a zero soil hydraulic conductivity) under the pavement.

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5 References

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