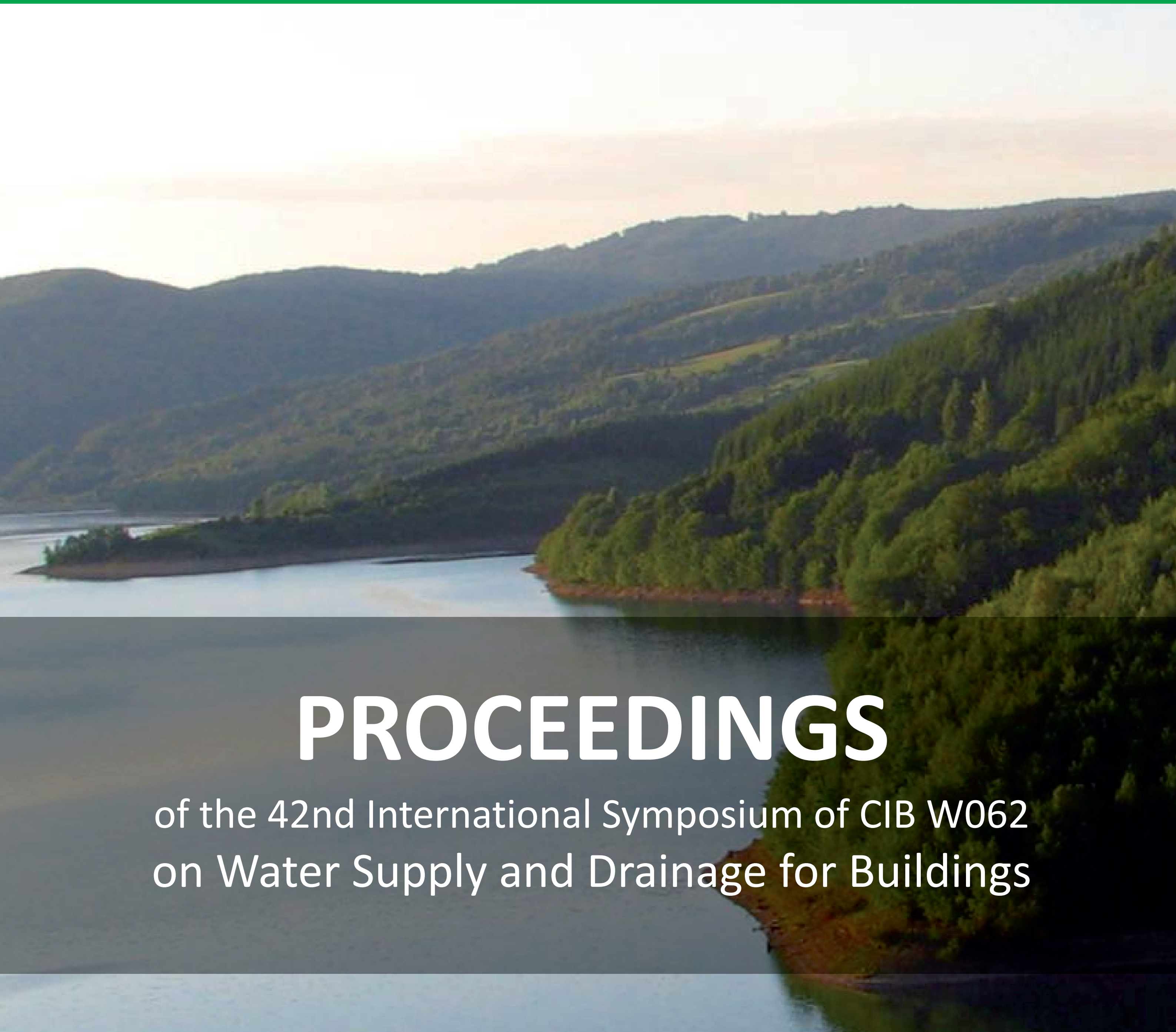

PROCEEDINGS

of the 42nd International Symposium of CIB W062
on Water Supply and Drainage for Buildings

29th August – 1st September 2016
KOSICE, SLOVAKIA

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KOSICE, SLOVAKIA

Organizers:

International Council for Research and Innovation in Building and Construction, CIB W062

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Foreword

The International Symposium of CIB W062 Water Supply and Drainage for Buildings has been held 41 times in various countries and regions of the world. It is one of the most influential groups within the field, with the symposium providing the highest-level international platform for academic exchange of research in water supply and drainage.

The **42nd International Symposium of CIB W062 Water Supply and Drainage for Buildings** takes place in Slovakia for the first time from August 29th to September 1st, 2016. The symposium, seeks openness, diversity, collaboration and development, and will provide a high-level international platform for academic exchange, displaying the most advanced research achievements and deepening international cooperation between experts, researchers and professionals from around the world. By showcasing cutting-edge technology, concepts and innovation, this forum promotes the research and development of new products and systems, achieves the goals of discovering new and developing talent, and advances both technology and international cooperation.

The theme of the symposium is "**Sustainable and water efficient buildings**,"

Internationally, and as part of the European Commission's policy review on Water Scarcity and Droughts, we know that we must pursue "water-saving culture" and create "a drought-resilient society" within the context of both climate change and water efficient buildings. **Water and drainage** are global challenges of the 21st century, both in terms of resource management and as the world's population grows and requires access to clean drinking water and sanitation. As a society we must ensure the provision of safe water and hygienic drainage systems by best, using technical knowledge, advances in research new concepts and through collaborative working.

The organisers would like to thank all authors for their contributions and are pleased with the breadth and extent of the research reported herein. The proceedings include presentation of more than 40 papers, which will be presented in five scientific sections:

A. Water demand and supply
B. Water efficiency
C. Drainage and sanitation
D. Computer modelling
E. Sustainability and climate changes

We would like to thank the organising committee, and the international scientific committee, for their advice on contributions to these conference proceedings. Finally, we would like to gratefully thank all those organisations and commercial companies who have made generous contributions and offered sponsorship for this symposium.

Lynne Jack — *Coordinator of CIB W062*

Zuzana Vranayova — *Organiser*

Keynote speech

Interconnecting Water

Long-Term Perspective on the Water Supply Chain

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Abstract

Climate change, the renewal of sewerage systems and increasing demands on water quality in lakes, rivers and ditches will require large investments in the water chain in years to come.
Stakeholders in the water supply chain agreed to tackle these challenges together. They intend to cooperate in the development of a more sustainable, efficient and transparent water supply chain. The document "*Interconnecting Water"* is a vehicle to create a long-term perspective. A prospect for the future that inspires, connects and provides guidelines for developments, activities and investments undertaken by the stakeholders involved: such as water companies, boards, regions, municipalities and water research institutions. But also a vision which invites parties from outside the water industry to come up with ideas and solutions. It is time to look beyond the boundaries of our own areas of expertise and to develop new, interdisciplinary alliances.

Keywords

Sustainability, water chain, future.

1 Introduction

Currently every Dutch household receives top-quality drinking water from the tap. We have an excellent drinking water system and we are justifiably proud of it. Residents experience the collection and processing of our wastewater as self-evident. Public health, a top priority, is 100% guaranteed, an invaluable asset for a society. Nevertheless, we want to make even better use of our water system, with the human being as the primary focus. We want to create a more flexible system, better able to respond to new insights and future technological innovations.

Besides, we aim to make the system more sustainable by implementing the Cradle-to-Cradle (C2C) principles in the water supply chain. This implies that waste materials will be separated at the source and re-used in useful new products, and that we will use our waste water for the generation of energy. The Cradle-to-Cradle principle will make sure that our current high standard of water quality will not suffer from the way we make use of our water.

We also want to increase the comfort experienced by our residents. Water can be used as a channel to transport energy. It can contribute to a clean and green habitat with plenty of water. This is only possible if the water is clean as well as kept in check. Finally, we want to be innovative and develop new technologies which are internationally applicable. In this way the document "*Interconnecting Water"* offers solutions for global issues of clean (drinking) water and sanitation and contributes to the achievement of the Millennium Development Goals.

The document *'Interconnecting Water'* outlines four possible future scenarios. These scenarios demonstrate what the realisation of our vision may look like. They provide no detailed elaborations nor a roadmap for future implementation. For some of the visions the techniques are as yet not even available, because we never had the intention to write a manual which can simply be followed. The idea is merely to provide inspiration through our scenarios.

In each scenario the citizen is the focus of our attention, so that a single concept of living forms the basis. Is has been developed for different living environments and takes the residents' comfort and well-being as its starting point. The underlying notion is that water should contribute to the quality of the habitat. Consequently a well-functioning water supply system is essential.

2 Domestic Water Supply in 2050

The first future scenario describes the water and energy flows in a house. By the year 2050 the level of comfort in kitchens and bathrooms will have improved. See Figure 1. Urine and faeces are separated in a totally new, 21st-century toilet facility. The faeces are collected in a filter, to be processed together with the other organic domestic waste to generate energy (green tube). Urine (yellow tube) passes through the filter. Any medicine residues are filtered out and the rest is processed locally into fertilizer. Kitchen and bath water (grey tube) is also processed locally.

Just like today, the taps provide high-quality drinking water. It has an excellent taste and fits well into a healthy lifestyle, so the residents drink it frequently and with satisfaction. The main washing agent is ozone, so that clothes leave the washing machine dry and wrinkle-free. The dishwasher operates on steam, which reduces its water consumption.

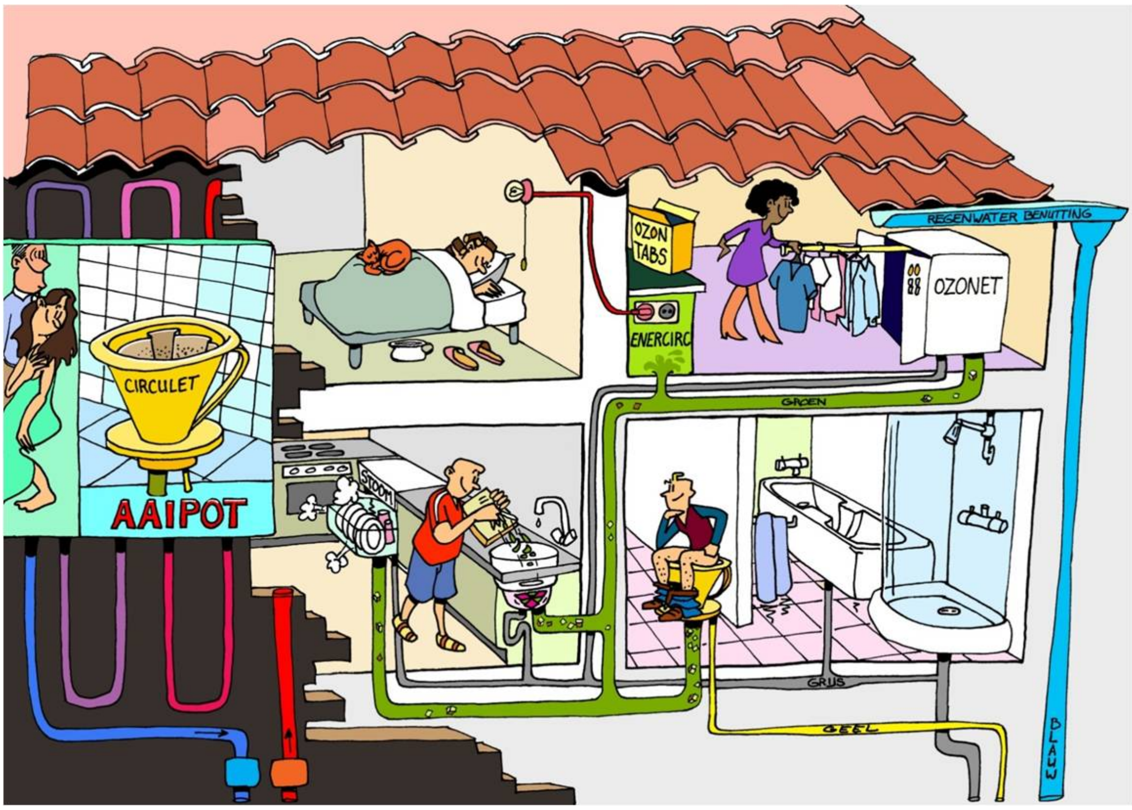

Figure 1 Domestic Water System in 2050

3 New Housing in 2050

This projection of a new residential area makes use of all sorts of innovations intended to reduce the water and energy consumption. See Figure 2. This area is ready for the future. The residents are well aware of their pioneering position. The techniques they already use with complete satisfaction will be applied in the whole country in the near future. The new concepts, such as a "green" habitat with plenty of water, all contribute to the residents' comfort and well-being.

Rain and waste water are no longer mixed. Rainwater is no longer drained; it is now used locally. For this purpose the houses are equipped with subterranean rainwater storage capacity and the water is used to water their gardens. In addition, the road has been built in a hollow shape and its road surface is water permeable. The excellent soil quality, with plenty of organisms, allows the water to pass through the soil quickly and easily. The roads flood regularly but always briefly, so that inconvenience is kept to a minimum. The residents accept is as natural. Local collection of rainwater prevents sewage overflows and there is a healthy water management system.

Water gardens have been constructed for the retention of extreme rainfall. The amphitheatre (also used as a basketball court) floods in periods of extreme rainfall. In dry periods the children play happily in the water gardens and amphitheatre. These measures result in even slower drainage of rainwater in the new residential area than in the rural area which it used to be. The sequence collection, storage and drainage has been optimally realized.

The rainwater basin is also used as a cold-heat-buffer, so that the houses have no need

for air-conditioning systems. In addition, there are plenty of local organic roofs and walls. They keep the neighborhood cool in summer. No heat islands arise as they do happens in many older areas. Motorized traffic is regarded as guests to the neighborhood; in principle children rule the streets.
Urine and faeces are locally collected separately and processed. Any medicine residues are removed from the urine and treated separately, keeping surface and drinking water free of them. Faeces and other organic waste are converted into and urine into fertilizer. Solar panels on the roofs provide most of the electric power.
Local capture and use of rainwater, as well as local wastewater processing make it possible to create residential areas completely independent of conventional wastewater treatment.

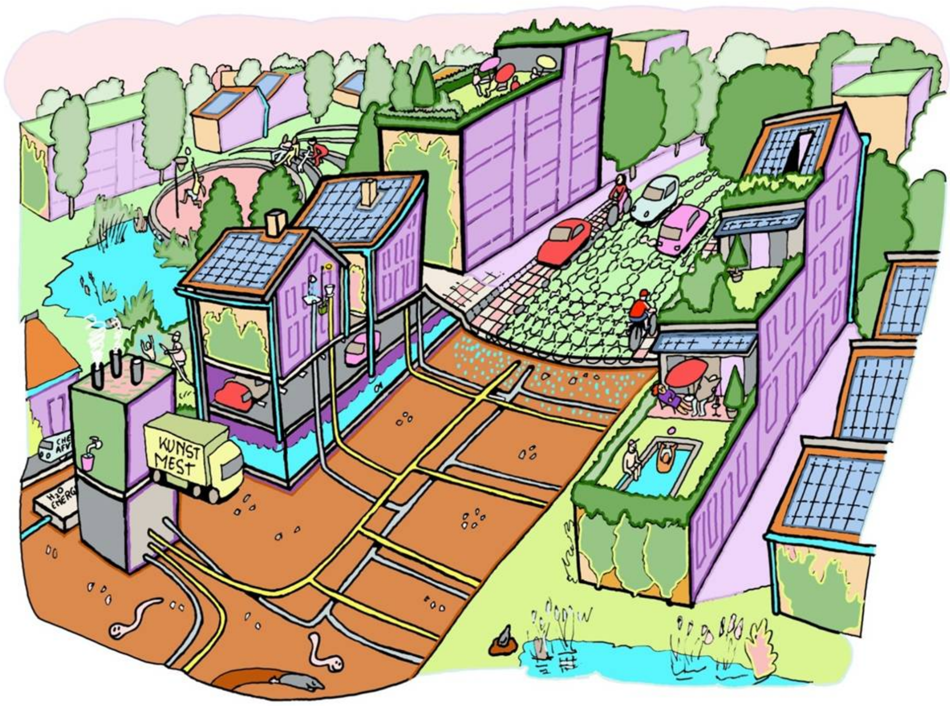

Figure 2 A new neighbourhood in 2050

4 Existing Housing in 2050

This scenario outlines the future of an existing urban area. It reflects the situation of recently renovated houses. See Figure 3. The designer team applied as many available innovations regarding water and energy as possible.
In this case not the rainwater but the wastewater is disconnected from the sewer system. The new sewer pipes that were applied in the year 2030, already had separate pipes for yellow and grey water at the time.
The return on this investment now becomes apparent. The sewer pipes have become rainwater pipes. Household wastewater is processed locally. Raw materials such as nitrogen, potassium and phosphate are filtered from the urine. The rainwater pipes serve the drainage of excess rain water. Their bottom side is water-permeable, which allows them to serve for either infiltrating or draining purposes, depending on the situation. This results in proper control of the city's groundwater level and prevents rotting

damage to the foundations.
Since not all areas have local wastewater treatment plants, the conventional treatment plants for mixed waste water are still in use. They have been modernized: new space-saving technologies are used. Sensors control the feed of wastewater to the purification plant far more accurately than in the past. The continuing reduction of mixed sewage water makes extra capacity of conventional treatment plants unnecessary.
The new bathroom and kitchen facilities are easy to assemble. Smart building technologies cause far fewer installation problems for the residents, so that they can use the new techniques immediately.
There is more space for water in the streets, the gutters are wider. The newly-built water tank stores some of the rainwater. In case of extreme rainfall the existing facilities for overflows come into action. Because the tubes in the renovated areas only contain rainwater, overflows no longer form an environmental hazard.

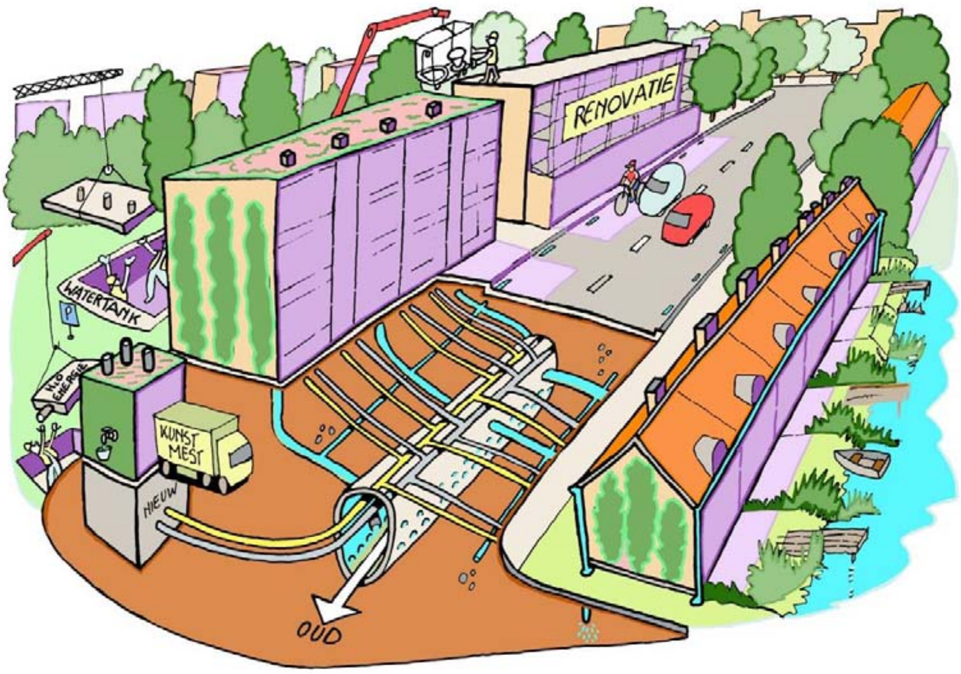

Figure 3 Existing Housing in 2050

5 Rural Area in 2050

This future scenario presents the opportunities for new forms of entrepreneurship in dealing with organic waste and energy in the interaction between urban and rural areas. See Figure 4. The scenario was developed for the agro-industry but the underlying concept can undoubtedly be projected on industrial sites.
Clustering of agricultural enterprises in rural areas forms the basis of this scenario. The intensive livestock farms within the cluster produce a surplus of fertilizer, which they process in a large fermentation plant. This fermentation plant also processes other waste streams, such as grass cuttings and organic waste from the residents of the nearby town.
The fermentation plant is also suitable for the processing of separately collected household wastewater from the countryside. The agricultural cluster thus reduces the

cost of sewage and water treatment for the connected residents of adjacent areas. New technologies also enable the fermentation plant to produce raw materials and high-quality fertilizers. Due to increased price levels in the global phosphates market, the agricultural cluster is able to generate considerable revenue from the sale of energy, raw materials and high-quality fertilizer. The agricultural cluster also has an advanced water supply system. The demand for particular levels of water quality (e.g. drinking, watering and process water) varies and the cluster can operate accordingly.
For reasons of food safety and animal welfare full closure of the water cycle is not possible but membrane technology allows partial closure of the water cycle for certain activities.

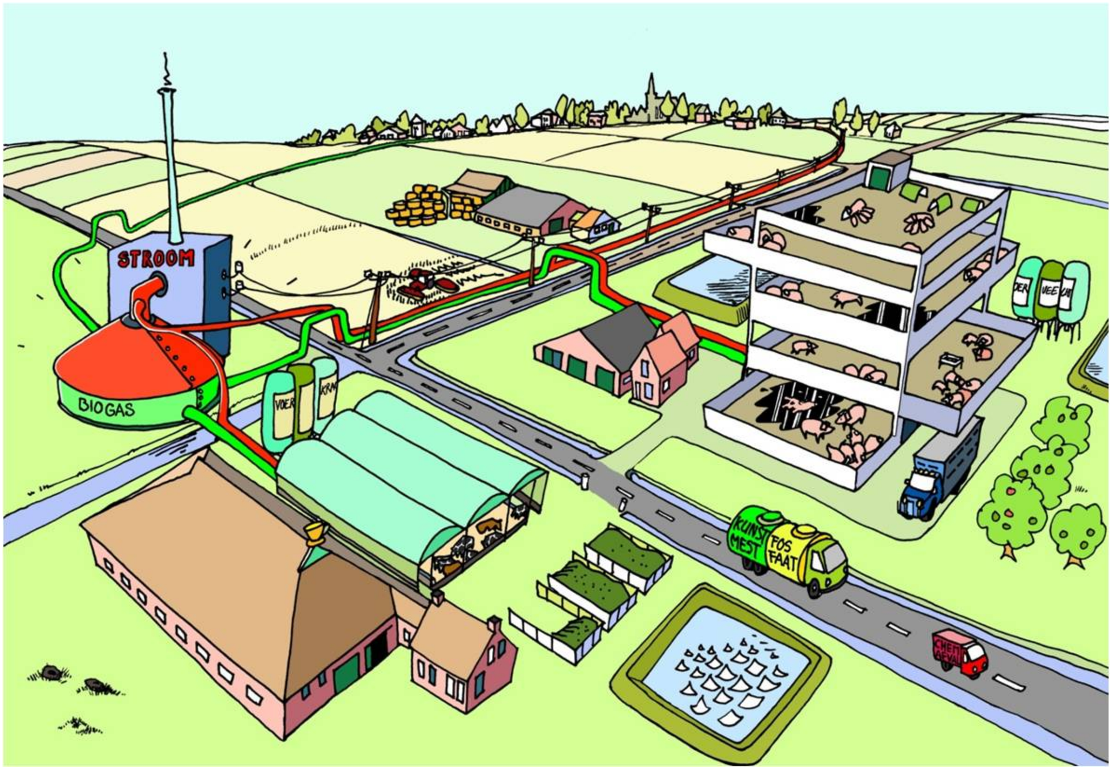

Figure 4 Rural area in 2050

6 Conclusions

The document *'Interconnecting Water'* outlines four possible future scenarios. Although some techniques are not yet available, it invites stakeholders in the water industry to think and look beyond their own disciplinary boundaries. The approach was developed for the Dutch situation but some of the described solutions may well be applicable internationally.

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8 Presentation of Authors

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Session A
Water demand and supply

The role of large dams in drinking water supply in eastern Slovakia

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Abstract

A drinking water in Slovakia is obtained from the underground and surface resources. The surface resources consist of large dams and of taking water directly from the rivers. Eastern part is one of the areas in Slovakia with a higher proportion of surface water on drinking water supply. A sufficient quantity of drinking water in this regions help to provide two large dams, which are administered by the Slovak Water Management Enterprise, s.e., Branche office Kosice. Starina reservoir is the largest in volume in Slovakia and range of the areas, in which it supplies drinking water is still expanding. Bukovec reservoir is important element in drinking water supply of large economic and urban agglomeration Kosice. The paper deals with the role of these water reservoirs in the supply of drinking water, with activities of their manager to ensure reliable and safe operation of the dams and also with measures in protection zones of water resource for achieving the best quality of raw water.

Keywords

Drinking water supply, surface resources, large dams.

1 Introduction

The main tasks of Slovak Water Management Enterprise, s.e., Banská Štiavnica (SWME) include:
- ensuring activities related to the management of water flows and river basin management,
- management of entrusted water flows and ensuring all of their functions.
- flood protection and
- securing the supply of water from rivers and water reservoirs for industry, agriculture and the drinking water supply.

These tasks are ensured by the enterprise through its four Branch Offices (BO), which are based in Bratislava, Piešťany, BanskáBystrica and Košice. The territorial scope of the individual branch offices is given by the basin distribution of the main watercourses in Slovakia - the Danube river basin, Váh and Hron river basins, while BOKošice in eastern Slovakia manages the Dunajec, Poprad, Hornád and Bodrog river basins.
The founder of the Slovak Water Management Enterprise, s.e. is the Ministry of Environment of the Slovak Republic.

Figure 1 Riverbasines and BranchOffices of SWME

2 Supply of surface water for drinking purposes

Geological conditions in eastern Slovakia, where much of the area is covered by the Carpathian flysch, are not favorable for the formation of underground water. Therefore, water consumption must be replenished from surface sources. Specifically, in relation to drinking water, compared to the regions of western Slovakia where water consumption is fully covered from the natural supply of good quality groundwater on Žitnýostrov; in eastern Slovakia up to 21 mil. m^3 of drinking water from the total amount of 45.9 mil. m^3produced by EastSlovakianWaterCompany, Inc., Košice in 2015 comes from raw surface water supplied by SWME, s. e., BO Košice. This ratio exceeds the Slovak average by more than double, where the share of surface water on the drinking water supply is approximately 20%. A significantpurchaser of surface water for drinking purposes in this region is alsoPodtatranská Water Company.
Just to complete the picture, we add that the total volume of surface water for drinking purposes supplied by BOKošice for all customers in 2015 was 23.3 mil. m^3 and the total volume of supplied surface water for all sectors together was 62.0 mil. m^3.

A total of 37 surface water drawing sites for drinking purposes are now registered in the territory managed by BOKošice, which are intended for water resource protection zones. The most important sources in this regard are artificial water reservoirs – the Starina and Bukovec water reservoirs.

3 Water reservoirs

3.1 Starina

The Starina water structure is located in the northeastern part of Slovakia, near the border area with Poland and Ukraine, in the Bukovské Hills, at the area of Poloniny National Park. It was built between 1981 and 1987. The reservoir was created by damming the Cirocha river valley with a 50 m high heterogeneous earthfill dam. With a total volume of 59.9 mil. m^3, Starina is currently the largest reservoir for drinking water in Slovakia. In addition to drinking water the reservoir serves as flood protection, ensuring an even flow in Cirocha downstream the dam and in small hydroelectric power plant it uses the hydropower potential of water. The Starina Reservoir was initially supposed to supply drinking water to the Humenné, Michalovce, Vranov, and Trebišov districts. Due to emergency shortage of drinking water in the city of Prešov and Košice in the 1980s and problems in preparing the Tichý Potok water reservoir, this concept was reviewed. Instead of building feeders for the Michalovce and Trebišov districts, the priority was to address the feeder for Prešov and Košice. The dam is naturally heterogeneous, with a central clay sealing, 7 m wide at the crown and approximately 310 at the heel, in the floodplain area. The length of the dam at the crown, which is at an elevation of 345.00 masl., is 311 m. Theflood flows, discharge of water from the reservoir and water abstraction for water supply purposes is ensured on the hydraulic structure by ancomplex outlet towerblock. Water for supply purposes is drawn from the reservoir by water supply withdrawals, placed at different depths below the surface. Four pipes with a diameter of 1,000 mm lead to the water abstraction engine hall from the inlet openings. Gate valves are fitted on each of them in the engine hall, where the pipes are then joined into a common pipeline with a diameter of 1,200 mm which continues in the pipe tunnel to the downstream heel of the dam and then through buried pipelines to the water treatment plant. The maximum designed take-off capacity of Starina reservoir is 1200 $l.s^{-1}$.

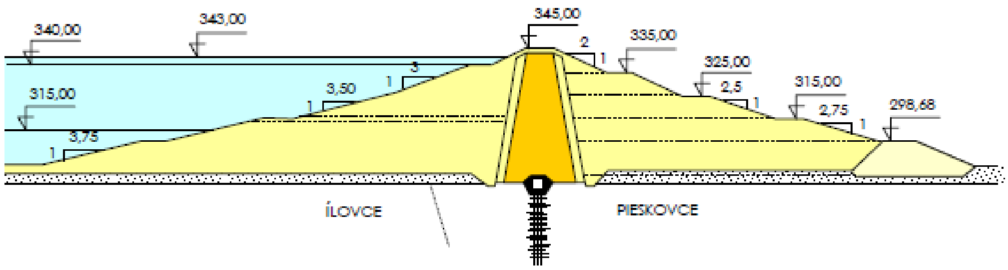

Figure 2 Scheme of the Starina Dam

3.2 Bukovec

The development of Košice was very intense during the fifties and sixties. Industrial production was expanding and the population of the city grew rapidly. Both of these

Figure 3 Waterreservoir Bukovec

factors also caused an increase in the consumption of drinking water in the urban area, so a decision wasadopted to build a surface water resource – a water reservoir. From several alternatives, the construction of a dam on the Ida River above the Bukovec municipality at a distance of about 15 km from Košice was selected and implemented. The majority of the water reservoir's basin belongs to the Volovské Hills orographic unit. The highest point of the basin is Kojšovahoľa (1246 masl.). The higher altitude of the basin and high forest coverage of the area (over 90%) were among the most important arguments when choosing a site for the construction of a water reservoir. The low concentration of settlement in the basin was an important argument as well. The water structure was built between 1969 and 1976. It has a similar construction to the Starina Dam, but it is higher (56 m) and the building materials from which the dam is built is the rockfill from a nearby quarry. The length of the dam at the crown is 340 m. Total reservoir capacity is 23.4 mil. m^3. Water collection points are built in complex outlet towerblock at four height levels. Each collection point has its own pipe diameter of 600 mm, except collection IV, which has two pipes given the required capacity. The individual pipes in the engine hall of water abstractions flow into a common pipe with a diameter of 1,000 mm, and thus the water is fed into the water treatment plant.The maximum water take-off capacity of Bukovec reservoir is set at 700 $l.s^{-1}$.

3.3 Protection of water quality

Besides the care of the actual water structure, i.e. the technical and operational safety of the dam and the functionality of all related structures and technological facilities, the

duties of the manager - SWME, s.e., BOKošice include the conservation of the quality and health safety of water from these water reservoirs. According to Sec. 32, Par. 4 of Act No. 364/2004 (Water Act), when taking water from water reservoirs the administrator of important water courses(SWME, s.e.) is obliged to submit a proposal for the determination of water resource protection zones. Water resource protection zones are divided into a first degree protection zone, which serves to protect the immediate proximity of the water abstraction point and the safety equipment, and a second degree protection zone, which serves to protect the water resource against threats from more distant places. To enhance the protection of the water resource the state water management authority may also determine a third degree protection zone. The decision of the state water management authority on the determination of water resource protection zones establishes their boundaries and the method of protection, especially prohibitions or restrictions of activities that harm or threaten the quantity and quality of water or the health safety of the water from the water resource, as well as technical adjustments to protect the drinking water sources and other measures to be carried out within the protection zone.
For the Starina Reservoir, there is an applicable decision of the District Environmental Office Košice - Countryside No. RU-577/1991-Mi dated 17 January 1992 on the sanitary protection zones of the Starina Reservoir and its management regimens, determining the first and the second degree protection zones and covering the entire

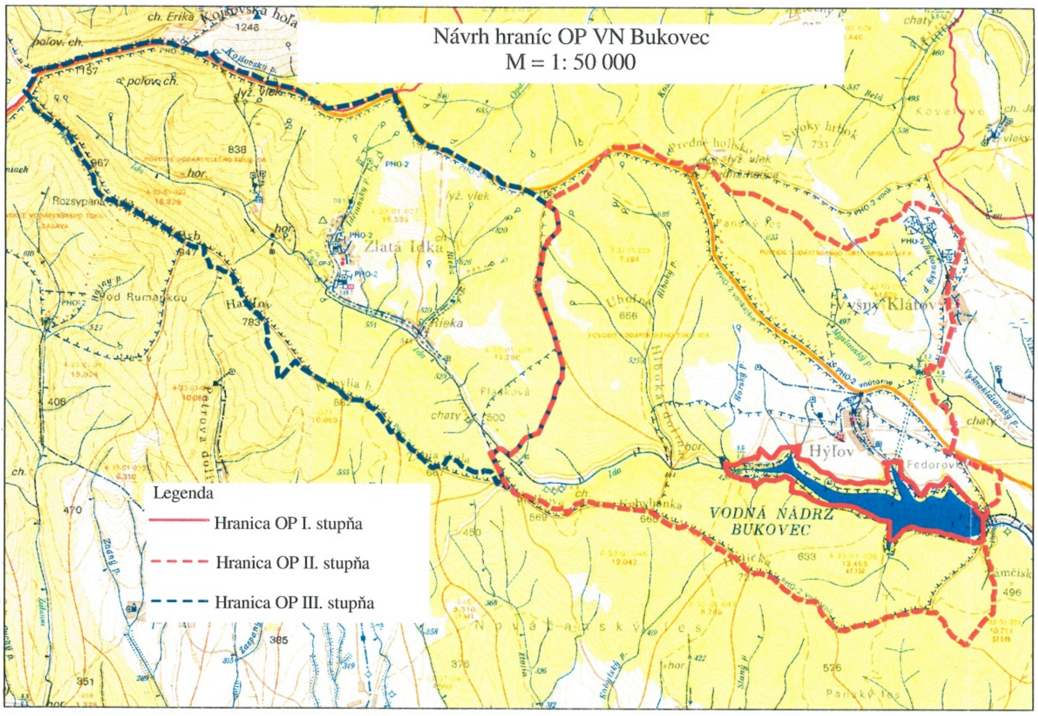

Figure 4 ProtectionzonesoftheBukovec waterresource

catchment area of the reservoir. During the construction of the water reservoir the entire territory was displaced. The biggest problem now is precisely the pursuit of displaced citizens to reclaim ownership of land and the effort of civic associations, communal forest and land companies, hunting and other associations and organizations that operate

in the second degree protective zone of the Starina Reservoir to obtain permission for the entry of vehicles into the protection zone.
In contrast, the catchment area of the Bukovec water reservoir was not displaced. The Decision of the District Environmental Office Košice - Countryside No. 41/1993 dated 17 February 1993 established first to third degree protection zones. Two villages are located in the protection zone - Hýľov and ZlatáIdka. In addition, theKojšovahoľa area is a very popular tourist site year-round. Monitoring and enforcement of the compliance with the regimen of the protection zones in such an exposed area is not an easy task.

3.4 Importance of water reservoirs

Currently, we are increasingly encountering extreme weather more often worldwide. It is perceived by the public to a greater extent when it is associated with flood events, flooding, material damages and the like. It is highly likely that the uneven distribution of rainfall in space and time will bring the opposite extreme: drought, even in our region. The yield of underground sources decreases in periods with a minimum of rainfall. In our geological conditions – the flysch zone – alternative solutions promoted by non-governmental organizations which propose to retain surface water by a large amount of small dams, which should subsidize the groundwater, cannot improve the situation. The only solution in this situation is that the water reservoirs allow the capture and rational management of specific amounts of water in concrete terms. The lesson for us is the experience of the dry years 1982 - 1983 and 1986 - 1987. The low inflow into the Bukovec Reservoir, the low yield of underground sources of drinking water and thus the forced long-term crossing of the projected reservoir drawing (more than 700 $l.s^{-1}$ compared to the average 473 $l.s^{-1}$) caused such a drop in water supplies that in the Košice agglomeration it was necessary to regulate the supply of drinking water. Therefore, the apparent high percentage of water supply in water reservoirs in recent average years does not mean sufficient reserves for extremely dry periods. It is therefore necessary to supplement drinking water supplies in eastern Slovakia by building the Tichý Potok water reservoir.

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Rethinking the sizing criteria in the water supply for buildings

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Abstract

Once the design flow and geometric characteristics of the pipes are known, the sizing of a building water network is reflected in the determination of the appropriate diameters for the various sections from a technical and economic point of view, ensuring the satisfaction of boundary conditions, translated in limits and restrictions of velocities and pressures. A calculation procedure that simultaneously in each section proceeds to size all conditions relating to velocities and pressures is not really expeditious and is moreover difficult to justify in practice, so over time the use of a criterion based only on a fixed value for the maximum allowable velocity was consolidated. Although simplistic, this criterion may not however be the most appropriate one for sizing the pipes, and we intend in this paper to rethink and discuss this usual practice. Based on a review of the literature, research, and practical experience, we propose reflection on the normal criteria of sizing used for water piping systems inside buildings, using design flows and a maximum fixed velocity; in addition, we analyse the advantages of using different criteria. Instead of criteria based on fixed velocities, we evaluate the advantages of using a criterion based on fixed head losses, reflected at variable speeds with the diameter. A new sizing criterion is thus proposed for water piping systems inside buildings, based alternatively on velocities varying with the diameters.

Keywords

Water supply, sizing criteria, maximum allowable velocity, head-loss criteria, variable velocities with the diameters.

1 Introduction

Once the characteristics of the installation are defined, the design flows and the limits and restrictions of velocities and pressures are usually the basic elements required for the design of a water piping network in a building.
In most installations, the simultaneous operation of all appliances and equipments is not predictable, so that, over the last decades, considerable effort has been invested in the development of methods for the determination of the design flows or predictable flows in the various pipes of the networks, translating adequately, the patterns of use of the installations.
Given that, as a rule, it is not possible to establish these patterns *a priori*, determination of the design flows inevitably has a high degree of imprecision, which justifies the fact that, with relatively diversified approaches, many authors have studied and proposed different methods for this determination. In fact, in the specialized bibliography, we can find methods based only on probability theory and purely empirical methods, as well as "mixed" methods, pondering, in different ways, those two extreme approaches.
In practice, we can consider four main categories of methods for determining the design flows: probabilistic or theoretical methods, methods based on weights or coefficients, graphic methods, and non-graphic empirical methods. In the first group may be included the method of daily cycles of use, mentioned by Gallizio (1964) [1] and Rodriguez-Avial (1971) [2], the Wise and Croft method (1957) [3], and methods based on the Bernoulli scheme (binomial law), the Monte Carlo simulation [4], etc. A new probabilistic method based on the Bernoulli scheme, but applicable with devices of different characteristics, was presented in 2001 [5].
In the group of methods based essentially on weights or coefficients should be noted, first of all, that Roy B. Hunter's method, from the National Bureau of Standards (Washington) [6], despite its simplicity of application, was conceived on the basis of probability theory (its original version is from 1924). Besides Hunter, other authors have developed and sought to improving this type of approach, and we might mention the method of the Brazilian Standard NB-92 (or German method) [7], the Howick method and, more recently, the European standard EN 806-3 [8].
Apart from the use of probability theory, Gallizio and Rodriguez-Avial developed mixed methods, using for example empirical tables for branches. The method developed by CSTB (Centre Scientifiqueet Technique du Batiment), in France, is also a mixed method [9].
Within the group of graphic methods may be included several methods that are based exclusively on the use of charts to determine the design flows, usually starting from the accumulated flows. This is the case, for example, of the methods of Delebecque (1969) [10] Hall (1977) [11] and Fawcett and Gay (1977) [12]. These methods, widely used until the 80s, have fallen into disuse with the development of computers. In the group of non-graphic empirical methods, numerous cases may be referred to, such as the so-called British method, the methods of Dawson and Bowman, or those of Bowman and Kalinske (1957) [3], etc.
Despite the effort invested in the development of methods targeting the highest possible approximation in the evaluation of design flows in building networks , these design flows are not sufficient, by themselves, for the sizing of the pipes furthermore, the lack of similar technical and scientific endeavor in setting the other essential parameters for the calculation voids, in great part, the stringency placed in the determination of the

design flows, leading to dimensioning's that are not, in many cases, the most appropriate.

2 Sizing criteria

If its design flows and geometry are known, the sizing of a water piping network in a building can be found by calculating the most suitable diameters for the various pipes in order to satisfy the boundary conditions and some constraints related to velocities and pressures. The fundamental equations of hydraulics, such as the continuity equation and Bernoulli's equation, in their simplified forms (considering that the flow does not change with time, the fluid is incompressible, and the pressure distribution in the cross-section is hydrostatic), allow us to relate the different variables and solve the questions of hydraulic design.

In practice, once the design flows are known, sizing requires the setting of another parameter, at least, which is generally the maximum admissible velocity or the maximum admissible head loss (unitary or total). It is also possible to consider the use of the economic design criterion (of network optimization) which was presented in 2008 [13], combining velocities and head losses, but the inherent calculation effort only justifies its application in particularly complex installations.

Maximum admissible velocity criteria are usually adopted. However, the possible range for this parameter, mainly set by reasons of noise control, varies significantly in multiple international regulations (from 1.0 m/s to 4.0 m/s), which results in very different possible diameters, taking into account the application of the continuity equation. In fact, it can be stated that the diameter of each pipe will result mainly from the maximum velocity that was fixed and not from the design flow, whose variation, whatever the method of determination used, will not be as wide. In the case of current Portuguese regulations, for example, the velocity should have a maximum of 2.0 m/s (and a minimum of 0.5 m/s) [14].

Although transformed into a more complex approach (since it requires the use of more complicated equations than that of the equation of continuity, such as the formula of Darcy-Weisbach), some authors argue that the sizing should be done by the maximum admissible unitary head loss criteria, instead of the maximum admissible velocity criteria. The first researcher to defend this criterion was Delebecque (1969), claiming that there are other factors beyond the velocity with influence noise levels (piping material, installed accessories, fluid viscosity, etc.) that can only be transformed by the maximum admissible unitary head loss criteria.

In reality, we can see that the sizing criterion proposed by Delebecqueis clearly more correct on a scientific basis, although more laborious, and that it leads to maximum velocities that are variable with the diameter. Thus, the possibility of maintaining the principle of maximum velocity, but admitting its variation with the diameter, seems to be the correct option for the sizing of piping systems, without overly complicating the calculation, as discussed in the following section. This is the option that is being considered in Portugal, where the current Regulation is under review.

3 Criteria for setting the velocity limits

The average velocity in the pipes should be limited, not only to prevent excessive noise but also to mitigate the effects of the water hammer and the wear or corrosion of the pipes. However, it is important to note that any of these effects are a function not only of the average velocity of the water, but also of the diameter, an aspect which is ignored when a maximum velocity independent of the diameter is set, as is the case in most situations.
In the case of noise, and in addition to Delebecque's considerations, it can be noted that small diameters generally correspond to terminal or individual branches, with a more meandering layout than that of the remaining pipes, which tends to aggravate noise problems.
Similarly, if the branch feeds only one device, closure is necessarily total, contrary to what happens in pipping that feed various devices, where the probability of a total simultaneous closing is practically nil. We can conclude therefore that the effects of water hammers become more significant in small diameters.
Finally, with regard to wear of the piping, Figure 1 shows that the same average velocity (*U*) in pipes of different diameters leads to higher shear stresses near the wall in the small diameters.

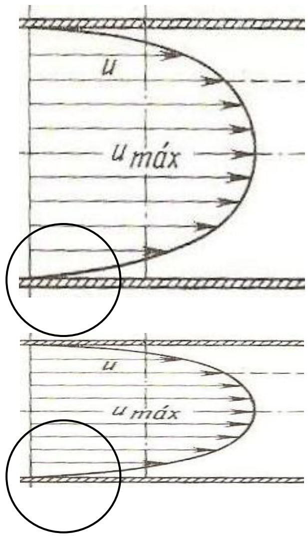

Figure 1 Velocity profiles for different diameter pipes with the same average velocity

The values proposed by Delebecque [10] for maximum unitary head losses are shown in Table 1, according the different levels of comfort desired for the installation. In Table 2 these values are converted into approximate values of average velocity for diameters of 15 mm and 40 mm (taking into account the current materials in building networks), using the abacus prepared by Delebecque for head losses calculation (based on the Flamant formula for cold water).

Table 1 Maximum unitary head losses in water piping systems inside buildings (values proposed byDelebecque)

DWELLINGS	Underground pipes	Pipes in basements	Pipes inside the building
Standard	0.15 to 0.35 m/m	0.10 to 0.20 m/m	0.07 to 0.15 m/m
Comfortable	0.10 to 0.30 m/m	0.07 to 0.15 m/m	0.05 to 0.10 m/m

Table 2 Maximum velocities in water piping systems inside buildings, in accordance with the criterion ofDelebecque

DWELLINGS	D_i (mm)	Underground pipes	Pipes in basements	Pipes inside the building
Standard	15	0.95 to 1.50 m/s	0.75 to 1.10 m/s	0.65 to 0.95 m/s
	40	1.80 to 2.90 m/s	1.40 to 2.10 m/s	1,15 to 1.80 m/s
Comfortable	15	0.75 to 1.40 m/s	0.65 to 0.95 m/s	0.55 to 0.75 m/s
	40	1.40 to 2.70 m/s	1.15 to 1.80 m/s	0.95 to 1.40 m/s

It should be noted that the Brazilian Standard NB-92 (1980), also considered maximum limits of velocity variables with the nominal diameter and not exceeding 2.5 m/s.The proposed formula was (with D in meters and U in m/s)

$$U \leq 14\sqrt{D} \tag{1}$$

This formula leads to the maximum velocities listed in the second column of Table 3 for various diameters.

Brigaux and Garrigou (1976) [15] have presented a relatively elaborate criterion establishing a fixed minimum velocity, and variable maximum velocities, with the inner/interio diameter (not exceeding 2.50 m/s).For design velocities the minimum value is 0.50 m/s, and the maximum value is given by the following expressions (with D_i in meters and U_{max} in m/s):

$$U_{máx} = 70\ D_i \quad \text{, for} \quad 0.010 \leq D_i \leq 0.016;$$
$$U_{máx} = 66\ D_i \quad \text{, for} \quad 0.017 \leq D_i \leq 0.022;$$
$$U_{máx} = 63\ D_i \quad \text{, for} \quad 0{,}023 \leq D_i \leq 0.033;$$
$$U_{máx} = 62\ D_i \quad \text{, for} \quad 0{,}034 \leq D_i \leq 0.040;$$
$$U_{máx} = 2.50 \quad \text{, for} \quad D_i > 0.040.$$

Table 3 presents the velocities corresponding to some current diameters (considering them as inner/interior diameters), thus enabling us to compare the criterion of Brigaux and Garrigou with the values obtained by applying the Brazilian Standard NB-92 (1980).

Table 3 Maximum velocities in water piping systems inside buildings in accordance with NB-92 (1980) and with Brigaux and Garrigou's criterion

Nominal orinteriordiameters(mm)	Maximum velocities (NB-92) (m/s)	Maximum velocities (Brigaux andGarrigou) (m/s)
15	1.60	1.05
20	1.95	1.30
25	2.25	1.60
32	2.50	2.00
40	2.50	2.50
50	2.50	2.50
60	2.50	2.50

Briefly analyzing Delebecque's criteria alongside those of the NB-92 and Brigaux and Garrigou (the only ones to propose velocity limits varying with the diameter), it may be noted that it is only the first one that proposes lower limits, not exceeding, in the majority of situations, the value of 2.00 m / s. However, this method becomes impractical when we resort to automatic calculation, and the separation between "standard" and "comfortable" dwellings is not clear.

The NB-92 (1980) criterion can be considered the most practical, but the maximum limits that it leads to are considered too high, bearing in mind the values recommended by other methods. Relative to this Standard, it should be noted that a significant reduction in the maximum velocity limit is observed in relation to the 1966 version. Indeed, in the NB-92 (1966) version the limit considered was 4 m / s, which was clearly excessive.

Brigaux and Garrigou's criterion is the only one which proposes a minimum limit for the design velocity. In relation to the maximum limits, this criterion is not very practical, and is deemed excessively detailed, but the proposed values can be considered more appropriate than those determined by the NB-92, although higher than those of Delebecque.

In the new Portuguese regulation a formula similar to the Brazilian Standard (1980) will be considered, but establishes maximum and minimum limits of 2.0 m/s and 0.5 m/s, respectively. The proposed formula, with U in m / s and D_i in mm, is:

$$U \leq 0.15\, D_i^{0.714} \qquad (2)$$

It can easily be shown that the exponent 0.714 corresponds to setting a constant value for the maximum unitary head loss. The coefficient 0.15 was proposed in previous studies conducted in Portugal [5].

To facilitate the application of the formula, the regulation will include tables for the various materials available in the market. As an example, some of these tables are presented below.

Table 4 Design flows as a function of the internal diameters for various thermoplastics pipes (proposal of the new Portuguese Regulation)

PEX (PN10)			
DN (mm)	D_i (mm)	Maximumvelocity (m/s)	Maximum design flow (l/s)
16.0	11.6	0.86	0.09
20.0	14.4	1.01	0.16
25.0	18.0	1.18	0.30
32.0	23.2	1.42	0.60
40.0	29.0	1.66	1.10
50.0	36.2	1.95	2.01
63.0	45.6	2.00	3.27
MULTILAYER PIPES			
DN (mm)	D_i (mm)	Maximumvelocity (m/s)	Maximum design flow (l/s)
16.0	11.5	0.86	0.09
16.0	12.0	0.88	0.10
18.0	14.0	0.99	0.15
20.0	15.0	1.04	0.18
26.0	20.0	1.27	0.40
32.0	26.0	1.54	0.82
40.0	33.0	1.82	1.56
50.0	42.0	2.00	2.77
63.0	54.0	2.00	4.58
PP-R (PN20)			
DN (mm)	D_i (mm)	Maximumvelocity (m/s)	Maximum design flow (l/s)
16.0	10.6	0.81	0.07
20.0	13.2	0.95	0.13
25.0	16.6	1.11	0.24
32.0	21.2	1.33	0.47
40.0	26.6	1.56	0.87
50.0	33.2	1.83	1.58
63.0	42.0	2.00	2.77
75.0	50.0	2.00	3.93

Table 5 Design flows as a function of the internal diameters for various metallic pipes (proposal of the new Portuguese Regulation)

STAINLESS STEEL			
DN (mm)	D_i (mm)	Maximumvelocity (m/s)	Maximum design flow (l/s)
15.0	13.0	0.94	0.12
18.0	16.0	1.07	0.22
22.0	19.6	1.26	0,38
28.0	25.6	1.52	0.78
35.0	32.0	1.78	1.43
42.0	39.0	2.00	2.39
54.0	51.0	2.00	4.09
63.0	59.0	2.00	5.47
76.1	72.1	2.00	8.17
89.0	85.0	2.00	11.35
108.0	104.0	2.00	16.99
COPPER			
DN (mm)	D_i (mm)	Maximum velocity (m/s)	Maximum esign flow (l/s)
15.0	13.0	0.94	0.12
18.0	16.0	1.07	0.22
22.0	20.0	1.27	0.40
28.0	25.0	1.49	0.73
35.0	32.0	1.78	1.43
42.0	39.0	2.00	2.39
54.0	50.0	2.00	3.93
76.1	72.1	2.00	8.17

4 Discussion

The determination of design flows is essential for the sizing of a water piping system inside buildings. However, knowledge of such design flows is not sufficient for the sizing, which requires the setting of other parameters such as the maximum admissible velocity or the maximum admissible head loss (unitary or total).

Over the last century, the technical-scientific community has invested significant effort in developing methods for an accurate determination of design flows or predictable flows, but similar effort has not been developed in relation to other essential design parameters, which may compromise the accuracy of the sizing.

The most common criterion corresponds to setting a constant maximum admissible velocity. Albeit undoubtedly a practical criterion, it is not the most correct one from a scientific point of view. The setting of maximum velocity variables with the diameter does not imply a significant additional effort of calculation, and is manifestly more accurate; this was the criterion adopted in the new Portuguese Regulation, which will soon be published.

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6 Presentation of Authors

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Peak flow rates measured in residential building

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Abstract

The main aim of the paper is to describe a measured peak flows of inside water supply installations in residential buildings carried out in Czech Republic. The measured peak flows were compared with design flow rates established according to different standards. This comparison showed the difference between the design flow rates and measured peak flows, what is usually the reason of the pipelines over dimensioning, therefore it is necessary to update some of the methods used in different standards.

Keywords

Peak flow rate, flow rate measurement design flow rate, flow meter.

1 Introduction

Numerous of countries are nowadays updating the methods of pipe sizing of in-building installations. Czech Republic applied research in accordance to test, in necessary to modify actual practices in determination of flow rates methods. This research was focusing on flow rates measurement in 10 residential buildings in cities: Bohumin and Cesky Tesin in Moravian-Silesian Region. Research was supported by long-term conceptual science and research development 2015 at Technical University of Ostrava in cooperation with Civil Engineering Faculty at Brno University of Technology.
Further measurements applied in more residential buildings can enable the improvement of the flow-rate determination of in-buildings installation. The main aim of this paper is to inform about the measurements applied in residential buildings in Bohumin and Cesky Tesin. The paper shows also the results of the measurements realized afterward in several residential buildings of city Brno, localized in South Moravian Region.

2 Flow rate measurement

Flow rate measurement was realized in residential buildings (bricks and panel construction) during time period from 07.09.2015 till 23.03.2016. During 14 days period was each building in Bohumin and Cesky Tesin fitted with electromagnetic flow meter OPTIFLUX 1000 and transducer Krohne IFC 100C DN 40, with measuring range up to 10 m^3/h (Figure 1). The sensor was measuring secondary data of water flow velocity and automatically calculated volume flow. Primary output - the analogue output was signal from 4 to 20 mA, which is corresponding to the value from 0 to 100% from range 0 to 10 m^3/h. The sensor was connected to a data logger Ahlborn 5690-2, respectively AHLBORN ALMEMO 5690-2 A TS, which contains a 24 bit A/D transducer. Before recording the data, were measured values converted to l/s. Analogue output has been according to the producer reduced with 3 seconds time constant. The second output - pulse output, with a value of 1 pulse = 1 ml was determined for small flow rates up to 0.67 l/s. According to the place where the measurement have been applied, were residential building designated on 4CT, 7CT, 9CT (Cesky Tesin) and 10Bo, 11Bo (Bohumin) (Table 2). The difference between measured volume flows on pulse and analogue outputs can reach 21%, therefore the maximum measured flow rate in measured buildings may have 21 % greater value than maximum flow rate.

Figure 1 Data logger AHLBORN ALMEMO A 5690-2 TS, flow meter OPTIFLUX 1000 placed after water meter in residential building Ceskem Tesine

Further measurement was realized in Brno, during the time period from 04.05.2016 till 24.05.2016. For measurement of flow rates was used flow meter VT 4025 MSHNS000F (Figure 2). Measured values of water flow were recorded each second and connected to a data logger AHLBORN ALMEMO A 5690-2 TS placed in lockable steel box (Figure 3).
Values of flow rates were measured in the main supply pipe and in the pipe leaded into the water heater, also in hot water supply pipe (measurement in Brno) (Table 3).

Figure 2 Flow meter VT 4025 MSHNS000F placed on the main supply pipeline of hot water in residential building Brno

Figure 3 Data logger AHLBORN ALMEMO A 5690-2 TS placed in lockable steel box

3 Determination of flow rates in residential buildings according to different standards

Maximal flow rates measured in different residential buildings, were compared with values of flow rates determined according to different standards used in Europe. Standards used for comparison were followed: Czech Standard CSN 75 5455, Slovak Standard STN 73 6655, Swiss instructions W3 a German Standard DIN 1988-300.

3.1 Draw-off flow rates

Establishment of design flow rates was based according to draw-off flow-rates (standards draw-off flow rates), different for each standards. The values of draw-off flow-rates of different standards are in Table 1.

Table 1 Draw-off flow rates according to different standards

Draw-off point	Draw-off flow-rate Q_A (l/s)			
	CSN 75 5455 STN 73 6655[1)]	EN 806-3[2)]	W3[3)]	DIN 1988-300[3)]
WC	0,10	0,10	0,10	0,13
Washbasin	0,20	0,10	0,10	0,07
Kitchen sink	0,20	0,20	0,20	0,07
Washing machine	0,20	0,20	0,20	0,15
Shower head	0,20	0,20	0,20	0,15
Bathtub	0,30	0,40	0,30	0,15

1) Flow rate from tap or inlet valve for flushing cistern.
2) Flow rate from tap and cold or hot water flow rate into mixing valves, combination taps or single taps, inlet valves for flushing cisterns.
3) Cold or hot water flow rate into mixing valves, combination taps or single taps, inlet valves for flushing cisterns.

3. 2 Estimated methods for design flow rates determination

There are several methods for design flow rates determination, which differs according to different conditions in countries, however some of them are still old and need a revitalization and some were recently established.

3.2.1 Determination of design flow rate according to CSN 75 5455 and STN 73 6655
Methods of design flow rate establishment for residential buildings according to Czech Standards CSN 75 5455 and Slovak Standard STN 73 6655 can be considered as old methods, which were used in former Czechoslovakia. This method was based on theory of probability and experiences in Germany during 40 years of 20.century [1], previously used in former Soviet Union [2]. This countries are nowadays using different methods, however in Czechoslovakia was initial method modified.

Establishment of design flow rate Q_D (l/s) is according to:

$$Q_D = \sqrt{\sum_{i=1}^{m}\left(Q_{Ai}^2 \cdot n_i\right)} \qquad (1)$$

Q_A - is draw-off flow-rate of individual draw-off points (flow rate from tap outlet) (l/s) (Table 1);
n - number of same draw-off points (washbasins, baths etc.);
m - number of draw-off points.
According to Czech standards [3] is during the peak water demands allowed a decrease of hot water temperature to 45°C. Therefore is during the design flow rate Q_D determination considered with the supply of draw-off points separately with cold or just with hot water. The design flow rates Q_D are in the part of cold water inlet into the water heater determined according to the greater value, which is usually the value of cold water design flow rate.

3.2.2 Determination of design flow rate according to EN 806-3
Methods used for design flow rates determination in residential buildings, indicated in EN 806-3 could be also considered as an older methods, however are based on Swiss method and theory of probability [4]. The values of draw flow rates Q_A (Table 1), were for simplify the estimation converted on loading units LU:

$$LU = 10 \cdot Q_A \qquad (2)$$

Determination of design flow rates are not included in this standards, however could be established according to diagram on Figure 4. LU of cold and hot water is in the place of cold water inlet into the water heater totalized.

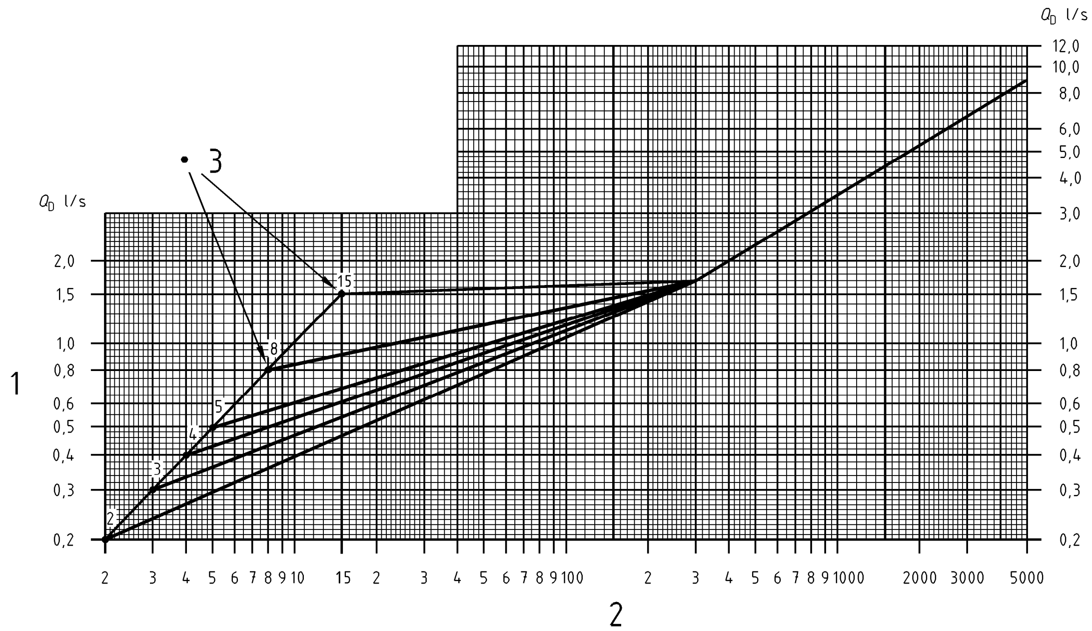

Figure 4 Dependence of design flow rate Q_D (l/s) on number of LU according to EN 806-3

1 – design flow rate Q_D, 2 – number of LU (sum of LU draw-off points supplied by corresponding part of pipe), 3 – Maximal value of each LU

3.2.3 Determination of design flow rate according to W3

Determination of design flow rates, given by Swiss instruction W3, were established according to the measurement of peak flow rates made in 30 houses of Basel and Zürich regions in 2010 [5]. The results of these measurements have not been published.

Establishment of design flow rate Q_D (l/s) is according to:

$$Q_D = 0{,}459 \cdot Q_T^{0{,}353} \tag{3}$$

Q_T - is total flow-rate (l/s) represents the sum of draw-off flow rates Q_A (l/s) (Table 1), according to $Q_T = \sum Q_A$.

Total flow rates Q_T of cold and hot water is in the part of cold water inlet into the water heater totalized.

3.2.4 Determination of design flow rate according to DIN 1988-300

Actual methods for design flow rate determination listed in DIN 1988-300, were updated in 2010 and 2011. These methods are based on version of German Standard from 1989 and results of peak flow measurements.

Establishment of design flow rate Q_D (l/s) is according to:

$$Q_D = 1{,}48 \cdot \left(\sum Q_A\right)^{0{,}19} - 0{,}94 \tag{4}$$

$\sum Q_A$ - is sum of draw-off flow rates (total flow-rate) Q_A (l/s), (Table 1).

Total flow rates $\sum Q_A$ of cold and hot water is in the part of cold water inlet into the water heater totalized.

4 Characteristic of residential buildings

Flats in residential buildings, where the measurement have been applied, have the basic equipment of sanitary devices. Each flat includes kitchen sink, toilet with flushing cistern, washbasin and bathtub or shower (Table 2). The number of washing machines was not clear, however according to fact that operation of common laundries was cancelled, is expected, that at least half of the flats have washing machine.
All residential buildings have central preparation of hot water, however the localization of water heater is different. Some of the buildings have water heater placed inside the building supplying the hot water through service pipe, other buildings have outside water heater placed in district heat exchanger station (Table 3). Therefore the values of flow rates were measured on the cold water inlet into the building.
One of the residential buildings - 4CT, have besides the flats also hair salon, what increased the value of maximal flow rate measured. In building 7CT were measured values of flow rates on the main water supply pipeline and flow rates on water heater inlet. For building 8Br were measured flow rates of hot water on the water heater inlet, placed on the district heat exchanger station.
The maximal flow rates measured during the measurement are listed in Table 3. These flow rates were compared with design flow rates established according to the Czech Standard CSN 75 5455, Slovak Standard STN 73 6655, Swiss instructions W3 and German Standard DIN 1988-300.

Table 2 Characteristic of residential buildings

Building	Number of flats	Number of residents	Types and number of sanitary devices					
			WC	Wash basin	Bathtub	Shower	Kitchen sink	Washing machine
1Bo	6	12	6	6	6	0	6	3
2Bo	6	13	6	6	6	0	6	3
3Bo	8	21	8	8	8	0	8	4
4CT	11 1)	22	11	13	10	1	11	5
5CT	16	34	16	16	16	0	16	8
6CT	34 2)	55	24	35	32	3	34	12
7CT	60	131	60	60	60	0	60	30
8Br	60	undetected	60	60	30	30	60	30
9CT	72	136	72	72	72	0	72	36
10Bo	78	149	78	78	52	26	78	39
11Bo	78	168	78	78	52	26	78	39

1) Hair salon in the building.
2) Three section building. Pipeline where flow meter has been placed is supplying 24 flats with cold water and hot water for water heater supplying 34 flats, included supply of hot water for wash basin in office.

5 Evaluation of the measured flow rates

Maximal flow rates measured in all buildings were lower than design flow rates, however the highest difference between the measured and designed flow rates was according to the CSN 75 5455 a STN 73 6655, especially when flow rates were measured individually for cold or hot water. As the reason for this difference, could be considered the application of old methods in this standards and fact that during

establishment of design flow rate in the pipes of cold or hot water is considering that draw-off points are supplied separately with cold or hot water, what is not corresponding the reality. However the measurement applied in building 8Br showed that hot water peak flow rate is higher even when the temperature of hot water is lower. This house doesn't have the regulation of circulation areas and the temperature of a main hot water supply is approximately 47 - 48 °C, what is causing that the temperature of a hot water standpipe is from 37 till 42 °C. This measurement will serve as a background of the further regulation of water circulation in regards to ensure that the hot water temperature in draw-off points will correspond the regulations used in Czech Republic. Measurement applied in building 7CT showed the difference between cold water peak flow rates in water service pipe and the hot water (measured on the water heater inlet). This difference was caused especially with the toilet flushing cistern and mixing valves or combination taps flow rates. Great difference between maximal measured flow rates and design flow rates was recorded, when the design flow rates were established according to EN 806-3 regulation. The difference is caused because of the older method of design flow rate determination used in this regulation. According to the current methods used for design flow rates determination in W3 and DIN 1988-300 is the difference between measured flow rates and design flow rates lower.
Measured values of flow rates are listed in Table 3 and Figures 5,6,7,8, where there is evident the variation of flow rate during the day, especially Figure 6 showed the duration of the peak flow rate which does not last too long.

Table 3 Maximal measured flow rates and design flow rates in residential buildings

Building	Number of flats	Number of residents	Maximal measured flow-rates (l/s)	Design flow-rates (l/s)				
				CSN 75 5455 STN 73 6655	EN 806-3	W3	DIN 1988-300	Note
1Bo	6	12	0,43	1,09	0,95	0,80	0,88	Cold water[3)]
2Bo	6	13	0,49	1,09	1,17	0,97	1,05	[4)]
3Bo	8	21	0,59	1,26	1,30	1,08	1,16	[4)]
4CT	11[1)]	22	0,72	1,49	1,40	1,21	1,30	[4)]
5CT	16	34	0,54	1,79	1,60	1,37	1,45	[4)]
6CT	34[2)]	55	0,44	2,55	2,20	1,68	1,72	[4)]
7CT	60	131	1,13	3,46	3,40	2,19	2,14	[4)]
			0,75	3,19	2,08	1,63	1,61	Hot water
8Br	60	undetected	1,08	2,95	1,90	1,58	1,61	Hot water
9CT	72	136	1,55	3,79	3,80	2,34	2,24	[4)]
10Bo	78	149	0,95	3,78	2,70	1,94	2,02	Cold water[3)]
11Bo	78	168	0,74	3,78	2,70	1,94	2,02	Cold water[3)]

1) Hair salon in the building.
2) Three section building. Pipeline where flow meter has been placed is supplying 24 flats with cold water and hot water for water heater supplying 34 flats, included supply of hot water for wash basin in office.
3) Service pipe is not supplying hot water from house water heater. Hot water is supplied from a district heat exchanger placed outside the building.
4) Water heater is placed inside the building and is supplying water from building service pipe.

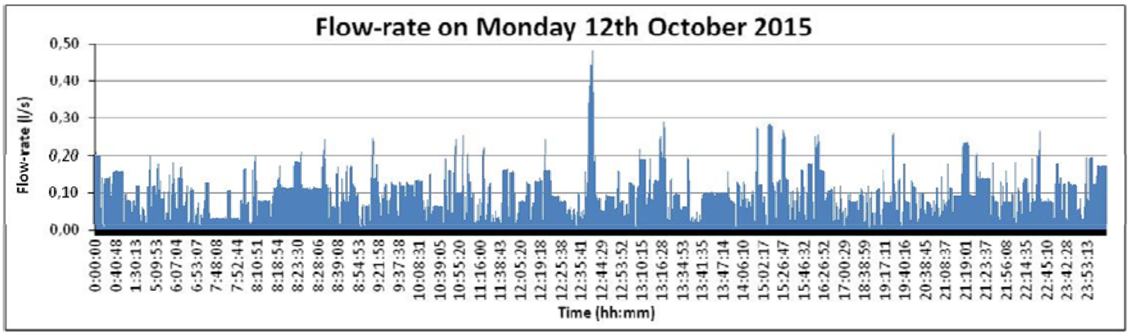

Figure 5 Hot water flow rates measured 10/12/2015 in 2Bo

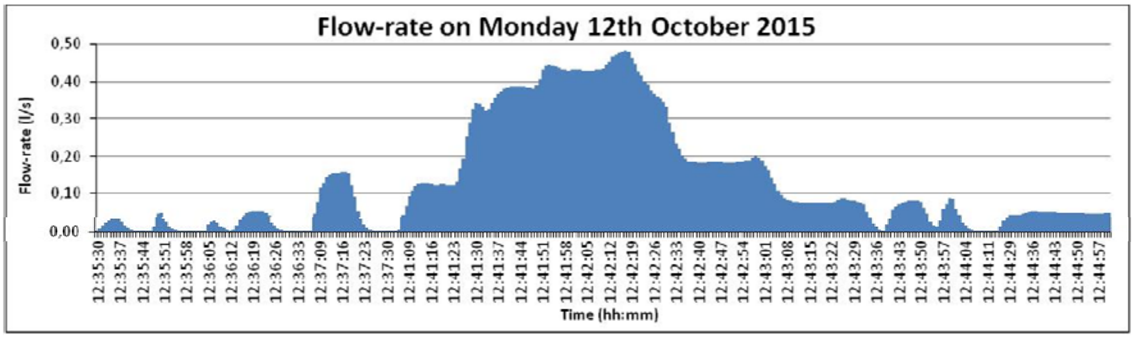

Figure 6 - Duration of peak flow rate 10/12/2015 in 2Bo

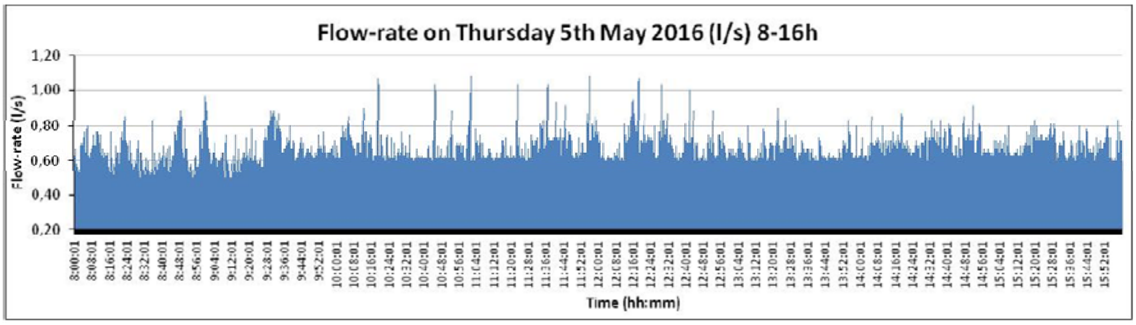

Figure 7 Hot water flow rates measured 05/05/2016 in 8Br. From diagram is also evident the circulation flow

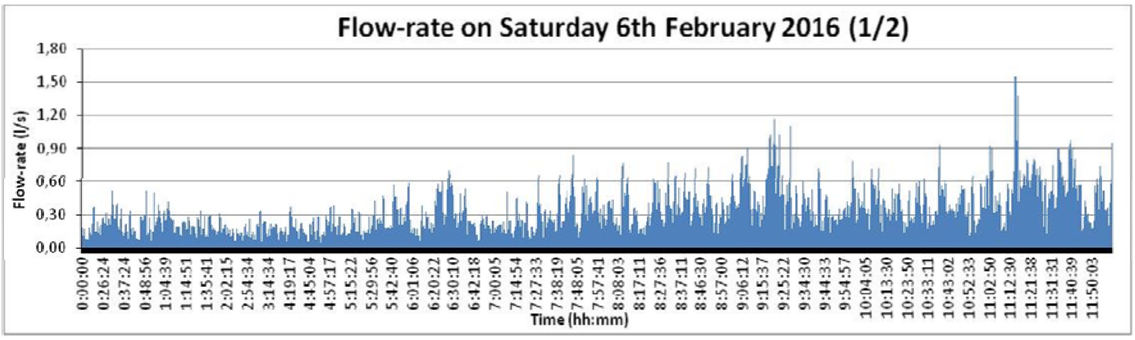

Figure 8 Hot water flow rates measured 02/06/2016 in 9CT

6 Conclusion

Evaluation of measured flow rates showed that the values of design flow rates according to CSN 75 5455, STN 73 6655 and EN 806-3 are too high. This fact is usually leading into over-dimensioning a water supply system and water stagnation. To ensure a more precise design flow rate determination it is necessary to update the evaluation settled for Czech Republic.

7 Acknowledgments

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8 Presentation of Authors

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Estimation of unit of design water supply amount based on municipal solid waste

Research on the Water Consumption during the Building Operation

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Abstract

During the recent years in Japan, there are the increasing in awareness of the energy and resources saving and popularize of water saving equipment, these changing of the living lifestyle cause the reducing of water supply at the building management. This research focused on the on the efficiency of the water saving equipment based on the water consumption data collected from modified water saving equipment in the office building over Japan for research purposes.
Furthermore, the times of usage of sanitary equipment were obtained by assuming the volume of general discharged water used by users. Based on the real water consumption data obtained from the education institutes located in Tokyo, the relation between volume of water usage before and after using the water saving equipment were observed and discussed.
The results show that the reducing of unit of water supply from the water saving equipment and the volume of discharged used water also can be used as the parameter to calculate the unit of water supply.

Keywords

Municipal solid waste, unit of water supply, water-saving equipment, actual measurement.

1 Introduction

The carbon dioxide, CO2, emission in Japan is gradually increasing, there is significant increases from the civilian sector, which including emission from the household and business activities. The CO2 emission from household and business activities as compare to others infrastructural activities correspond to about 40 percent in overall emissions. In order to construct a low carbon society, the reduction of carbon emission becomes an important issue.
As refer to the CO2 emission from infrastructure or building related activities, most of CO2 are emitted from the operation process. The usage and discharge of water and energy consumed during the building's operation corresponding to the burden on the environment.
From the view of water usage to achieve energy and resources saving, the water saving equipment are being introduced and the reuse of water and rain water are being carried out.
However, regardless of the reducing in water usage, in order to utilize the water usage data obtained from the survey regarding water usage volume before normalize of the water saving equipment, issues of the oversized volume of appliances and the deviation of water supply unit became the problems of research. The unit of water supply over water used was discussed as from Kurosawa［1］, which survey of the water consumption conducted in the office building show that the actual water consumption and the water supply deviation in the initial design was 47.8±19.6 Litters/(person・day).
In addition due to the water-saving of Low performance in carrying of dirt and Decrease in rotational speed in drinking water tank associate with the decrease in the remaining chlorine concentration has become a problem.
In addition to such problem in Japan, the method of water supply was using a water storage system instead of directly supply, this is due to lesson learnt from the Great East Japan Earthquake where the supply of water needs to be ensured during emergency situations. These also forces the decision made in the changing of design basis of water supply. From the mentioned issues, in order to make a suitable design based on the water saving equipment, the investigation of actual water usage activities was important. However, it is important to identify user activities inside the building for the investigation of water usage data, but it is very difficult.
In this research, general discharging of water by human activities within the building was assumed to be the parameter related to the number of people involved in the water usage within the building for obtaining the volume of waste water discharged in order to investigate the current unit of water supply.

2 Overview of researched building and measurement value

The overview of data used in researching building and its evaluation was as shown in Table1. During the investigation and its evaluation, the actual data of the 26 domestic office building were used to understand the installation of the water saving appliances and the volume of water supplied in recent year. Furthermore, the water saving appliances was modified based on the data obtained from all the education institutes located in Tokyo which were completed in the year 1989, also the data during the year 2010 to 2011 was excluded due to the different energy saving measures were taken after the Great East Japan Earthquake. Hence, there is total of 6 years data (2006 to 2008 and 2012 to 2014) for the evaluation process.

Table 1 Summary of investigated building and the actual data

	Education Institutes (University)	Office Building
Investigated number	1	26
Building summary	University located within Tokyo with area approximate 50,000m^2	The office building in while Japan with the area of 1,500m^2 to 40,000m^2
Investigation values	･User numbers ･Potable water consumption ･Non-potable water consumption ･General discharged waste (paper, container, combustible rubbish, others) ･Electricity consumption	･User numbers ･Water consumption ･General discharged waste (paper, container, others)
Remarks	･Flush toilet Changing of the level type with flush valve of 15L to sensor type with flush valve of 10L ･Hand washing basin Changing of manual valve to automatic tap	･Toiled facilities change to water saving type

3 The relation between the volume of water usage and the activities in building

3.1 The water usage volume in the educational institution and the changing of number of users

Figure 1 shows the monthly water consumption and the number of users (registered students and staffs) at the education institutions from the year 2006 to the year 2013. The water consumption before modification of water saving equipment during the year 2006 to 2008 was 22,000 m^3, and the water consumption after the modification was 20,000 m^3, which shows the decreasing trend of water consumption. Besides, the efficiency of the water saving equipment decreased when there is an increase in the number of users.

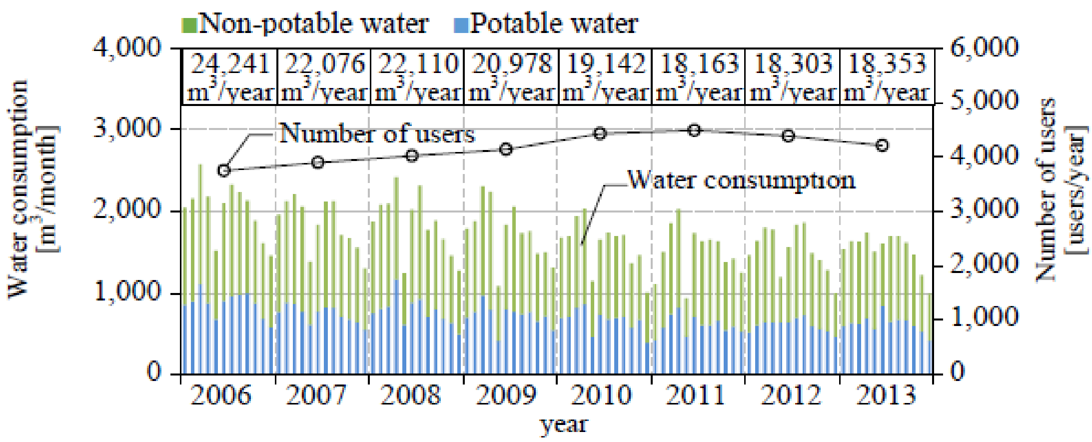

Figure 1 Changes in the water consumption and users

3.2 The relationship between the water consumption, electric power and waste discharged

From Figure 1, the number of users in the subscribed in the education institute can identify, but the working hours of the office building cannot be determined as the users' activities inside the building as the changing of lecture timetable, the actual number of users which carry out activities inside the building is necessary to determine.
Further, the water consumption, Energy consumption, such as electric power and waste discharge can be cited as an index representing the frequency of use of operational building. Hence, the relation between general wastes discharged volume caused by the users' activities inside the building and water consumption and electric power was investigated.

3.2.1 The relationship between the water consumption and electric power
Figure 2 shows the relationship between water consumption and electric power.
With water consumption is reduced after refurbishment, electric power from the influence of Thoroughness of the thinned-out lighting and off of the lighting by power-saving request after the Great East Japan Earthquake and Rotation stop operation control of the air conditioning equipment is reduced.
This is in building operational phase, it can be said that an example of energy consumption characteristics that were, including the electric power that indicates the amount of activity of the building by the condition change of control conditions and facility management has changed.

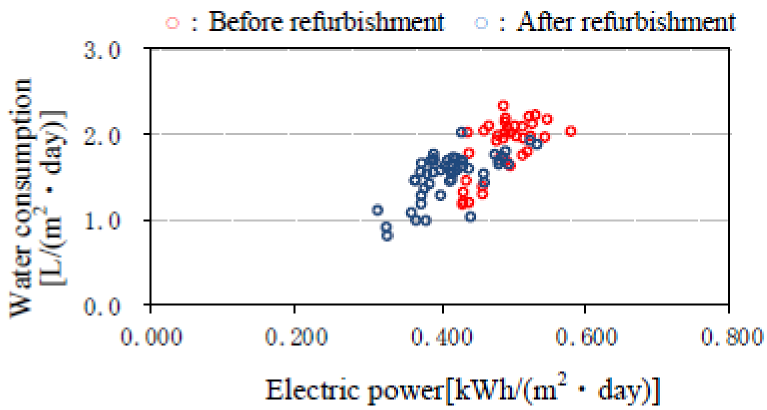

Figure 2 The relationship between the water consumption and electric power

3.2.2 Relation between the water consumption and the discharged volume if combustible rubbish, bottles, cans and PET
The recycling of item from general waste discharged at Education Institutes were paper, bottles, cans and the combustible rubbish also distinguish as cigarette butts, used tea leaves, paper trashes and kitchen wastes. Except for the paper which can be stored for a certain period and discharged together at the end of the year, the relation between combustible rubbish, bottles, cans and water usage volume was shown in Figure 3. From Figure 3, it clearly indicates that the waste discharged volume and the water consumption was increased which caused the users' activities in the building.

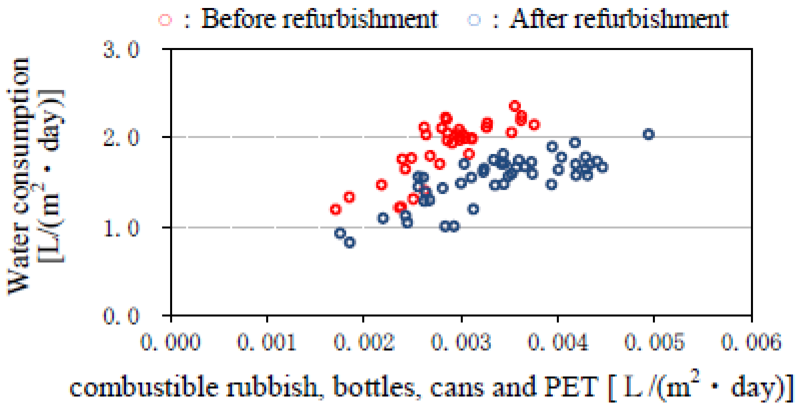

Figure 3 Relation between the water consumption and municipal solid waste

3.2.3 Relation between the water consumption by application and combustible rubbish, bottles, cans, PET.

In order to obtain the relation between water usage, volume and the discharged volume of combustible rubbish, bottles, cans and PET, the combustible rubbish, bottles, cans and PET were classified to the water consumption to potable water and non-potable water application as shown in Figure 4.

As the result, it's also clearly shown that the relation between to the discharged combustible rubbish, bottles, cans and PET based on the users' activities in the building, especially the water consumption on the toilet cleaning water were related to the Non-potable water application.

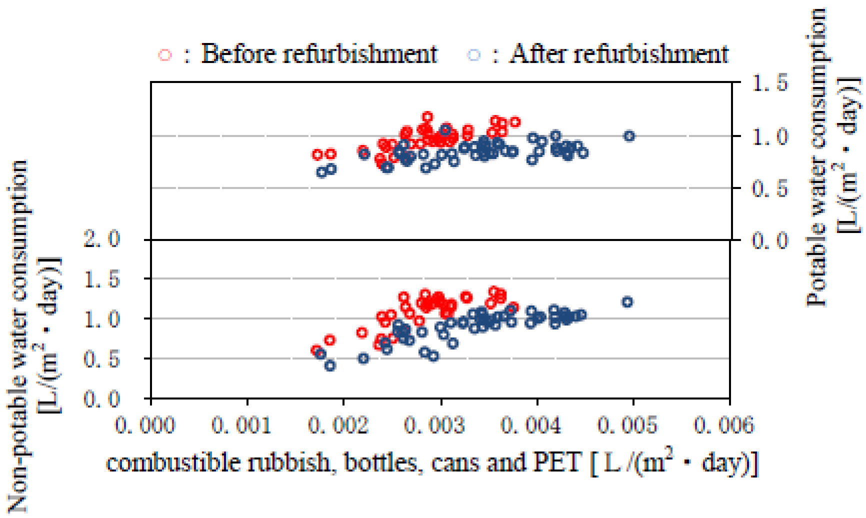

Figure 4 Relation between the water consumption by application and combustible rubbish, bottles, cans, PET

3.3 Estimation of number of people in the building

3.3.1 Estimation of the design parameter

The assumption value made for the design parameter as the unit of water supply and targeted water users were unidentified during the initial design stage. The unit of water supply of the initial design in the office building was from 60 to 100 L/(person·day), hence, the average value of 80 L/(person･day) was taken into the measure.

The ratio of water application is drinking water to general use water was 40% to 60 % and correspond to the current appliance volume of average 80L, estimated potable water supply was 32 L/(person･day) and non-potable water supply was 48 L/(person･day).

Furthermore, the water storage tank was designed based on the assumption of 50% of daily water consumption and the current non-potable water receiving water tank was for daily water consumption except for the water used in the cafeteria, and it shows the result of daily water consumption was $192m^3$.

Therefore, the initial design of the water supply tank volume of $192m^3$ was divided by the non-potable water supply of 48 L/(person･day), resulted in 4,000 number of users. This number of users obtained was almost same as the number of students and staff in the Education institutes. As the relation between unit of water supply in the cafeteria and the non-potable water storage, the current water storage for potable water was $171m^3$ which makeup of $64m^3$ for drinking water and $107m^3$ for cafeteria general usage. If the large volume water storage in the cafeteria was divided by the unit of water supply in the cafeteria of 35.7 L/(person･day), as refer to the reference [2], the results show the number of water users of 6,000 people and 4,000 people when water supplied to 1.5 round per person. Hence, it was able to obtain the required design parameters from the cafeteria conditions.

3.3.2 Investigation of the actual number of person in the building

As compare the ratio of waste discharged volume from education institute as refer to [3] to the waste discharged volume from the office building, the ratio of waste discharged from Education Institutes to the average value of waste discharged volume from office buildings in Tokyo area, it shows the almost same ratio.

From this, the combustible waste discharged volume in the year 2005 divided to the combustible waste discharged volume of 0.167kg per person from office buildings in Tokyo, the actual users in the building can identify.

Besides, by comparing the waste discharged volume from Education Institutes as refer to [3], the actual time of one user stay in the campus building was 60% to 70% less than the time in office buildings.

From the observations, by taking the consideration of the correction value, the actual number of users in the building in one day was 1,150 persons.

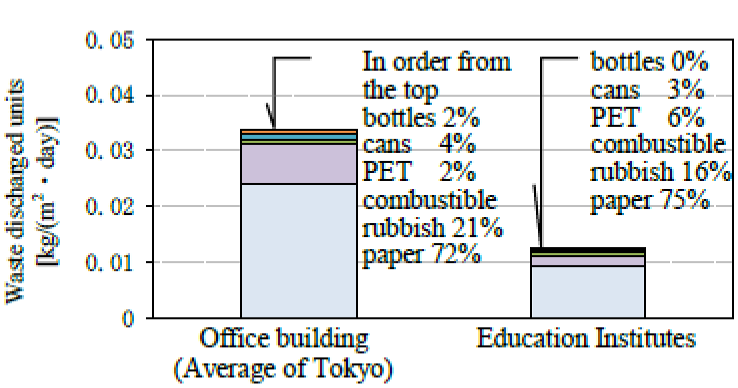

Figure 5 Comparison of the general waste discharged units

$$N = \frac{BW_S}{BW_T} \times \frac{W}{MSW} \div \frac{W_S}{MSW_S}$$

(1)

N : Actual number of person in building [person]
BW_S : Discharged volume of Combustible rubbish from Education Institutes [person・day]
BW_T : Discharged unit [3] of combustible rubbish in Tokyo [kg/(person・day)]
W_S : Volume of water used by the bus in Education Institutes[L/(m^2・day)]
W : Water usage volume from reference [4][L/(m^2・day)]
MSW_S : General waste discharged volume from the Education Institutes [kg/(m^2・day)] MSW : General waste discharged volume from reference [5] [kg/(m^2・day)]

3.3.3 Validity of the combustible rubbish discharge unit

In order to get the validity of the combustible rubbish discharge unit for the person in a building, the investigation of the combustible rubbish discharge unit of one person in the year 2001 was shown Figure 6. From the investigation, the number of people in the building was calculated from the combustible rubbish discharged volume (kitchen waste + combustible rubbish + others).

The variation of the combustible rubbish discharge unit from the investigation affected by the tenant in the building can be observed. However, the average value of the investigation is 0.169kg/(person・day), which the average value of the investigated office building in Tokyo was 0.167kg/(person・day). There was not huge different of the combustible rubbish discharge unit per person and hence, the unit used for the estimation of a number of people was reasonable.

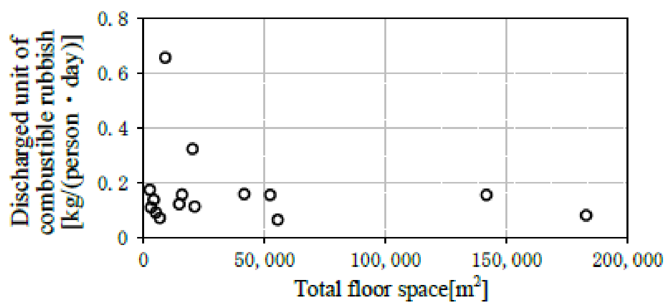

Figure 6 Comparison of the combustible rubbish

4 Unit of water supply

4.1 Comparison of the unit of water supply

The number of people in the building obtained in the previous section was used to calculate the water supply volume. Figure 7show the comparison between the water supply volume after refurbishmentof water saving appliances and the previously investigated result in the education institutes. The water usage before modification of water saving appliances was the maximum of 79.7 L/(person・day) and the minimum of 39.2 L/(person・day),hence with the average of 62.6 L/(person・day). whereas the water usage volume after using the modified water saving appliances, the water usage was maximum of 63.0 L/(person・day) and the minimum of 23.9 L/(person・day), hence with the average of 40.0L/(person・day). The standard average water usage was 80 L/(person・day), hence, this show the decreases of the water usage volume. The result

was similar to theprevious investigation resultof average 49.1 L/(person･day) and previous study of 47.8±19.6 L/(person･day).
In addition, the reduction of water usage has also been confirmed in the average is 49.1 ℓ / (person･days) and the office building of the past survey. This result is similar to both the average value 49.1ℓ by past Survey to previous studies [1]47.8 ± 19.6ℓ / (person･days).

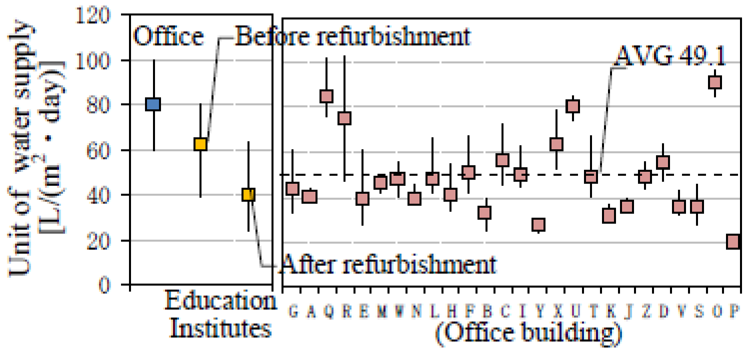

Figure 7 Comparison of the unit of water supply

4.2 Comparison of the unit of water supply based on application

Figure 8 show the water supply volume based on large and medium water volume application. As refer to the potable water supply, the maximum volume before refurbishment is 37.3 L/(person･day), and the minimum is 16.6 L/(person･day), which average is 26.4 L/(person･day).

The maximum volume after refurbishment is 28.0 L/(person･day) and the minimum of 9.4 L/(person･day), which with the average of 16.5 L/(person･day).
Besides, the non-potable water supply before refurbishment show the maximum of 45.8 L/(person･day) and the minimum of 22.6 L/(person･day), with the average of 36.2 L/(person･day).
The maximum volume of medium volume water supply after refurbishment is 38.1 L/(person･day) and the minimum of 13.9 L/(person･day), which with the average of 23.5 L/(person･day). In the Education Institutes, the potable water supply decreased by an average of 9.9 L/(person ･day), non-potable water supply also decreased by an average of 12.8 L/(person ･day), which show the effect of the refurbishment water saving appliances.
Furthermore, the non-potable water consumption was reduced by 35%, due to the changing from the Flush valve 15 lever type to flush valve 10 sensor type where the reduction ratio was approximately equivalent to 30 %, and the waste emission was as one of the parameters to derive the unit of water supply.

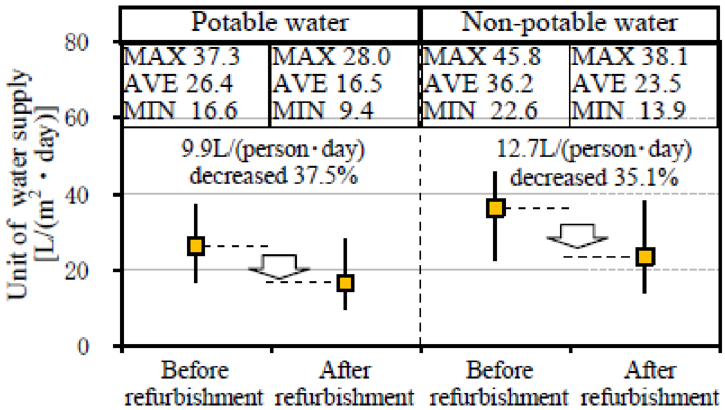

Figure 8 Comparison of the water consumption by application

5 Conclusion

Data obtained from the office building which undergoes the modification of water saving appliances was used to understand the actual water supply volume, waste discharged from business-based was assumed to be one of the parameters for human-related water consumption. The data of before and after modification of water saving equipment which obtained from the education institutes was compared and its relation with water usage volume was observed. The observations were shown as below.

1. The investigation of unit of water supply based the actual data obtained from water saving equipment in the office building show that average of 49.1 L/(person･day).
2. The activities in the investigated education institutes were less than the activities in the office building. Estimation of the unit of water supply based on the characteristic of waste discharged was considered as one of the parameters to determine the unit of water supply.

6 Acknowledgments

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Effect of thermal insulation on the hot water temperature - test measurements

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Abstract

One possibility of reducing the energy consumption in buildings is to reduce heat loss in their hot water distribution system. The aim of this paper is to present the results of research which focused on energy efficiency of the distribution system of hot water in residential buildings. As part of the research, test measurements of water temperature on the hot water distribution line and air temperature around the distribution line have been carried out. Test measurements were conducted during continuous and intermittent operation regimes in the distribution system, but in two separate stages. The first stage of measurements took place before the reconstruction of the hot water distribution system, when pipes weren't insulated with thermal insulation. The second stage took place after the reconstruction of the system, when pipes were fitted with thermal insulation. The aim of the research was to determine the variation of water temperature in the distribution system in those different stages and highlight the effectiveness of the insulation on the hot water distribution system.

Keywords

Distribution system, hot water, heat loss, test measurements.

1 Introduction

To obtain information on the variation of the hot water (HW) temperature in the distribution system and in the hot water circulation system, experimental measurements have been carried out. These experimental measurements were preceded by a theoretical analysis of the distribution system taken into account, from which it became clear that the greatest heat losses in that particular distribution system (45 years old non-modernized residential buildings) are from hot water risers and HW circulation. The conducted analysis shows that after using thermal insulation for risers in a residential building, it is possible to achieve savings of up to 52 % of the heat loss.

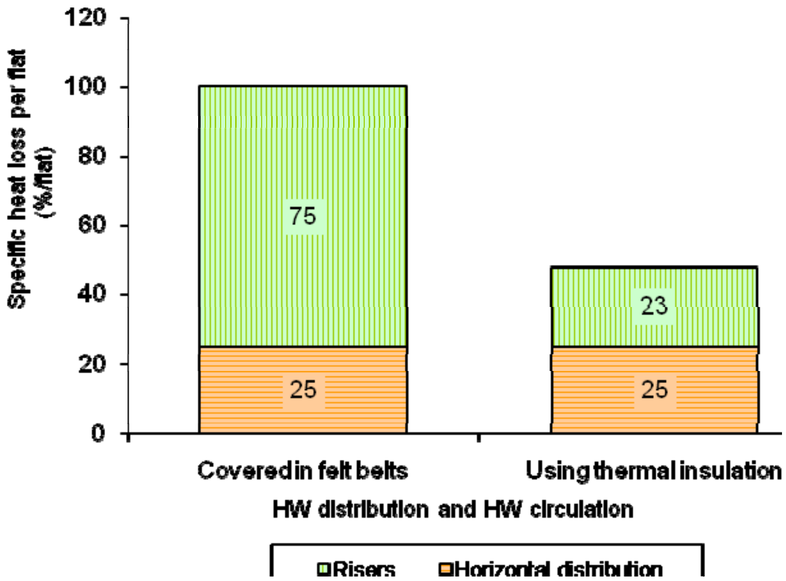

Figure 1 The specific heat loss of the hot water distribution system in a residential building per flat - (% / flat)

Therefore, a hot water riser in that residential building was selected as subject of the test measurements. The aim of the measurements is to detect what changes will result in the variation of the hot water temperature in real conditions of use in the residential building.

2 The characteristics of the measured system

Our residential building is located in a neighbourhood of Kosice. From a structural point of view, it is a prefabricated block of flats (type T 06 B), which is supplied with heat and hot water from a central heating system. This residential building consists of eight residential floors and one technical floor.

Hot water is fed into the building by an underground pipe mounted in the hot water channel coming from the heat exchanger station. In the technical floor, hot water and circulation pipes come out from the hot water channel and run under the ceiling to each riser position. Hot water is distributed to individual flats by risers. One hot water supply riser feeds 8 residential consumption nodes located one above the other (Figure 2). In each residential consumption node, the following plumbing fixtures are supplied with hot water: wash basin, bathtub and kitchen sink.

The measurements were carried out from April to October. During this period of test measurements, the residential building systems went through a reconstruction process, i.e. the HW riser, the HW circulation and cold water distribution were refurbished. The measurements were carried out in continuous HW circulation and intermittent HW supply, or intermittent HW circulation.

2.1 Characteristics of the distribution system before reconstruction

The original inlet hot water riser was made entirely of DN32 galvanized steel threaded pipes. Thermal conductivity of the steel tube is λ = 46.5 W/(m.K). The length of the hot water riser is 21.2 m. Hot water circulation riser was made of DN20 galvanized steel threaded pipes. The length of this riser is also 21.2 m.
Before reconstruction, hot water supply and circulation piping was covered in felt belts. Thermal conductivity of the felt belt is λ = 0.07 W/(m.K). Felt belts, according to design analysis, cannot be considered as an effective thermal insulation for HW pipes.
It should be mentioned that cold water pipes were also covered in felt belts.

2.2 The characteristics of the distribution system after reconstruction

The new supply HW riser was made of a combination of DN32 and DN25 galvanized steel threaded pipes. The DN32 riser segment is 12.7 meters long and the DN25 segment is 8.4 meters long. Thermal conductivity of steel pipe is λ = 46.5 W/(m.K).
The new circulation HW piping is made entirely of plastic multilayer tubing PE-Al-PE with an outside diameter of 16 mm and wall thickness of 2 mm. Corresponding nominal diameter for these circulation HW pipes is DN12. Thermal conductivity of the plastic pipe is λ = 0.43 W/(m.K). All pipes are covered in PE insulation having 10 mm thickness. (λ = 0.04 W/(m.K).

3 The methodology of measurement and used measuring instruments

3.1 The methodology of the test measurements

The aim of the test measurements was an experimental monitoring of the actual temperature:

- water temperature in the pipe supplying each individual flat;
- water temperature in the circulation system, at the boiler;
- air temperature in the **installation** shaft;
- air temperature in the room where there is a service shaft.

Test measurements for HW distribution pipes have been done separately in two stages: before reconstruction, then after reconstruction. The measurements were conducted during continuous and intermittent operation regimes of the distribution system. Recording interval of the measured temperatures was determined according to the severity of the ongoing processes in the distribution system. A temperature recording interval of 3 minutes or 5 minutes was used for intermittent operation, especially for cooling of hot water, but a 30 minutes measurement interval was used mainly for continuous operation.

3.2 The measuring instruments

For the test measurements, temperature sensors were used in connection with the recorder PMICRO-T. For the pipes, temperature monitoring has been performed using the contact

resistance PT1000 temperature sensor, which was installed on the cleaned pipe and then perfectly thermally insulated. Each temperature sensor was connected to the recording device via a communication cable. For sensing the air temperature in the installation shaft a Microwire sensor was used, which was freely suspended in the shaft and connected to the recording device via a communication cable.
At a set time interval, each measuring instrument measured temperature value and stored it in its own memory.

Technical parameters of PMICRO-T measuring instrument:

Temperature range:	- 40 °C to 125 °C
Temperature resolution:	0.065 °C
Maximum uncertainty:	0.5 °C
Temperature sensor for water:	surface resistance PT100
Temperature sensor for air:	digital Microwire
Number of entries:	10400
The structure of the record:	day, month, year, hour, minute, temperature
Interval measurement:	1 to 255 minutes
Dimensions:	44 x 32 x 22 mm
Coverage:	IP 40
Transfer rate:	9200 bit /sec
PC connection:	RS232 COM port

3.3 Deployment of sensors

The placement of temperature sensors is shown in Figure 2. As was mentioned before, in pipes the temperature sensors were attached to the wall of the pipe and then covered with thermal insulation. Air temperature sensor was freely suspended in the shaft.

4 Test measurements of the distribution of hot water

Test measurements were conducted in two separate stages: with continuous and intermittent operation of the distribution HW supply. The first stage took place before reconstruction of HW riser and the second stage took place after the reconstruction of HW distribution.

4.1 Test measurements with continuous operation of the HW distribution system before the reconstruction of the distribution

The test measurements were carried out in May and April, during continuous operation of the distribution system. The recording interval of the measured temperatures was 30 minutes. Figures 3 and 4 present the weekly variation of the measured temperatures of hot water, respectively hot water circulation.

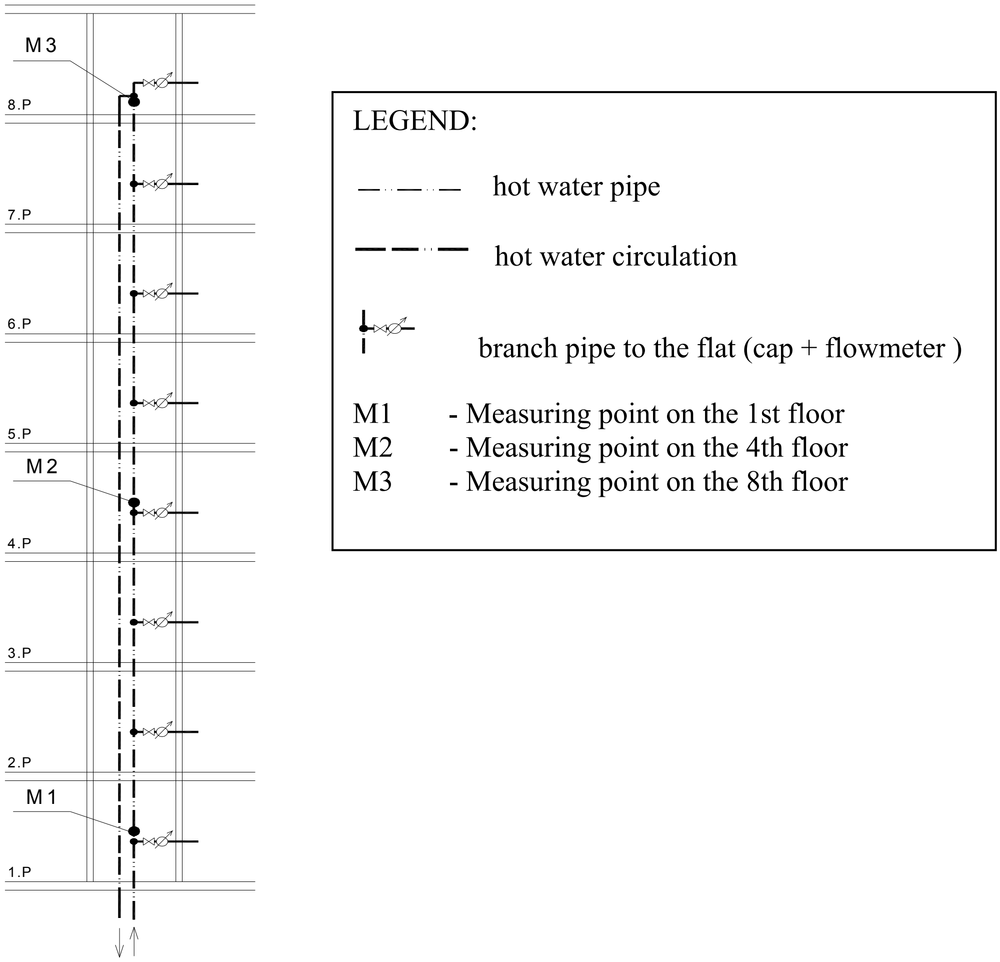

Figure 2 The placement of the temperature sensors

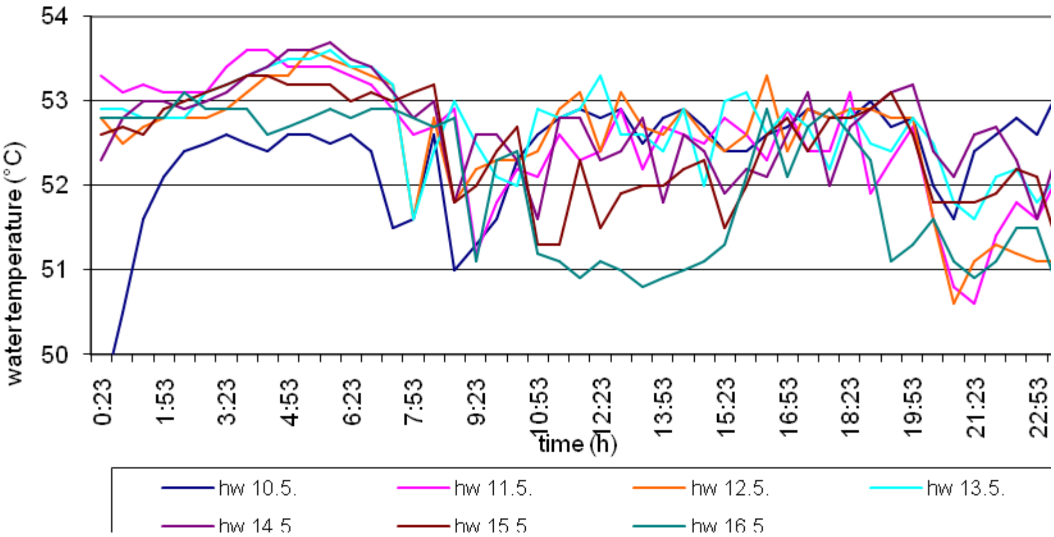

Figure 3 The variation of the HW temperature in the distribution pipes without insulation

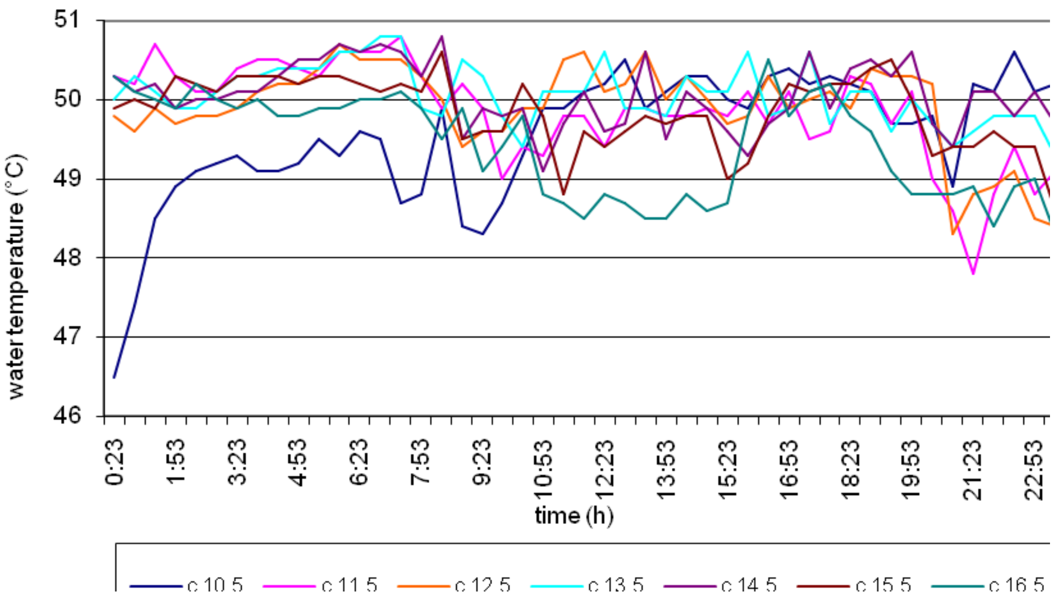

Figure 4 The variation of the HW temperature in the circulation pipes without insulation

From Figures 3 and 4, it is obvious that in the pipes without insulation, the temperature variation along a day is uneven. In the HW pipes, temperature values spread from 50.5 °C to 53.7 °C. In the HW circulation pipes, temperatures were recorded from 47.5 °C to 50.8 °C.

Those uneven water temperatures are mainly affected by the hourly variation of water consumption along the day (demand pattern). Between 20.00 to 23.00 hours, where there is the highest consumption of the hot water, the HW temperature is the lowest. By contrast, between 3.30 to 6.00 hours, the temperature is highest. This is due to the fact that water is not taken from the system. In view of the fact that the mode of water consumption is different for each day, there is also a different evolution of temperatures.

When there is no water consumption in the distribution system (and HW only circulates in the system), it is possible to achieve a constant temperature at the installed temperature sensor. This situation is unrealistic in practice and even undesirable, as distribution line should be used to distribute hot water to points of supply.

Following the variation of temperatures, it is possible to state that the HW removed from the system during peak consumption is replaced by a somehow colder mix of water produced by storage water heaters, causing a change in HW temperature in the system.

Since the amount of hot water removal from the system is non-uniform and is dependent on the human factor and also the performance of the water heater is designed for constant power, the water outlet temperature of the heater varies for each time point.

4.2 Test measurements with continuous operation of the HW distribution system after the reconstruction of the distribution

The test measurements were carried out in June, after the reconstruction of the HW distribution and were carried out during continuous operation of the distribution system. The recording interval of the measured temperatures was 30 minutes. Figures 5 and 6 show the weekly variation of the measured temperatures of hot water, respectively hot water circulation.

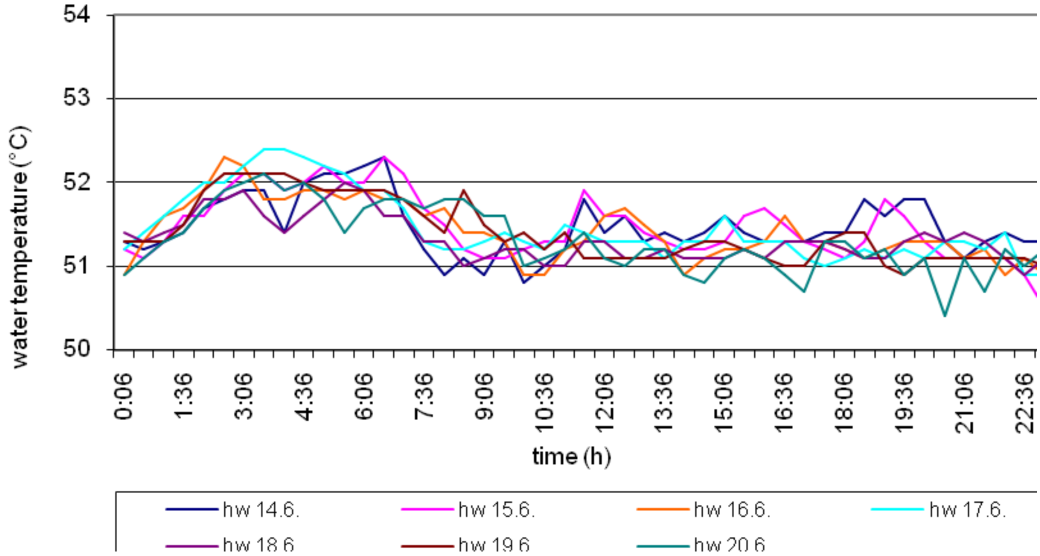

Figure 5 The variation of the HW temperature in insulated distribution pipes

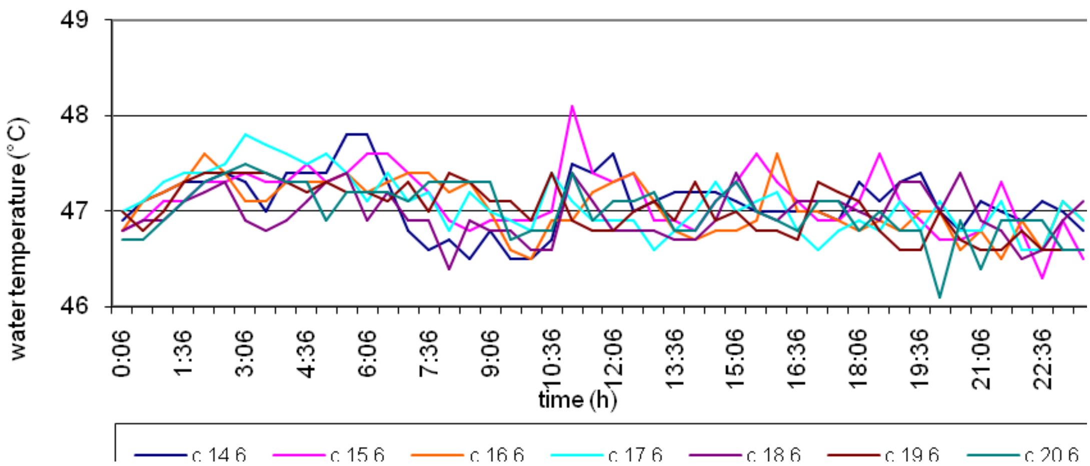

Figure 6 The variation of the HW temperature in insulated circulation pipes

From Figures 5 and 6 it is clear that the temperature variation of the heat-insulated tubes is less uneven than for non-insulated pipes.
In the HW pipes, temperature values spread from 50.5 °C to 52.5 °C. In the HW circulation pipes, temperature values were recorded from 46.1 °C to 48.2 °C.

5 Discussion

The total heat requirement to ensure supply of hot water in the flat consists of a heat demand for hot water delivered to the flat (heat consumed by the consumer) and the heat demand to ensure hot water distribution (heat losses of hot water distribution pipes). For the analysed residential building we calculated specific and proportional heat consumption of the hot water supplied to the flat and the heat loss of hot water distribution. The specific heat consumption for heating of hot water supplied to the flat and specific heat loss of hot water distribution is shown in Figure 7.

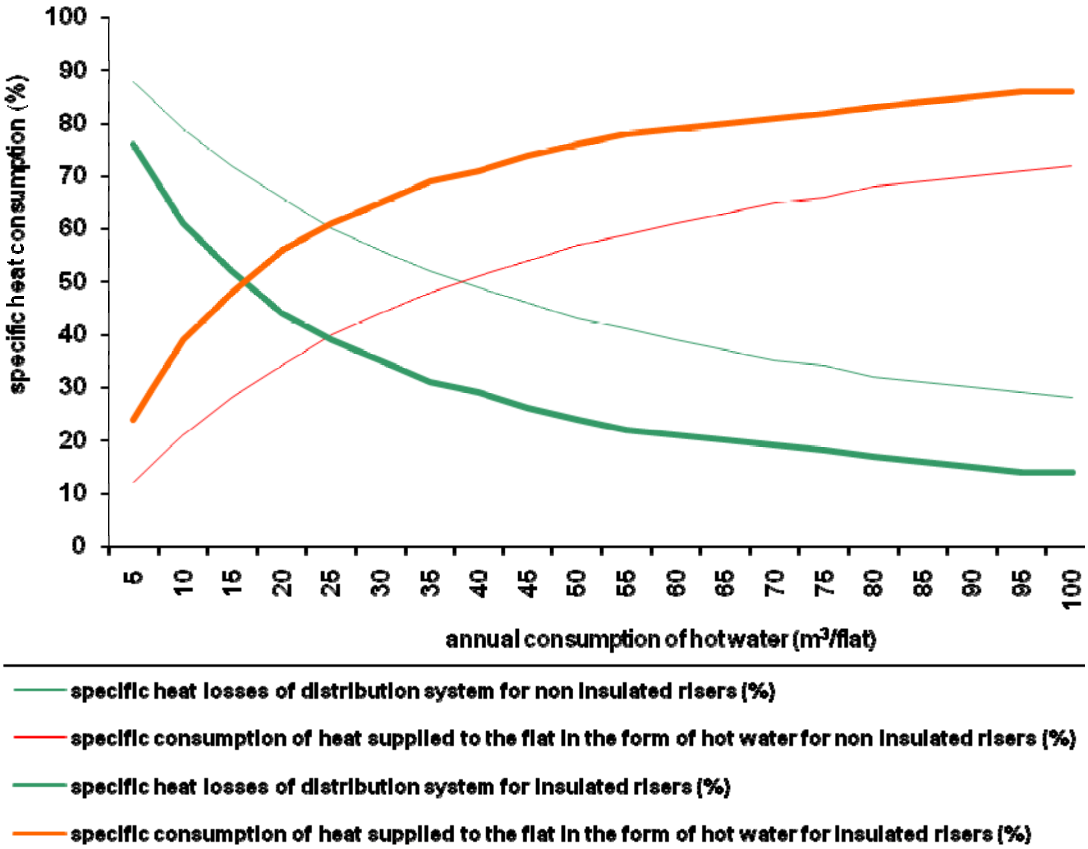

Figure 7 Specific consumption of heat supplied to the flat in the form of hot water and specific heat loss of hot water distribution system, depending on the annual consumption of hot water (%/flat)

The specific heat loss of hot water distribution with risers covered in felt belt (λ = 0.07 W/(m.K)) 4 mm thickness is 7.11 GJ/flat per year. The specific heat loss of hot water distribution with risers with thermal insulation (λ = 0.04 W/(m.K)) 20 mm thickness is 2.98 GJ/flat per year. The analysis considered the theoretical quantity of heat consumed to heat 1 m^3 of water from 10 °C to 55 °C with Q = 0.18738 GJ /m^3.

From the graph in Figure 7, it is possible to determine for any hot water consumption in the flat what will be the percentage of heat consumed for the distribution of hot water and the percentage of heat consumed in the form of hot water supplied to the flat for insulated and non-insulated hot water risers.

For example, in a residential building with a riser covered in felt belts, for an average flat with three inhabitants, with an annual consumption of hot water 60 m^3/flat, the total theoretical annual heat consumption will be Q = 18.33 GJ/flat. For that flat (Figure 7), 61% of the heat consumed is for hot water supplied to the flat and 39 % of heat is lost, as heat dissipates from the distribution pipes.

After using thermal insulation with a thickness of 20 mm (λ = 0.04 W/(m.K)) for risers, the theoretical total annual heat consumption is Q = 14.20 GJ/flat. For that flat (Figure 7), 79 % of the heat consumed will be for hot water supplied to the flat and 21 % of heat will be lost, as heat dissipates from the distribution pipes.

After using thermal insulation for risers in residential buildings, heat consumption can be theoretically reduced by 75 % in comparison to the original heat consumption.

6 Conclusion

To ensure the comfort parameters and hygienically clean hot water in an apartment building it is necessary to provide the hot water temperature in the range of 50 °C to 55 °C. It appears from the test measurements that the hot water temperature in the distribution system before insulating the pipes was in the range of 50 °C to 54 °C and in the hot water circulation pipes was in the range of 48 °C to 51 °C.
After insulating the distribution pipes, the temperature of hot water was in the range of 51 °C to 52 °C and in the hot water circulation pipes was in the range of 46 °C to 48 °C.
From our experimental measurements it is possible to observe a decrease of the temperature in the distribution pipes by about 2 °C, thus making possible to achieve savings in energy, while ensuring comfort and hygiene and quality requirements for hot water.

7 Acknowledgments

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9 Presentation of Authors

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Session B
Water efficiency

A Monte Carlo model for evaluating the carbon-reducing impacts of the water efficiency labelling scheme on showers for bathing in Hong Kong

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Abstract

In Hong Kong, the voluntary Water Efficiency Labelling Scheme (WELS) on showers for bathing is a shower water conservation initiative of the HKSAR Government. As shower water consumption has been identified as a potential area for carbon emissions reductions, this study proposes a Monte Carlo model for evaluating the carbon-reducing impacts of WELS on showers for bathing. The simulation results indicate that full implementation of WELS rated showerheads with $k \leq 4.02$ can reduce water consumption by 37%, energy consumption by 25% and carbon dioxide (CO_2) emissions by 26%.

Keywords

Water saving showerhead, water consumption, energy use, carbon reduction, policy.

1 Introduction

Shower water consumption has been identified as a potential area for carbon emissions reductions [1]. In Japan, over 50% of carbon dioxide (CO_2) emissions come from hot water supply systems [2], whereas in Hong Kong, energy use for water heating in residential buildings in 2013 was about 19% of total energy consumption (21% was for space conditioning) [3]. A voluntary Water Efficiency Labelling Scheme (WELS) on showers for bathing has been implemented in Hong Kong since 2009 to encourage shower water conservation [4]. According to their nominal flow rates, showerheads are classified into four water efficiency grades, namely Grade 1: ≤0.15Ls^{-1}, Grade 2: 0.15-0.2Ls^{-1}, Grade 3: 0.2-0.27Ls^{-1} and Grade 4: ≥0.27Ls^{-1}. However, this labelling scheme is not well-recognized by the end-users in terms of water/energy savings as well as carbon emissions reductions and a review is needed for further promotion of the scheme [5,6]. This study proposes a Monte Carlo model for evaluating the carbon-reducing impacts of WELS on showers for bathing.

2 CO_2 emission from showers for bathing

Per capita annual CO_2 emissions M_p (kg-CO_2 ps^{-1} yr^{-1}) from hot showers are linked to water consumption V_p (m^3 ps^{-1} yr^{-1}) and energy consumption E_p (GJ ps^{-1} yr^{-1}) using emission factors α (kg-CO_2 m^{-3}) per unit water consumed and β (kg-CO_2 GJ^{-1}) per unit energy consumed respectively [7,8],

$$M_p = \alpha V_p + \beta E_p \qquad (1)$$

$$V_p = \frac{v}{60} \sum_j N_j t_s \qquad (2)$$

$$E_p = \phi \rho c_p \sum_j V_{p,j} \left(T_o - T_j \right) \qquad (3)$$

where v (L min^{-1}) is the showerhead flow rate, N_j is the number of showers taken by a resident per day, j is a day in a year, t_s (s) is the showerhead operating time, ρ (=1000kg m^{-3}) is the density of water, c_p (=4.2×10^{-6} GJ kg^{-1} K) is the specific heat capacity of water, T_o (ºC) is the shower water temperature, T_j (ºC) is the cold water temperature as given by Equation (4), and ϕ=1 for hot water showers but 0 for cold water shower [8],

$$T_j = 10.4 T_a^{0.29} \qquad (4)$$

The showerhead flow rate v (L min^{-1}), which is subject to the user adjustments and is limited by the maximum water supply flow rate available, is described by,

$$v = \begin{cases} v_p & ; v_p \le v^* \\ v^* & ; v_p > v^* \end{cases} \qquad (5)$$

The user preferred showerhead flow rate v^* (L min^{-1}) is given by a cumulative distribution function $\int_0^{v^*} f(v^*)dv$, and is expressed by a probabilistic user acceptance φ as given below, where a probabilistic occupant acceptance of 0.03-0.97 is within a showerhead flow rate range of 3-18Lmin^{-1} [9],

$$\varphi = \frac{\exp(-4.88 + 0.47v^*)}{1 + \exp(-4.88 + 0.47v^*)} \tag{6}$$

The maximum showerhead flow rate v_p (L min^{-1}) available from the water supply system is determined by the showerhead water pressure P (kPa) and the showerhead resistance factor k (kPa min^2 L^{-2}),

$$v_p = \sqrt{\frac{P}{k}} \tag{7}$$

The showerhead water pressure P (kPa) is given by the difference between the static pressure at the showerhead P_s (kPa) (in the design range of 150 to 350kPa for typical high-rise water supply systems) and the pressure drop along the water supply pipe P_L (kPa),

$$P=P_s-P_L \tag{8}$$

In a typical high-rise water supply system, a pipe pressure drop from $P_{L,0}$ to $P_{L,1}$ corresponding to a flow rate from v_0 to v_1 due to the number of showerheads connected can be approximated by the following expression, where the design pipe friction loss range is P_L/L_e=0.1-0.5kPa m^{-1} with an equivalent pipe length range of L_e=100-300m [10,11].

$$\frac{P_{L,1}}{P_{L,0}} \sim \sqrt{\frac{v_1}{v_0}} \tag{9}$$

3 Simulations

Table 1 summarizes the attributes for hot showers in Hong Kong from open literature data. Monte Carlo simulations were used in this study to obtain the confidence intervals for the energy consumption estimates needed to compute CO_2 reductions [8]. In the simulations, a uniformly distributed random number $x\in[0,1]$ was taken from a random number set generated by the prime modulus multiplicative linear congruential generator and the input parameters for Equations (1)-(8) (i.e. $\zeta_i = \{N_s,\phi\},\{t_s,T_o,T_a,k,P_s,P_L,L_e\}$) were sampled from the distribution functions. The input value $\zeta_{i,x}$ of each parameter ζ_i was then determined from the descriptive distribution function $\tilde{\zeta}_i$ at percentile x.

$$\zeta_i = \zeta_{i,x}\,;\; \int_0^{\zeta_{i,x}} \tilde{\zeta}_i d\zeta_i = x\,;\; \zeta_i \in \tilde{\zeta}_i \tag{10}$$

Two reference sources were used for model validation. First, data from a survey conducted by Hong Kong Water Supplies Department (HKWSD) were taken as simulation inputs [6]. According to the survey, 39%, 27%, 22% and 13% of the showerheads currently in use were with flow rates equivalent to WELS Grades 1, 2, 3 and 4 respectively (corresponding to *k* values of 4.02, 2.26, 1.27 and 0.81 respectively). The predicted average per capita daily consumption as graphed in Figure 1(a) is 54.5 L ps^{-1} d^{-1}, i.e. 1% lower than the surveyed value (55 L ps^{-1} d^{-1}).
Second, the annual amount of domestic hot water energy consumed (water used in cooking excluded) in Hong Kong reported by Hong Kong Electrical and Mechanical Services Department (HKEMSD) was taken as a reference (i.e. 1.645 GJ ps^{-1} yr^{-1}) [3]. Based on the data from HKWSD, the predicted energy consumption for September to May is 1.1 GJ ps^{-1} yr^{-1} (sd=0.09 GJ ps^{-1} yr^{-1}), a 30% below the HKEMSD reference value. Based on the year-round showering patterns of Hong Kong residents from open literature data [8,9], the predicted energy consumption is 1.66 GJ ps^{-1} yr^{-1}; and as shown in Figure 1(b), it is 1% higher than the HKEMSD reference.

Table 1 Input parameters

Parameter	Values	Distribution	Reference
Water-CO_2 emission factor, α (kg-CO_2 m^3)	0.94	Constant	[8]
Energy-CO_2 emission factor, β (kg-CO_2 MJ^{-1})	0.20	Constant	[7]
Number of showers per resident per day, N_j ($hd^{-1}d^{-1}$)	range=1-3, mean=1.6 (Jun-Aug) range=1-3, mean=1.1 (Sep-May) /1.04 (Sep-Jan)	Discrete Discrete Discrete	[8] [8] [6]
Showerhead operating time t_s (s)	mean=496−13*k*, CI=185-1093 mean=402, CI=178-910	Log-normal Log-normal	[9] [6]
Hot showers, ϕ	97% (Jun-Aug), 100% (Sep-May)	Discrete Discrete	[8] [8]
Shower water temperature, T_o (ºC)	mean=36.2 + 1.1*k*, range=33.4-42.7, sd=2.6	Normal	[9]
Ambient temperature, T_a (ºC)	Hong Kong weather data in the years of 1884-1939, 1947-2006	Normal	[8]
Showerhead resistance factor, *k* (kPa min^2 L^{-2})	mean=3.8, sd=1.74 0.81-9.04	Discrete Uniform	[6] [9]
Static water pressure at showerhead, P_s (kPa)	range=150-350	Uniform	[10]
Pipe friction loss, P_L (kPa m^{-1})	range=0.1-0.5	Uniform	[10]
Supply pipe length, L_e (m)	range=100-300	Uniform	[11]

sd=standard deviation; CI=99% confidence interval

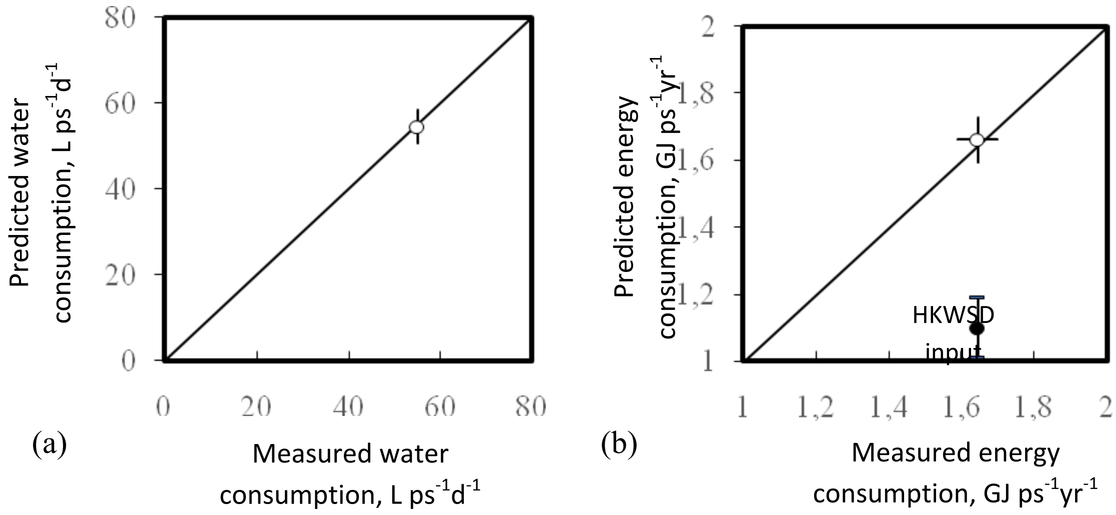

Figure 1 Model validation: (a) Per capita daily shower water consumption; (b) Per capita annual hot water energy consumption

Table 2 Impacts of water efficiency labelling scheme on showers for bathing in relation to water savings, energy savings and CO_2 emissions reductions

Scenario	**Water consumption (m^3 ps^{-1} yr^{-1})**	**Energy consumption (GJ ps^{-1} yr^{-1})**	**CO_2 emissions (kg-CO_2 ps^{-1} yr^{-1})**
Existing: *k*=0.81-9.04 (mean=3.8, sd=1.74)	24.3	1.66	355
(1) For *k*≥1.27	21.0 (–14%)	1.50 (–10%)	321 (–10%)
(2) For *k*≥2.26	17.5 (–28%)	1.35 (–19%)	286 (–19%)
(3) For *k*≥4.02	15.4 (–37%)	1.24 (–25%)	262 (–26%)

Table 2 presents the impacts of WELS on showers for bathing in relation to water savings, energy savings and CO2 emissions reductions. Based on the per capita hot shower requirements of 114 MJ ps^{-1} yr^{-1} for water use and 1660 MJ ps^{-1} yr^{-1} for heating, the estimated value of CO_2 emissions is 355 kg-CO_2 ps^{-1} yr^{-1}. This estimate is equivalent to 2.55×10^9 kg-CO^2 yr^{-1} for a population of 7.188 million in Hong Kong by the end of 2013. Scenarios for *k*≥1.27, 2.26 and 4.02 are shown in the table and the results indicate that full implementation of WELS rated showerheads with *k*≥4.02 can reduce water consumption by 37%, energy consumption by 25% and CO_2 emissions by 26%.

4 Conclusion

This study reviewed WELS on showers for bathing and proposed a Monte Carlo model for evaluating the carbon-reducing impacts of WELS on showers for bathing. The model was demonstrated to be a suitable evaluation tool.

5 Acknowledgment

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7 Presentation of Authors

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Clean performance of hair rinsing via different water flow patterns of water-saving shower heads

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Abstract

Cleaning performance always impacted by water flow patterns from shower heads. Based on previous investigation, water demand in hair rinsing is higher than other activities during the shower period. This study focuses on the clean performance of hair rinsing via different water flow patterns of water-saving shower heads. Different water flow patterns involve with users' cleaning sensation, water spray area, and skin touch feeling, it also impacts the showing time and water demand. Five water-saving shower heads (<6 l/min) with three different water flow patterns, such as straight, linear, and spray were adopted in the shower room for hair rinsing experiment by 40 subjects with long hair, medium long hair, and short hair. The results present that water flow pattern in spray (4-5 l/min) is the most popular by subjects because of wide spray area and high water pressure. In the other hand, subjects spends long time for hair rinsing with the water flow pattern of shower head in straight and linear (3-5 l/min), because of concentrated area and low water pressure. Water demand for long hair rinsing with the same water-saving shower head is significant larger than it with medium long and short hair. Therefore, the hair rinsing performance with water flow pattern of shower head in spray is better than the patterns in straight and linear, because of the short rinsing period with good skin touch feeling and high clean sensation.

Keywords:

Clean performance of hair rinsing, water flow patterns, water-saving shower heads.

1 Introduction

Water demand of water supply of residential building in Taiwan are toilet flush and shower. Most hot water demands during the shower periods in the residential building because of hot and humid climate. Hot water not only demands water but also consumes energy for heating. Saving hot water supply could reduce water demand and energy consumption.
Based on previous investigation [1], over than 850 persons were invited to take shower, measured their water demand and asked their shower behavior. It shows most people take shower for body clean and hair clean (about 60%) [2], as show in Figure 1. Water demand in hair rinsing is higher than other activities during the shower period, cleaning performance always impacted by water flow patterns from shower heads. Many people take soap and shampoo during the shower period, but around 250 people demand more than the average volume in 50l, because of over 2 times soaping and hair washing, as shown in Figure 2.

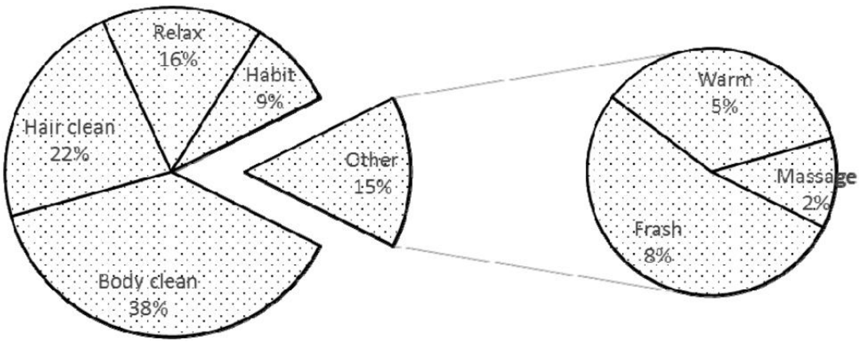


Figure 1 Investigation of shower purpose [2]

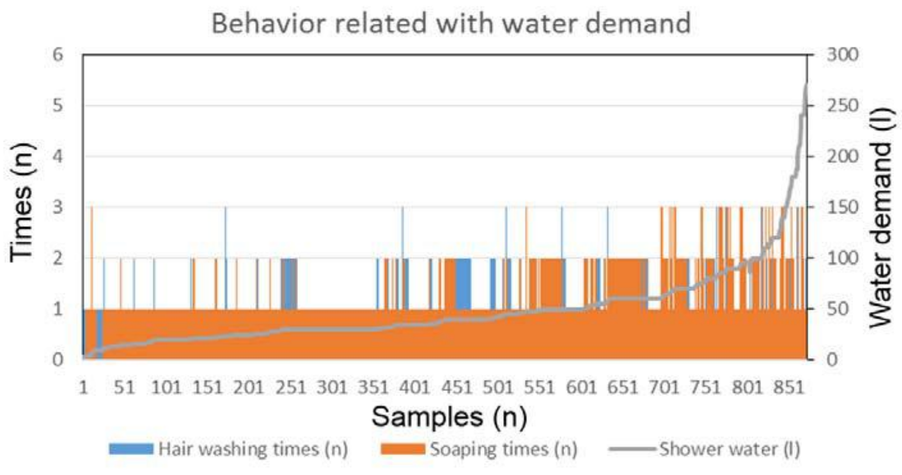


Figure 2 Behavior related with water demand [1]

Water sense report [3] also investigated the showerhead performance via 12 type showerheads with 1.5-2.2GPM in Flow rate, Temperature, Force, Coverage, and Rinse in by 23 users, as Figure 3. The results shows Hair rinsing ability is Extremely Important. Therefore, water saving form changing the flow patterns of shower head is the main point for saving water.

Showerhead	Flow Rate	Temp	Force	Coverage	Rinse	% No Buy
S	2.5					0%
R	2.5					11%
L	2.0					14%
M	2.0					14%
V	2.5					20%
E	2.5					25%
K	1.6		X			40%
Q	1.5					43%
U	1.5			X		57%
N	1.5					60%
O	1.5					63%
H	2.5		X			63%
A	2.5			X	X	67%
F	1.0		X	X	X	71%
I	2.5		X	X		75%
C	0.7	X		X	X	83%
G	1.5		X	X	X	83%
P	1.5					83%
J	2.5	X	X	X		83%
T	1.5		X	X	X	100%
B	2.0	X	X	X	X	100%
D	2.5					100%

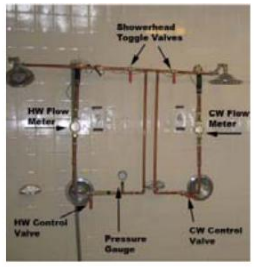


Table 2: Importance of Various Showerhead Attributes

Category	Level of Importance
Strength of spray	Extremely Important
Hair rinsing ability	
Overall appeal of spray	Very Important
Spray coverage / width of spray	
Distribution of spray	
Face rinsing ability	Quite Important
Body rinsing ability	
Noise level	
Size of showerhead	Only Slightly Important
Variety of sprays provided	
Attractiveness of showerhead	Not at all Important

Figure 3 The Results of showerhead performance study [3]

This study focuses on the clean performance of hair rinsing via different water flow patterns of water-saving shower heads. Different water flow patterns involve with users' cleaning sensation, water spray area, and skin touch feeling, it also impacts the hair rising time and water demand.

2 Methodology

Investigation is the directly way to collect information of the water saving via hair rinsing period by users. Two phases of investigation are subject and object evaluation, this study operate these two phases at the same time, as shown in Figure 4.

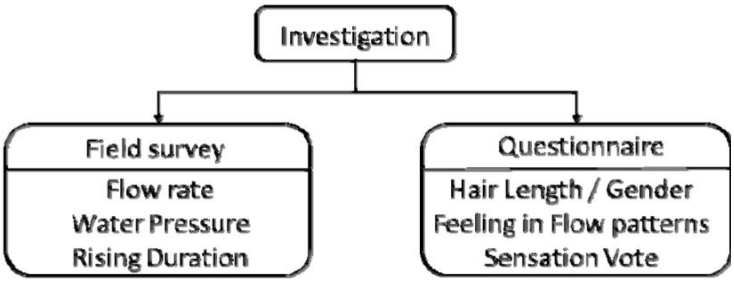


Figure 4 Two phases of investigation

To make sure the feeling description words (sentences) of flow patterns by users during the hair rising is the first step, then follow the description words to design a questionnaire to investigate the sensation vote and rinsing period by flow mater, as shown in Figure 5.

Figure 5 Feeling description words (sentences) of flow pattern by pretest users

The questionnaire divides into 4 sensation descriptions with 9 details and 5 items to vote the sensation in 5 different showerheads. The Topics are water flowing sensation (cover range, well distribution, and touch force on the skin), flowing pattern (partition of water impact, cleaning of head skin), comfort (water impaction, bubble flowing speed, water spilt, and hair tied), and total sensation. The sensation items are divided into “Very Poor”(-2), “Poor”(-1), “Neutral”(0), “Good”(+1), and “Very Good”(+2). The question are shown as Table 1, and the analysis methodology is following the statistic method to evaluate the accumulative percentage (φ) by mean (μ) and standard difference (σ) between comfortable and uncomfortable sensation as the Eq. 1[4].

Table 1 Questionnaire Design

Sensation Vote / Sensation Description	Very Poor	Poor	Neutral	Good	Very Good
	-2	-1	0	1	2
	Uncomfortable		Neutral	Comfortable	
	$\theta < 0$		$\theta = 0$	$\theta > 0$	
Water flowing sensation					
Flowing pattern					
Comfort					
Total sensation					

$$\varphi = (2-i) + (2i-3)\int_{-\infty}^{\varphi} \tilde{\varphi}(\mu_{\varphi,i}, \sigma_{\varphi,i})\,d\varphi \qquad (1)$$

$$i = \begin{cases} 1; & \theta < 0 \\ 2; & \theta > 0 \end{cases}$$

The evaluated accumulative percentage results could draw as the diagrams to show several trends to compare the comfort and hair rinsing periods, as Figure 6. Figure A shows that the slop of comfortable sensation (θ >0) accumulative percentage line is steep, the rinsing period rang is narrow. In the other hand, the slop of uncomfortable (θ<0) accumulative percentage line is gentle, the rinsing period rang is wide. Figure B shows that there is no uncomfortable sensation vote, so it doesn’t present the uncomfortable (θ<0) accumulative percentage line. Figure C shows that there is no comfortable sensation vote, so it doesn’t present the comfortable (θ>0) accumulative percentage line.

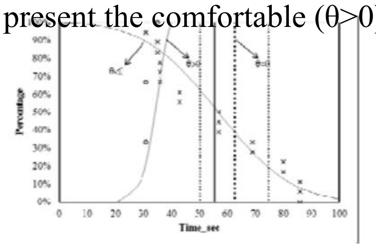


Figure A

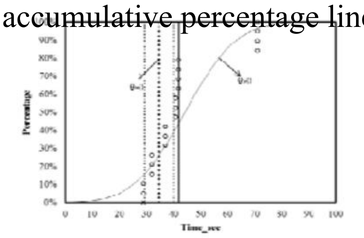


Figure B

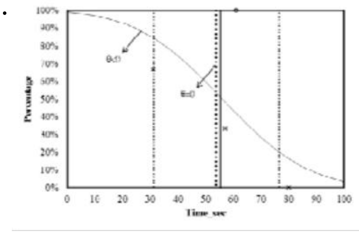


Figure C

Figure 6 The evaluated accumulative percentage results show several trends

Some measurement instruments are adopted by field survey, such as “flow rate meter” for measuring the flow rate during rising period, “thermometer” for rising water temperature, “water pressure meter” for measuring the pressure and checking the rising period, “data logger” for record the data by each testers, “Skin Touch sensor” for sensing the oil generated of head skin. The control valves were setup for 5 different showerheads in the same flow rate, as shown in Figure 7.

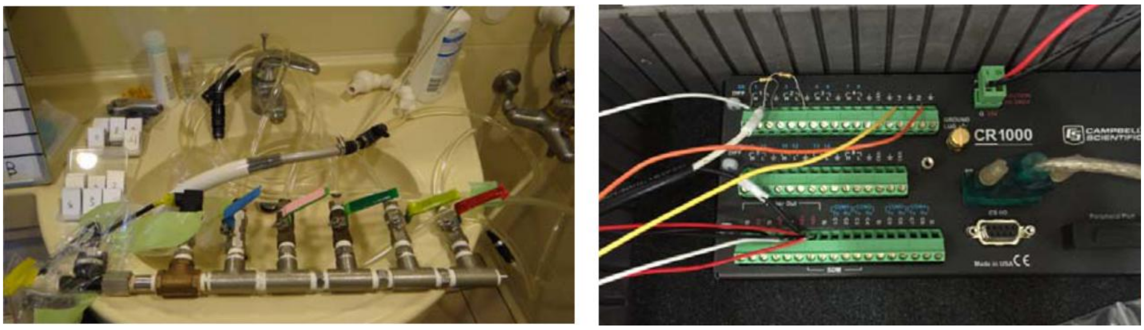
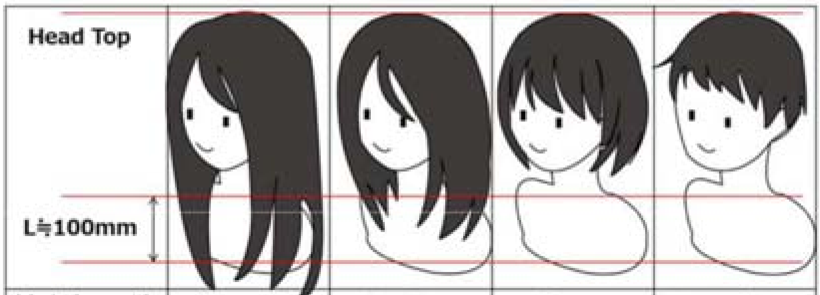


Figure 7 Measurement instruments were setup for recording the data

3 Investigation

The investigation were hold in 2 main cities (Taipei and Taichung) for comparing the difference between the user behaviors. The 40 testers were invited and divides into 4 hair characters with long hair (LF), medium length (MF), short hair (SF), and very short hair (SM), the hair length and genders were setting as Table 2. Before the investigation, the test procedure was introduced to the testers before hair rising. Due to the same controlled factors in water pressure, flow rate, and same rising space, 2 shower rooms were controlled in the same condition in Taipei and Taichung, as shown in Figure 8.

Table 2 Testers were divides into 4 hair characters

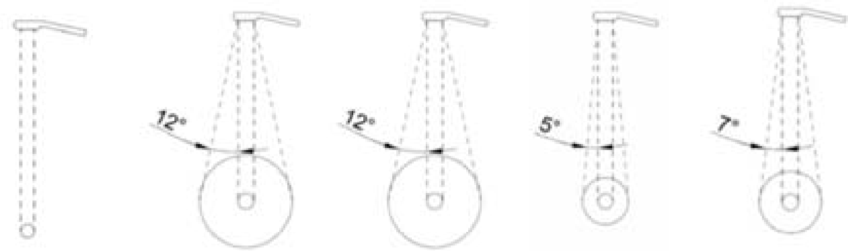


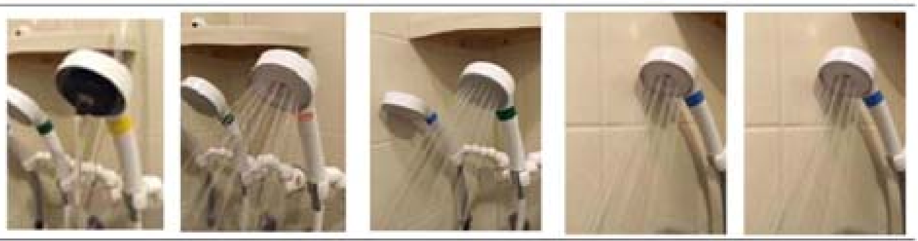
Hair Length	Long	Medium	Short	Very Short
Genders	Female	Female	Female	Male
Samples	14	13	7	6

Figure 8 Taipei and Taichung test shower rooms and introduction of the procedure

Five showerheads with different characters were selected to rinse the hair, they are all marked with different color for identify, as Table 3. The investigated procedure includes 1.Check water temperature as comfortable, 2.Hang on the shower heads, 3. Push shampoo and bobble the hair, 4. Risne hairs till clean and recorded the water using period, 5. Paste the sensation vote marks (the color presented the different showerhead) on the white board in 9 details, as shown in Figure 9.

Table 3 Five showerheads with different characters





Shower ID	Yellow	Pink	Blue	Black	Green
Diameter × Holes	ϕ20×1,10	ϕ1.2×40	ϕ0.7×40	ϕ1.2×22	ϕ1.2×36
Spray Angle [∘]	0	12	12	5	7
Hole Diam. [μm]	-	3100	1500	2800	3010
Velocity [m/s]	0.3	2.2	6.5	4.0	3.5
Spray range[mm]	10	160	180	100	130
Flow rate [L/min]	6	6	6	6	6

Figure 9 Sensation vote with different showerheads

The rinsing period (*t*) was recorded and pasted on the white board by each tester for different showerhead, the water demand (*Q*) could be evaluated via the same flow rate (*v*) in 6 l/min as Eq. 2. The raw data measured by instruments to compare with the recorded data and also checked the correction, as show in Figure 10.

$$Q = v \times t \tag{2}$$

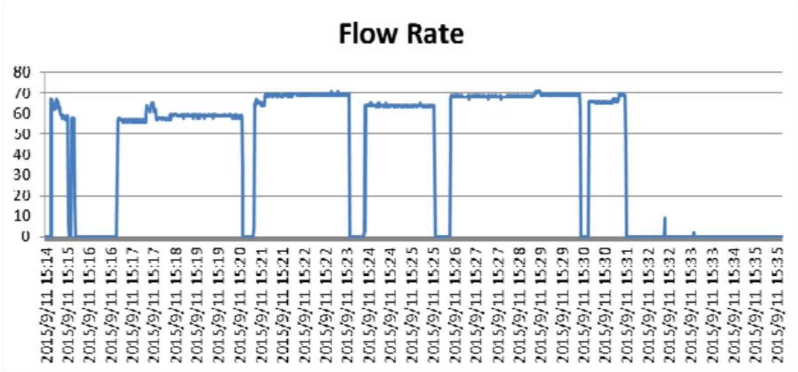


Figure 10 Raw data measured by instruments

The results show that the measured rinsing hair periods are between 25 to 150 seconds. Try to determine the water demand by 90% users, check the diagram of accumulative percentage and make sure most water using periods (hair rinsing and clean feeling) are between 25sec. to 75sec., as shown in Figure 11.

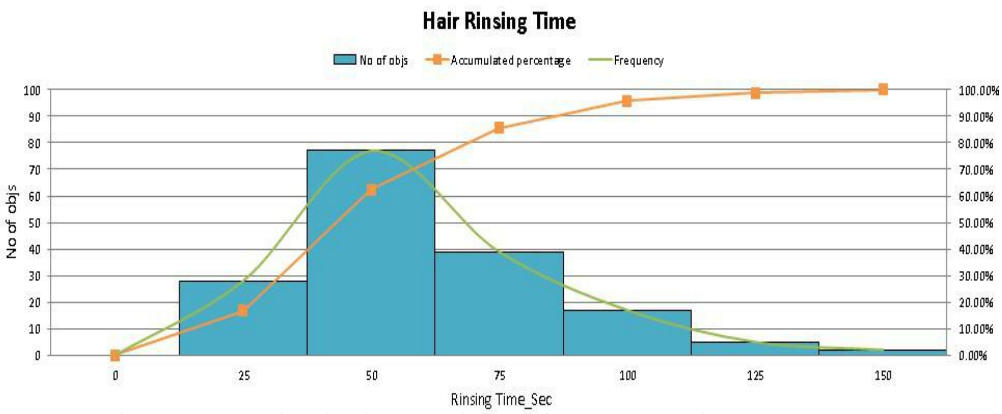
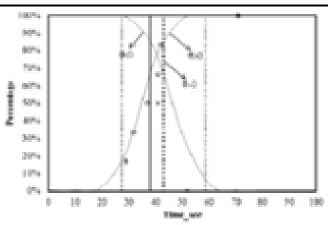
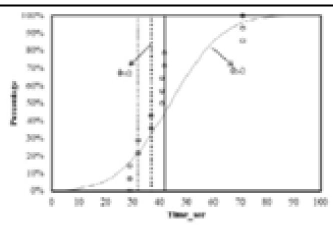
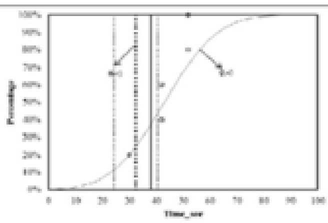
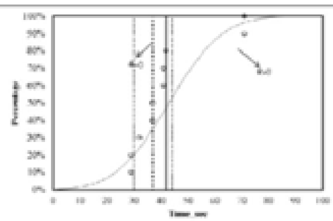
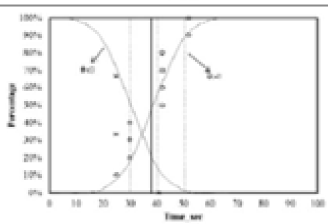
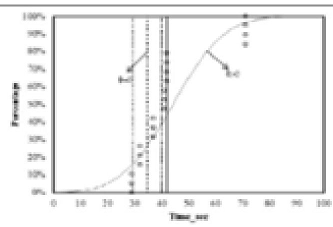
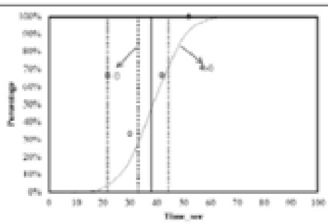
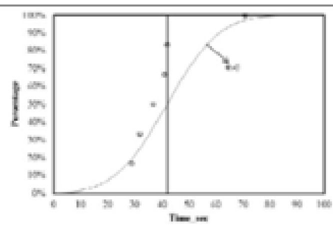


Figure 11 Hair rinsing periods of accumulative percentage

4 Discussion

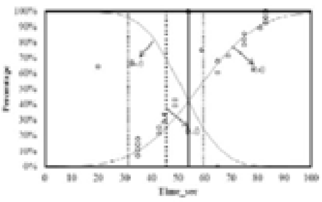
Compare with the showerheads comfort and rinsing period by 40 testers in long hair, medium length, short hair, and very short hair. The first step is evaluated the trends by Eq.1 and accumulative percentage diagrams between every showerhead, different hair length, and hair rinsing period, one example in Green showerhead is shown in Table 4. The average rising periods (Mean) and PR 50 (percentile rank) in different sensation votes are also comparing in Table 4. The accumulative percentage diagrams can be easy read by the trends of sensation vote and also read the mean hair rinsing period. Most users in medium hair length prefer Green showerhead because the trends only presented with comfortable sensation line (θ > 0). The mean hair rinsing period can be evaluated in cross point of comfortable sensation line (θ > 0) and uncomfortable sensation line (θ < 0). Otherwise, the results can be checked the mean hair rinsing period in comfortable sensation (θ > 0), Neutral sensation (θ = 0) and uncomfortable sensation (θ < 0). The table also shows the sensation description of users with different water flow patterns of showerheads. The water flow patterns of showerheads, sensation vote, and water demand (could be calculated by Eq.2) can be easily evaluated via Table 4. The optima clean performance of hair rinsing in different water flow patterns of water-saving shower heads could be found.

Table 4 Sensation vote and hair rinsing period in green showerhead as an example

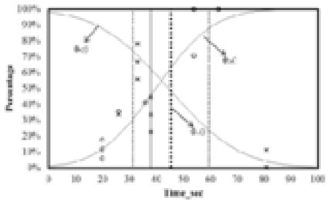
Sensation Description	Long Hair Length	Hair Rinsing period: Sensation Vote	Mean (Sec)	PR50 (SEC)	Medium Hair Length	Hair Rinsing period: Sensation Vote	Mean (Sec)	PR50 (SEC)
Water flowing sensation		θ>0	34.8	35		θ>0	44	44
		θ=0	43	43		θ=0	37	37
		θ<0	46.5	47		θ<0	29	-
		Total	38			Total	42	
Flowing pattern		θ>0	43.6	43		θ>0	43	42
		θ=0	32.4	32		θ=0	37	37
		θ<0	-	-		θ<0	-	-
		Total	38			Total	42	
Comfort		θ>0	38.7	38		θ>0	44.2	42
		θ=0	40.2	-		θ=0	34.5	35
		θ<0	30.3	30		θ<0	29	-
		Total	38			Total	42	
Total sensation		θ>0	41.3	38		θ>0	42	42
		θ=0	33	33		θ=0	-	-
		θ<0	-	-		θ<0	-	-
		Total	38			Total	42	

Sensation Description	Short Hair Length	Hair Rinsing period	Very short Hair Length	Hair Rinsing period

Water flowing sensation

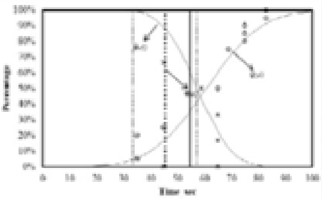


Sensation Vote	Mean (Sec)	PR50 (SEC)
θ>0	57.4	59
θ=0	46.0	45
θ<0	51.6	50
Total	54.0	

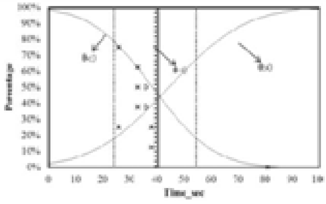


Sensation Vote	Mean (Sec)	PR50 (SEC)
θ>0	39.7	40
θ=0	45.5	45
θ<0	44.5	44
Total	41.9	

Flowing pattern

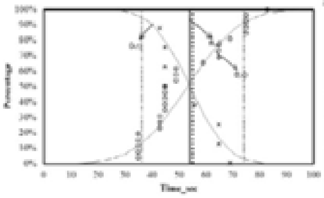


Sensation Vote	Mean (Sec)	PR50 (SEC)
θ>0	60.7	61
θ=0	45.3	45
θ<0	57.3	57
Total	54.5	

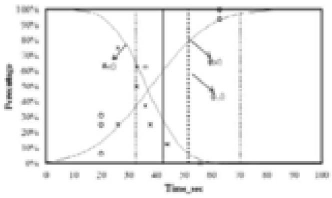


Sensation Vote	Mean (Sec)	PR50 (SEC)
θ>0	44.38	44
θ=0	39.4	40
θ<0	38.5	39
Total	40.5	

Comfort

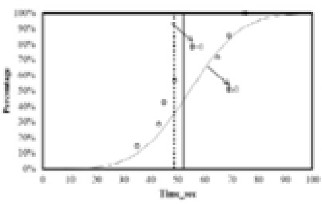


Sensation Vote	Mean (Sec)	PR50 (SEC)
θ>0	53.1	52
θ=0	55.2	55
θ<0	54.1	54
Total	54.1	

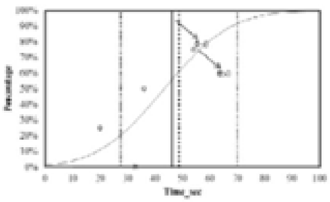


Sensation Vote	Mean (Sec)	PR50 (SEC)
θ>0	38	38
θ=0	51.5	51
θ<0	36.5	35
Total	42.4	

Total sensation



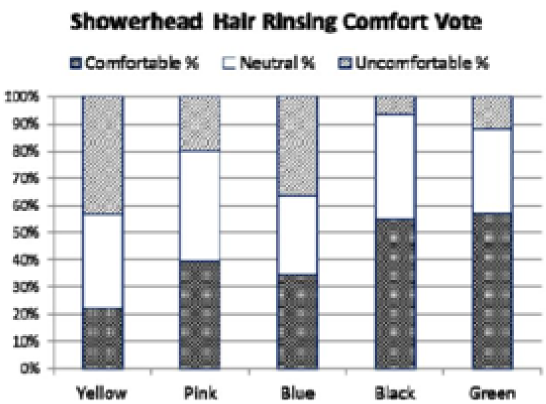
Sensation Vote	Mean (Sec)	PR50 (SEC)
θ>0	54.4	55
θ=0	37	49
θ<0	-	-
Total	52.2	

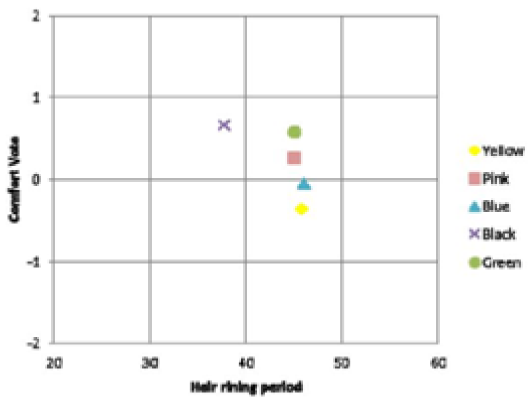


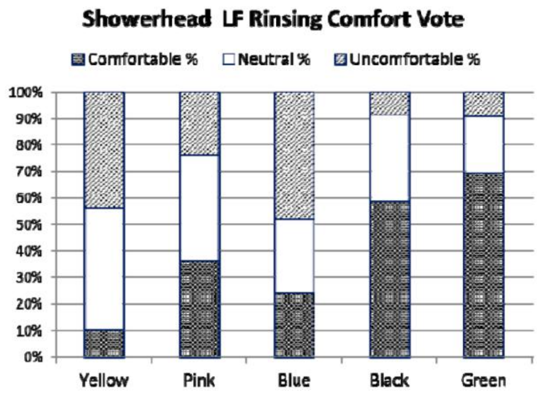
Sensation Vote	Mean (Sec)	PR50 (SEC)
θ>0	43.2	42
θ=0	48.7	50
θ<0	33	-
Total	46.2	

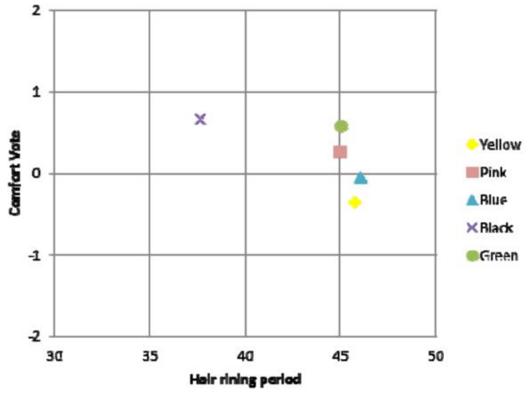
After evaluated the sensation vote tends and the hair rinsing period, the analysis results could be organized as Table 5 to present the high comfort vote and low hair rinsing period in different hair length type and showerheads with different flow patterns.

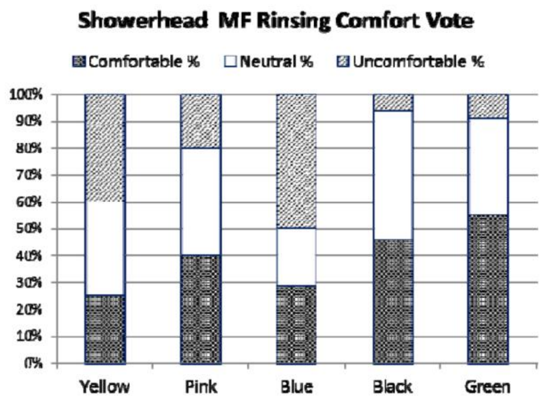
Table 5 Evaluation of comfort vote and rinsing period in different hair type and showerheads

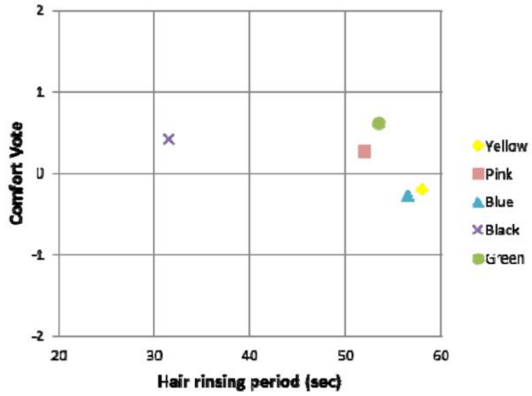


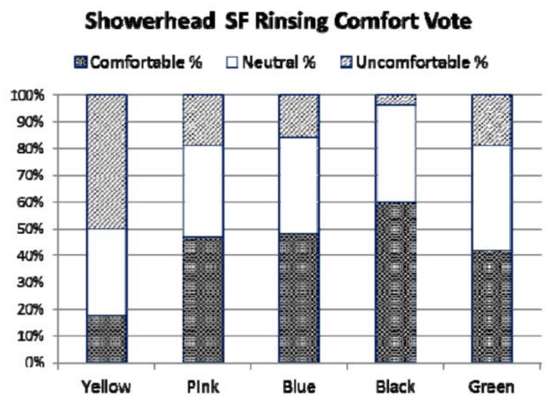


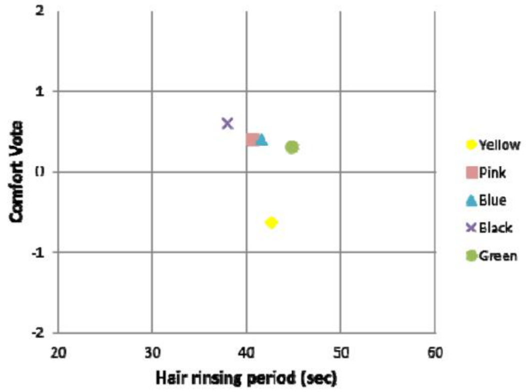

Showerhead LF Rinsing Comfort Vote
Comfortable %
Neutral %
Uncomfortable %
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Yellow
Pink
Blue
Black
Green

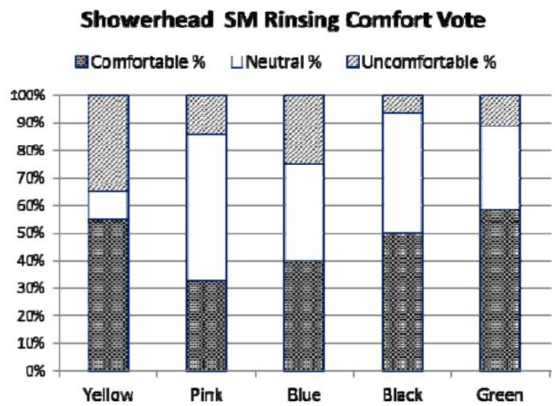

Comfort Vote
Hair rining period
Yellow
Pink
Blue
Black
Green

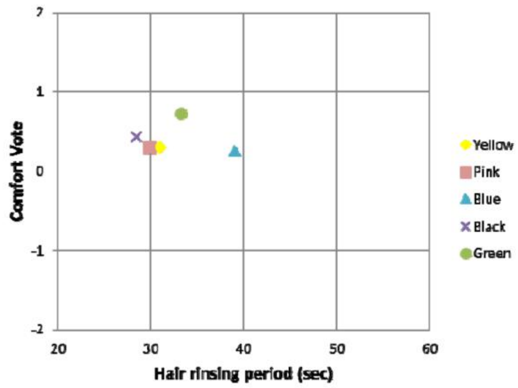

Showerhead MF Rinsing Comfort Vote
Comfortable %
Neutral %
Uncomfortable %
Yellow
Pink
Blue
Black
Green


Comfort Vote
Hair rinsing period (sec)
Yellow
Pink
Blue
Black
Green


Showerhead SF Rinsing Comfort Vote
Comfortable %
Neutral %
Uncomfortable %
Yellow
Pink
Blue
Black
Green


Comfort Vote
Hair rinsing period (sec)
Yellow
Pink
Blue
Black
Green


Showerhead SM Rinsing Comfort Vote
Comfortable %
Neutral %
Uncomfortable %
Yellow
Pink
Blue
Black
Green


Comfort Vote
Hair rinsing period (sec)
Yellow
Pink
Blue
Black
Green

Total results in the first raw of Table 5 are organized from the different hair length type and weighted the comfort vote rate to match the showerhead and the rinsing period. The optima comfort vote and water saving in the flow pattern is Black showerhead, the second one and the third one are Green and pink showerhead.
Compare with these showerheads characters in Black, Green, and Pink in Table 3. The popular flow patterns drop into the "*Diameter* x *Holes*" around φ1.2mm x 30±15, "*Spray Angle*" around 5-7 degree, "*Hole Diameter*" around 3000μm, "*Velocity in 6L*" around 3.5±1 m/s, and "*Spray range under 300 mm*" around 100±30 mm.

5 Conclusion

Hair rinsing period in different hair length is related with the hair rising period, especially in long hair usually demands more water than the water demand in very short hair. The normal rinsing hair period is between 40 second and 60 second one time, it means the water demand between rinsing hair is around 4L/time - 6L/time. The water flow is controlled in this study but the water pressure is related with the showerhead design, normally >0.25MPa. Spray angle around 5-7 degree and the spray area around 100±30 mm under 300mm from the showerhead are the optima range for clean and water saving.

6 Acknowledgement

The authors would like to thank TOTO LTD to collaborate this research and financially supporting, we also thank the Ministry of Science and Technology of Taiwan, for financially supporting this research under Project Contract No. MOST 104-2221-E-025 - 012.

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8 Presentation of Author

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Evaluation of water using comfort and cleaning performance by three different water-ejection modes in residential building

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Abstract

Using water comfort and cleaning sensation are always impacted by water-ejection mode in the residential building, especially using water with detergent for cleaning. Different water-ejection modes involve with the user sensation, using period, flowing rate, and water pressure. Based on the field survey in this study, three different water saving ejection modes (< 6 l/min), such as straight, aerated, and spray of showerhead and faucet were mostly adopt in shower room, lavatory, and kitchen. Most of directly water using activities with detergent, such as showering, hair rinsing, hand washing, face washing and dish washing were investigated in this study. More than 50 persons are investigated with same water pressure and flow rate to shower, rinse hair, wash hand, wash face, and wash dish. The results present that the users' cleaning sensation always accompanied with the comfort water saving ejection mode, most investigators like aerated sensation but do not like widely spray sensation. The water demand in three different water saving ejection modes with cleaning is almost the same, because water saving ejection in lower flow rate spends longer washing period. Therefore, water saving ejection in aerated mode is the optimum selection with washing comfort and well clean sensation.

Keywords:

Using water comfort, cleaning sensation, water saving ejection mode.

1 Introduction

Water shortages are becoming more severe in Taiwan. People are attempting to take steps to save water in any way possible. Water saving fixtures can help; the more comfortable they are to use and the higher their performance, the greater is the significance of their water saving effects.
The spaces in residential buildings where water is used include the kitchen, shower room, and lavatory. Wang calculated that hot water use for showering, hair rinsing, hand washing, face washing, and dishwashing accounted for about 60 % of the water demand per person per day in Taiwan [1]. Therefore, this study discusses water fixtures of showerhead and faucet.
Water saving is related to the performance and comfort of water fixtures [2]. Lee et al. found that shower water demand is related to shower comfort, and is influenced by the pressure of the water supply [3]. Kondo et al. found that adopting spray ejection is most water efficient in a faucet [4]. Yabe et al. showed that spray ejection mode faucets give more satisfaction than those using aerated or straight mode faucets [5].
Thus, it can be seen that water demand is related to user comfort and water ejection mode. Therefore, the aim of this study was to focus on different showerhead and faucet water-ejection modes and their effect on comfort and cleaning performance, in relation to factors including water pressure, flow rate, spray angle, spray diameter, and number of holes. The characteristics of the best water ejection mode were then identified.

2 Methodology

To understand which kind of showerhead and faucet water-ejection mode is the most comfortable and has the highest cleaning performance, experiments in this study adopted different water-ejection modes for showerhead and faucet aerators. The investigation comprised water use experiments, and questionnaires. Physical parameters of period of water use, water temperature, and detergent amount were collected via sensors and a data logger.
The experiments were divided into showerhead and faucet groups. The showerhead experiments included hair rinsing and showering. These two water use behaviours account for the greatest proportion of hot water demand in residential buildings. The faucet experiments included dish washing, hand washing, and face washing. Although faucet water demands are not the greatest by volume, they occur with the most frequency of all water uses in residential buildings. An overview of the method of investigation and installation of sensors is shown in Figure 1 and 2.

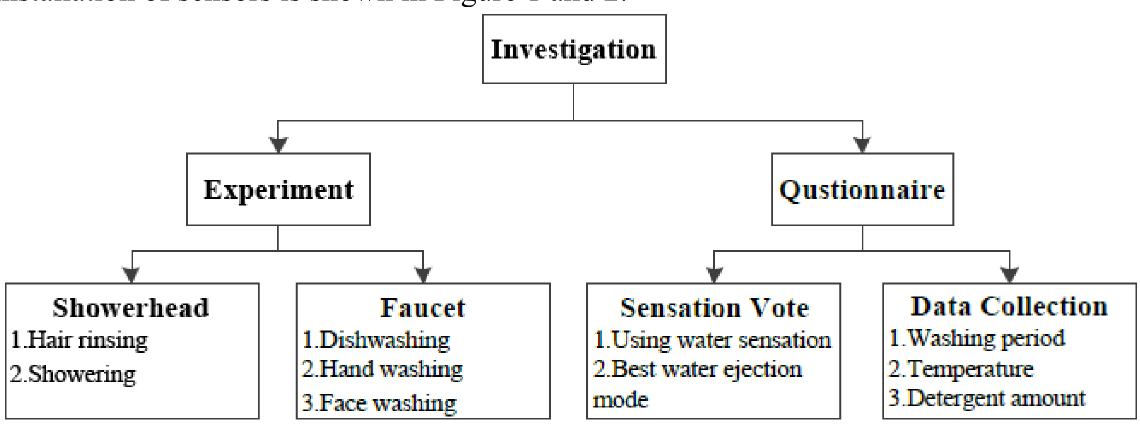


Figure 1 Two phases of observation in investigation

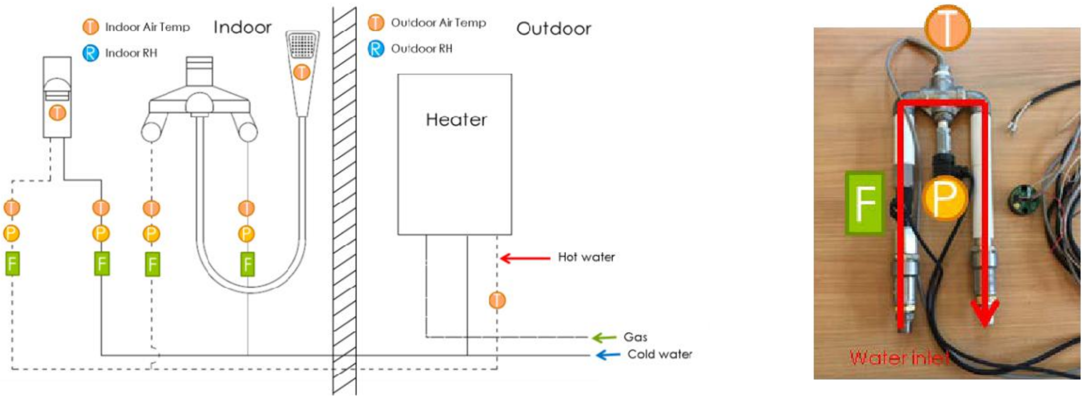


Figure 2 Ideal of sensors installation

The questionnaire was divided into a comfort sensation vote and data collection. Water comfort sensation values were given for water pressure, flow rate, water concentration, temperature, water splash level, and overall experience. To easily understand the distribution of comfort sensation votes for the water devices, votes were given according to a seven point scale as shown in Table 1.

Table 1 Rating scale of comfort sensation

Sensation Vote	Very dissatisfied	Dissatisfied	Slightly dissatisfied	Neutral	Slightly satisfied	Satisfied	Very satisfied
Levels	−3	−2	−1	0	1	2	3

To understand the cleaning performance of showerheads and faucets, a water collector of concentric circles was designed to evaluate the faucet and showerhead spray coverage ratios. The diameters of the concentric circles of the collector were 6 cm, 9 cm, 12 cm and 15 cm, as shown in Fig 3. Water supply pressure was also considered with spray coverage ratio. The amount of water in each circle was measured and converted to a percentage. The height from the showerhead to the water collector was 30 cm and from faucet to water collector was 8 cm, as shown in Fig 4. The spray coverage was measured at 0.5 kg/cm2, 1 kg/cm2, 1.5 kg/cm^2 and 2 kg/cm^2.

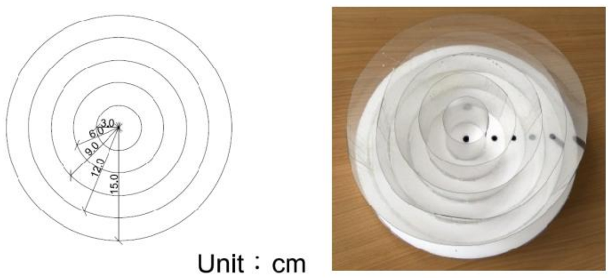


Figure 3 Water collector

Figure 4 Spray coverage measurement

Water demand (*Q, L*) is related to water use periods (*t, sec*) and flow rate (*V, L/min*), and evaluated using Eq. 1.

$$Q = V \times t \qquad (1)$$

3 Investigation

The investigation was divided into three phases. The first phase included the showerhead and faucet experiments. The second phase included completion of the comfort sensation questionnaire. During the final phase, showerhead and faucet spray coverage was measured.

3.1 Showerhead experiments

The showering experiment investigated real site shower conditions with eco showers (ES) and users' own showers (investigated showers; IS) to compare user shower comfort with the same water supply pressure in each sample. The water ejection mode of the ES is air mixed with water droplets, or aerated water ejection. Each water drop is composed of 30 % air. Forty four households and 71 samples were investigated. The 44 IS head types and one ES head type are shown in Table 2.

Table 2 Showerhead water ejection characteristics

Ejection mode	Eco Shower (ES)	Investigated Shower (IS)
Showerhead		
Holes	46	68 (Average of 44 IS)
Flow rate (L/min)	6.6	7.3 (Average of 44 IS)
Spray angle (°)	5.5	5 (Average of 44 IS)

The investigation took place over seven days. On the first day the user's shower head (IS) was set up to measure water flow conditions and user sensations over the first and second day. On the third day the IS was exchanged for the ES to measure water flow conditions and user sensations over days three to six. Devices were uninstalled on the seventh day.
The hair rinsing experiment adopted five different showerheads to compare the comfort and cleaning performance of different water ejection modes on different hair lengths. Showerhead characteristics are shown in Table 3.

Table 3 Showerhead characteristics (hair rinsing)

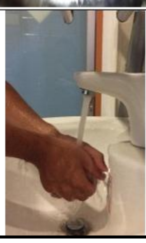
Shower ID	Yellow	Pink	Blue	Black	Green
					
Water ejection mode	Straight	Spray	Spray	Spray	Spray
Diameter × Holes	φ 20 × 1,10	φ 1.2 × 40	φ 0.7 × 40	φ 1.2 × 22	φ 1.2 × 36
Spray angle (°)	0	12	12	5	7
Diameter of drops (μm)	-	3100	1500	2800	3010
Spray coverage (mm)	10	160	180	100	130
Flow rate (L/min)	6	6	6	6	6

Users were divided into groups: 10 long haired females (LF), 10 females with medium length hair (MF), 10 short haired females (SF) and 10 short haired males (SM). Each user rinsed their hair with each of the five showerheads (Table 3) after shampooing. The first shower use, i.e. before application of shampoo, was not recorded, to ensure that rinsing was based on clean hair. The rinsing period was recorded as the water discharge time. The shower water pressure was set to maximum for each experiment to allow comparison of rinsing performance and user comfort with different water ejection modes.
The experiment consisted of rinsing hair, filling in the comfort sensation questionnaire, and recording data (shower period and comfortable water temperature). A timer was used to record the water discharging period. After hair rinsing, the water temperature was measured and then the comfort sensation questionnaire completed.

3.2 Faucet experiments

The faucet experiment adopted a faucet aerator to exchange different water ejection modes, as shown in Table 4.

Table 4 Faucet water ejection characteristics

Ejection mode	**Straight mode**	**Aerated mode**	**Spray mode (hollow cone)**
Dish washing			
Hand washing **Face washing**			
Holes	1	12	36
Flow rate (L/min)	6	5.4	5.4
Pressure (kg/cm^2)	0.4	0.5	0.5
Spray range (cm)	0.8	1.25	8.6
Spray angle (°)	0	0	15

The dishwashing experiment included 15 items: plates (large, medium and small), rice bowl, soup bowl, tumbler, teacup, spoon, fork, knife, a pair of chopsticks, wok, stockpot, spatula and big spoon. These items were selected from the 'Methods of Testing Performance of Quality House Components, Dishwashers, BLT DW: 2005 Standard Specification' [6], and are shown in Fig 5. Taiwanese food including chicken drumsticks, ribs, fried vegetables, sausage, egg, rice with minced pork sauce, bamboo shoot soup, and black tea were selected to fill the items.

Figure 5 Washing items

The first step of the dishwashing experiment was using real food to dirty the items for washing, and then removing the food. The second step was to measure the detergent amount (before using), and the air temperature. Next the users started dishwashing and the author used a timer to measure the water discharge time. The fourth step was to measure the detergent amount (after using) and water temperature after users finished the experiment. The final step was completion of the comfort sensation questionnaire.

The experimental design for hand and face washing was similar, because these two behaviours are simple and undertaken in a lavatory basin. The faucet equipment was the same as that used in the kitchen dishwashing experiment. Users were told to wash their hands as they would after using the toilet, and their faces as they usually would in their own home.

The hand washing experiment was undertaken as follows. The first step was to measure the detergent amount (before using). In the second step users began washing their hands and the author used a timer to measure the water discharge time. The third step was to measure the detergent amount (after using) and the water temperature after users finished the experiment. The final step consisted of completion of the comfort sensation questionnaire.

4 Discussion

4.1 Showerhead water use comfort and cleaning performance

The water-saving flow rate of a faucet is under 10 L/min in Taiwan. Therefore, the optimum water supply pressure is around 0.5 kg/cm^2, as shown in Fig 6. The ES sprays 80 % of water in φ 12–24 cm, whereas the IS sprays 80 % of water in φ 6–18 cm, as shown in Figure 7. The comfort sensation results show that most users found the ES more comfortable than the IS, as shown in Figure 8. To clearly understand the reason for this result, the 44 IS were divided into three types in order to better compare their characteristics with those of the ES: IS-a (IS comfort sensation is better than that for ES), IS-b (IS comfort sensation is equal to ES), and IS-c (IS comfort sensation is worse than ES), as shown in Table 5. The average ES water demand is less than IS-a and IS-c. Water demand of IS-c with a wide spray angle is about 17 L more than other showerhead types, as shown in Figure 9. This shows that water demand and user comfort sensation are related to spray angle.

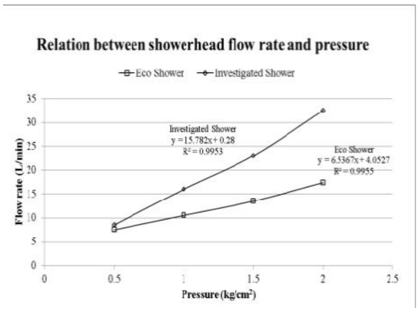


Figure 6 ES flow rate and pressure

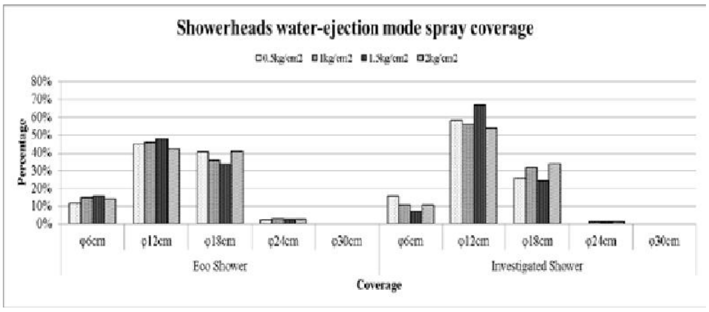


Figure 7 Showerheads water-ejection mode spray coverage

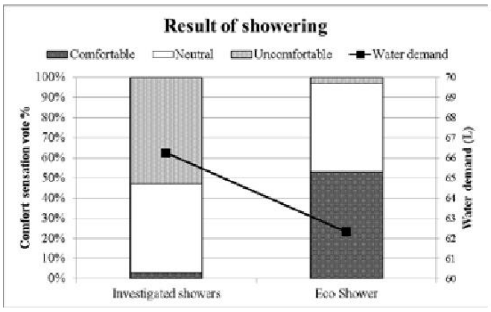


Figure 8 Showering comfort sensation vote

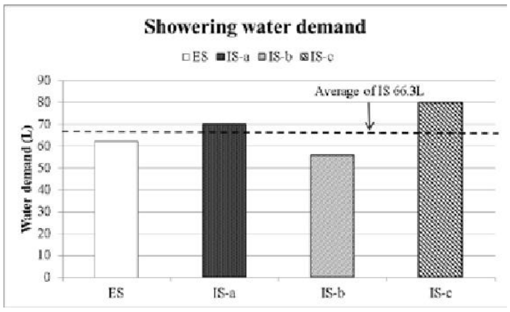


Figure 9 Showering water demand

Table 5 Three different types of investigated shower (IS)

Ejection mode	IS-a	IS-b	IS-c
Showerhead			
Holes	40	55 (average)	56 (average)
Flow rate (L/min)	5.9	7.8 (average)	7.2 (average)
Spray angle (°)	5.6	4 (average)	6 (average)

Water demand for hair rinsing is around 4–5 L, as shown in Figure 10. The spray ejection mode of the black showerhead was more efficient than the others, because the spray angle is 5°; the concentrated water flow can remove shampoo easily. The black type was also the most comfortable, followed by green and then pink. The result of the hair rinsing experiment shows that users prefer water ejection characteristics comprising small spray angles and large drop diameters.

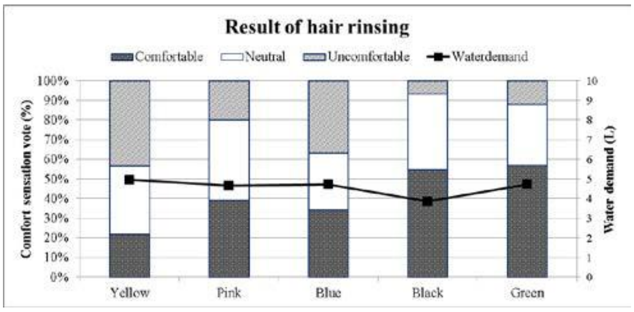


Figure 10 Hair rinsing comfort sensation vote

Showerhead using performance is related to water pressure. High pressure is not water-saving and uncomfortable, because high pressure is resulting in tingling and water-waste. Low pressure is inefficient to washing. The optimum pressure is around 0.5kg/cm^2~ 1kg/cm^2.

4.2 Faucet water use comfort and cleaning performance

The water-saving flow rate of a faucet is under 9 L/min in Taiwan. Therefore, the water saving pressure is between 0.5 kg/cm^2 and 1 kg/cm^2, as shown in Figure 11. The results of the three behaviours measured are similar. Aerated water ejection is the most comfortable and also saves the most water. Normal dishwashing water demand is around 14.4 L, hand washing demand is around 1.5 L and face washing demand is around 2.8 L, as shown in Figures 12–15.

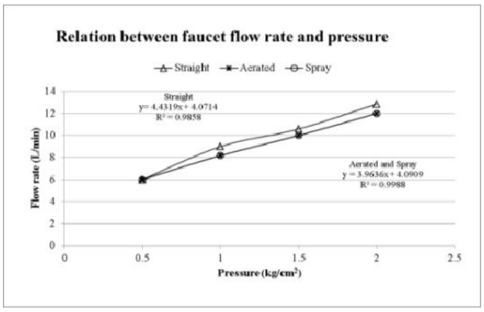


Figure 11 Faucet flow rate and pressure

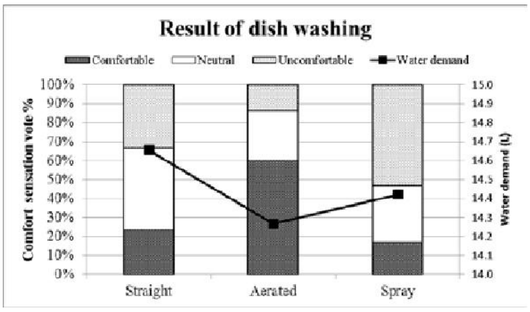


Figure 12 Result of dish washing

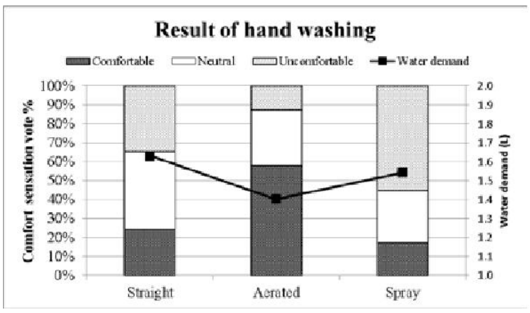


Figure 14 Result of hand washing

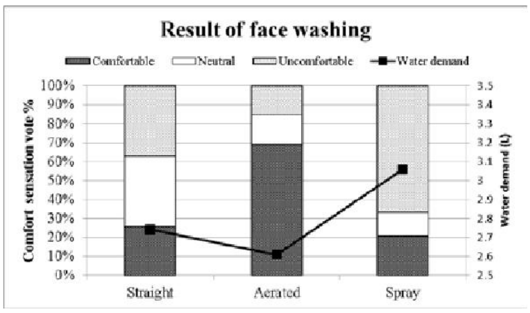


Figure 15 Result of face washing

Water spray coverage is no different under different water pressure conditions. Based on water saving pressures of 0.5 kg/cm^2 and 1 kg/cm ^{2}, water spray coverage of straight and aerated modes are more concentrated than that of the spray mode, as shown in Figure 16.
The results show that the concentrated mode has high cleaning performance for faucet behaviours, because water flow is concentrated on the items or hands. Therefore straight and aerated modes have high washing efficiency.

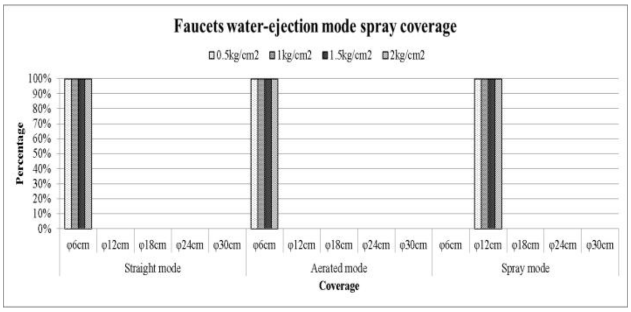


Figure 16 Faucets water-ejection mode spray coverage

Table 6 Water use experiment performance overview

Water ejection mode	Showering	Hair rinsing	Dish washing	Hand washing	Face washing
Straight					
Aerated	○, △	○, △	○, △	○, △	○, △
Spray					

○ = Most comfortable mode, Most water efficient mode

Table 6 shows that the results of shower and faucet use are similar; aerated water ejection, in which water is mixed with air, is the most popular. The popular showerhead and faucet characteristics are shown in Table 7.

Table 7 Characteristics popular showerhead and faucet

	Holes	Pressure (kg/cm^2)	Spray angle (°)	Flow rate (L/min)	Spray range (cm)
Showerhead	22–44	0.5-1	4-7	6–7.8	10–13
Faucet	1–12	0.5	0	5.4–6	0.8–1.25

5 Conclusion

Water using comfort and cleaning performance are rated to the different water-ejection modes. Aerated water ejection, in which water flow is mixed with air, is the best selection for showerheads and faucets in residential buildings. The characteristics of the best water .flow are a small spray angle, narrow spray range and a small number of holes. Therefore, water saving ejection in aerated mode is the optimum selection for washing comfort and to obtain a clean sensation.

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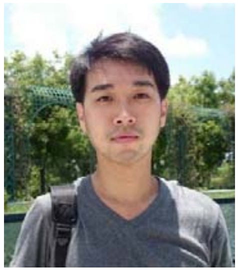
8 Presentation of Author



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Household adoption of water-efficient technologies in the UK: current state and future potential

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Abstract

Rising populations and climate change impacts are anticipated to place considerable strain on water supplies around the world. Using water more efficiently and, if possible, cutting overall demand are key goals for cities of the future. The adoption of water-efficient technologies (such as dual flush toilets, low flow showerheads, and water efficient washing machines) is acknowledged as offering substantial water saving potential. Currently, however, water-efficient technologies are not widespread in the UK. For water efficiency to become the norm, a better of understanding of the barriers and deterrents are needed.

This study uses a household survey to examine the socio-demographic indicators that affect the uptake of water-efficiency technologies within the UK and assesses the potential household water savings that could be achieved from greater penetration of water-efficient technologies within UK homes.

The study found that almost half of the households surveyed had no water-efficient technology installed at home. This is found to be dependent upon both the age and income of the user. Whilst most users had a favourable attitude to water efficiency, many give little consideration to the amount of water they use each day. Findings show that water savings of up to 37% could be achieved by retrofitting standard water technologies with water-efficient alternatives. By helping to understand the socio-demographic indicators of water efficiency behaviour, this study provides a means for providing targeted initiatives and incentives for raising awareness and uptake of water-efficient technologies.

Keywords

Water efficiency, end-user behaviour/demand, socio-demographic indicators.

1 Introduction

Water supplies around the world are facing growing challenges leading to an increasing deficit between the demand and availability of water. Population growth, particularly in urban areas, and lifestyle changes, due to heightened expectations of comfort and cleanliness, are escalating the demand for water [1], whilst the impacts of climate change, such as rising temperatures and reduced summer precipitation, are reducing the overall availability of water [3].

The UK water industry supplies more than 16 billion litres of water every day to domestic and commercial customers [8]. Since 1930, per capita water consumption has increased by around 1% a year and is now approximately 150 litres per day [30].

In order to ease the pressure on water supply systems, more and more attention is being given to demand management practices, such as the use of water-efficient technologies, which provide scope for reducing the unnecessary consumption of water. A number of studies have reported the relative reductions in water consumption attributed to replacing standard technologies with water efficient alternatives. Studies by Maddaus [13| and the American Water Works Association Research Foundation [2] observed reductions of 158 litres/household/day and 146 litres/household/day, respectively, by installing water efficient toilets and showers. Mayer *et al*. [22,23,24] 2found that by replacing all standard technologies with more highly efficient alternatives, water consumption was reduced by between 228-419 litres/household/day (equating to a 37-50% reduction). Lee *et al.* [12] report water savings of 200 litres/household/day (equating to a 31% reduction) by replacing standard toilets, showerheads, and taps with water efficient alternatives in senior and low income households. A study of toilet and showerhead replacement programmes in the UK, reported water savings of up to 145 litres and 40 litres, respectively [28]. A report by the European Commission [8] estimates that by replacing all standard household technologies with water efficient alternatives, overall household water consumption could be reduced by around 32%. A similar study by the Institute for International and European Environmental Policy [7] estimates savings of up to 41%.

By reducing household water consumption, water-efficient technologies can also help reduce energy consumption and carbon emissions related to heating water [4]. Some 25% of the total energy used by UK households is used for heating water. Of all the carbon emissions in the UK, 6% are from water use and 89% of this comes from heating water in the home. The remaining 11% comes from treating and distributing the water [15] .

Whilst a number of water-efficient technologies are available on the market today, uptake within the UK has been generally slow [11]. Most kitchen and bathroom fittings tend to have long lifespans and are, on average, only replaced every 15 years due mainly to aesthetic reasons [16]. A report by Defra [5] estimates that 62% of existing housing in the UK has a toilet with a high flush volume which exceeds 6 litres. There is, therefore, a large potential for improved water efficiency in existing buildings.

This study first compares the penetration of water-efficient technology ownership within the UK and other countries using household survey data. It then assesses the potential water savings that could be achieved in UK households through the retrofit of water efficient technologies.

2 Methodology

A mixed method data collection procedure was followed for this study. A household survey of water-efficient technology ownership was conducted and then a desktop modelling study of the water saving potential of replacing standard water technologies with water efficient alternatives was then carried out. The methods and assumptions are described below.

2.1 Household survey

The survey was designed to collect new empirical evidence of people's attitude and awareness of water conservation as well as assessing the adoption of water-efficient technologies within UK homes. Specifically, the survey asked respondents if any of the following water-efficient technologies were installed at home: (i) dual flush toilet; (ii) low flow showerheads; (iii) water efficient washing machine; and (iv) water efficient dishwasher. Respondents were also asked a series of questions to obtain socio-demographic information of each household (age, income, composition, employment).

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.

2. 2 Water saving potential

A baseline scenario against which to compare the water saving potential of retrofitting water-efficient technologies was set as the average per capita water consumption for existing residential buildings in the UK: 150 litres/person/day [30]. The water consumption associated with each technology was calculated based on the water use characteristics of the individual item (volume per use or flow rate) and frequency of use, corresponding to an overall proportional share of water consumption as shown in Figure 1.

2.2.1 Usage characteristics

For WCs, to allow the comparison of the water consumption of single flush and dual flush models, a full flush to reduced flush ratio of 1:3 has been assumed for the dual flush models. Frequency of use was set as 4.9 flushes per person per day [16].

An average shower duration of 5 min was assumed, with a frequency of use of 0.85 showers per person per day (6 showers per week) [17].

It was assumed that baths are filled to 40% capacity due to displacement by the user, and frequency of use was set to 0.14 baths per person per day (1 bath per week) assuming there is also a shower [18].

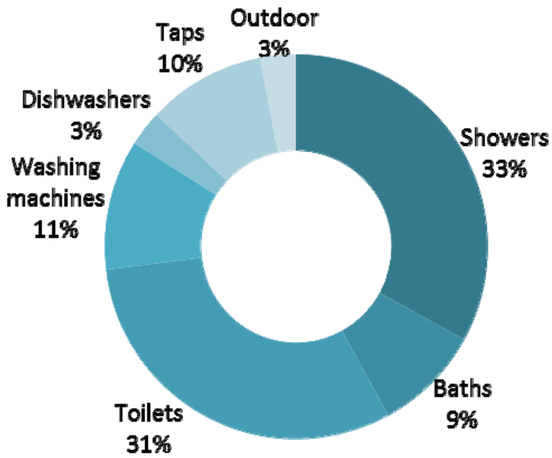


Figure 1 Average household water use (European Commission, 2009)

Taps (both washbasin and kitchen) were assumed to be used on average for a duration of 0.67 min (40s) and to be used 17 times per day per person [19].
Washing machines and dishwashers were assumed to be used 0.3 and 0.28 times per day per person, respectively. This is based on average annual usage of 260 and 246 times per year, respectively [20,21], and on an average UK household occupancy of 2.4 persons [27]. The assumptions of water consumption characteristics are summarised in Table 1 for each water-using technology.

Table 1 Water use characteristics of water-using technologies

Item	Water use characteristic	Frequency of use (uses/capita/day)	Duration of use (min/use)	Source
WC	litres/use	4.9	n/a	MTP, 2011b
Shower	litres/min	0.85	5	MTP, 2011c
Bath	litres/use	0.14	n/a	MTP, 2011d
Taps	litres/min	10	0.67	MTP, 2011e
Washing Machine	litres/use	0.3	n/a	MTP, 2011f
Dishwasher	litres/use	0.28	n/a	MTP, 2011g

2.2 2 Water consumption characteristics

Standard water consumption characteristics of each device are assumed for the baseline scenario. These are then compared with those of water-efficient alternatives. For example, whilst WC flush volumes are now restricted to 6 litres, cisterns holding 7 litres, 9 litres, and over 13 litres are still present in existing housing stock within the UK [16]. A standard flush volume of 9.5 litres was assumed in this study. This is then compared with the consumption characteristics of a water-efficient alternative: a dual flush WC with a flush volume of 6/4 litres (6 litre full flush and 4 litre reduced flush) was assumed.
Typical flow rates for showers range from 3 to 8 litres/min for electric showers and from 10 to 12 litres/min for mixer showers [17]. A standard shower flow rate of 11.6 litres/min were assumed, and compared with a low flow shower flow rate of 8 litres/min.
Baths with water capacity volumes up to 250 litres are not uncommon [18]. These equate to 100 litres of water per use (assuming a 40% volume up to the overflow). This study assumes a standard bath volume of 97 litres per use, with a reduced capacity of 66 litres assumed for the water-efficient alternative.

Tap flow rates typically range from 1.68 litres/min (most efficient) to 3.54 litres/min for washbasins, and from 2.40 litres/min to 3.54 litres/min for kitchen taps [19]. As this study does not differentiate between tap type, a standard flow rate of 2.3 litres/min was assumed, and compared with a low flow tap flow rate of 1.7 litres/min.
The water consumption of a standard washing machine is typically within the range of 40 to 75 litres/cycle, reducing to 30 to 40 litres/cycle in the "Eco" setting [29]. A standard water consumption of 55 litres/cycle was assumed for this study, and compared with an Eco setting water consumption of 35 litres/cycle.
Finally, the water consumption of a standard dishwasher is typically within the range of 7 to 19 litres/cycle, reducing to 8 to 12 litres/cycle in the Eco setting [29]. A standard water consumption of 16 litres/cycle was assumed, and compared with an Eco setting water consumption of 10 litres/cycle. Table 2 summarises the standard and water-efficient consumption values for each water-using technology assessed in this study.

Table 2 Water consumption characteristics of water-using technologies

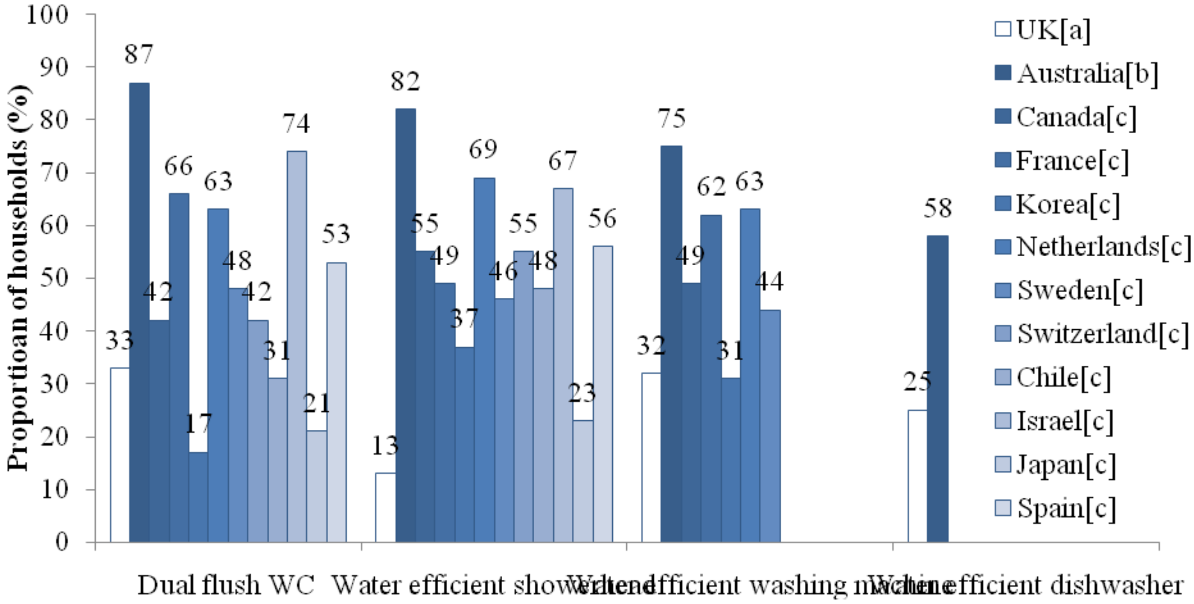
Item	Water use characteristic	Water Consumption	
		Standard	Water-efficient
WC	litres/use	9.5	4.5*
Shower	litres/min	11.6	6
Bath	litres/use	97	66
Taps	litres/min	2.3	1.7
Washing Machine	litres/use	55	35
Dishwasher	litres/use	16	10

*Assuming 6/4 dual flush toilet (ratio of 1 full flush for 3 reduced flushes)

3 Results

3.1 Adoption of water-efficient technologies

The household survey examined the adoption of water-efficient technologies within UK households. Respondents were asked if they owned any of the following technologies: dual flush toilets, water efficient showerheads, water efficient washing machines, or water efficient dishwashers. To gauge the state of current adoption of these technologies within the UK with potential future penetration, the results of this study have been compared with data of water-efficient technology ownership from other countries, see Figure 2.
The most adopted water-efficient technology in the UK is the dual flush WC with 33% of respondents confirming ownership. Whilst this is higher than the numbers reported in Korea (17%), Chile (31%), and Japan (21%), it is considerably lower than the majority of other countries, particularly Australia where 87% of households report owning a dual flush WC.



[a] Data from this study.
[b] Data from [6].
[c] Data of water efficient washing machine ownership from [25], and all other data from [26].

Figure 2 Household ownership of water-efficient technologies by country

Just 13% of UK households report owning water-efficient showerheads. In other countries, the range of ownership ranges from 23% in Japan to 82% in Australia. Some 32% of UK households own a water-efficient washing machine, compared to a range of ownership from 31% in Korea and 75% in Australia. And finally, whilst the share of ownership of water-efficient dishwashers is not available for most of the other countries in the studies compared, the data for Australia shows an ownership share of 58% of households, whilst the share is only 25% for UK.

In general, the ownership of water-efficient technology is lower in the UK than in other countries. Australia constantly tops each poll. Causes for this are likely to be due to factors such as government sponsored programmes to promote the uptake of water-efficient technologies in countries such as Australia and Mexico in order to reduce water consumption [25], and water efficiency labelling programmes in countries such as Australia, Israel, and the Netherlands [26].

Analysis of the socio-demographic influences of water-efficient technology ownership in the UK, the survey indicated that the likelihood of owning such technology is higher for older respondents and for those with higher incomes, which is consistent with other studies [10,25]. It should be noted that a large proportion of respondents (45%) reported owning none of the water-efficient technologies.

3.1.1 Potential water saving

The potential water savings achieved by retrofitting standard water-using devices with water-efficient alternatives is illustrated in Table 3. Whilst the reduction of outdoor water use was not considered in this study, it is included for completeness.

Table 3 Potential household water savings from water efficient appliances

Item	Standard			Water efficient			Reduction	
	l/use	l/p/d	l/hh/d[i]	l/use	l/p/d	l/hh/d[i]	l/p/d (l/hh/d)	%
WC	9.5	46.6[a]	111.7	4.5[j]	22.1[a]	52.9	24.5 (58.8)	52.6
Shower	58[b]	49.3[c]	118.3	40[k]	34[c]	81.6	15.3 (36.7)	31.0
Bath	97	13.6[d]	32.6	66	9.2[d]	22.2	4.3 (10.4)	32.0
Taps	1.5[e]	15.4[f]	37.0	1.1[l]	11.4[f]	27.3	4.0 (9.6)	26.1
WM	55	16.5[g]	39.6	35	10.5[g]	25.5	6 (14.4)	36.4
DW	16	4.5[h]	10.8	10	2.8[h]	6.7	1.7 (4.0)	37.5
Outdoor	4.5	4.5	10.8	4.5	4.5	10.8	-	-
Total	-	150	361	-	94	226.8	55.8 (134.0)	37.2

(a) Assuming 4.9 flushes per person
(b) Assuming 5 minute shower with 11.6 l/min flow rate
(c) Assuming 0.85 shower per person (6 showers per person per week)
(d) Assuming 0.14 bath per person (1 bath per person per week)
(e) Assuming 40 second use at 2.3 l/min flow rate
(f) Assuming 10 uses per person
(g) Assuming 0.3 load per household (260 loads per household per year)
(h) Assuming 0.28 load per household (246 loads per household per year)
(i) Assuming 2.4 persons per household
(j) Assuming 6/4 dual flush WC (ratio of 1 full flush for 3 reduced flushes)
(k) Assuming 5 minute shower with 8 l/min flow rate
(l) Assuming 40 second use at 1.7 l/min flow rate

Whilst the actual water saving potential will vary for every person and household due the dependency on personal water use habits and also upon the actual efficiency of each water-using technology, the overall potential for reducing per capita and household water consumption is clear. All appliances offer considerable savings, however, both the WC and the shower can be seen to provide the greatest opportunity to save water, with estimated reductions in water consumption of 24.5 litres/person/day (58.8 litres/household/day) and 15.3 litres/person/day (36.7 litres/household/day), respectively. Retrofitting all standard appliances with water-efficient alternatives is shown to give an overall reduction in household water consumption of 134 litres per day (a 37.2% reduction) which represents a potential annual saving of 48,916 litres of water per household.

4 Conclusion

This study examined the current share of water-efficient technology within UK households and found that adoption of such devices is relatively low compared with other countries. Just 33% of UK households were found to own a dual flush toilet, just 13% owned a low flow showerhead, 32% owned a water-efficient dishwasher, and 25% owned a water-efficient dishwasher. Some 45% of those surveyed owned none of these water-efficient technologies. Whilst this number is surprisingly high, it represents a significant potential for water savings within UK households.

Results of the desktop study into the water-saving potential of retrofitting standard water-using appliances with water-efficient alternatives found the WC and shower provided the greatest opportunity to save water at home. The study confirmed that overall household water consumption could be reduced by 37% by replacing all standard appliances with water-efficient technologies.

Whist the potential for greater water savings exists, new government policies and strategies will be necessary if these savings are to be realised. Rebate schemes to encourage the uptake of water-efficient technologies, and labelling schemes to help raise awareness, have been effective in other countries. This study found that the uptake of water-efficient technologies were less likely amongst younger and lower income households. Initiatives targeting these socio-demographic sub-groups would, therefore, be most effective.

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6 Presentation of authors

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Evaluation of water efficiency from adoption of rainwater reuse system in green buildings

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Abstract

Taiwan Green Building evaluation system established from 1999, then thousands green buildings had been approved by this system. The water saving planning, reclamation of rainwater, re-utilization of recycled water, and the imported design of water saving sanitary appliance of the building have led to direct and significant impact on effective utilization of water resource and positive benefits of energy saving carbon reduction policies. The investigation on the water consumption of the building awarded with green building mark had be verified. In this study the actual cases awarded by green building certification since 2000 to 2013 are taken as the research subjects, the rainwater harvesting system is the focus of this research. Through the field survey, the water efficiency from rain water harvesting operation was evaluated and confirmed. This research used 91 cases of green buildings which involved the rainwater harvesting system design and operation to be the validation. The evaluation result shows average 54% water saving rate in these cases involved rainwater harvesting system. Initially, the average rainwater substitution rate is 28%. It is proved the significant contribution to water efficiency from adoption of rainwater reuse system in green buildings.

Keywords

Carbon emission, climate change, green building, water conservation, rainwater harvesting system.

1 Introduction

The green building evaluation system used in Taiwan was first applied in 1999 and initially utilized a building's water efficiency as the threshold index for determining the building's environmental impact. Since 1999, more than a thousand buildings have been certified as green buildings using this evaluation system. The quantitative effects of water conservation efforts should be provided to policy makers as a form of positive feedback. Theoretically, water-saving designs and the adoption of water-saving facilities should benefit buildings in terms of their water usage efficiency [1–4]. However, actual real-world water usage is complex, being affected by a wide range of human behaviors and other factors [5,6]. Regarding the issue of the effective use of water resources, the actual water consumption of a building with a green building certification should be different from those of buildings without water-saving designs. Relatedly, the question of whether substantial water-saving effects are achieved by such designs, as well as questions regarding their energy-saving and carbon-reduction benefits, are widely discussed, with various investigations having been undertaken to answer them [7,8]. To date, however, there are still no solid means of verifying or providing clear evidence to determine the quantitative effects of various water conservation strategies. A model for estimating water-saving benefits in order to clarify the effective use of water resources was established in previous research. To that end, an empirical investigation of buildings with green building certification was conducted to verify the values estimated by the model after statistical analysis. More specifically, quantified values of reasonable water-saving benefits for Taiwan for every year were derived to examine the effects of water conservation and to validate the proposed model. In this study the actual cases awarded by green building certification since 2000 to 2013 are taken as the research subjects, the rainwater harvesting system is the focus of this research.

2 Water indexes and evaluation

This study focused on the water conservation measures for green buildings in Taiwan with the aim of providing a quantitative procedure for proving water-saving efficiency. The water conservation index is a ranking system for the adoption of water-conserving items, including water closets, urinals, faucets and baths, and for the reuse of rainwater and grey water.

As a practical process of the assessment of the water index of a green building's water resource indicator system ***WI*** value, the applied building should submit the proof documents about the saving water design items; then, the referee committee would confirm and determine the final rating value of the ***WI*** index. This rating system focuses on the saving water design and the adoption of water efficiency facilities for green buildings. The evaluation consideration engages the design and facility, not including usage patterns or behavior styles. Therefore, the rating value of saving water is a conceptual assessment for the water efficiency parameter without real water saving volume.

To more precisely estimate the quantity of water actually consumed by a given green building, the factor of operating time was added to the building categories when estimating the baseline for the quantity of water consumed. After the water consumption per unit of the floor area of a building with green building certification was acquired, this study used statistical quantitative methods and an empirical investigation for comparison and analysis, determining the actual gross water consumption as a basis for estimating the quantity of a building's annual water conservation. Accordingly, the baseline for annual water consumption for each category of building Wty (m^3/year) was established, and the formula for the estimated quantity of annual water conservation Wst (m^3/year) is provided as Equations (1)–(4).

$$W_{ty} = A_f \times WUI \quad (1)$$

$$W_{st} = W_{ty} \times (WI \div 9) \quad (2)$$

$$R_{sw} = W_{st} \div W_{ty} \times 100\% \quad (3)$$

$$R_{rs} = W_{rs} \div W_{ty} \times 100\% \quad (4)$$

W_{ty}: Annual water consumption for each category of building (m^3/year). A_f: The floor area of a building (m^2).
WUI: Water consumption density per unit area of a building ($m^3/m^2 \cdot$year).
WI: Water index of a green building's water resource indicator system ($0.0 \le WI \le 9.0$).
W_{st}: Annual water saving of building (m^3/year).
W_{ty}: Annual water consumption of each category of building (m^3/year).
R_{sw}: Annual water saving rate of building (%).
R_{rs}: Annual rainwater substitution rate of building (%).

The score for the water resource indicator system for a green building's rating assessment system, ***WI***, is the key parameter for estimation. This study used the real cases with green building certification, and each case has a certified rating value of the ***WI*** index. The average values of the water resource indicator rating scores for 2007– 2013 (***WI***) were, for the most part, normally distributed between 3.0 and 5.0. According to the survey green building certificated cases, the annual water saving rate R_{sw} and rainwater substitution rate R_{rs} would be estimated.

3 Building category and water usage baseline

The water demand and the actual water consumption of buildings are actually quite complex, not only because of the difference in building types, but also because even among buildings of the same type, individual buildings may differ substantially due to factors, such as building age, occupancy, density, *etc*. Moreover, a building's usage and demand patterns will change after the actual construction is completed. All of these factors cause considerable difficulty in accurately estimating water consumption. Therefore, in order to more accurately estimate the actual consumption of green buildings to serve as the basis for assessing water-saving efficiency, the operating time factor was added to the factor of building types as one of the water consumption estimation criteria. Herein, the water unit intensity (***WUI***) formula is defined by the parameters of occupancy density, yearly water usage and occupancy rate, shown as Equations (5)–(8).

$$WUI = P_{di} \times Q_{wi} \times F_{ri} \tag{5}$$

$$P_{di} = \prod_{i=1}^{12} P_{di} \quad ; \quad 0.03 \le P_{di} \le 1.2 \tag{6}$$

$$Q_{wi} = \prod_{i=1}^{8} Q_{wi} \quad ; \quad 1 \le Q_{wi} \le 130 \tag{7}$$

$$F_{ri} = \prod_{i=1}^{5} F_{ri} \quad ; \quad 0.4 \le F_{ri} \le 0.8 \tag{8}$$

WUI: Water consumption density per unit area of the building ($m^3/m^2 \cdot$year).
P_{di}: Person density (person/m^2).
Q_{wi}: Yearly water usage (m^3/person/year).
F_{ri}: Occupancy rate (%).

This study proposes ***WUI*** as the definition of building water usage density and to serve as the baseline of building water usage to evaluate the water efficiency of building water consumption. Due to the various categories of buildings, this study, in accordance with existing literature and relevant research and investigations, divided the buildings according to 52 different types of water utilization based on the building's utilization time characteristics in order to estimate the baseline for water consumption more precisely. After estimating the parameter levels for the standardized building water consumption and water consumption parameters, the baseline for each type of water consumption was estimated.

Table 1 ***WUI*** for space categorizations of the 52 types of baseline water usage.

Building Type	Groups	Category	P_{di}	Q_{wi}	F_{ri}	*WUI*
Type A (Public meetings)	A-1 assembly hall	A11	0.25	10	0.5	1.25
		A12	0.80	10	0.5	4.00
		A13	0.80	10	0.5	4.00
		A14	1.20	10	0.4	4.80
	A-2 transportation	A21	0.35	10	0.4	1.40
Type B (Business)	B-1 entertainment	B11	0.80	5	0.5	1.50
		B12	0.40	5	0.5	1.00
	B-2 department store	B21	0.25	5	0.5	0.63
		B22	0.25	5	0.5	0.63
		B23	0.35	5	0.5	0.88
	B-3 catering building	B31	0.35	10	0.5	1.75
		B32	0.35	5	0.5	0.88
		B33	0.40	25	0.7	7.00
	B-4 hotel	B41	0.05	100	0.7	3.50
Type C (Industry, warehousing)	C-1 special warehouse	C11	0.03	10	0.5	0.15
		C12	0.03	10	0.5	0.15
		C13	0.03	1	0.4	0.01
		C14	0.03	1	0.4	0.01
		C15	-	-	-	-
	C-2 general warehouse	C21	0.10	25	0.7	1.75
		C22	0.10	25	0.7	1.75
		C23	0.10	40	0.7	2.80
		C24	0.10	40	0.7	2.80
Type D (Leisure, culture and education)	D-1 convenience store	D11	0.25	5	0.5	0.63
		D12	0.25	60	0.5	7.50
		D13	0.15	130	0.5	9.75
	D-2 cultural and educational facility	D21	0.15	25	0.7	2.63
		D22	0.40	10	0.6	2.40
	D-3 elementary school building	D31	0.40	10	0.6	2.40
	D-4 school building	D41	0.40	10	0.6	2.40
		D42	0.20	25	0.7	3.50
	D-5 tutoring center and childcare	D51	0.40	10	0.6	2.40
Type E (Religion, funeral and interment)	E religion, funeral and interment	E11	0.80	10	0.5	4.00
Type F (Health, welfare, rehabilitation)	F-1 healthcare	F11	0.10	100	0.7	7.00
		F12	0.10	10	0.5	0.50
		F13	0.10	10	0.5	0.50
		F14	0.30	5	0.5	0.75
		F15	0.30	5	0.5	0.75
		F16	0.15	25	0.7	2.63
	F-2 social welfare	F21	0.05	100	0.5	2.50
	F-3 child welfare	F31	0.05	100	0.5	2.50
	F-4 prison	F41	0.05	100	0.5	2.50
Type G (Office, service)	G-1 finance and securities	G11	0.15	25	0.7	2.63
	G-2 office space	G21	0.15	25	0.7	2.63
	G-3 shop and clinics	G31	0.25	5	0.5	0.63
Type H (Residence)	H-1 lodge and care house	H11	0.05	100	0.7	3.50
	H-2 house	H21	0.04	100	0.8	3.20
		H22	0.03	100	0.8	2.40
		H23	0.02	100	0.8	1.60
Type I (Dangerous goods)	I dangerous factory or warehouse	I11	0.03	1	0.4	0.01
		I12	0.03	1	0.4	0.01

Overall, other than accommodation or medical buildings, which involve everyday-life water demands, the per-capita water demand per unit of buildings in general is mainly determined by the use of toilets and for cleaning activities. The water demands of accommodation buildings, on the other hand, include the water needed for cleaning and bathing, toilet flushing, cooking and other purposes. Based on the unity and efficiency principle of the estimation formula and for the sake of consistency in our assessments, water consumption was translated into average per-capita water consumption per unit for all building types. A building's total water consumption is mainly influenced by the two factors of per-capita consumption per unit and user density, and basically, these two factors are independent variables.
With regard to the building category, spatial contrasts were computed by referring to 52 types of space according to building categories A–I under the building code of Taiwan.

4 Investigation and validation

In this study the actual cases awarded by green building certification since 2000 to 2013 are taken as the research subjects with totally 1224 cases, the rainwater harvesting system is the focus of this research. Through the field survey, the water efficiency from rain water harvesting operation of 568 cases was evaluated and confirmed which involved the rainwater harvesting system design and operation to be the validation. The adoption rate of rainwater harvesting system design and operation in green building certificated cases is around 50% in general since 2000 to 2013, as shown in Figure 1.

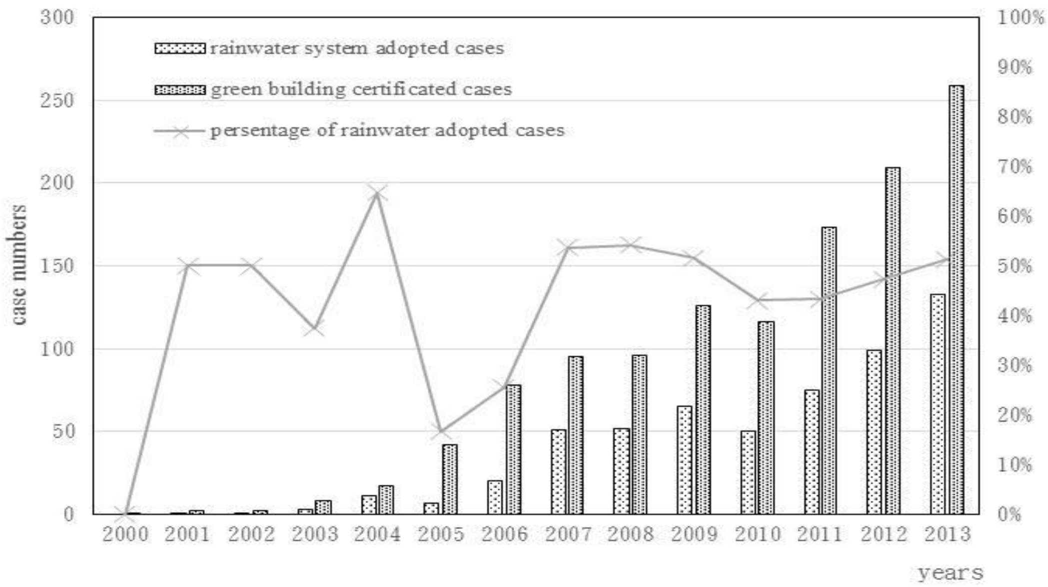

Figure 1 Green building certificated cases with rainwater system design

This study selected 91 green building certified cases with confirmed data to validate the efficiency of rainwater system. Due to the water quality standard and utility needs, the water saving rate was limited under 60% in evaluation system. Meanwhile, the rainwater substitution rate has maxima for different building type and utility needs. Herein, three groups of building types were defined from the 52 categories as residential, commercial and productive usage.

Table 2 The residential use for rainwater substitution rate

Category	Building types	Daily water usage (l)	Available substitution volume (l)	Maxima substitution rate (%)
residential use (1)	H21,H22,H23	250	50	20%
Usage items	 (Residence)			
residential use (2)	B41,F21,F31,F41,H11	200	50	25%
Usage items	 (welfare, rehabilitation)			
Commercial use	A11,A12,A13,A14,A21,B11,B12,B21,B22,D21,D22,D23,D31,D41,D42,D43,D44,D51,E11,F16,G11,G21,G31	90	50	55%
Usage items	 (Public meetings)			
productive use(1)	F11,F12,F13,F14,F15	250	50	20%
Usage items	 (Health)			
productive use(2)	B23,B31,B32,B33	140	50	35%
Usage items	 (Business)			
productive use(3)	B12,D11,D12	200	50	25%
Usage items	 (Leisure, culture and education)			
productive use(4)	C11,C12,C13,C14,C21,C22,C23,C24,I11,I12	90	50	55%
Usage items	 (Industry, warehousing)			

The residential use is daily usage for life including drinking, bathing, washing and etc.. The commercial use is daily usage for working area mostly is for toilet, washing, cleaning and etc.. The productive use is the usage for production area and the utility is vary and comprehensive including factory, restaurant, sport center, hospital and etc.. The usage includes producing process, toilet, washing, cleaning and etc.. Table 3 shows the analysis of water usage and the maxima substitution rate for all categories of building types. Therefore, each category has maxima rainwater substitution rate for calculation from 20% to 55%. According to the reasonable limitation of maxima substitution rate, the green building certificated cases could be evaluated from water saving rate to rainwater substitution rate which the contribution framework of rainwater system adoption could be identified and recognized.

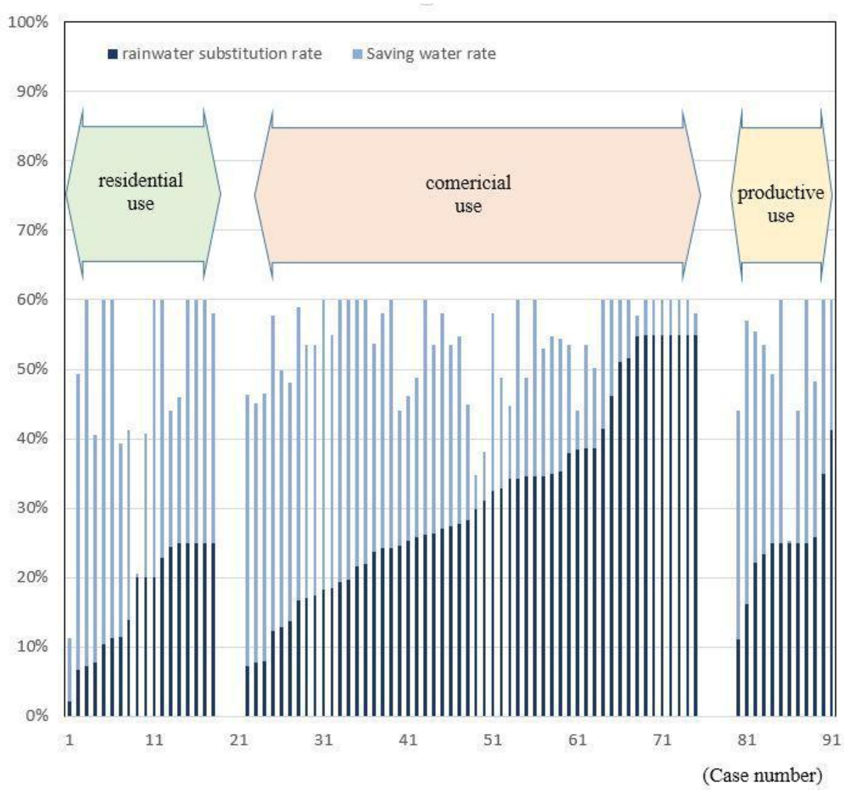

Figure 2 Distribution of rainwater substitution rate and water saving rate

This study used 91 cases of green buildings which involved the rainwater harvesting system design and operation to be the validation. Figure 2 shows the distribution of rainwater substitution rate and water saving rate of three group's buildings. It reveals that the rainwater substitution rate of residential use has lower rate of average 17%. As a result, the evaluation result shows average 54% water saving rate in these cases involved rainwater harvesting system. Initially, the average rainwater substitution rate is 28% as shown as Figure 3.

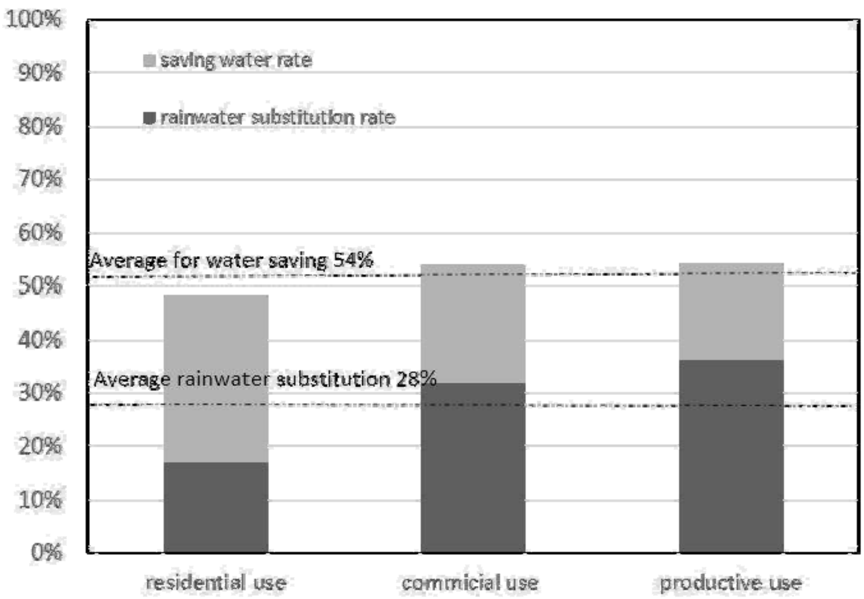

Figure 3 Comparison of rainwater substitution rate of three group's buildings

5 Conclusion

In this study the real cases awarded by green building certification since 2000 to 2013 are taken as the research subjects, the rainwater harvesting system is the focus of this research. Through the field survey, the water efficiency from rain water harvesting operation was evaluated and confirmed. This research used 91 cases of green buildings which involved the rainwater harvesting system design and operation to be the validation. The evaluation result shows average 54% water saving rate in these cases involved rainwater harvesting system. Initially, the average rainwater substitution rate is 28%. It is proved the significant contribution to water efficiency from adoption of rainwater reuse system in green buildings.

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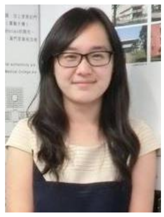

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Session C
Drainage and sanitation

A study of water saving toilet with urine splash prevention function

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Abstract

In recent years water saving technology of toilet has been advancing rapidly, so we have been sold some types of 4 liter toilets in Japan. We have already reported those structures and results of experimental evaluation in 36th ~ 38th CIB W062 Symposium. To add new value to our product, we launched a 4 liter toilet with urine splash prevention function by detergent foam recently. There are few reports about influence that the high flow rate drainage of toilet with detergent foam gives to trap water seals of the other devices. In this report, we'd like to introduce the results of the above in by making a comparison between with foam and without foam.
1. The feature of the 4 liter toilet with urine splash prevention function
The new 4 liter toilet has a foam generator. It mixes water, air, and detergent, and creates micro-foam by pressure change. The detergent foam is supplied to a toilet bowl, and works as cushioning for splash prevention when men urinate with standing.
2. Experimental evaluation
We did experiments the average drainage flow rate and the influence on the drainage stack system. As a result, average drainage flow rates were the equal performances regardless of with or without foam, and the influence of drainage with foam on trap water seal of other devices was increased compared to the drainage without foam. However, it was accepted level.

Keywords

4-liter toilet, tankless toilet, drainage flow rate, detergent foam.

1 Introduction

Water-saving technology in Japanese toilets has made great progress. More than 10 liter of water for flushing was required in the1980s, but a product that saves water by only using 4 liter was released in 2011 and a product that requires an even smaller flushing water volume has gone on sale recently.
Since there are many small houses in Japan and the toilet space is also small, a compact toilet that allows usage in a limited space is popular.In such a circumstance, a water-saving type tankless toilet is gradually becoming popular on the market combined with its stylish design. In addition, the Japanese have a high sensitivity to cleanliness in the environment, and there are many products on the market in recent years that appeal to cleanliness as an additional value.
There are various kinds of filth in toilets, among them, urine splash that is caused when a man urinates while standing, making the back of the toilet seat and the edge of the toilet bowl dirty, and it even splatters out of the bowl; therefore it is a big factor in the filth that annoys customers.
In spring 2016, we released a water-saving type of tankless toilet with a function that prevents urine splash, which is caused when men urinate while standing, using a foam cushion effect by supplying fine detergent foam to a toilet bowl.
We have studied the influence that a water-saving type toilet has on a drainage plumbing system and the results were also reported in this symposium, but the research results related to the influence that drainage containing detergent foam has on a piping system have not been reported enough. Especially in high-rise housing, it is possible for it to have an adverse impact on a drainage plumbing system, such as blocking a pipe with a lot of foam that is generated by a shock when drainage travels down. We have studied the influence that drainage with detergent foam has on a drainage plumbing system from a product development stage. We report the research results here.

2 The structure of a 4 liter toilet with a urine splash prevention function

2.1 The urine splash prevention function

A prevention of urine splash is realized by using a detergent foam that is generated through a foam generator installed within a toilet and is supplied to the toilet bowl. When you pass urine in a condition that has detergent foam, urine splash is prevented by the cushioning effect of the detergent foam. (Refer to Figure 1.) Based on the evaluation we performed, the amount of splash was reduced to about 10% compared to a condition without detergent foam. The detergent foam is supplied by moving the toilet seat up in order to pass urine or by pushing a dedicated button, and it is simultaneously drained every time a toilet is flushed.

Figure 1 A picture showing passing urine towards foam supplied to a toilet bowl

2.2 The structure of a foam generator

A foam generator has a structure similar to a Venturi tube as shown in Figure 2. In order to generate detergent foam, it is required to mix water, air, and detergent, and to fragment them. Water is directly supplied from a water supply pipe and it is ejected from a nozzle by water pressure. When water flows into the fine pipe part of the tip, the air is spontaneously sucked in due to a low pressure caused by the venturi effect. Detergent is supplied via a small pump. Pressure becomes increased in the expanding part of the pipe of the foam generator. Supplied water, air and bubbles are fragmented through the shearing effect generated by this pressure change, and micro-foam is created.

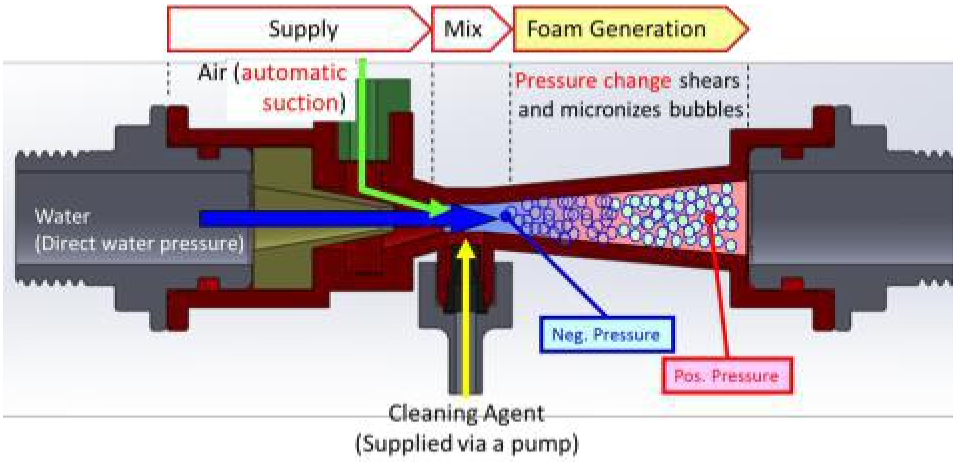

Figure 2 The structure and principle of a foam generator

2.3 Existing 4 liter toilets

We used two types of 4 liter toilets that are already sold for evaluation. (Because this research was performed in a product development stage and a closet bowl that should be installed in practice was not ready.) Regarding these toilets, we reported them in this symposium in the past.

2.3.1 A tankless toilet with electric pressure equipment

This system, hereafter called “Type A,” is a tankless toilet characterized by applying pressure to supplied water using an electric pump. (Refer to Figure 3.)Since there is no jet nozzle, its noise is similar to the level of a conventional gravity flush toilet. In addition, since this system discharges water for flushing using pressure provided by a pump, it is not affected by supply water pressure. The flushing water volume is no different from a conventional tankless toilet and the size is also about the same. The above are realized with a high flow pump and balance and timing of flushing water discharge.

2.3.2 A tankless toilet with a non-electric source accumulator
This tankless toilet applies pressure to supplied water using a mechanical accumulator. (Refer to Figure 3.) This system can save the volume of water for flushing compared to a conventional tankless toilet by combining the water supply that is directly connected to waterworks and compressed water supplied from an accumulator. We call this 4 liter tankless toilet “Type B” in this report.

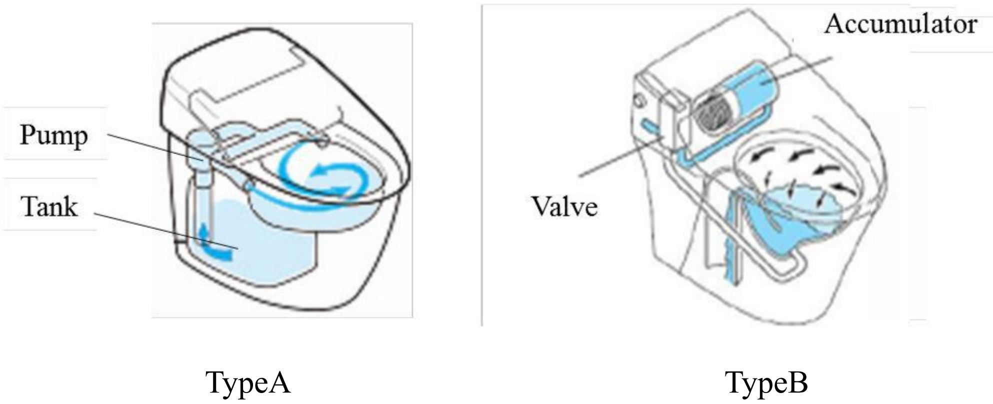

Figure 3 The structure of the existing toilets

3 Summary of the methods of experimentation

In order to confirm whether a new toilet with a function to prevent splash meets the required performance in Japan, we examined the characteristics of drainage that contains detergent foam. We performed a comparison evaluation with and without detergent foam to examine the influence of foam. In addition, in order to understand the characteristic differences in a toilet, we conducted the evaluation using two types of toilet, Type A and Type B. As mentioned in section 2, regarding a case without foam, we had evaluated both Type A and B and reported the results in the past, but we re-evaluated them and are describing the results of this time.

3.1 Measurement of drainage flow rate

We examined the drainage flow rate of a toilet by installing a testing device shown in Figure 4. The change of inflow pressure into a water tank was measured by a pressure transducer and it was converted to a change of flow rate. This is a method based on SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan; Japanese plumbing systems are normally designed in accordance with a standard established by this society.)-S220.
In a case with detergent foam, a designated amount of detergent foam was injected from an external foam-generating unit.

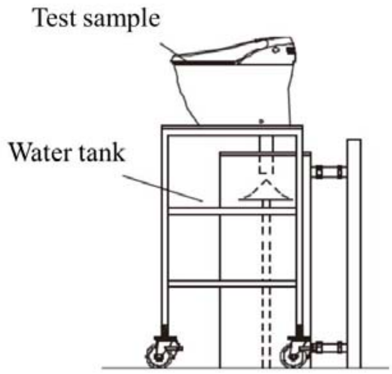

Figure 4 A drainage flow rate measurement device

3.2 Measurement of an influence on the trap water seal of other devices by toilet flushing

In order to evaluate the influence of drainage containing detergent foam on the trap water seal of other devices, we performed a drainage test using a simulation tower at Kanto Gakuin University shown in Figure 5. The diameter of the vertical pipe was 100 mm. The diameter of the horizontal main pipe was 125 mm, its gradient was 1/150 and an overhead ventilation pipe was set on the top of the vertical pipe. Test samples were set on the 7th and 8th floors of the tower. We measured the following three items after flushing toilets.

(1) Water level in a horizontal main drainpipe
(2) Pressure in a horizontal branch drainpipe on each floor
(3) A change in the trap water seal of other devices

Regarding (3), we established three types of traps, a trap for a washing machine pan, a trap for a washbasin, and a trap for a bathtub. Among them, we especially focused on the trap for a pan, which was most affected by a flushing toilet. Evaluations were performed with two flushing patterns. The first pattern was a simultaneous flushing in two toilets on the 7th and 8th floors, and the second pattern was a single flushing of one toilet on the 8th floor. The drainage time lag between the two toilets was set for 1 second. Because the pressure change in the pipe was maximum in preliminary experiments.A sewage sample, four layers of 90 mm of the JIS standard (Japanese Industrial Standards) single layer toilet paper that was folded four cycles, was placed flat in a toilet bowl and drained after immersing it in the sealed water for 15 seconds. A
designated amount of detergent foam was injected from an external foam-generating unit and drained 10 seconds after. Evaluations were performed combinations of with and without detergent foam and with and without a sewage sample.

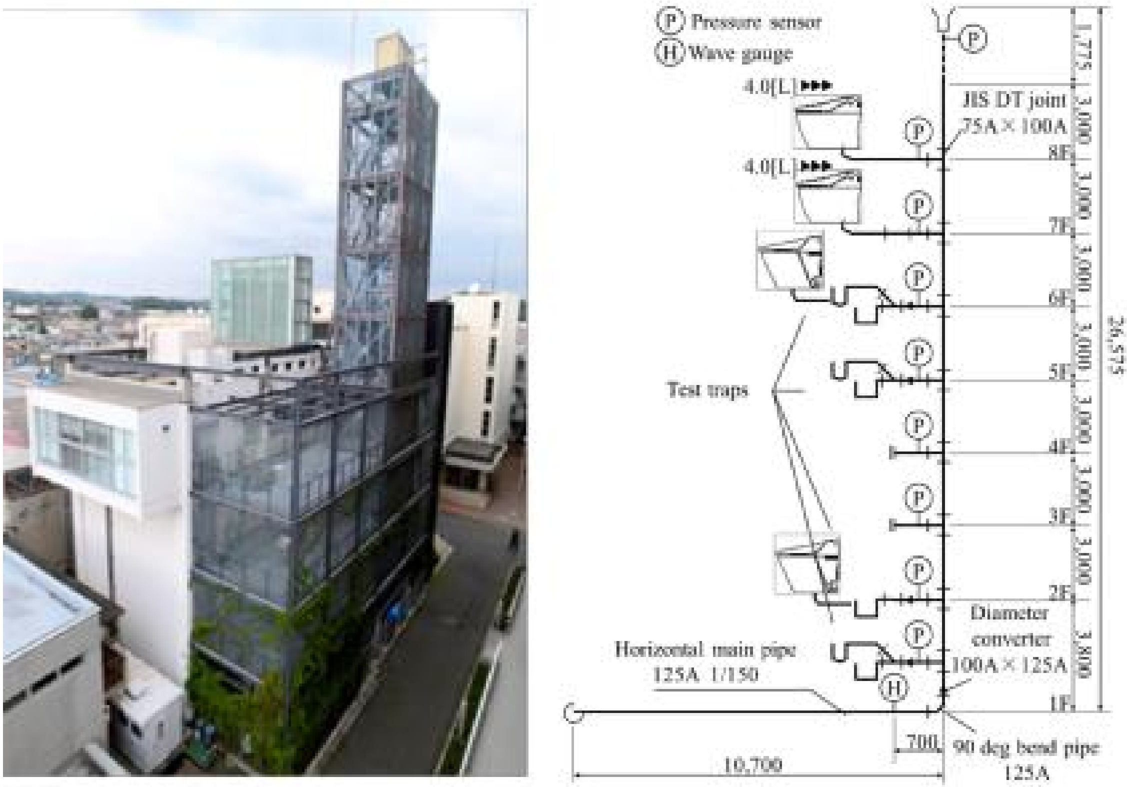

Figure 5 A picture and figure of the equipment with vertical

4 Results and discussion

4.1 Drainage flow rate

Table 1 and Figure 6 show characteristics of the samples. The average drainage flow rate (qd) and maximum flow rate (qmax) were about the same value with and without detergent foam in both Type A and B. In addition, flow rate curves were also about the same shape and it was considered that there was no difference in the drainage characteristics of the apparatus.

Table 1 Characteristics of test samples

	Foam	Volume	Drainage time	Average flow rate	Maximum flow rate
		W[L]	td[s]	qd[L/s]	qmax[L/s]
Type A pressurization	Without foam	4.08	1.2	2.04	1.96
	With foam	4.23	1.4	1.82	1.87
Type B Direct connection	Without foam	3.93	2.5	0.94	1.84
	With foam	4.00	2.2	111	1.97

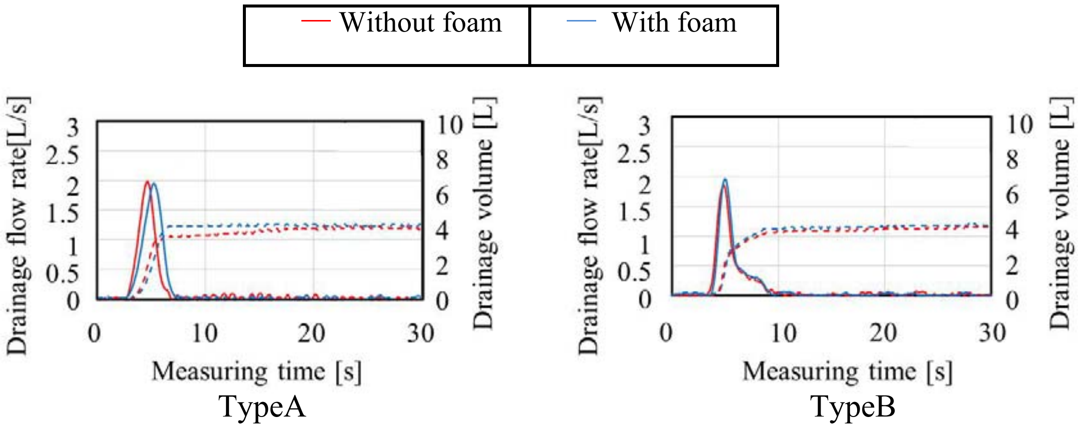

Figure 6 Drainage characteristic curves

4.2 Water level inside of the horizontal main pipe

Figure 7 shows the maximum water level measured at 700 mm from the core of a vertical pipe of the horizontal main pipe when drainage is continuously performed in one toilet on the 8th floor. (When foam and sewage samples were drained, the maximum water level also included their height.) There was a tendency that the maximum water level was high with drainage containing detergent foam, but it did not reach the water level that causes a blockage of the horizontal main drainpipe in either condition. Figure 8 is a picture of a drainage pipe that contains detergent foam.

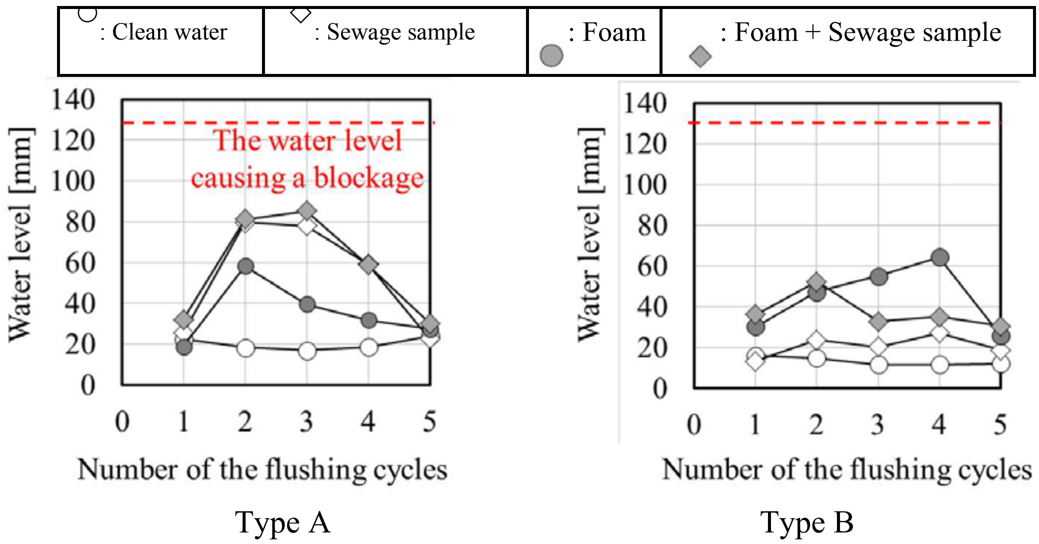

Figure 7 Water level with detergent foam in a horizontal main drainpipe (Single drainage of one toilet on the 8th floor)

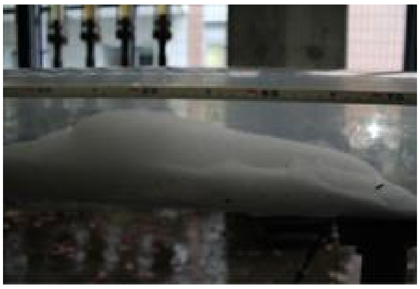

Figure 8 Drainage in a horizontal main pipe with drainage containing detergent foam

4.3 The fluctuation of pressure in the pipe

We found that a horizontal main pipe was not blocked by foam, but the fluctuation of pressure in the pipe may become bigger due to drainage of detergent foam. As a result of this evaluation, the fluctuation of pressure in the pipe tended to be larger when the drain had detergent foam but it was at an acceptable level. Figure 9 shows the maximum and minimum pressure when two toilets were flushed on the 7th and 8th floors at the same time. The maximum pressure was about 180 Pa and the minimum pressure was about -380 Pa even in Type A that had larger fluctuation when two toilets were simultaneously drained, and the results were within ±400 MPa, the SHASE standard of Japan. The large pressure fluctuation due to mixing of detergent foam is suspected to be caused by poor air permeability due to foam filling a section of a drain stack pipe while it flows down in the pipe. In addition, foam had a greater impact on Type A compared to Type B, and it is considered that the flushing method be involved with it.

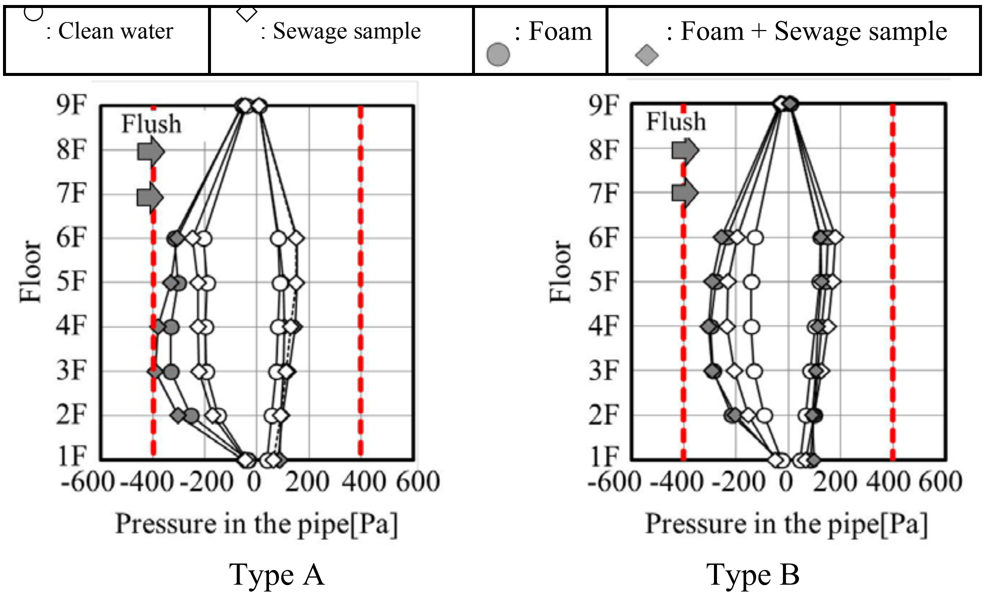

Figure 9 Pressure distribution
(Simultaneous drainage in two toilets on the 7th and 8th floors)

4.4 The fluctuation of water levels of the trap water seal of other devices

Since we found that the fluctuation of pressure in the pipe was at an acceptable level, we evaluated the influence on the water seal of other devices on lower floors and this revealed that the risk of breaking the trap water seal of other devices was low in reality. Figure 10 shows Δhmax, the loss of a trap water seal level of a pan trap after flushing 5 cycles in a row without a water supply. Δhmax was 25 mm in Type A that had a larger loss, and it was only about half of the 50 mm that was required to break the water seal.

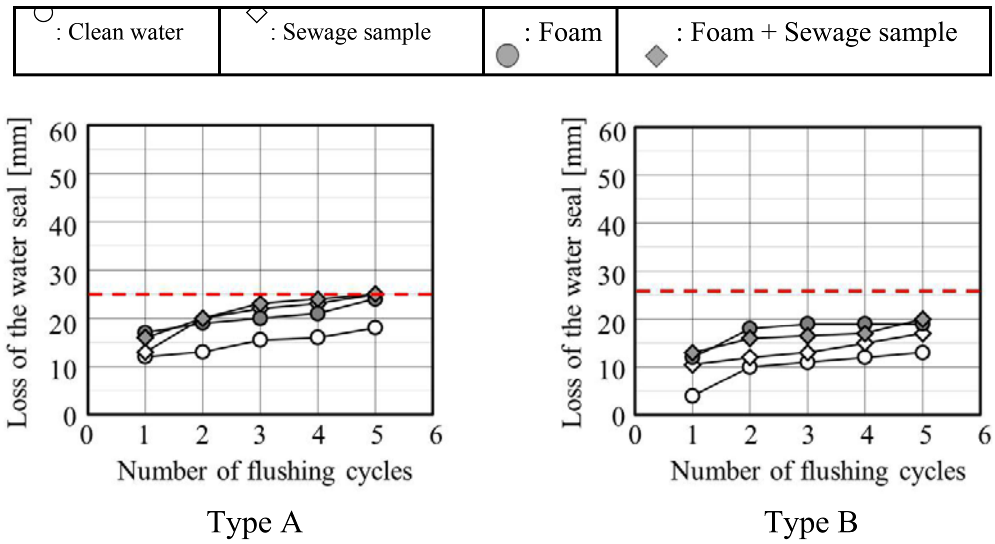

Figure 10 Loss of pan trap water seal after flushing (Simultaneous drainage in two toilets on the 7th and 8th floors)

5 Conclusions

We confirmed the following regarding a new toilet with a urine splash prevention function.

1) There was no difference in the flow rate characteristics between with and without detergent.

2) When detergent foam was drained, a horizontal main pipe was not blocked with foam.

3) When drainage was performed with detergent, the fluctuation of pressure in the pipe in the piping system was bigger compared to drainage without detergent foam, but it was at an acceptable level.

4) The risk that drainage containing detergent foam will break a trap water seal of other devices was not high.

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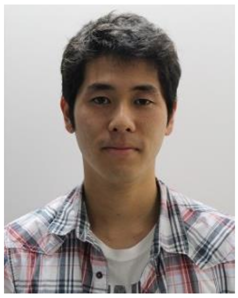

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Study on system development for achieving the improvement of carrying performance of sequentially arranged water-saving toilets

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Abstract

This basic study was intended to acquire knowledge that is conducive to devising a piping section and a flushing method to improve the carrying performance of a toilet system comprising sequentially arranged water-saving toilets, and subsequently establishing technological development of such a toilet system and a performance evaluation method for the same. At the International Symposium CIB W062 held in Beijing in 2015, a study involving drainage experiments using a toilet system comprising five sequentially arranged water-saving toilets was presented, by which how the carrying performance was affected mainly by the backflow in the horizontal fixture drain branch and pipe gradients was identified. This paper reports a thorough discussion on further knowledge, which was acquired through the study, conducive to improving the carrying performance, including, in particular, optimizing the shape and installation method of inflow fittings and determining a most appropriate fixed-time-period flushing method.

Keywords

Carrying performance, water-saving toilets, horizontal fixture drain branch.

1 Background and objectives of the study

As part of global warming prevention, water-saving technologies for sanitary facilities have been advancing at a fast rate in recent years to support securing water resources. In particular, water-saving toilets are a focal point. As well as in private homes, water-saving toilets are more readily used in offices, but installing them in a sequential fashion raises some concerns in terms of interfering with carrying performance.
At the 41st International Symposium of CIB W062 in Beijing, the previous report1) presented the knowledge acquired about fixture discharge characteristics and carrying performance when adopting a water-saving toilet system comprising five sequentially arranged water-saving toilets with 4.8L or 6.0L flush water.
This report focuses on the horizontal fixture drain branch to which sequentially arranged water-saving toilets are connected, and examines, through experiments, how the carrying performance is affected by the shape of horizontal fixture drain branch fittings and different intervals for fixed-time-period flushing carried out after wastewater becomes stagnant. The report also considers a method conducive to improving the carrying performance.
The matters discussed in the study are as follows.
(1) Acquiring fixture discharge characteristic values
(2) Identifying single flush/combined flush carrying characteristics and relevant issues
(3) Discussion on the amount of water for fixed-time-period flushing and flushing intervals.

2 Experiment overview

2.1 Experimental horizontal fixture drain branch system

As shown in Figure 1, the experiment involves an experimental horizontal fixture drain branch system comprising a 5m pipe, which uses JIS-A 5207-approved type II water-saving toilets with 6.0L flush water. The system simulates a series of toilet booths installed in an office building, in which five experimental toilets are sequentially connected to an above-floor horizontal fixture drain branch that is fixed onto a slab floor surface.
The experimental toilets are installed at 1m intervals. Toilet (I) is positioned at the most upstream side of the experimental horizontal fixture drain branch, and toilets (II) to (V) are then positioned downstream of the horizontal fixture drain branch. 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 (100A×125A) are attached to the ends thereof.
The horizontal fixture drain branch is also provided with a loop vent pipe (50A), which is erected at a position one level below the most upstream side of the horizontal fixture drain branch, and extends downstream of the horizontal fixture drain branch. On-off valves are installed in the parts connecting the horizontal fixture drain branch and the loop vent pipe together, and the normal state of the valves is closed. The pipe pitch is 1/100. Photo 1 shows the fittings that are used for connecting the toilets to the horizontal fixture drain branch. The fittings come in two different shapes; flexible DT type (hereinafter referred to as 'DT fitting') and flexible LT type (hereinafter referred to as 'LT fitting'). The LT fitting is attached to the

horizontal fixture drain branch in such a manner as to create an angle of approximately 45° relative to the horizontal fixture drain
branch in order to facilitate the inflow of wastewater from each toilet, while the DT fitting is attached roughly at the right angle so as to increase resistance against the inflow of wastewater. The use of different fitting shapes, as well as changing the arrangement of the fittings, allows observing how different fitting conditions affect the carrying distance of waste.

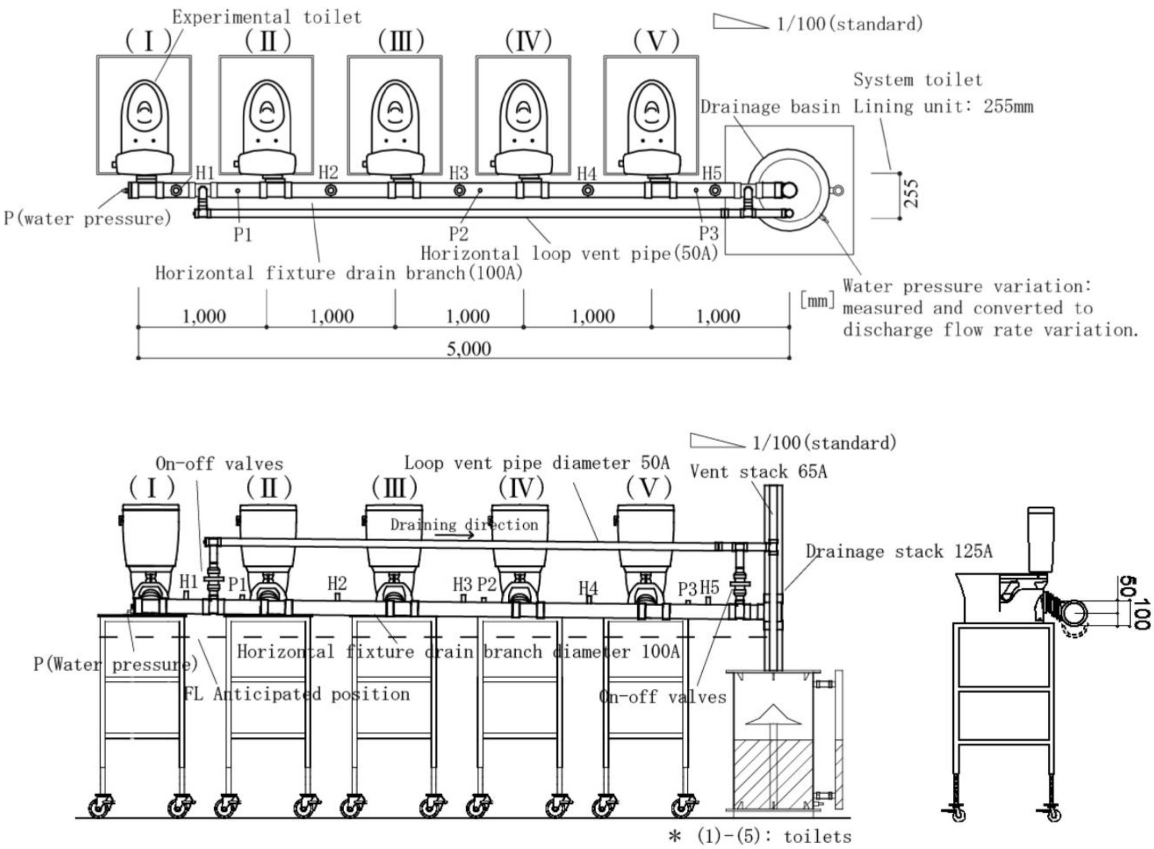
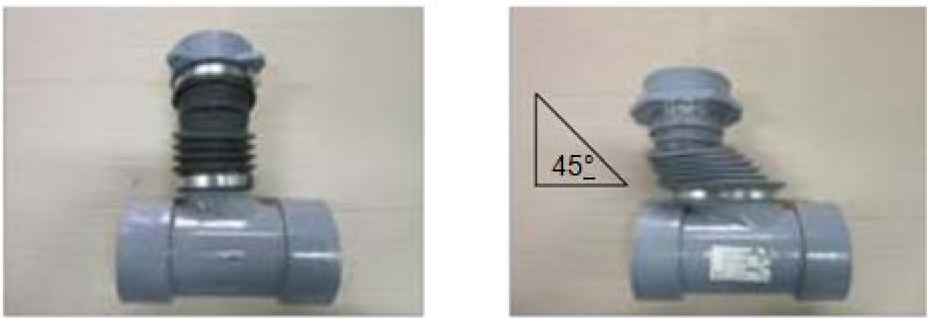


Figure 1 Experimental horizontal fixture drain
a) planar, b) elevation, c) cross section(toilet (I))



(1) DT fitting **(2) LT fitting**
Photo 1 Different types of fittings

2.2 Fixture discharge characteristics experiment

The fittings fitted to the experimental horizontal fixture drain branch system are all

DT and LT fittings, and fixture discharge characteristics are measured in accordance with SHASE-S2202 when the experimental toilets are respectively flushed using clean water only. Figure 2 shows an example of the variation of discharge flow rate and the variation of discharge volume when toilet (V) is flushed. In Figure 2, the maximum fixture discharge flow rate, q'max [L/s], refers to the maximum value of discharge flow rate. Moreover, the draining time, td[s], refers to the period between the time when 20% of the total discharged water has been drained and the time when 80% of the same has been drained, and the average fixture discharge flow rate, qd'[L/s], refers to the average discharge flow rate, which is calculated from the draining time by formula (1).
In addition, a water pressure sensor is attached to the cleaning port located at the upstream end of the horizontal fixture drain branch to measure the variation of water pressure, P[Pa].

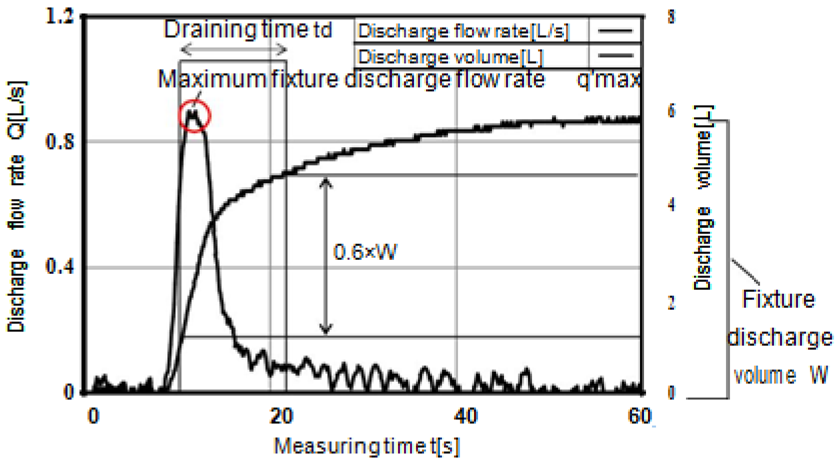


Figure 2 Fixture discharge volume / fixture discharge flow rate curves - example using toilet (V)

2.3 Single-flush / combined-flush carrying performance experiment

The carrying performance experiment includes a single-flush experiment and a combined-flush experiment, in which three types of experimental waste substitutes, shown in Table 1, are each flushed down the experimental toilets. Using the waste substitutes, toilets (I)-(V) are flushed, individually, in the single-flush experiment, and two or more toilets are flushed in the combined-flush experiments. Each carrying distance is then measured from the core of the most upstream fixture drainpipe (see Figure 1) to the tail of each waste substitute where it stopped. As for the flushing timing in the combined-flush experiment, the toilets are flushed in sequence, starting with the most upstream toilet (I), at 1-second intervals, so that the flows of discharged water from the toilets collide with each other as they pass the joining points.

2.4 Fixed-time-period flushing experiment

From the results obtained in the single-flush and combined-flush experiments, the carrying performance is also examined in the case where the type of the fitting used for the most upstream fixture connection is changed. Moreover, in the case of a single-flush

pattern that causes the shortest carrying distance, the most upstream toilet (I) is flushed, with clean water only, 0.5 hours to 63 hours (roughly 2.5 days) after the drained waste substitute stopped in the horizontal fixture drain branch, and the further carrying distance made by the fixed-time-period flushing is measured.
The items to measure and the measuring methods are as indicated in the previous report1). As shown in Figure 1, ultrasonic water level sensors are disposed at H1 to H5 to measure the water level in the pipe, H [mm], at the time of flushing, and a water pressure sensor is also disposed at P to measure the variation of water pressure in the cleaning port, P[Pa]. Moreover, in order to check for induced siphonage, pressure sensors are disposed at P1 to P3 near the fixture drainpipes to measure the air pressure. In the drainage basin, the variation of discharge flow rate in the pipe, Q [L/s], and the fixture discharge volume, W [L], are measured.

Table 1 Experimental waste substitutes

Type	Experimental waste substitute	Description
D		1-ply toilet paper, laid flat, 1m x 6 pieces
D'		2-ply toilet paper, laid flat, 1m x 6 pieces
BL*		1-ply toilet paper, laid flat, 0.9m x 4 pieces

* In accordance with Better Living BLE WC:2013

Table 2 Flushing patterns used in the carrying performance experiment

(1) Single-flush experiment

Flushing pattern			Toilet (I)	(II)	(III)	(IV)	(V)
Single flush	1 toilet at a time	No.1	○				
		No.2		○			
		No.3			○		
		No.4				○	
		No.5					○

*○: Toilet(s) used for testing

(2) Combined-flush experiment

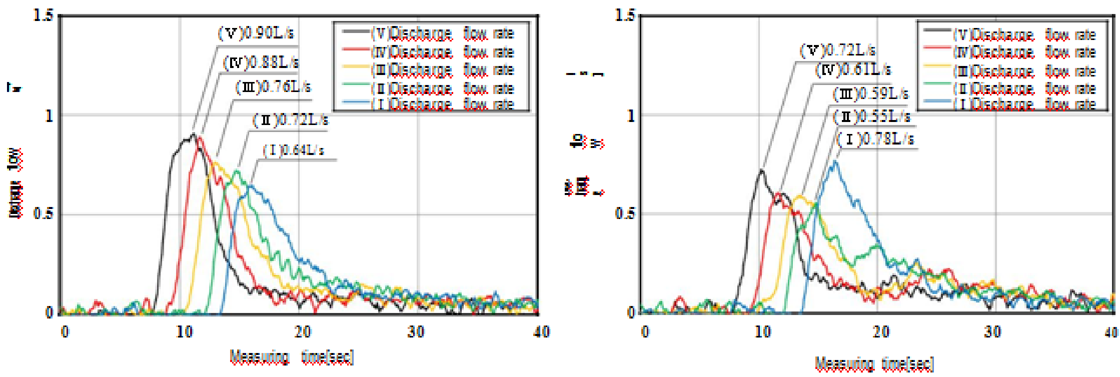
Flushing pattern			Toilet (I)	(II)	(III)	(IV)	(V)
Combined flush	2 toilets at a time	No.6	○	○			
		No.7	○		○		
		No.8	○			○	
		No.9	○				○
	3 toilets at a time	No.10	○	○	○		
		No.11	○	○			○
		No.12	○		○		○
		No.13	○			○	○
	4 toilets at a time	No.14	○		○	○	○
		No.15	○	○		○	○
		No.16	○	○	○		○
	5 toilets at a time	No.17	○	○	○	○	○

3 Results and discussions

3.1 Fixture discharge characteristics experiment

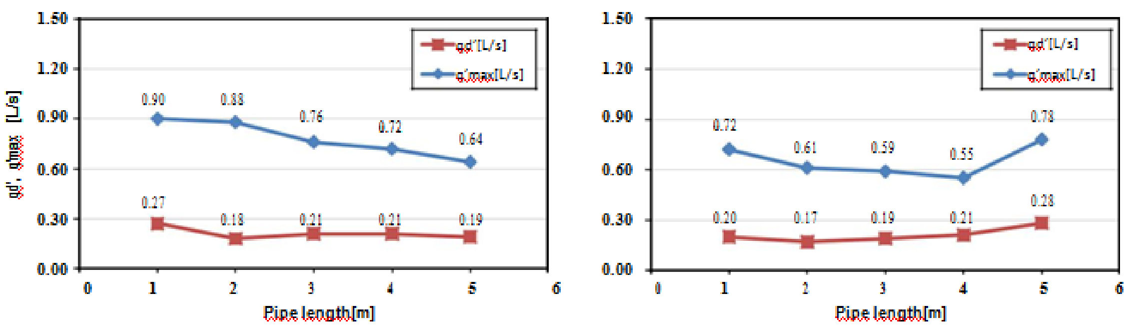
Figure 3 shows discharge flow rates, which were measured when the experimental toilets were flushed individually with clean water, using LT and DT fittings, respectively, and Figure 4 compares the variation of qd' (average fixture discharge flow rate) and the variation of q'max (maximum fixture discharge flow rate) in relation to the length of the pipe. When LT fittings were used, the highest q'max was measured from the most downstream toilet (V), which is the closest to the drainage stack, and there is a trend that the further away the toilet is from the drainage stack, the lower the discharge flow rate, i.e., the lowest q'max was measured from the most upstream toilet (I). A very
similar trend was found in the case of qd'. Therefore, it is clear that the LT fitting is

most effective, when used for connecting the most downstream toilet (V), in ensuring good performance in carrying the water to the drainage stack, and the said fitting is least effective when used for connecting the most upstream toilet (I). In contrast, in the case of the DT fitting, the highest discharge flow rate was measured from the most upstream toilet (I), and the lowest discharge flow rate was measured from toilet (II) which is adjacent to toilet (I). This suggests that draining from the most upstream toilet (I) is carried out most effectively without backflow because the fitting for connecting the said toilet is provided with a cleaning port at the end thereof, while draining from toilets (II)- (V), to which the drainpipes are connected on the upstream side of the toilets, is hindered by backflow, hence low q'max values.



(1) LT fitting **(2) DT fitting**

Figure 3 Fixture discharge flow rate curves and the variation of maximum discharge flow rate in relation to the fitting type



(1) LT fitting **(2) DT fitting**

Figure 4 Variations of qd′and q′max in relation to the length of the pipe

Figure 5 shows the variation of water pressure, which was measured at the cleaning port when toilet (I) was flushed, and Figure 6 shows the variation of water level, which was measured with the water level sensor at H1 on the upstream side. In addition, Photo 2 shows the state of drained water in the cleaning port of each of the DT and LT fittings. With regard to the variation of water pressure, the water pressure reached a maximum value of approximately 137Pa in the case of using the LT fitting, and approximately 269Pa in the case of using the DT fitting, creating a disparity of approximately 132Pa. As for the variation of water level, the water level reached a maximum value of approximately 22mm in the case of using the LT fitting, and approximately 33mm in the case of using the DT fitting, resulting in that using the DT fitting caused the water level to increase by approximately 11mm compared to the LT fitting.

It is evident from these results that compared to the LT fitting, using the DT fitting generates a backflow frequently on the upstream side of the horizontal fixture drain branch, thus, increasing the water pressure and water level in the cleaning port. Therefore, a powerful drainage flow ensures that wastewater reaches the downstream side of the horizontal fixture drain branch, and from the results shown in Figure 4, it is considered advantageous to use the DT fitting, rather than the LT fitting, for ensuring good drainage performance when draining from the most upstream toilet (I).

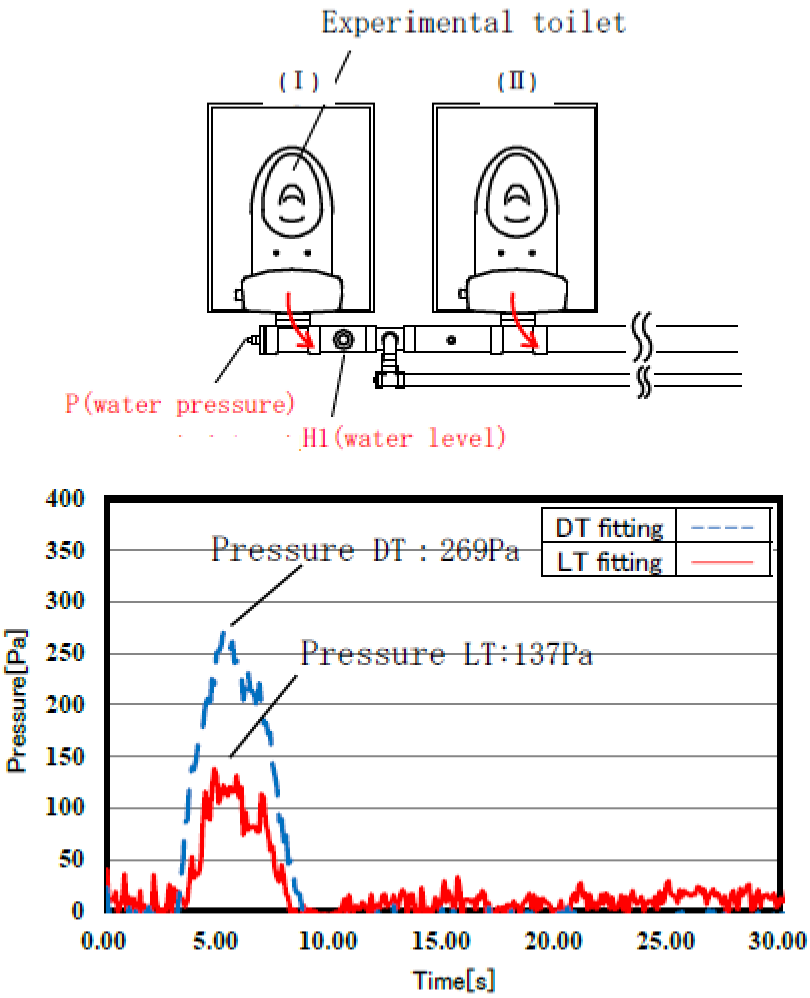


Figure 5 Water pressure values compared in the cleaning port when flushing with clean water

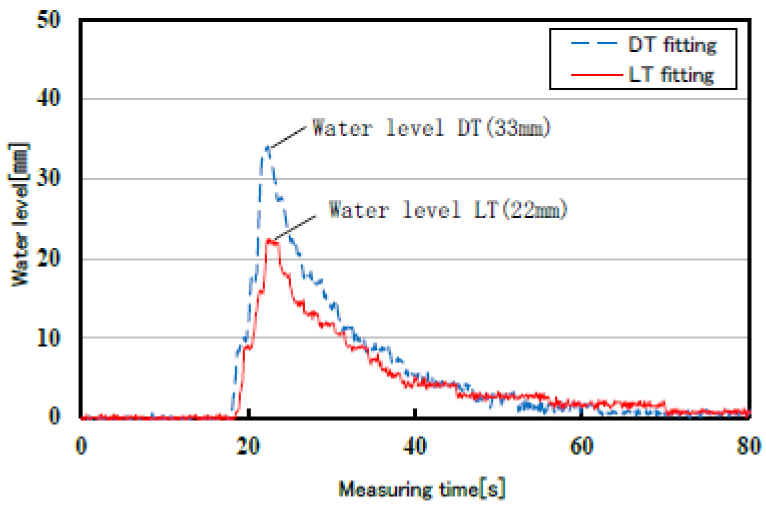
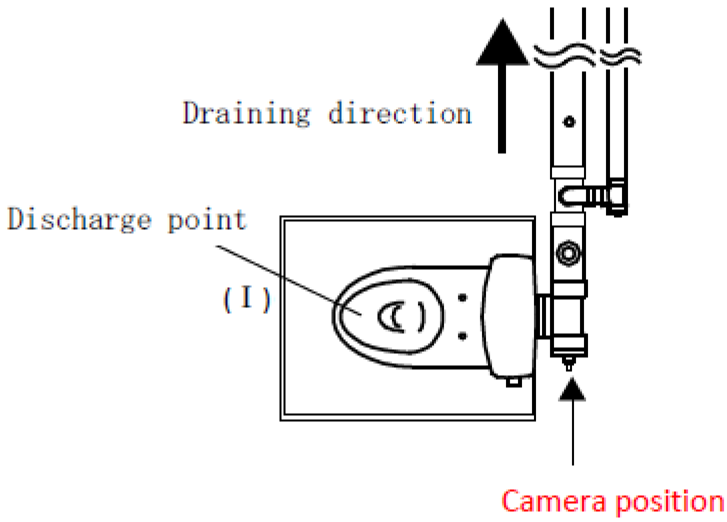
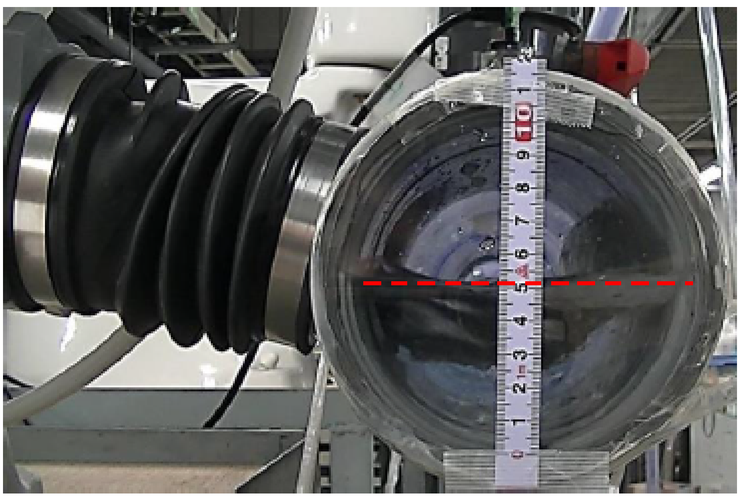


Figure 6 Water levels compared at H1 in relation to the type of fitting





（1） DT fitting

（2）LT fitting

Photo 2 The maximum water level in the cleaning port using each fitting when draining (toilet (I))

3.2 Carrying performance experiment

3.2.1 Single-flush experiment

3.1 On the basis of the results of the fixture discharge characteristics experiment, Figure 7 shows the results of the single-flush experiment in which the same type of fittings were used for connecting the experimental toilets to the horizontal fixture drain branch. In the case of using waste substitute BL, it was drained completely in all of the flushing

patterns when LT fittings were used, but stopped along the horizontal fixture drain branch in some of the flushing patterns when DT fittings were used. In the case of using waste substitutes D and D', which are more difficult to drain, they made shorter carrying distances than BL, and stopped along the horizontal fixture drain branch in all of the flushing patterns, with the exception of toilet (V), when LT fittings were used. When DT fittings were used, D and D' also stopped along the horizontal fixture drain branch in all of the flushing patterns. Moreover, it was found that in all of the flushing patterns, with the exception of toilet (I), using the LT fitting facilitated the carrying performance better than the DT fitting, while using the DT fitting facilitated the carrying performance better than the LT fitting in the case of draining from toilet (I). These results suggest, similar to the results shown in Fig. 5 and 6, that the DT fitting, when compared to the LT fitting, generates a backflow that increases the water pressure and water level in the pipe end, thereby creating a powerful drainage flow. Therefore, it is considered more advantageous to use the DT fitting than the LT fitting for connecting the most upstream toilet (I).

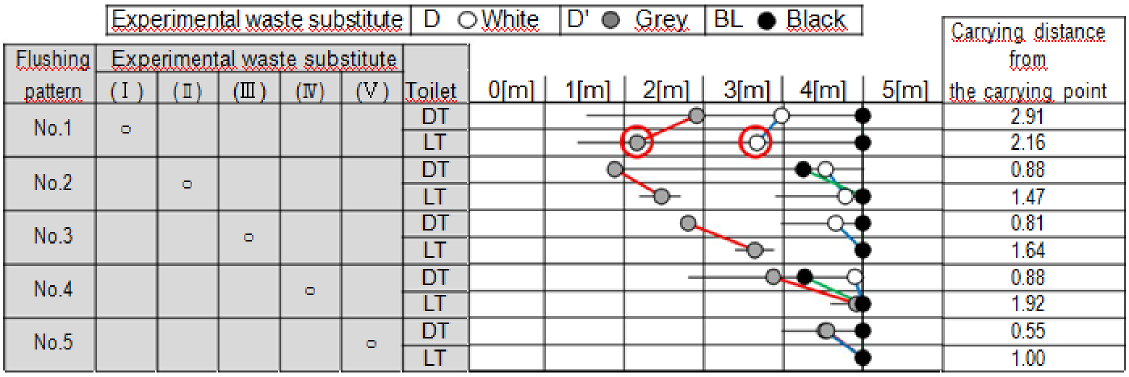


Figure 7 Results of the single-flush experiment

3.2.2 Combined-flush experiment

Figure 8 shows the results of the combined-flush experiment. It was found that the carrying performance was better, generally, when LT fittings were used for connecting the toilets to the horizontal fixture drain branch than when DT fittings were used. However, in flushing patterns 8, 9, 13, 14, 15 and 17, the carrying performance was better when DT fittings were used than when LT fittings were used. This is thought to be because the toilets are arranged with a space therebetween, they did not cause a backflow to each other, and when DT fittings were used, the discharged water was pushed out of the cleaning port by such a force that a strengthened drainage flow increased the force of carrying waste, as in the single-flush experiment.

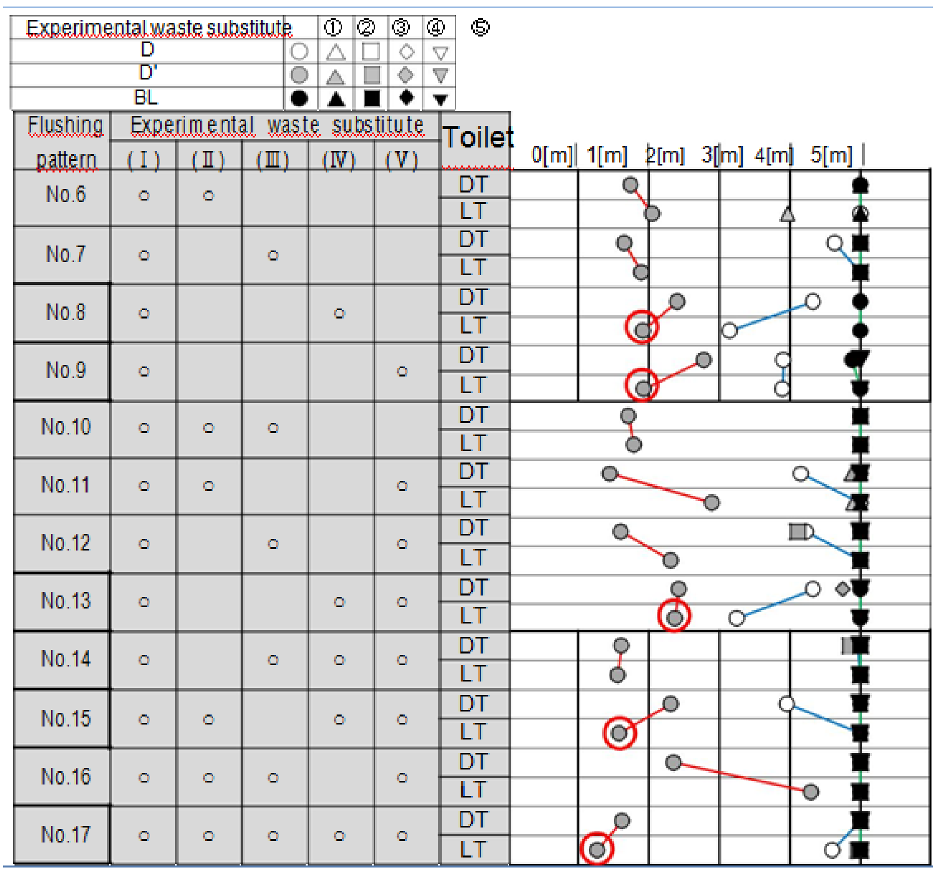


Figure 8 Results of the combined-flush experiment

3.2.3 Proposal of a horizontal fixture drain branch system for improved carrying performance

On the basis of the results of the single-flush and combined-flush experiments, a system for improved carrying performance has been proposed, which is shown in Figure 9. The system employs the combined use of two types of fittings, i.e., the DT type is used for connecting the most upstream toilet (I) and the LT type is used for connecting the other toilets (II)-(V) . Figure 10 shows the results of the single-flush and combined-flush experiments using the proposed system. The flushing patterns 8, 9, 13, 14, 15 and 17 were used, in which the carrying distances were longer when using the DT fitting than when using the LT fitting during the combined-flush experiment, and waste substitute D' was also used. According to Figure 10, in all of the patterns, the carrying performance is as good as, if not better than, when using the DT fitting only. This confirms that the carrying performance is improved by using a DT fitting only for connecting the most upstream toilet to the horizontal fixture drain branch and using LT fittings for connecting the other toilets to the same instead of using just one type of fitting, i.e., DT or LT.

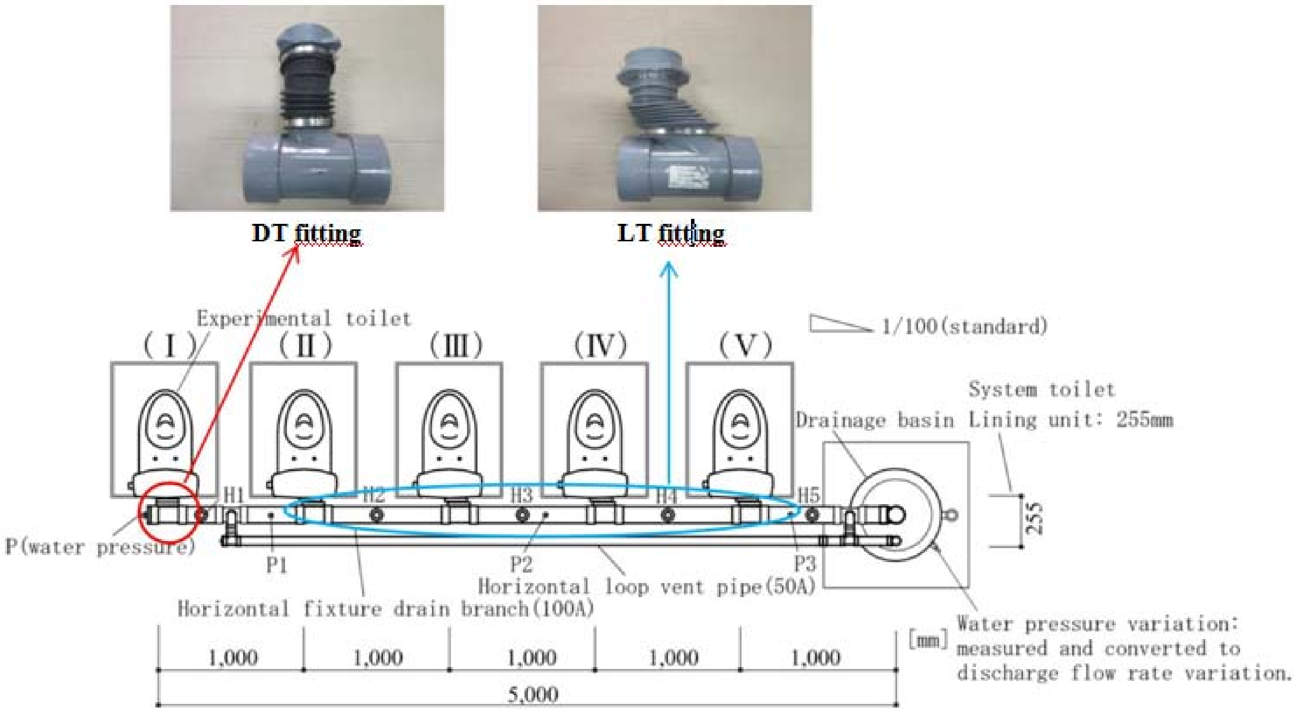
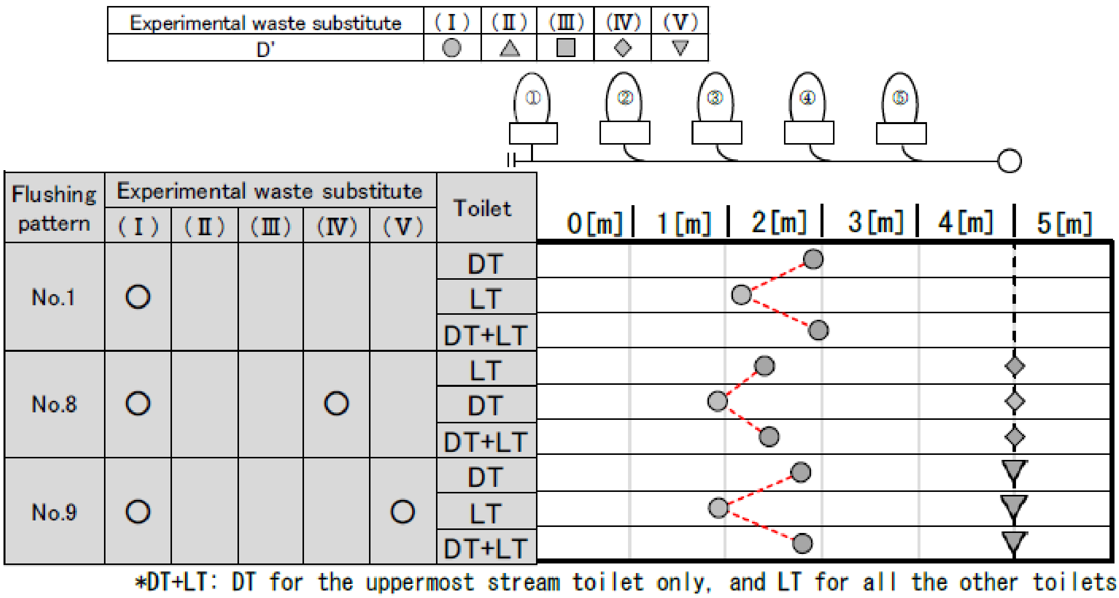
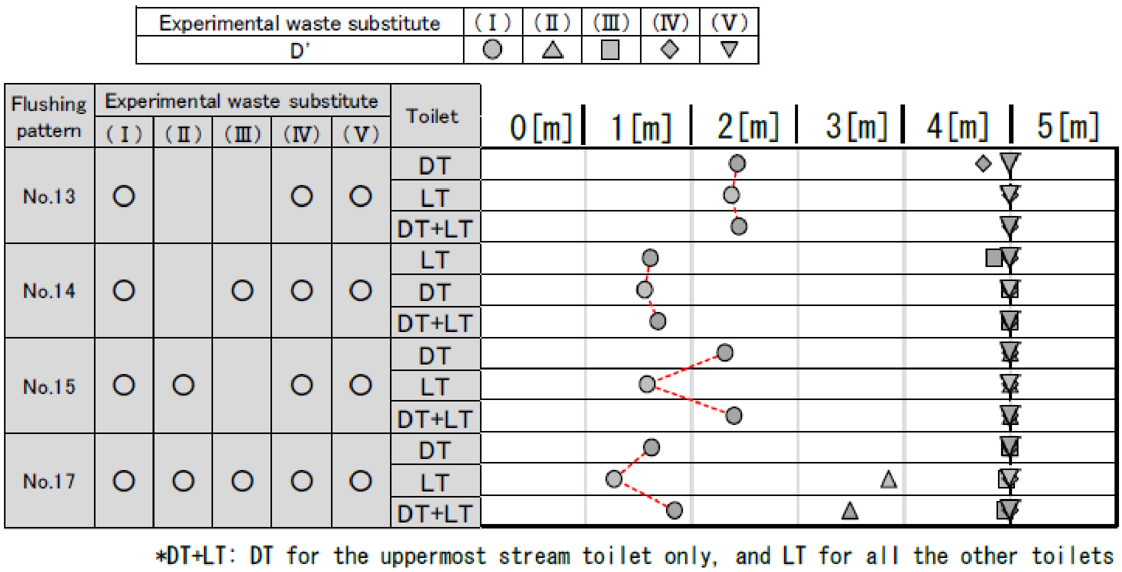


Figure 9 Horizontal fixture drain branch system for improved carrying performance by the combined use of DT and LT fittings



(1) Experiment results (1 or 2 toilets flushed in sequence)



(2) Experiment results (3, 4 or 5 toilets flushed in sequence)

Figure 10 Experiment results by the proposed system for carrying performance improvement

3.3 Fixed-time-period flushing experiment

Figure 11 shows the results of the experiment in which DT fittings were used for connecting all of the experimental toilets and the toilets were each flushed during a fixed period of time. Incidentally, flushing pattern 2 was applied, in which the carrying performance was the poorest when using the DT fitting according to the results of the single-flush experiments shown in Figure 7. The carrying performance results obtained by the fixed-time-period flushing experiment using a pipe pitch of 1/100 indicate that the wastewater can be drained into the drainage stack by two consecutive flushes using 6L of water each time (total of 12L) during a predetermined period of time; 63 hours (roughly 2.5 days) including office closing hours. This confirms that flushing using 12L of water at an interval of 63 hours ensures adequate carrying performance.

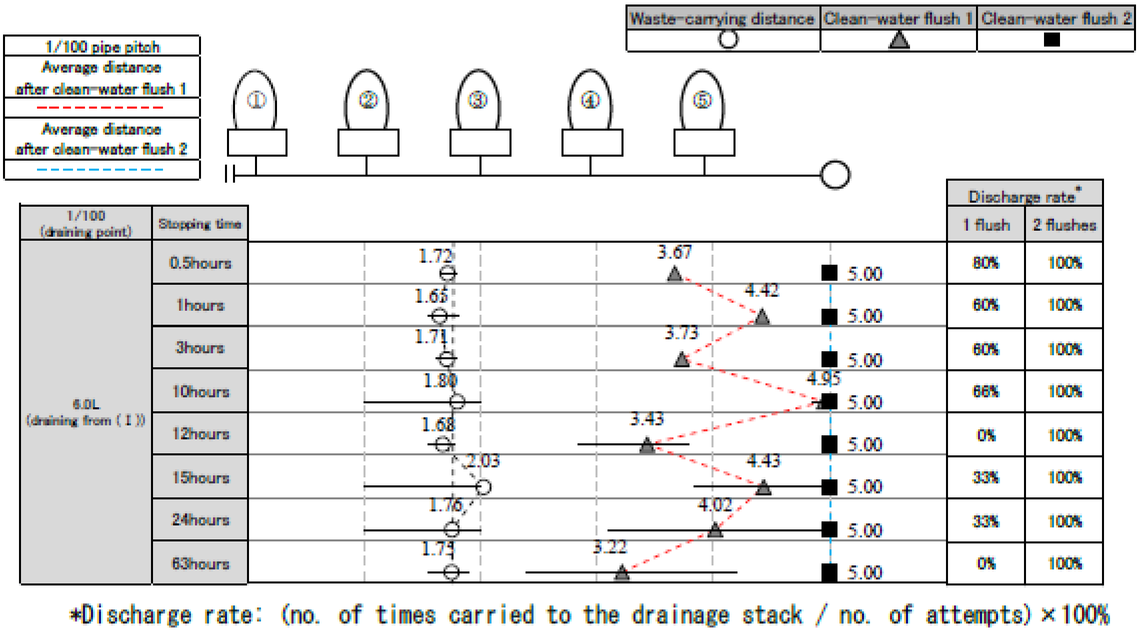


Figure 11 Results of the fixed-time-period flushing experiment (6.0L)

4 Conclusion

Subsequent to the experiments, the study discussed how the shape of fittings used in the horizontal fixture drain branch section affected the carrying performance and how the effect of the fixed-time-period flushing method facilitated the carrying performance. Consequently, the following knowledge was acquired:

(1) In the experimental horizontal fixture drain branch system comprising a horizontal fixture drain branch that is fixed onto a slab floor surface, to which five JIS-A 5207-approved type II water-saving toilets are sequentially connected, the configuration, in which a DT fitting is used for connecting the most upstream toilet and LT fittings are used for connecting the other toilets, improved the carrying performance. This suggests that the combined use of different types of fittings for sequentially connecting toilets to a horizontal fixture drain branch improves the carrying performance.
(2) Regular flushing programmed to carry out flushing within a fixed period of time; 63 hours (roughly 2.5 days) including office closing hours, proves to be effective in ensuring adequate draining into the drainage stack.

5 References

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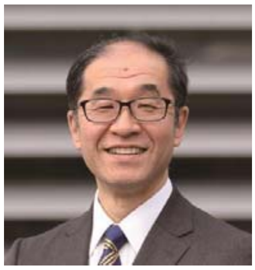
6 Presentations of Authors

Toshiya Kawaguchi is a master of the Otsuka Laboratory, Kanto Gakuin University. He is a member of AIJ and SHASE. His current study interests are to acquire knowledge that is conducive to devising a piping section and a flushing method to improve the carrying performance of a toilet system comprising serially arranged water-saving toilets.



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Analysis of influence of connection of WC on pneumatic pressure in pipes

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Abstract

In the design of a drainage system, allowable drainage flow quantity (drainage capability) is defined for each pipe diameter in order to prevent seal water from breaking. In Japan, SHASE-S 218 (Heating, Air-Conditioning, and Sanitary Standard) stipulates the evaluation standard for drainage capability. Regardless of presence or absence of connection of the traps, there are two types of test criteria. One is that pressure in pipe should fall within ± 400Pa, and the other that seal loss should be less than 25 mm. Nevertheless, recent studies revealed that connecting of traps attenuates pneumatic pressure in pipes and causes a tendency of power spectrum distribution to change. This phenomenon may be attributable to the fact that seal water vibration is a response phenomenon to pneumatic pressure vibration, and that they affect each other.1) In view of this, we conducted discharge experiments based on SHASE-S 218 with and without traps (including WC) using a real size drainage experimental system to clarify how the connection of WC might influence pneumatic pressure.

Keywords

Drainage system, trap, induced siphonage, vibration reply phenomena.

1 Introduction

In Japan, SHASE-S 218 (Heating, Air-Conditioning, and Sanitary Standard) stipulates the test method for drainage capability of drainage stack system. The judging criteria consists of the following two conditions: one that allowable pressure in pipe should fall within ± 400Pa, and the other that seal loss should be less than 25 mm. Although discharge is made from fixtures with varying flow rates in actual drainage system, constant discharge has been the standard discharge mode used in testing to circumvent the problem of selecting a representative fixture for testing. However, there has only been a few quantitative comparisons of pressure vibration in pipe and seal loss in water-saving sanitary fixtures widely used today and in constant discharge in test conditions, and therefore drainage capability may not have been properly evaluated.[2)]

In view of this, we conducted discharge experiments in a real-scale drainage tower to analyze pressure vibration in pipes and seal water fluctuations, and clarified the effect of WC connection on pressure vibrations in pipes, and the relationship between pressure and seal loss as they occur in constant discharge and fixture discharge.

2 Outline of Real-Scale Drainage Tower Experiment

2.1 Purpose

Experiments were conducted to collect data of pressure vibrations in pipes in horizontal branch drainages on each floor and seal water fluctuations and residual seal depths in various test traps when constant discharge load based on SHASE-S218 was applied.

2.2 Experimental drainage system

The outline of the experimental drainage system is shown in Figure 1, and dates of experiments and weather conditions in Table 1. The system used in the experiments is a special fitting drainage system equivalent to a fifteen-story building. Test WCs were installed either on each floor between the 2nd and 12th floors, or on 2nd, 7th and 11th floors. When a WC was used in combination with a contrary bell trap, the trap was placed on the 8th floor and the WC on the 9th.

PVC caps were placed at the ends of horizontal branch drainage on the floors where no traps were connected. Discharge load was made from the 13th ~ 15th floors, and load variations were made in terms of load type and flow rate.

Table 1 Dates of experiments and weather conditions

Experiment condition	WCs		WC
	Between the 2nd and 12th	2nd, 7th and 11th	Contrary bell trap
Dates of experiments	September 14, 2015	November 7, 2013	September 15, 2015
Weather conditions	Cloudy	Cloudy	Cloudy

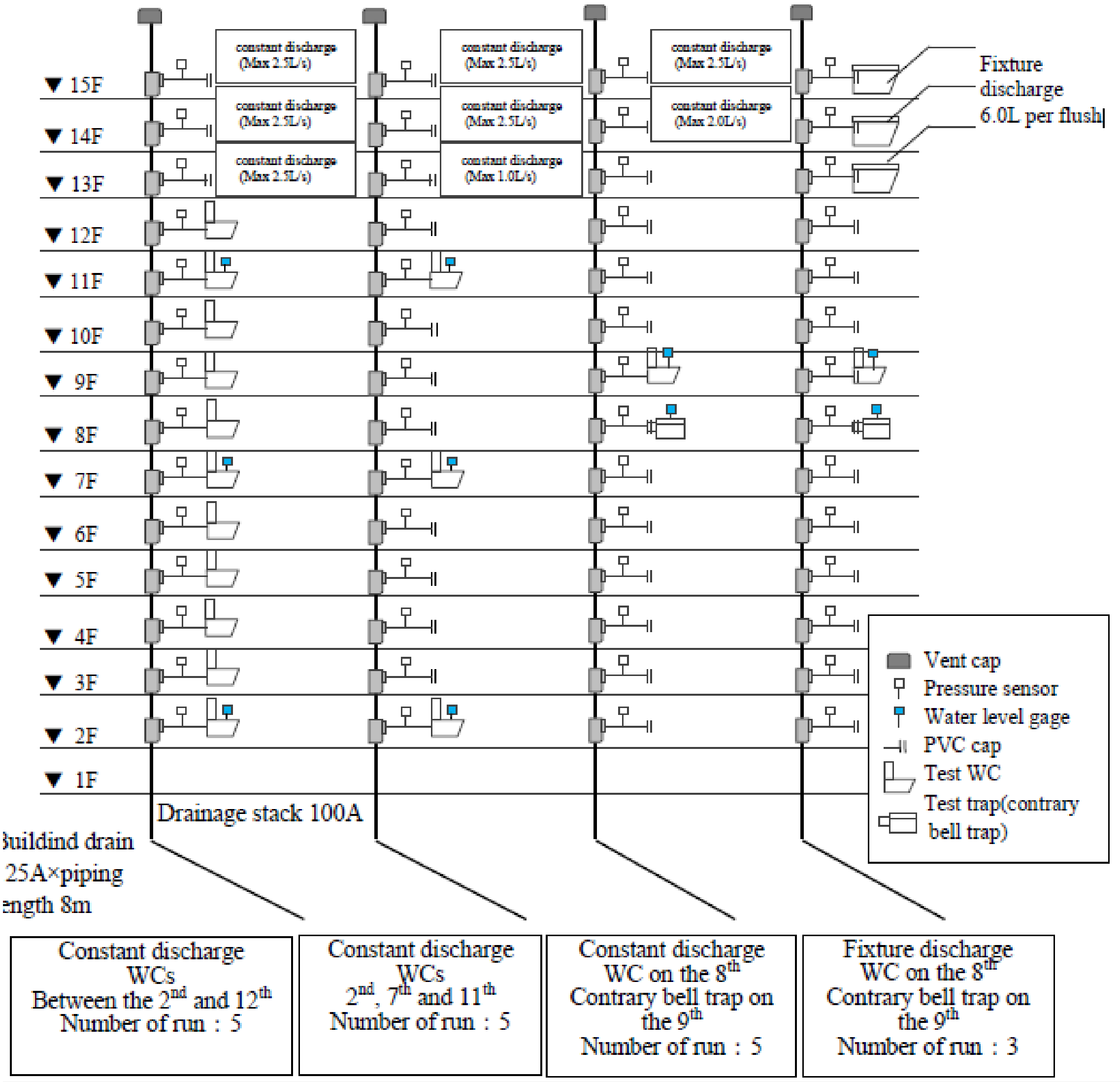


Figure 1 Outline of the experimental drainage system

Table 2 Basic parameters of test traps

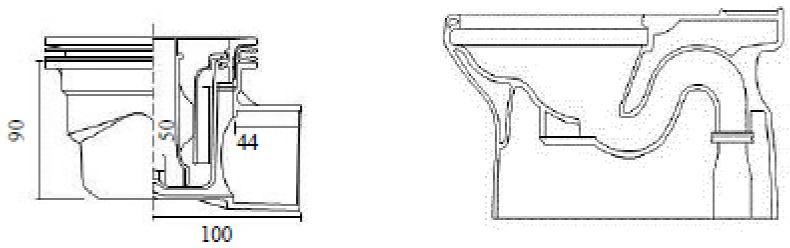
Test WC Test trap	Seal depth [mm]	Seal water [mL]	Ratio of leg's cross sectional area [-]	Characteristic frequency [Hz]	Average drainage rate of fixture [L/s]
Contrary bell trap	50	330	1	2.34	-
WC A	58	2,400	0.16	1.27、2.47	2.2

2.3 Measuring Conditions

Based on SHASE-S218, constant discharge loads (1.5L/s, 3.0L/s, 4.0L/s, 4.5L/s, 6.0L/s) and fixture discharge loads from one to three WCs were applied. Discharge was made 5 seconds after measuring commenced. Pressure vibrations in pipes, seal water fluctuations and residual seal depths were measured at a sampling cycle of 20 m/sec (50 Hz) without low-pass filters. Measurements were made for one minute after the target flow rate was reached in constant discharge, and for 40 seconds in fixture discharge. In both conditions discharging started 5 seconds after the beginning of measurement.

2.4 Test WC and test trap

The cross-sectional views of a test trap with a water level sensor and a test WC are shown in Figure 2, their basic parameters in Table 2. WC of siphonic drainage type with 6.0 L per flush was used as test WCs. All traps were filled as default.



Contrary bell trap WC A [mm]

Figure 2 Cross-sectional views of a test trap and a test WC A

3 Effects of load type on pressure vibrations in pipes and seal water fluctuations

3.1 Purpose

Fluctuation wave patterns were analyzed to clarify the pressure vibrations in pipes for each load type and the characteristics of seal water fluctuation.

3.2 Method of analysis

The wave patterns of pressure vibrations in pipes and seal water fluctuation were compared for each load type. Standard deviations (SD) were calculated and pressure vibrations in pipes and seal water fluctuation were quantitatively compared.

3.3 Results

3.3.1 Constant discharge load

Figure 3 shows the representative wave patterns of pressure vibrations and seal water fluctuations when WCs were placed on all the floors and three floors. Figure 4 illustrates SD of seal water fluctuation when fixed flow rate load was 4.0 L/s.

The ranges of seal water fluctuation wave patterns for each discharge type increased as the discharging floor got lower. This can be clearly seen in Figure 4. SDs of seal water fluctuation on the 2nd floor for both all-floor WC placement and 3-floor placement were approximately 2.5 times larger than those on the 11th floor. This can be attributed to the fact that the pressure vibration in pipes on the lower floors mainly consisted of positive pressure as opposed to that on the higher floors that consisted of negative pressure.

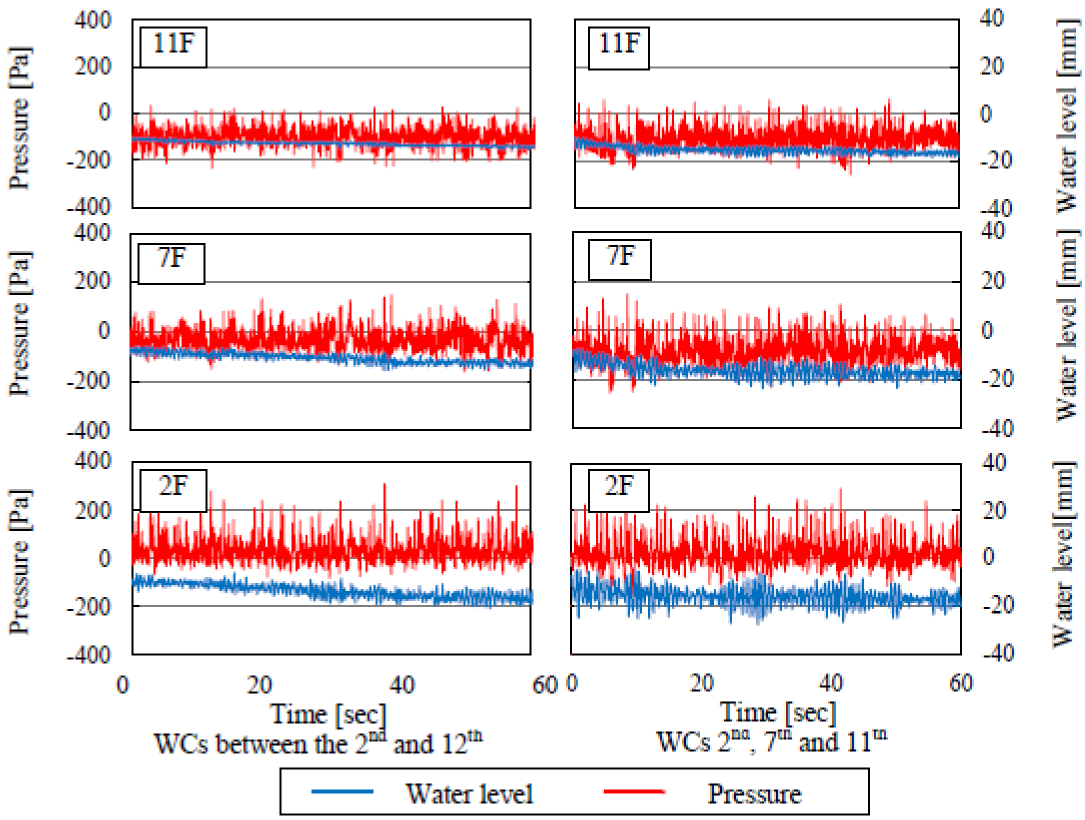


Figure 3 Examples of pressure fluctuation wave patterns and seal water fluctuation wave patterns (4.0L/s)

Figure 4 also indicates that the range of seal water fluctuation wave patterns in all-floor WC placement was smaller than that in 3-floor placement. It can be assumed that in all-floor placement, seal water on each floor had an influence on pressure vibration in pipes, and as a result pressures in pipes were made to reduce near the floors where traps were connected.

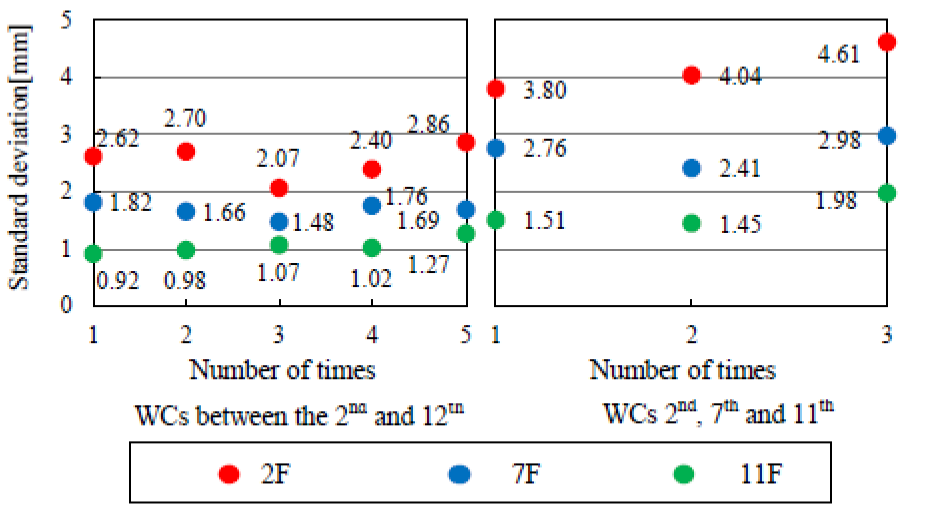


Figure 4 Illustrates SD of seal water fluctuation(4.0L/s)

3.3.2 Fixture discharge load

Figure 5 shows some examples of the wave patterns of pressure vibration in pipes and seal water fluctuation. The wave patterns of seal water fluctuation corresponded with pressure vibration as seal water fluctuated in response to pressure in pipes when maximum pressure was produced right before discharged water passed through, and then seal loss occurred. Seal water in contrary bell trap had larger range of fluctuation than WC.

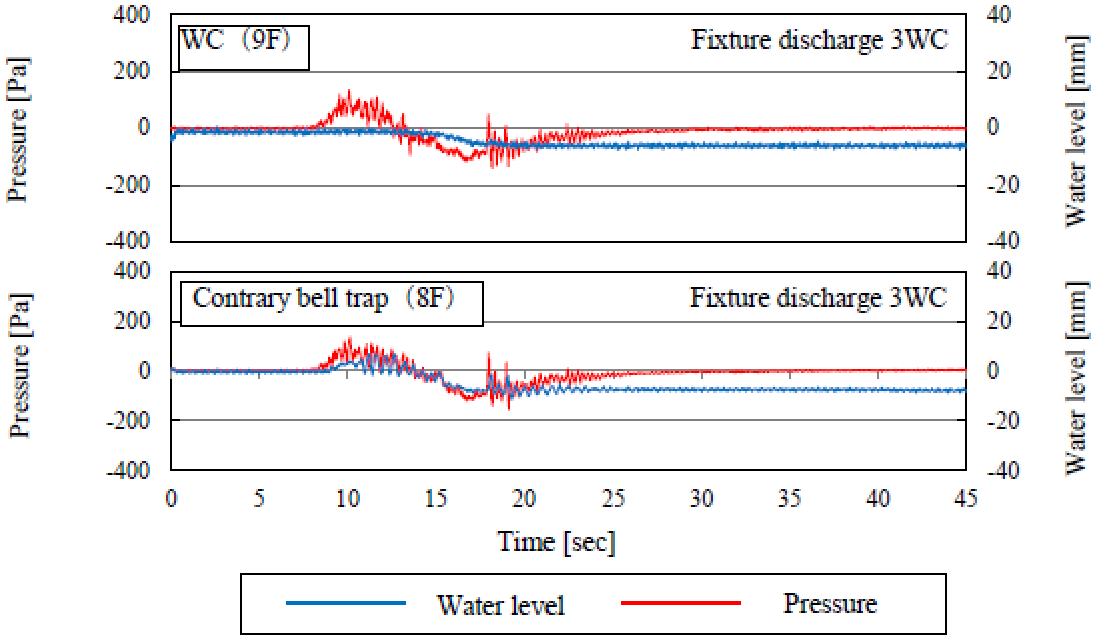


Figure 5 Examples of the wave patterns of pressure vibration in pipes and seal water fluctuation

3.3.3 Comparison between constant discharge load and fixture discharge load sd of seal water fluctuation is shown in figure 6. seal water fluctuation wave

SD of seal water fluctuation is shown in Figure 6. Seal water fluctuation wave patterns differed greatly depending on the load type. Figure 6 clearly shows this with SD of seal water fluctuation in contrary bell trap being two to three times larger than that in WC. The structure and water seal of trap may have been the cause of difference in seal water fluctuation among traps.

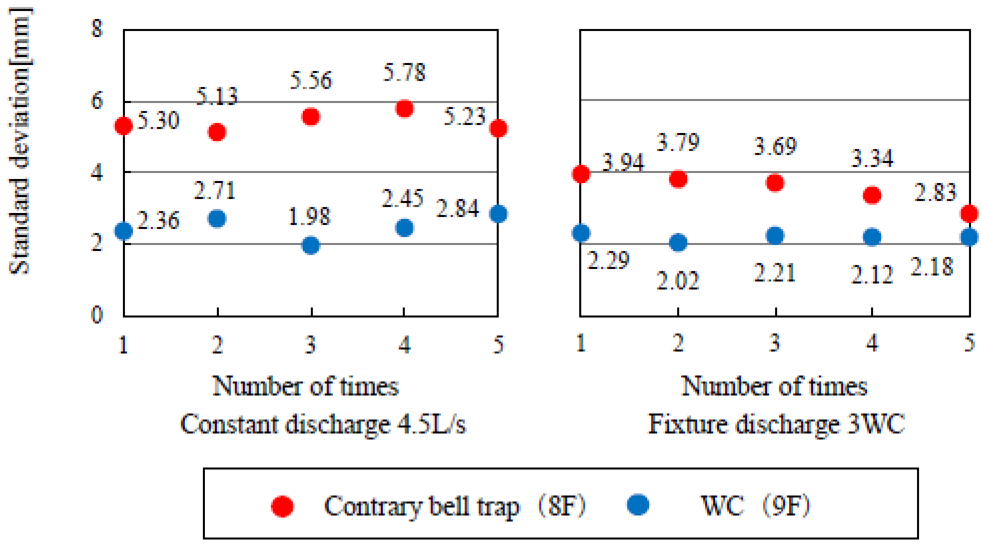


Figure 6 SD of seal water fluctuation

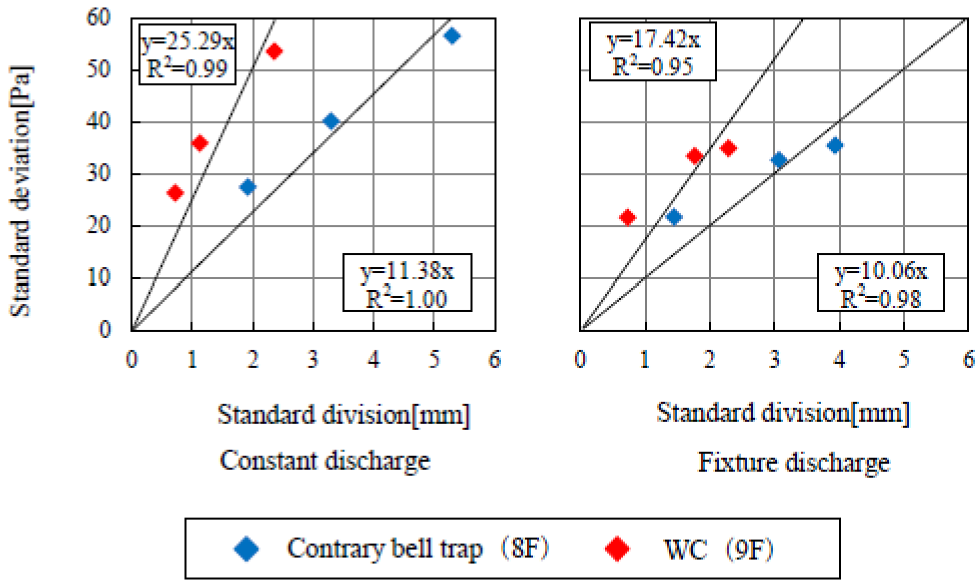


Figure 7 Scatter diagrams of SDs of pressure vibration in pipes and seal water fluctuation, and their primary regression equations

The scatter diagrams of SDs of pressure vibration in pipes and seal water fluctuation, and their primary regression equations are shown in Figure 7. The regression coefficient a and the ratio of regression coefficient of constant discharge to fixture discharge αare shown in Table 3. Form Figure 7, it was found that there is a high correlation between SD of pressure vibration in pipes and SD of seal water fluctuation as the determination coefficient R2 was 0.95 ~ 1.00, which is quite high for both constant discharge and fixture discharge. The ratio of regression coefficient αwas 1.13 for contrary bell trap on the 8th floor and 1.45 for WC on the 9th floor (Table 3).

Table 3 Regression coefficient a and the ratio of regression coefficient of constant discharge to fixture discharge αTable 4

Floor	Regression coefficient (a)		Ratio of regression coefficient (α)
	Constant discharge	Fixture discharge	
8(Contrary bell trap)	11.38	10.06	1.13
9(WC)	25.29	17.42	1.45

4 Effects of Load Type on Pressure in Pipe and Seal Loss

4.1 Purpose

We conducted experiments in a real-scale drainage tower and analyzed pressures in pipes and seal loss to clarify the relationship between discharge type and seal loss on each floor according to the number of WCs installed, and to quantitatively compare pressure in pipes and seal loss between fixture discharge load and constant discharge load.

4.2 Method

Seal losses in each type of discharge and load were compared. The correlation of seal loss of trap with minimum pressure on the floors where traps were placed was also examined.

4.3 Results

4.3.1 Constant Discharge Load

The relationship of seal loss on each floor in each type of discharge is shown in Figure 8. In constant discharge of 4.0 L/s, seal loss was largest on the 2^{nd} floor and smallest on the 11^{th} floor. This may be explained by the fact that positive pressures dominated on the 2^{nd} floor, and as seen in Figure 3, that seal loss as a result of locally produced positive pressures of 300 Pa overrode seal loss produced by negative pressures. In constant discharge of 6.0 L/s, seal losses tended to be roughly equal on the 2^{nd}, 7^{th} and 11^{th} floors. This seems to have been caused by the comparable negative pressure produced on these floors when discharge flow rate was 6.0 L/s.

4.3.2 Constant Discharge Load

Seal loss on each floor for each discharge type is shown Figure 9. For both contrary bell trap and WC, seal loss in constant discharge was larger than that in fixture discharge. The scatter diagram and primary regression equation for minimum pressure in pipe and seal loss in each load type are shown in Figure 10. The regression coefficient a and the ratio of regression coefficient of constant discharge to fixture discharge αare shown in Table 4. Figure 10 shows that the determination coefficient.

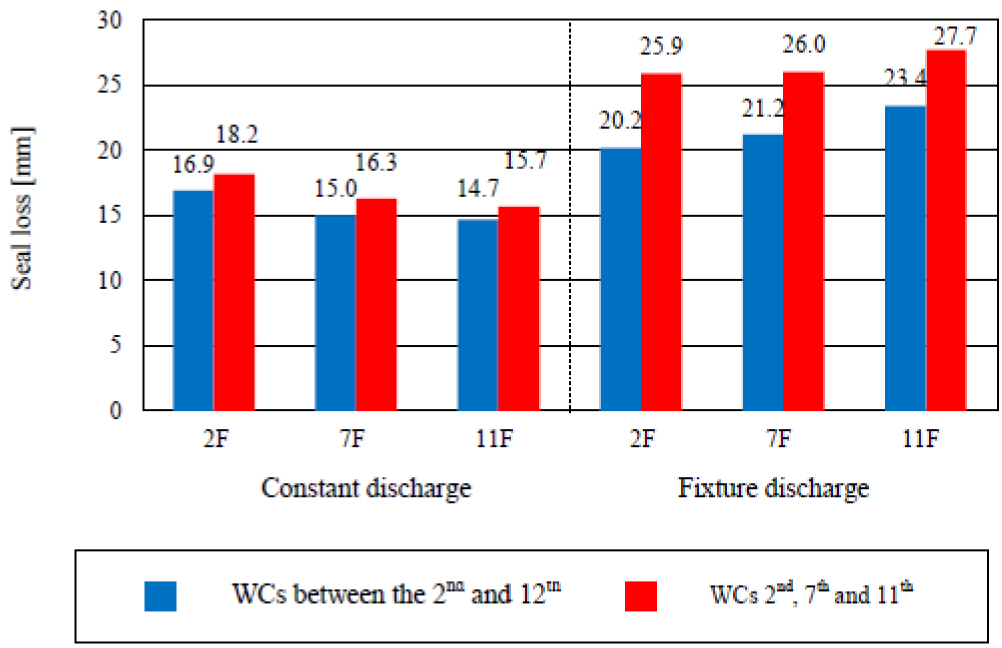


Figure 8 Relationship of seal loss on each floor in each type of discharge

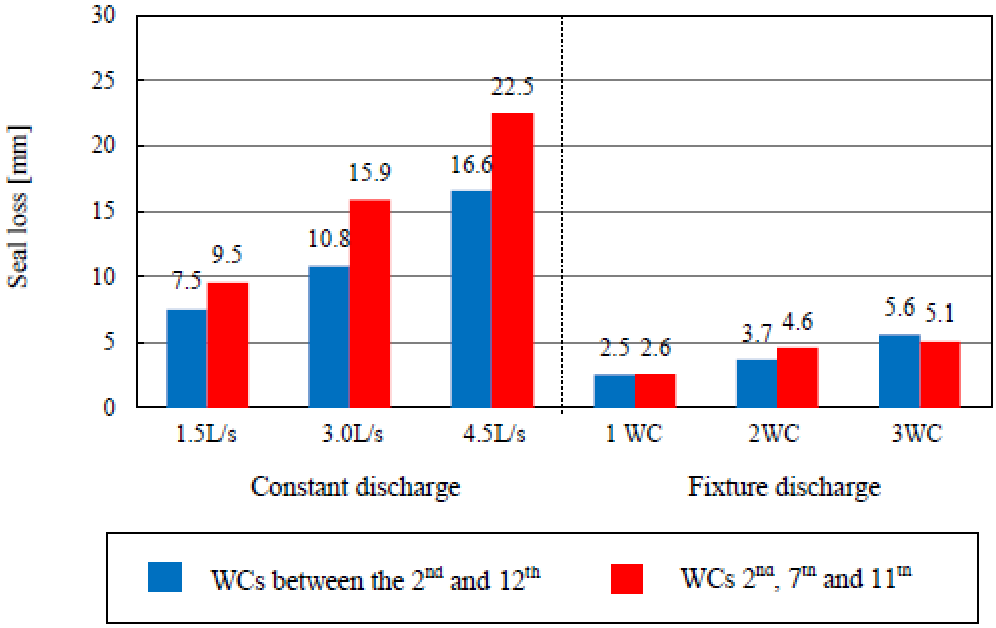


Figure 9 Seal loss on each floor for each discharge type

R2 was high (0.72 ~ 0.92) indicating a high correlation between minimum pressure in pipe and seal loss. In Table 4, the ratios of regression coefficient for contrary bell trap (8th floor) and WC (9th floor) were 1.63 and 1.98 respectively. From this it can be expected that seal loss in contrary bell trap would be about 1.6 times, and that in WC is about 2 times as large in constant discharge as in fixture discharge given a similar level of negative pressure are present. Also there seems to be a significant difference in the ratio of regression coefficient α among the test traps.

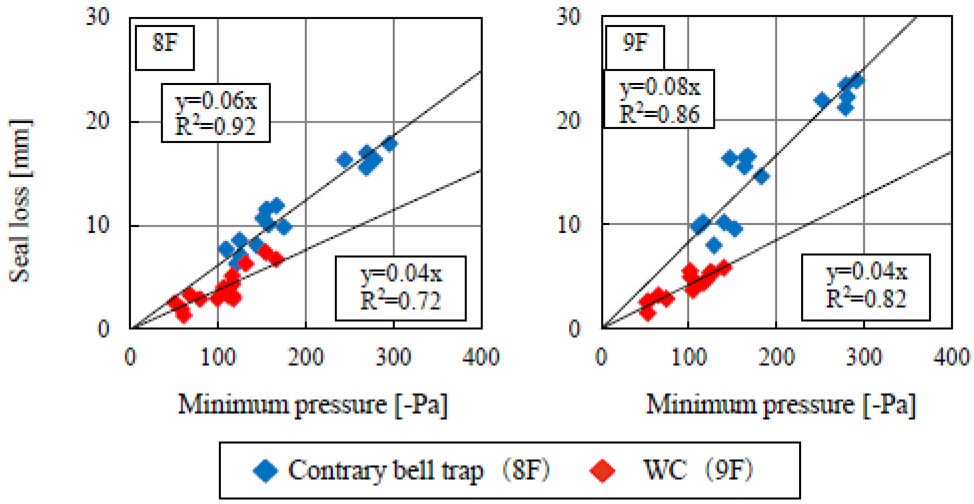


Figure 10 The scatter diagram and primary regression equation for minimum pressure in pipe and seal loss in each load type

Table 4 Regression coefficient a and the ratio of regression coefficient of constant discharge to fixture discharge α

Floor	Regression coefficient (a)		Ratio of regression coefficient (α)
	Constant discharge	Fixture discharge	
8(Contrary bell trap)	0.062	0.038	1.63
9(WC)	0.083	0.042	1.98

5 Conclusion

In this study, pressure vibration in pipes and seal water fluctuation data collected in a real-scale drainage tower experiments were analyzed. The results can be summarized as follows:

1) The greater the number of WCs installed, the less likely the occurrence of seal loss. The factor here seems to be the water seal of traps that are connected.
2) The range of seal water fluctuation wave patterns tended to be larger on the lower floors than on the higher floors.
3) Seal loss in contrary bell trap is approximately 1.5 to 2 times larger in constant discharge than in fixture discharge. However, no significant differences in seal loss due to load type were observed in WC.

The problem of reducing seal loss and seal water fluctuation SDs with increasing water seal is yet to be resolved in the future. We also need to give consideration to the method of evaluating the effects of seal loss on pressure vibration in pipes.

6 Reference

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2. Takahashi M., Sakaue K., toyama T., fujimura K. (2014), Characteristics of pressure in test drainage system with traps for flow capacity, *Proceedings of CIB W062 International Symposium (pp. 199-210)*

7 Presentation of Authors

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Study on a technology to suppress calcified urine in a horizontal branch drainpipe system where multiple urinals are installed successively

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Abstract

As part of the measure to prevent global warming, water efficiency of urinals as well as water closets has become essential. Moreover, blockage of drainpipes caused by adhesion and deposition of calcified urine after long-term use has become a problem in public and office buildings, where multiple urinals are installed successively. This experimental study aims at the basic verification for the development of a toilet system that helps suppress adhesion and deposition of calcified urine in multiple water efficient urinals installed successively. Performance evaluations on three indices of backflow distance, rise in water level and residual concentration in the drainpipe were conducted using a system consisting of a horizontal branch drainpipe and three urinals installed successively. We have verified the influence of different drainage fittings, and effective periodic cleaning method to clean high-concentration residual water that remains in the system after flushing. As a result of this study, we have gained the basic knowledge in order to propose a cleaning method and an ideal system of horizontal branch drainpipe to suppress adhesion and deposition of calcified urine.

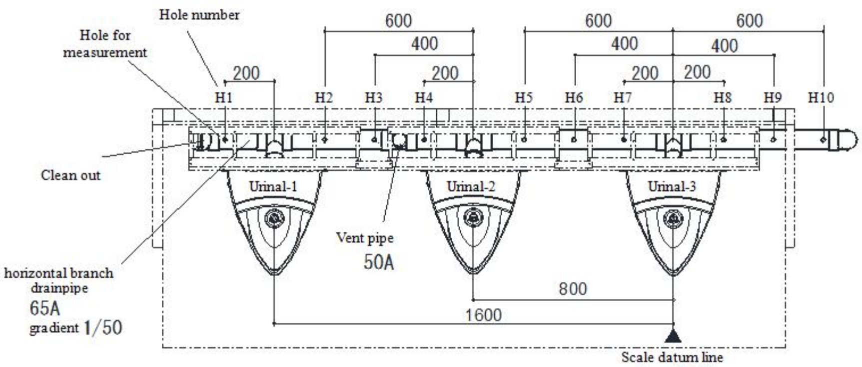
Keywords

Multiple urinals installed successively, calcified urine, water-efficient-type.

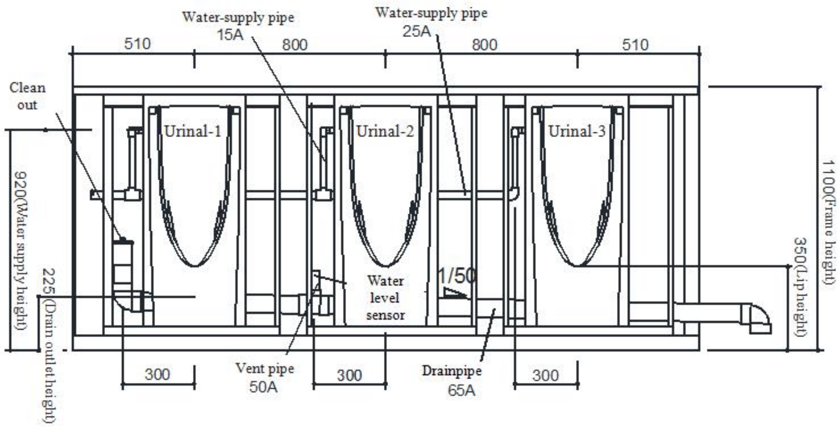
1 Introduction

As part of the measure to p revent global warming, water efficiency of u rinals as well as water closets has become e ssential. In addition to water efficiency, there is a demand in Japan to improve mainte nance and cleaning performances. Moreover, blockage of drainpipes caused by adhe sion and deposition of calcified urine after lo ng-term use has become a problem in public and office buildings, where multiple urin als are installed successively. (See photograph 1[1)])
This experimental study aims at the basic verification for the develop ment of a toilet system that helps suppress adhesion and deposition of calcified urine in multiple water-efficient urinals installed n ext to each other.

Photo 1 Horizontal branch drainpipe for urinals and appearance of adhesion and deposition of calcified urine in the drainpipes



(1) - Top view



(2) - Front view

Figure 1 Horizontal branch drainpipe system used in the experiment

2 Overview of the experiment

2.1 Horizontal branch drainpipe system used in the experiment

As equipment for this test, urinals whose flush volume can be switched between 2.0L, 1.0L and 0.5L to clean the system after use are implemented. 2.0L, 1.0L and 0.5L flushes presume, standard-type, water-efficient-type and super-water-efficient-type, respectively. Figure 1 shows the horizontal branch drainpipe system to which the urinals are installed for this test. In the Figure, we have numbered the urinals, urinal-1, urinal-2 and urinal-3 from upstream to downstream. In addition, there is a hole for measurement on the upper surface of the horizontal branch drainpipe at the point 200mm upstream measured from the center of the point where the horizontal branch drainpipe and drainpipe for urinal-1 are connected. In addition to this hole, which will be referred to as H1, H2 to H10 are present at 200mm pitch in the areas excluding the back of each urinal, allowing totals of 10 holes for measurement. We adopted a 65A-diameter horizontal branch drainpipe, JIS-DT-fittings (referred to as Tees) for drainage, and gradient of 1/50.

2.2 Overview of various experiments

Three types of experiments were performed as below:

1) Performance evaluation of a standard horizontal branch drainpipe system, assuming use in office buildings or the like.
2) Similar experiment to confirm the influence of drainage fitting structure, conducted after changing the JIS-DT-fittings in the horizontal branch drainpipe system in experiment (1) to JIS-LT-fittings (Usually referred to as Sanitary Tees).
3) Evaluation of the cleaning water for periodic cleaning which is expected to be effective in suppressing adhesion and deposition of calcified urine.

On a different note, the calculation based on the drainage loads revealed that the diameter of a standard horizontal branch drainpipe with three urinals installed, would be either 40A or 50A. However, considering the likelihood of blockage of the drainpipe caused by adhesion and deposition of calcified urine, we decided to use a 65A-drainpipe, which is larger than the calculated value.

2.3 Cleaning method and drainage load patterns

Cleaning method for experiment (1) and (2) is normal cleaning after use. 1%-concentration salt water is used as urine substitute. Based on the actual volume and flow rate of urination by a male adult, 300mL of urine substitute is poured into the urinal at flow rate of approximately 25mL / s. The urinal is then flushed with 1.0L, 2.0L or 0.5L of water. With this series of operation as 1 cycle, 3 cycles are performed successively. After 3 cycles, items of Clause 2.4 described below are measured.

Drainage load patterns are single-instrument drainage and multiple-instrument drainage with merging flow. To confirm single-instrument drainage, normal cleaning is performed in one of the urinals. To confirm multiple-instrument drainage with merging flow, normal cleaning is performed in two or more urinals. Example of drainage timing of normal cleaning at each urinal to confirm multiple-instrument drainage with merging flow is shown in Figure 2. For multiple-instrument drainage

with merging flow, based on the drainage timing of normal cleaning at urinal-1 located upstream, drainage of urinal-2 and urinal-3 is to merge the drainage coming from upstream with 1 second time lag at each urinal.
In experiment (3), after 3 cycles of operation in aforementioned ex periment (1) of urinal-1, periodic cleaning is performed at the same urinal.
There are two methods of p eriodic cleaning as described below:

A. Flushing 2.0L clea ning water in a single flush
B. Flushing 2.0L clea ning water in two flushes:

20 seconds after flushing 1.0L of cleaning-water, another 1.0L of cleaning-water is flushed.
After periodic cleaning, ite m c) of Clause 2.4 described below is mea sured in order to verify and compare effects.

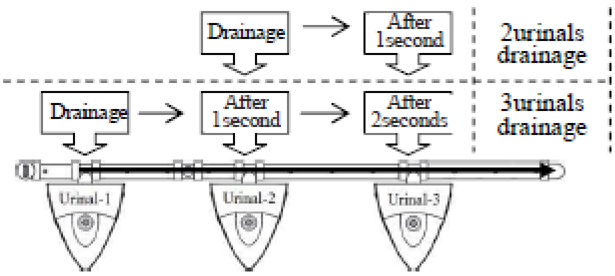


Figure 2 Example of drainage timing of normal cleaning at eac h urinal in the multiple-instrument drainage with merging flow

2.4 Measurement items and measurement methods

There are three evaluation indices in this study as described below:

a) Backflow distance:

Visually confirm the point to which cleaning water backflows toward upstream of the horizontal branch drain pipe.
The datum position of the measurement shall be the center of the mer ging point of the horizontal branch drainpipe behind each urinal.

b) Rise in water level in the horizontal branch drainpipe:

Take a straight scale with calligraphy practice paper placed vertical, put it into the hole for measurement. Me asure the height of calligraphy practice paper that was wetted by the cleaning water.

c) Concentration of residual urine substitute:

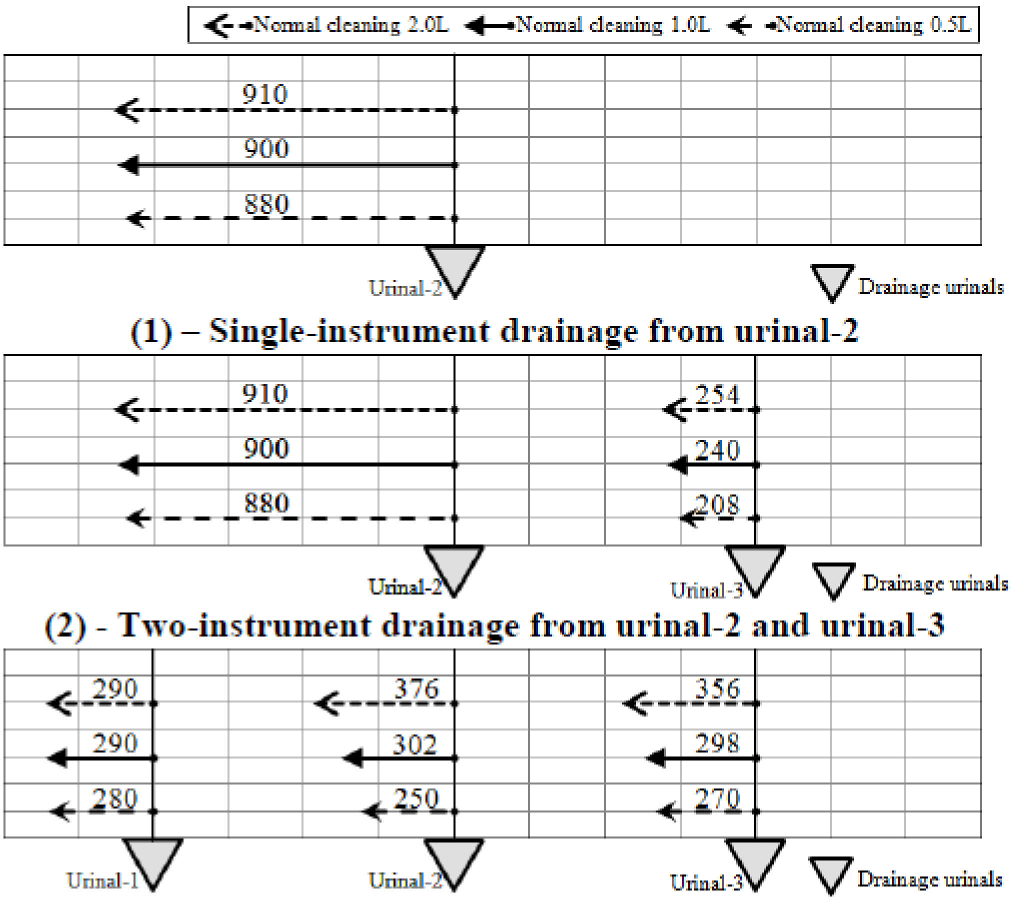
After cleaning, take the u rine substitute remaining in the horizontal branch drainpipe from the hole for measurement, measure electrical conductivity, a nd calculate the concentration from the ratio of electric conductivity of the charged urine substitute. (1% concentration saline)

3 Results and discussion

3.1 Experiments to evalua te performance in the horizontal branch drainpipe system

Measurement results at each flow volume in the horizontal branch d rainpipe system using JIS-DT-fittings are shown in Figure 3 to Figure 5. Figures 3, 4 and 5 show respectively, backflow distance, rise in water level and the concentration of residual

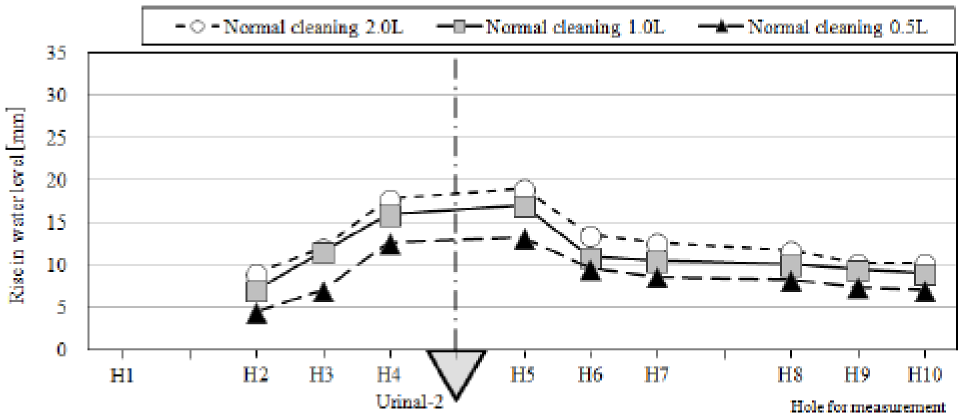
urine substitute in the horizontal branch drainpipe. (1) shows single-instrument drainage from urinal-2, (2) shows two-instrument drainage from urinal-2 and urinal-3, and (3) shows three-instrument drainage from urinal-1, urinal-2 and urinal-3.
According to Figure 3, in both single-instrument drainage and multiple-instrument drainage with merging flow, as the volume of cleaning water was increased, the backflow distance also increased. We believe that the flow rate from the urinal being greater than that of the flow toward downstream of the horizontal branch drainpipe accounts for this. With larger volume of water and longer cleaning time, more cleaning water flows toward upstream, resulting in the increased distance of backflow. Also, the backflow from the urinal located downstream goes as far as the position of adjacent urinal located upstream.



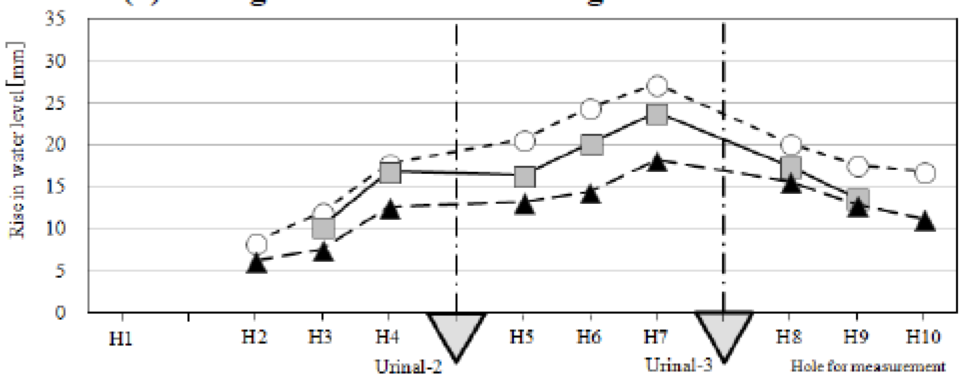
(3) -Three-instrument drainage from urinal-1, urinal-2 and urinal-3
Figure 3 Backflow distance

According to Figure 4, in both single-instrument drainage and multiple -instrument drainage with merging flow, as the volume of cleaning water was increased, water level in the horizontal branch drainpipe was also elevated. In addition, at the point where the drainage from each urinal collides in multiple-instrument drainage with merging flow, water level was elevated to up to approximately 1/2 of the diameter of the drainpipe, when measured from the bottom of the drainpipe.
According to (1) and (2) of Figure 5, there was almost no difference in the concentration of residual urine substitute in single and two-instrument drainage, irrespective of the volume of cleaning water. We believe that the water with high-concentration urine substitute in the urinal trap initially discharged toward both up

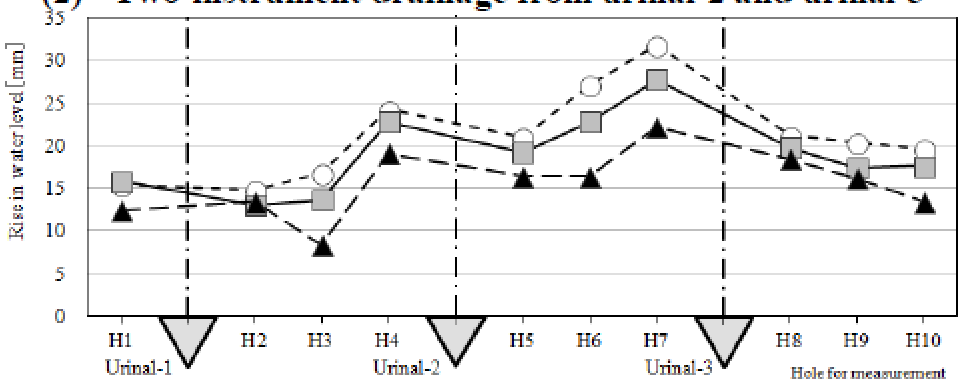
and downstream, and the backflow of water with high-concentration urine substitute accounts for this.



(1) – Single-instrument drainage from urinal-2



(2) - Two-instrument drainage from urinal-2 and urinal-3

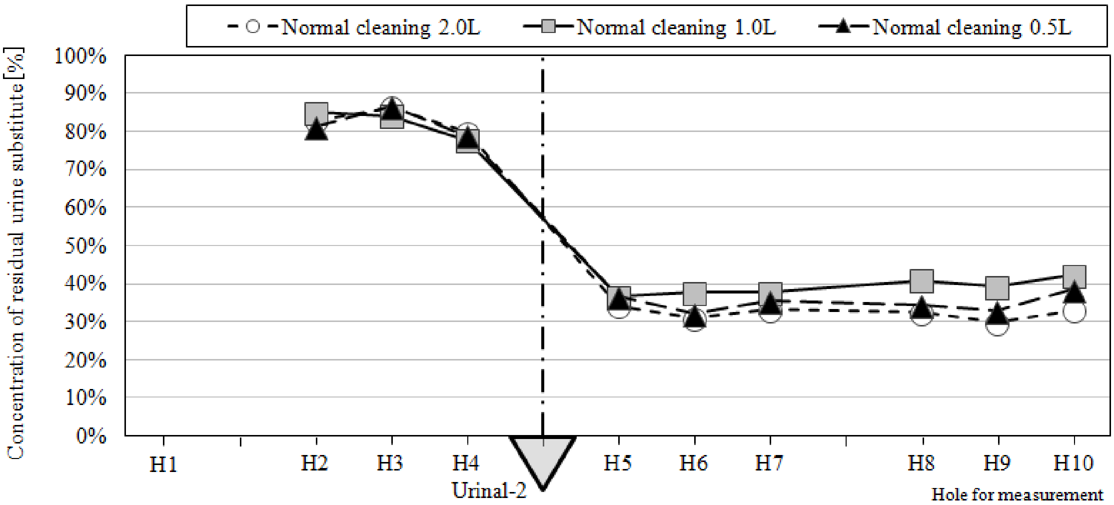


(3) - Three-instrument drainage from urinal-1, urinal-2 and urinal-3

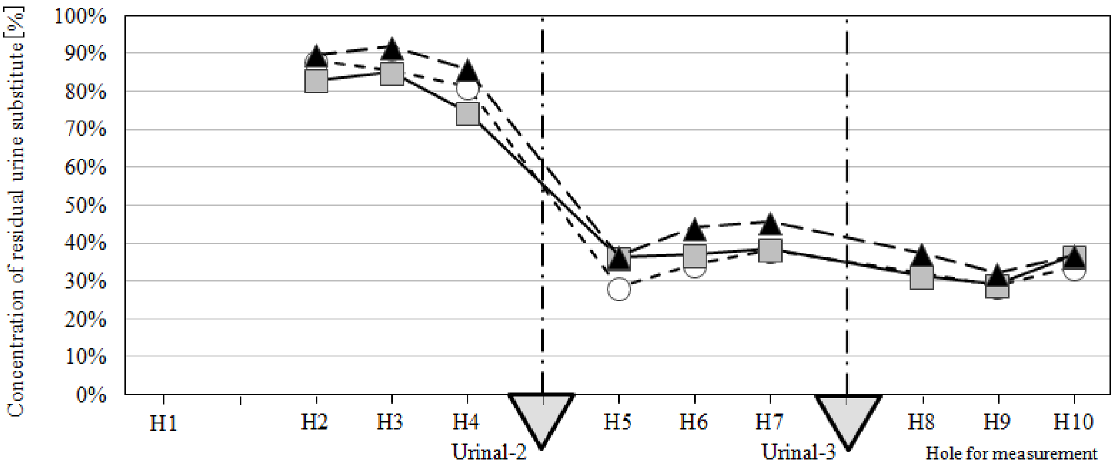
Figure 4 Rise in water level in the horizontal branch drainpipe

At first, water with high-concentration urine substitute backflows. Subsequently, water with low-concentration urine substitute is drained from the urinal, but most of this flow is directed toward downstream of the horizontal branch drainpipe. Simultaneously, water with high-concentration urine substitute upstream is pushed up even further. Once the drainage from the urinal completes, water with high-concentration urine substitute backflowing at the end of the sequence, will eventually come down. Regardless of the volume of cleaning water, concentration of residual urine substitute exceeds 30% in downstream following completion of drainage. Furthermore, the concentration upstream is considerably high at approximately 80%. On the other hand, in the three-instrument drainage shown in

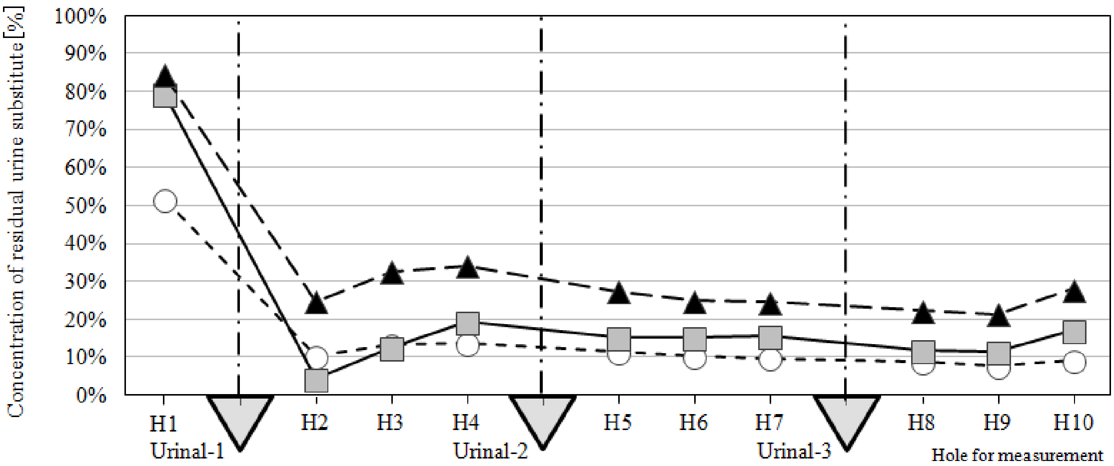
(3) of Figure 5, concentration of residual urine substitute decreases as the volume of cleaning water is increased. Therefore, there is a maximum difference of approximately 20% between 0.5L and 2.0L flushes.
As explained above, by varying the volume of cleaning water among 2.0L, 1.0L and 0.5L, backflow distance and rise in water level in the horizontal branch drainpipe will also vary. On the other hand, we have also learned that given that there is enough space upstream of the urinal lo cated upstream, even if the backflow hits the maximum distance without constraint s, concentration of residual urine substitute remained nearly unchanged. Given these r esults, we conclude that there is feasibility in reducing the volume of water for norm al cleaning from 2.0L for standard-type to either 1.0L for water-efficient- type or 0.5L for super-water-efficient-type.



(1) – Single-instrument drainage from urinal-2



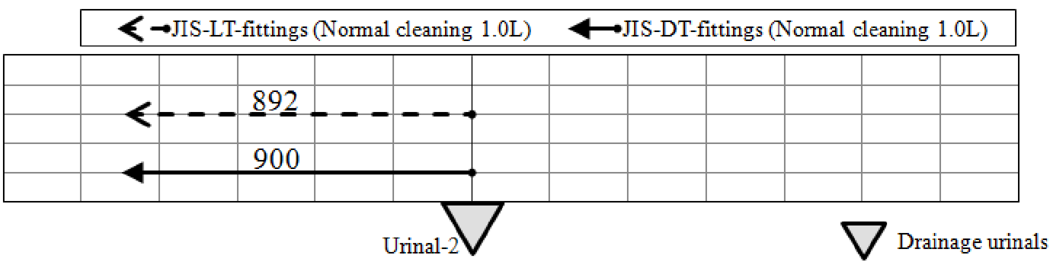
(2) - Two-instrument drainage from urinal-2 and urina l-3



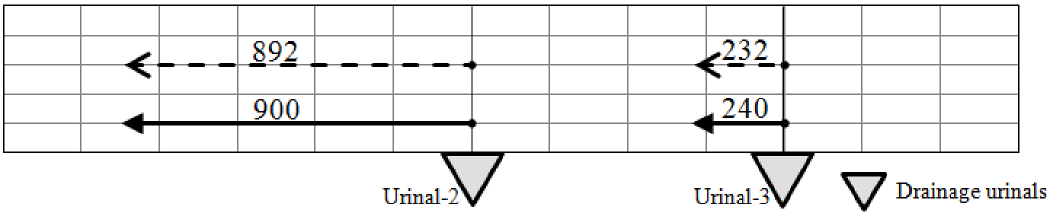
(3) - Three-instru ment drainage from urinal-1, urinal-2 and urinal-3
Figure 5 Concentration of residual urine substitute

3.2 Experiment to confir m effects of drainage fitting structure

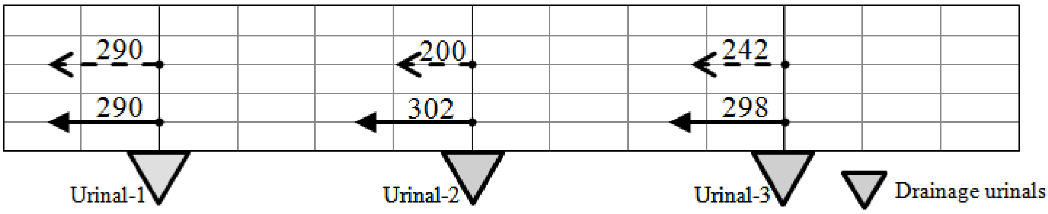
Figure 6 shows a compari son of backflow distance where JIS-LT-fitti ngs and JIS-DT-fittings were used respect ively in the horizontal branch drainpipe, with volume of cleaning water being 1.0L. Backflow distance was less significant where JIS-LT-fittings were used versus where JIS -DT-fittings were used:
-approximately 8mm in the single-instrument drainage shown in (1);
-approximately 48mm at the position of urinal-2, and approximat ely 8mm at the position of urinal-3 in the two-instrument drainage shown in (2); and
-approximately 102mm at the position of the urinal-2, and approximately 56mm at the position of urinal-3 in the three-instrument drainage shown in (3).
In addition, at the position of urinal-2 in both single-instrument drainage and multiple-instrument drainage with merging flow, the difference of backflow distance resulting from use of different fitting s was found to be more significant. This can be explained by the fact that the curvature radius at merging point of JIS-LT-fittings is l arger than that of JIS-DT-fittings, and that the merging point is located toward downstream.



(1) – Single-instrument drainage from urinal-2

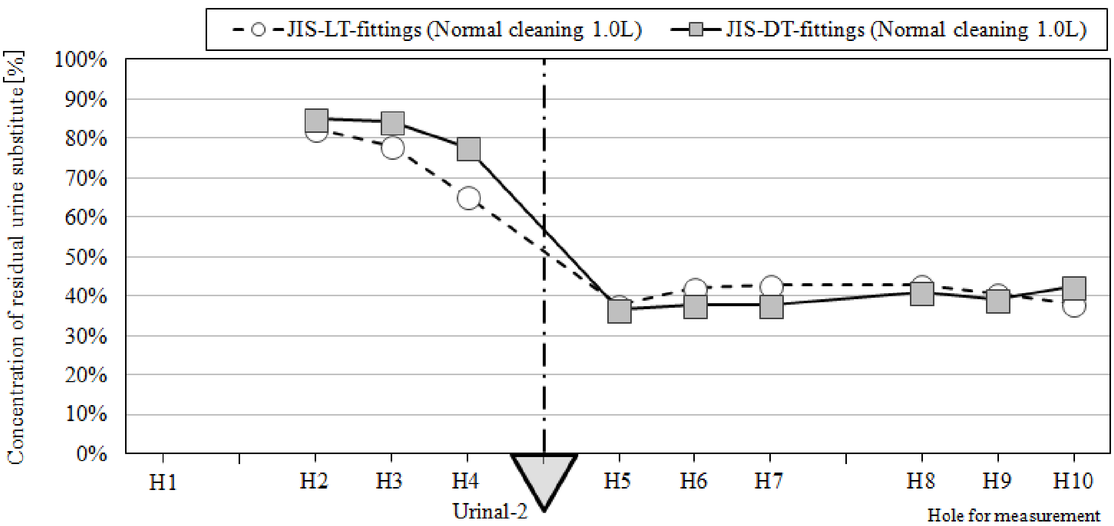


(2) - Two-instrument drainage from urinal-2 and urina l-3

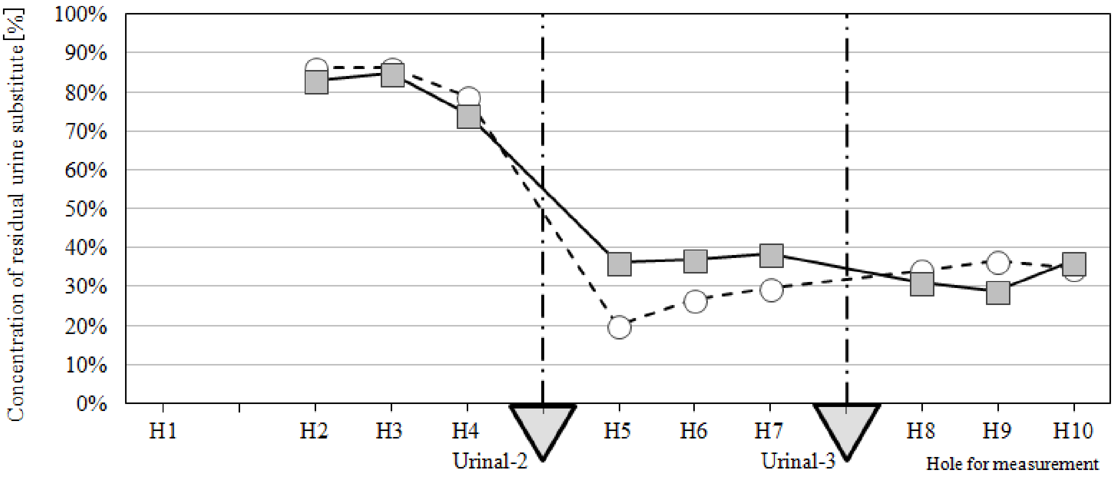


(3) - Three-instru ment drainage from urinal-1, urinal-2 and urinal-3
Figure 6 Backflow distance

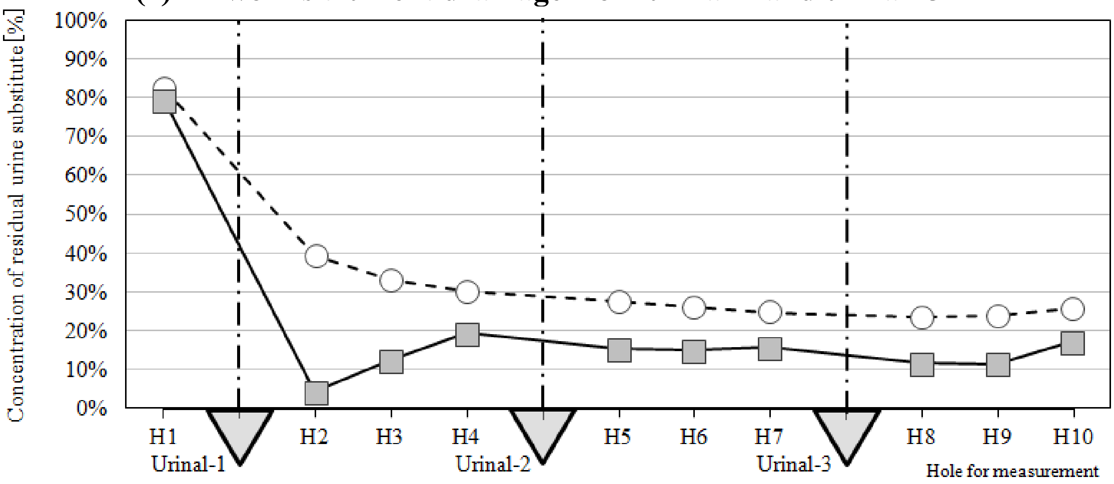
Figure 7 shows the compaarison of concentration of residual urine su bstitute resulting from use of different fittings, with volume of cleaning water being 1.0 L. According to (1) and (2) of Figure 7, there was almost no difference found in concentration of residual urine substitute in single and two-instrument drainage. On th e other hand, at certain points in the areas behind urinial-2, concentration of residual urine substitute was found to be lower wh ere JIS-LT-fittings were used versus where JIS-DT-fittings were used. This is explained by the fact that this area at the merging point of JIS-LT-fittings is partially stirred w ith water with low-concentration urine substitute in the latter half of drainage action. (3) of Figure 7 shows that the concentration of residual urine substitute with three-instr ument drainage with JIS-LT-fittings is hig her compared to JIS-DT-fittings. This high-concentration of urine substitute is believed to be caused by the high-concentration urin e substitute drained from urinal-1, which re mains pushed up to the part of the clean o ut located in the upstream end, and flows down in the end without being stirred in the process. Thus, given that the cleaning water hits the maximum distance without any constraints, slight stirring effect can be expected, but not in cases with restrictions.



(1) – Single-instrument drainage from urinal-2

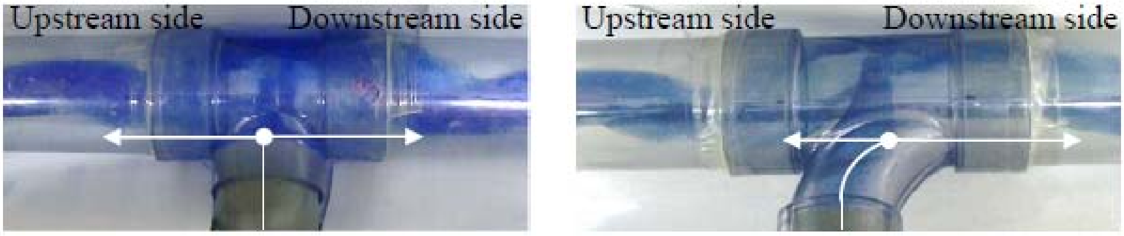


(2) – Two-ins trument drainage from urinal-2 and urina l-3



(3) – Three-instru ment drainage from urinal-1, urinal-2 and urinal-3
Figure 7 Concentration of residual urine substitute

Photograph 2 shows the fl ow of water in the fittings incurred by the drainage from the urinal. (1) shows the case with JIS-DT-fittings and (2) shows the case with JIS-LT-fittings. As the comparison of (1) and (2) reveals, while there is almost no difference in the flow toward up and d ownstream where JIS-DT-fittings are used, the flow toward downstream is stronger and the flow toward upstream is weaker wher e JIS-LT-fittings are used. When backflow distance of the cleaning water is restricted as it is in the upstream of urinal-1 causing weaker flow upstream, it is believed that the cleaning water in the latter half with low-concentration urine substitute w ould not travel upstream following the initial backflow of high-concentration urine substitute. Instead, most of this low-concentr ation urine substitute is directed downstrea m. Judging from above results, in multiple-instrument drainage with merging flow, concentration of residual urine substitute is higher where JIS-LT -fittings are used co mpared to where JIS-DT -fittings are used. Also, in view of the spatial restrictions of the horizontal branch drainpipe system, JIS-DT-fittings are considered more desira ble as drainage fitting.



(1) The case of JIS-D T-fittings **(2) The case of JIS-LT-fittings**

Photo 2 Water flo w in the fittings incurred by the drainage from the urinal

3.3 Experiment to confir m the effect of periodic cleaning

Figure 8 show the concentration of residual urine substitute follow ing normal and periodic cleanings at each flush volume of normal cleaning at urinal-1. Regardless of the flush volume of norm al cleaning, concentration of residual urine substitute in the horizontal branch drainpip e following periodic cleaning was decreased to less than 1%. Although concentration of residual urine substitute upstream of urinal-1 is extremely high after normal cleaning, it is lowered once periodic cleaning is perf ormed, obtaining the same effect as in down stream. Since periodic cleaning is also effective in cleaning the areas upstream, and the same level of cleaning effect can be obtained at any flush volume of normal cleaning , it is possible to reduce the concentration of residual urine substitute in the horizont al branch drainpipe, and it is believed to be effective in suppressing calcified urine .

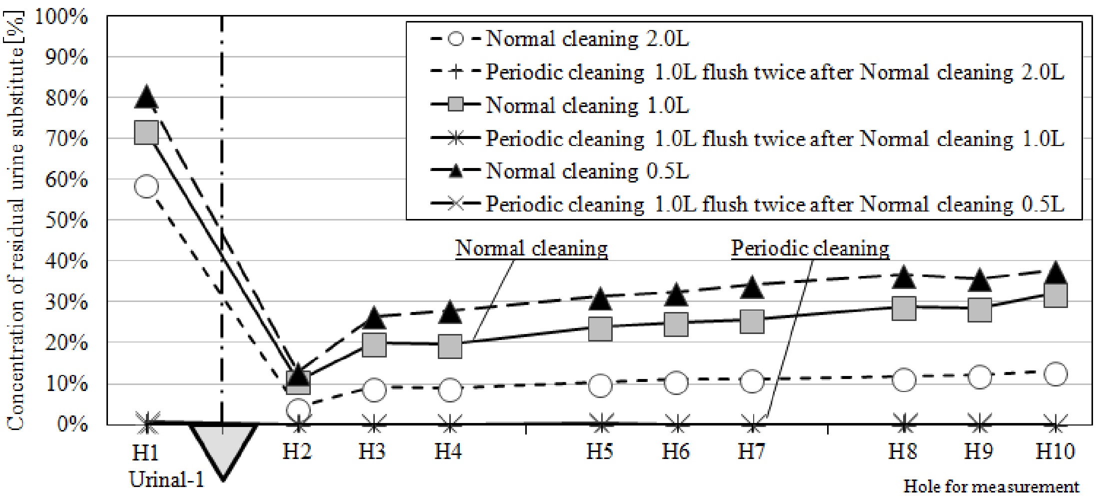


Figure 8 Concentratio n of residual urine substitute after normal cleaning and periodic cleaning

Figure 9 shows the compaarison of concentration of residual urine su bstitute resulting from different cleaning m ethods of periodic cleaning (A and B show n in Clause 2.3). Where 1.0L was flushed t wice, concentration of residual urine substitute was lowered by up to approximately 0.4% compared to where 2.0L was flushed in a single flush, and to less than half as a whole. As in the case of normal cleaning, since the amount of backflowing cleaning water is restricted, more cleaning water will backflow when
flushed twice. Since periodic cleaning allows more clean water to backflow, sufficiently reducing high-concentration urine substitute remaining after normal cleaning, it is believed that this leads to suppression of calcified urine in the entire

horizontal branch drainpipe.

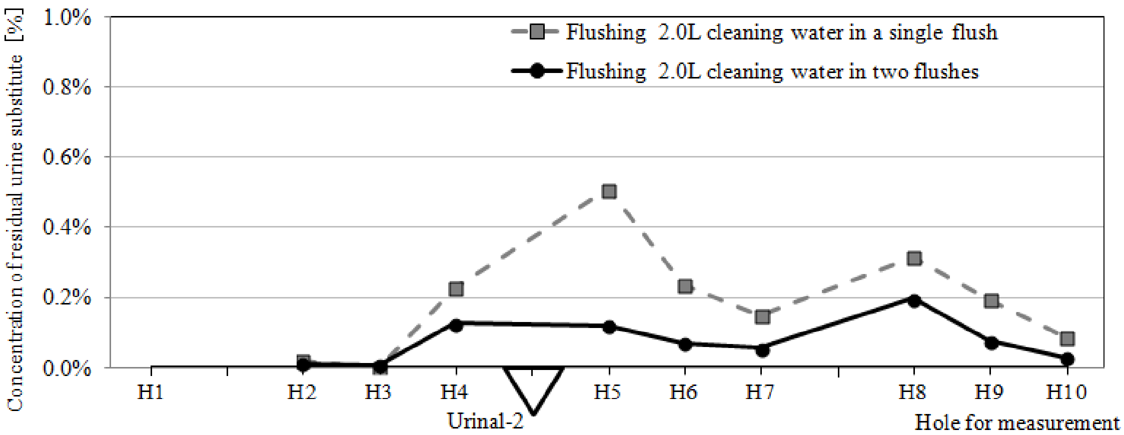


Figure 9 Comparison of concentration of residual urine substitute after periodic cleaning caused by different cleaning methods

4 Conclusion

Regardless of the flush volume of normal cleaning, water with high urine concentration in the trap of the urinal backflows, and the concentration of residual water in horizontal branch drainpipe remains high following normal cleaning. Since it was confirmed that the concentration of the residual water is about the same level regardless of the volume of cleaning water, use of 0.5L water for normal cleaning for a super-water-efficient-type is considered feasible. Concerning the structure of the drainage fittings, considering the results of concentration of residual urine substitute in the multiple-instrument drainage with merging flow, and spatial restrictions of the horizontal branch drainpipe system, JIS-DT-fittings is considered more desirable. Periodic cleaning is effective in reducing the concentration of residual water in the horizontal branch drainpipe, and multiple flushes rather than a single flush is believed to be more effective. It is our understanding that this is also effective in suppressing calcified urine. Based on above results, we conclude that the basic knowledge on the configuration of horizontal branch drainpipe system suitable for suppression of calcified urine and a method of periodic cleaning has been obtained.

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A study on characteristics of siphonic drainage systems with extra small diameter piping

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Abstract

Drain water is produced by the air conditioner during cooling operation or dehumidifying operation, and drain pipes are necessary to discharge it. However, these joints often produce a water leak accident.
The use of the siphonic drainage system with flexible pipes makes it possible to drain with no slopes and no joints, and it also expects to step over other pipes. In this paper, we conducted experiments on the air conditioning drain using siphonic drainage system with PVC tube (φ4,6,8,10mm) and 10m long actual-scale horizontal piping models. We also conducted experiments with two types of supply flow rate (0.4, 0.85L/min), using drain pump, and two types of piping, horizontal piping and step over piping, which assumed the pipe to step over other pipes. Finally, we analyzed the flow characteristics and compared with those of theological results.
It became clear that there were suitable pipe diameter (8,10mm), and these results had slight differences between horizontal piping and step over piping.

Keywords

Drainage system, siphonic, small diameter piping, air conditioner.

1 Introduction

The siphonic drainage system derives its power of transport from siphonic negative pressure generated by the fill flow of discharged water through the pipe. Having strong power of transport and requiring no slope in piping, it gives freedom to designing [1].

The previous studies have made some useful propositions on the use of siphonic drainage system in wastewater discharging. Also some reports have been made on the flow characteristics in siphonic drainage models targeting at application to long piping such as factory disposal [2].

In the current study, some experiments were conducted in view to applying siphonic drainage system to air-conditioning drain. There is a possibility of water leak in the conventional air-conditioning drainage piping that relies on gravity with a large number of fittings connected. It also requires slope and puts restrictions on the freedom of designing piping layouts. On the other hand, the siphonic drainage system that uses flexible pipes requires fewer connections and reduces the risk of water leak. In addition, it expands the freedom of designing as it does away with slope for discharging. Furthermore, it can save space by utilizing extra small diameter piping to match the flow rate of drain water, and even expects to step over other pipes.

In view of the situation, we made a drainage model simulating an air-conditioning drain pipe and conducted experiments to examine flow phases by the pipe diameter and flow characteristics when step over piping were made. We have also verified the accuracy of theoretical values by comparing them with actual measurements.

2 Method

2.1 Experimental Device

The outline of a piping model is shown in Figure 1. Transparent flexible PVC tubes (φ4,6,8,10mm) were used and drain pumps with the supply flow rate of 0.4, 0.85 L/min were placed at the inlet section. With the horizontal length of 10 m, and the outflow head of 1.5 m; the piping was laid out in such a way that step over pipings could be made at 2 m and 6 m from the inlet section. There were five bent sections and pressure was measured at three points; the inlet section, outlet section and measuring tank.

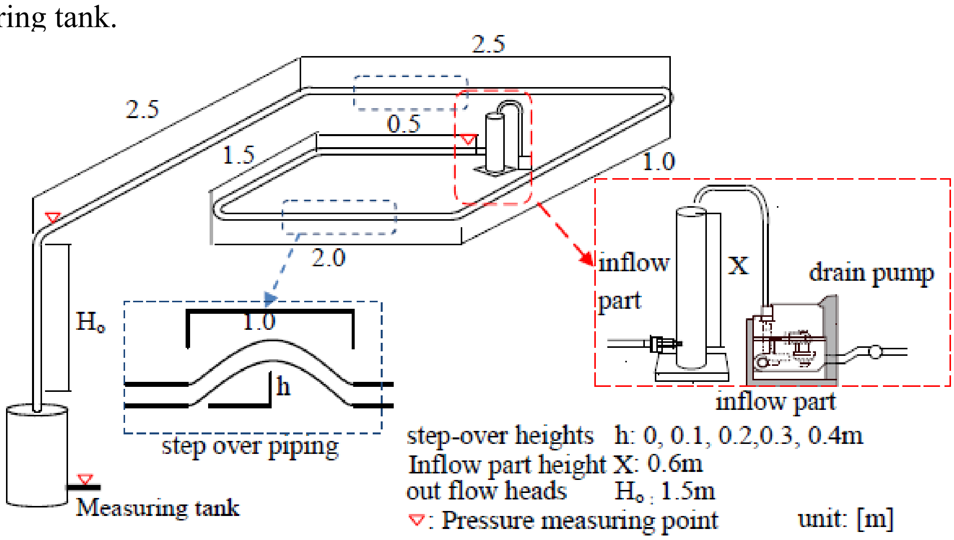


Figure 1 Outline of experimental device

2.2 Experimental conditions

Experimental conditions are shown in Table 1. Four different diameters pipes: φ4mm, 6mm 8mm, 10mm were used. Either one step over piping at 2 m from the inlet section, or two step-over piping at 2 m and 6 m were made with the step-over heights of 0.1 m, 0.2 m, 0.3 m, or 0.4 m. When there were two step over piping, they had the same step-over heights.
Measurements were made three times for two minutes each after water is supplied from the drain pump to the inflow part in each experimental condition (48 patterns in total).

Table 1 Experimental Conditions

diameter of piping [mm]	supply flow rate [L/min]	the number of step over piping	step-over height [m]
4 • 6 • 8 • 10	0.40	0 • 1 (2m point) • 2 (2m and 6m point, examine only 10mm)	0.1 • 0.2 • 0.3 • 0.4
	0.85		

3 Results and Discussion

3.1 Flow Phase

3.1.1 Without Step Over Piping

Although Siphonage occurred in all experimental conditions, there were leaks from the inflow parts with the pipe diameters 4mm and 6mm. The pressure that was required to keep the pipe filled with water seemed to have been too high and caused water to flow over the inflow parts. Pressure vibrations by the pipe diameter at the supply flow rate of 0.4 L/min. without step over piping are shown in Figure 2.
Three different flow phases (referred to as the siphon model A, the siphon model B, and the siphon model C below) according to the relationship of supply flow rate with pipe diameter and discharge flow rate were observed. The flow phase models are shown in Figure 3.
In the siphon model A, siphonage repeatedly occurred and ended in accordance with the fluctuations or water level in the inflow parts. Siphonage stopped when no water was left in the inflow part and air entered the pipe. It was seen in the pipe diameter 10mm in this experiment. In the siphon model B, siphonage with low pressures continued even after the water in the inflow parts disappeared and air entered the pipe, and continued only when supply and discharge flow rates were brought into balance. This was seen in the pipe diameters 10mm and 8mm. In the siphon model C, siphonage occurred as in the other models, and continued without the water level going down as the supply flow rate was large in relation to discharge flow rate. It was seen in the pipe diameters 4mm and 6 mm.
When air entered extra small diameter pipes (φ4, 6, 8, and 10mm), air and water got separated (Figure 4). This may be attributed to the effects of surface tension that was prominent in small diameter pipes. Siphonage also occurred as siphonic negative

pressure was exerted on air as well.

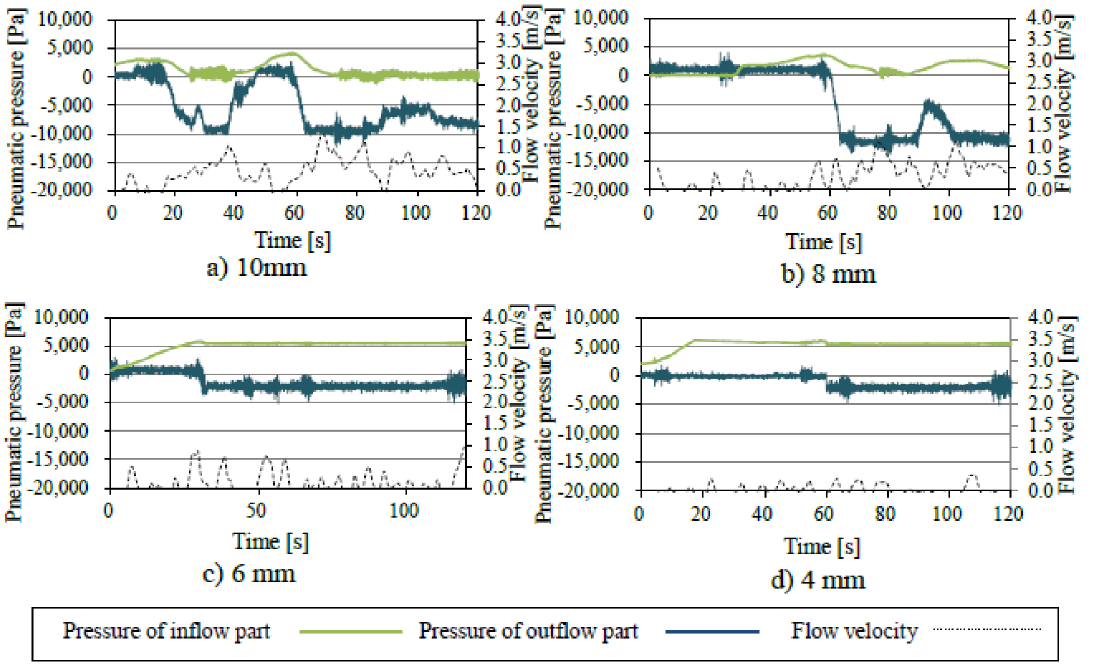


Figure 2 Fluctuations in pressure vibration in pipe and flow velocity (water supply rate of 0.4 L/min. without step over piping)

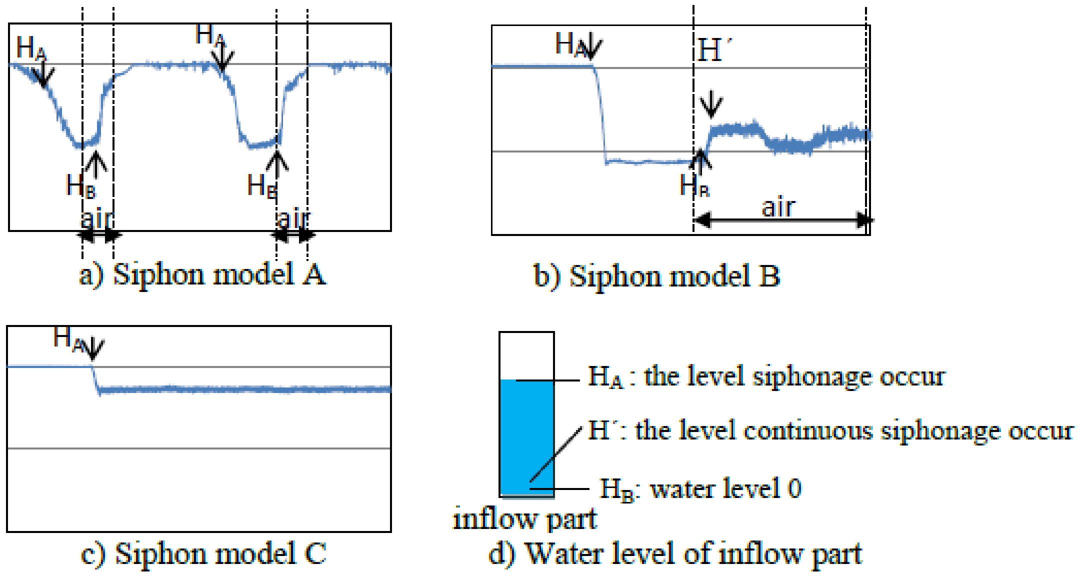
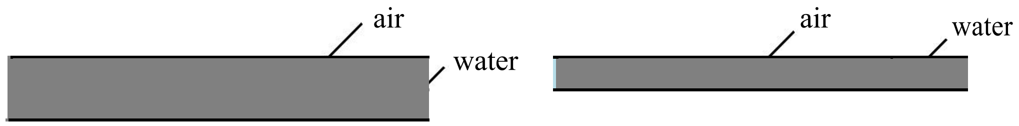


Figure 3 Flow phase models in extra small diameter piping



a) Small diameter piping (φ20,25mm) b) Extra small diameter piping (φ4,6,8,10mm)

Figure 4 Air caught in small and extra small diameter piping

3.1.2 With step over piping

With the pipe diameter 8mm and step-over heights of 0.3 and 0.4 m, water overflowed from the inflow parts before it got to the step-over sections, and discharge became impossible. This was due to the fact the height of the inflow part was low in relation to the height of the step over piping.

The relationship between pressure vibration in pipe and flow velocity with pipe diameter 10mm, pump supply rate of 0.85 L/min., step-over height of 0.2 m, both one step-over and two step-overs are shown in Figure 5. There were no effects of increase in the number of step over piping on pressure vibration or flow velocity. Siphonage occurred with 10mm pipe and one step over piping regardless of the height of the step-over. However, when step over piping were made at two locations with step-over heights of 0.3 m and 0.4 m, discharged water overflowed from the inflow parts before it reached the outflow parts, which made discharge impossible (Table 2).

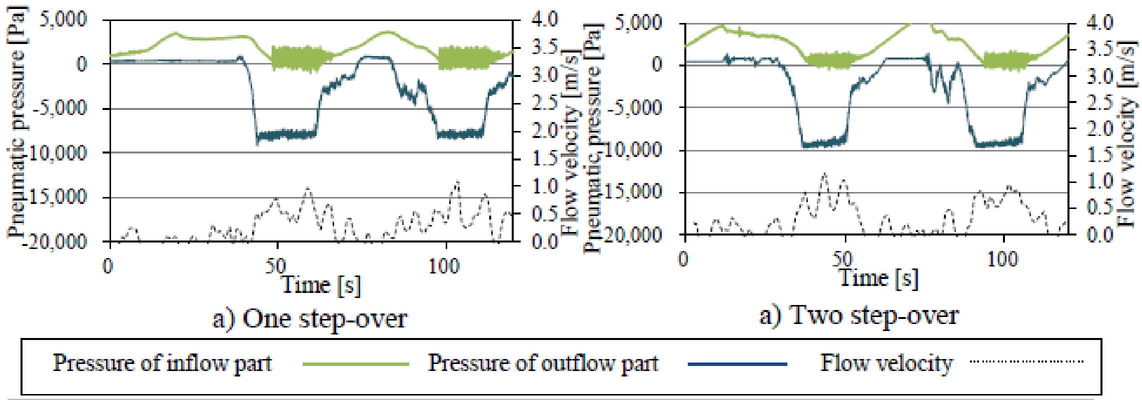


Figure 5 Fluctuations in pressure vibration in pipe and flow velocity (φ10mm, supply flow rate 0.85 l/min. step-over height 0.2 m)

Table 2 The drainable conditions (by step-over height and pipe diameter)

step-over height / pipe diameter	0m	0.1m	0.2m	0.3m	0.4m
10mm	OK	OK*	OK*	OK	OK
8mm	OK	OK	OK	NG	NG
6mm	NG				
4mm	NG				

* Also OK while setting two step-over.

3.2 Symphonic Negative Pressure

3.2.1 Maximum Negative Pressure

Maximum negative pressures in each experimental condition are shown in Figure 6. As there were considerable fluctuations in maximum negative pressure, the average was obtained based on the values taken from 0.5 seconds before and after the maximum values. There was a tendency of maximum negative pressure becoming higher as the pipe diameters increased. The height of the step over piping was found to have little effects on maximum negative pressure.

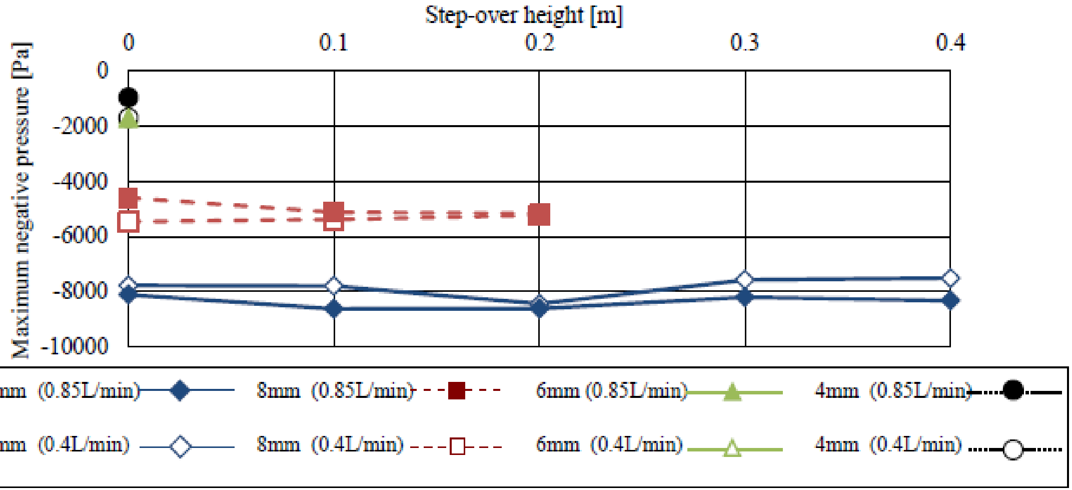


Figure 6 Maximum negative pressure summarized by diameter and supply flow rate

3.2.2 Comparison of theoretical and actual maximum negative pressure

The comparison of actual maximum negative pressure in each pipe diameter and theoretical values calculated from the equation in Table 3 [3] are shown in Figure 7. The values measured in preliminary experiments were used for the pipe coefficient of friction and partial resistance in the symphonic negative pressure equation.
The theoretical and actual values roughly corresponded with each other for 10mm, and the actual values became smaller in comparison with the theoretical values as the pipe diameters reduced in size. This is due to the fact that while the calculation formula for symphonic negative pressure simulates discharge in fill flow, air in pipes absorbed negative pressure in real situations. It may also be attributed to increasing resistance such as surface tension in pipes with 10mm diameter or smaller.

Table 3 Siphonic negative pressure 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]

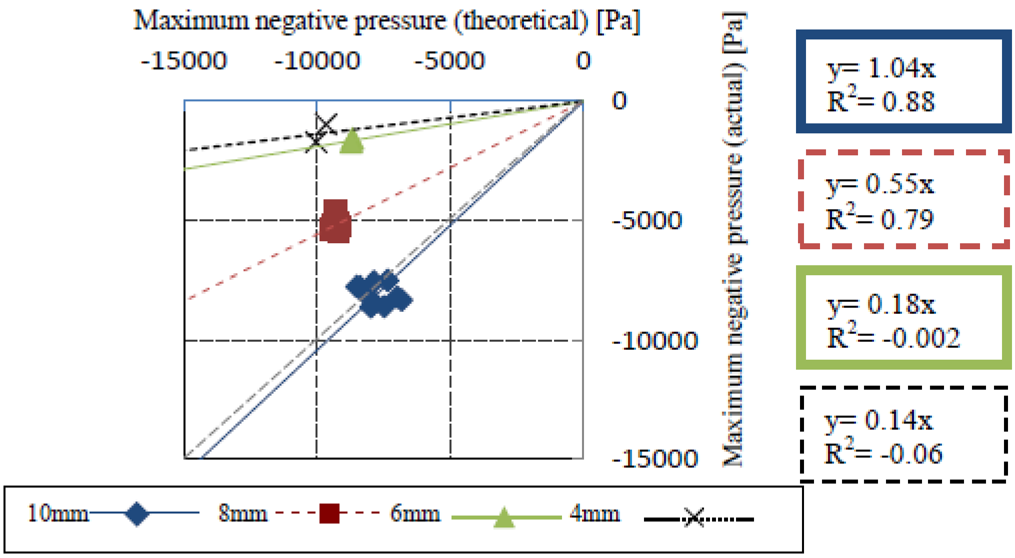


Figure 7 Actual and theoretical maximum negative pressures

3.3 Flow velocity

3.3.1 Maximum flow velocity

Maximum flow velocities in each experimental condition are shown in Figure 8. The values when maximum negative pressure was generated were used as the values for maximum flow velocity, and as there were considerable fluctuations in actual values, the average was obtained based on the values taken from 1 second before and after the maximum velocity was reached.

Flow velocity roughly ranged less than 1m/s regardless of the pipe diameters and the heights of step over piping.

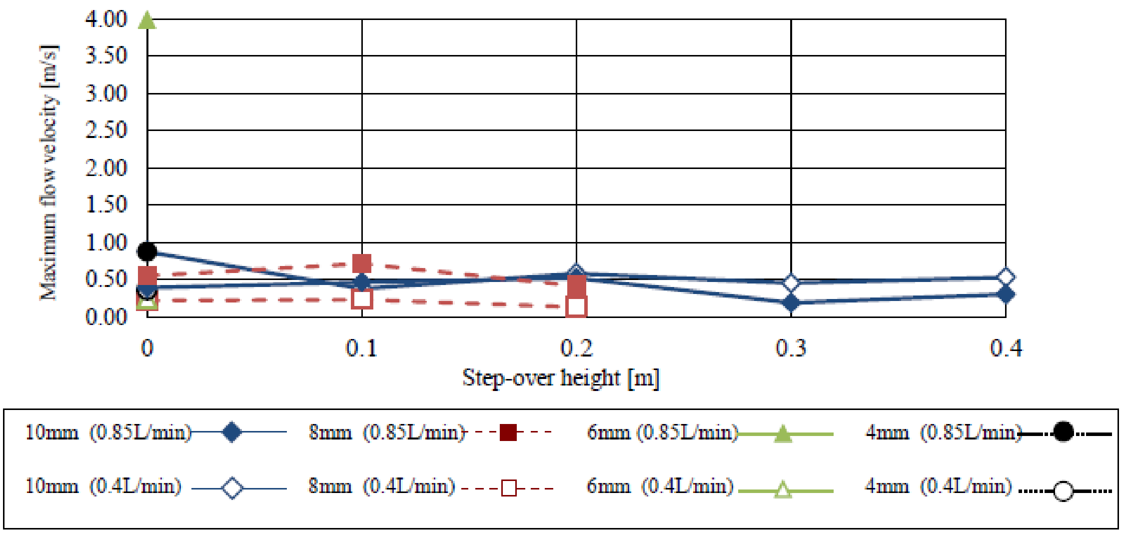


Figure 8 Maximum flow velocity summarized by diameter and supply flow rate

3.3.2 Comparison of theoretical and actual maximum flow velocity

The comparison of actual maximum flow velocities and theoretical values calculated from the equation in Table 4 [3] are shown in Figure 10. The values measured in preliminary experiments were used for the pipe coefficient of friction and partial resistance in the flow velocity equation.

While the theoretical values were smaller than actual values in 10mm and 8mm pipes, the actual values exceeded theoretical values in 6mm and 4mm. This is due to the fact that while the calculation formula for flow velocity simulated discharge in fill flow, the actual flow rate decreased because of air in pipes. Errors in measurement seemed to have increased as the flow rates were small in 6mm and 4mm and the water level in the measuring tank went up only marginally.

Table 4 Flow Velocity formula

$$v = \sqrt{\frac{2gH_s}{\lambda \frac{l}{d} + \sum \zeta + 1}}$$

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 [-]

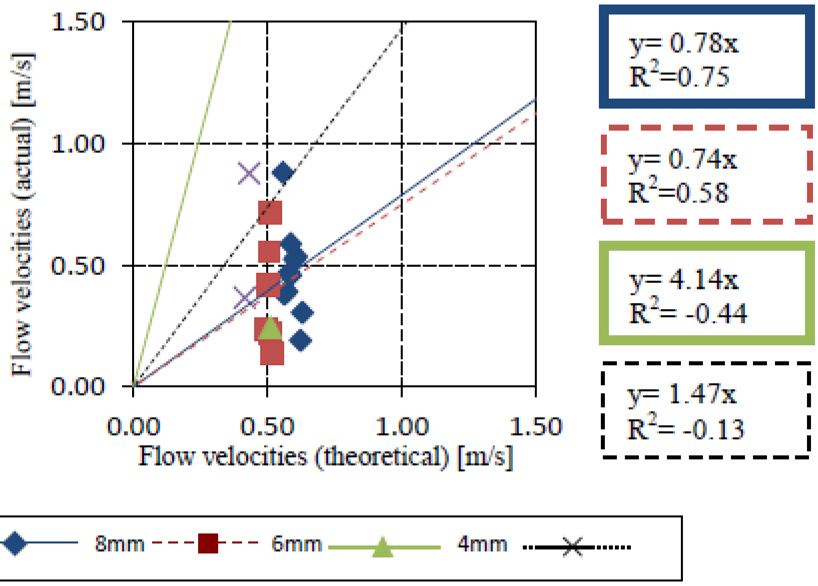


Figure 10 Actual and theoretical flow velocities

4 Conclusions

The following findings were revealed in this study:

1) Three different flow phases were confirmed depending on the relationship between supply flow rates and discharge flow rates in different size pipes. The siphon model A, in which siphonage repeatedly occurred and ended in accordance with the

fluctuations or water levels in the inflow parts, was seen in 10mm pipe. The siphon model B, in which siphonage with low pressures continued after the initial siphonage ended, was seen in 10mm and 8mm pipes. The siphon model C, in which siphonage continued without the water levels going down, was seen in 4mm and 6mm pipes. Discharge from 4mm and 6mm pipes became impossible as water overflowed from the inflow parts.

2) Increasing the number of step-over had no effects on pressure vibration in pipes or flow velocity. Discharge from the step-over piping was possible up to 400 mm high with one step over piping, 200 mm high with two step-over in 10 mm and 200 mm high with one step over piping in 8 mm.

3) There was a tendency of maximum negative pressure getting larger as the pipe diameter increased indicating that the height of step over pipings had little effects on maximum negative pressure. The flow velocity ranged below 1 m/s regardless of the diameters of pipe or the heights of step over piping.

4) Theoretical values of maximum negative pressure for 10mm corresponded approximately to the actual measurements. The actual measurements became smaller in comparison with the theoretical values as the pipe diameters reduced in size. This was because air in the pipe absorbed negative pressure, and resistance inside the pipe increased as the pipe diameter reduced in size. As for maximum flow velocity, actual measurements with 10mm and 8mm were smaller than theoretical values because of the influence of air in the pipe while actual measurements were larger than theoretical values with 6mm and 4mm as the margin of error increased with smaller discharge flow rates.

Further studies with varying horizontal lengths and supply flow rates are needed to clarify suitable conditions for application of siphonic drainage.

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Is the European standard EN 12056-3 the appropriate method to calculate the capacity of eaves gutters?

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Abstract

Although a European standardised calculation method for the capacity of eaves gutters exists since 2000, described in EN 12056-3, many countries still apply their own national method. In Belgium two methods are preferred besides the European one: a method described in the Belgian standard NBN 306, valid since 1955, and a method based on the French standard NF DTU 60.11.P3 (1988 and revised in 2013). However the calculation results according to these 3 methods differ significantly. To justify a generalised use of only one method, the Belgian Building Research Institute decided to verify which method is most valid. For this purpose, the capacities of commonly used eaves gutters in Belgian practice were measured in standardised conditions. This paper presents the measurement results which prove that calculating according to the European standard EN 12056-3 is the best choice for gutter dimensioning.

Keywords

Rainwater discharge, eaves gutters, dimensioning.

1 Introduction

Several formulas can be found in literature to calculate the capacity of roof guttersand in Belgium 3 of them are customary used:a method described in the Belgian standard NBN 306 [1], a method given in a previous version of the French Standard NF DTU 60.11.P3 [2] and the calculation method[1] proposed in the European standard EN 12056-3 [3].
In the Belgian and French standard[2], the calculation of the cross sectional area of the gutter relies on the Chézy formula for steady uniform flow in open channels and the results are tabulated in function of the connected horizontal roof surface on one hand and the gutter slope on the other: solutions can directly be deduced from these tables, an approach which is easy in use and therefore frequently used.The European method requires the use of formulas and graphs: this method is less applied as the calculation of the gutter capacityis experienced as complicated. This is also the only method where a safety factor is applied: the final capacity is obtained by multiplying the result of calculation with a factor of 0.9.
These design methodslead to very different results, which can best be illustrated with an example. Suppose that rainwater runs off a roof into a half-round gutter with a design flow rateof 2litres per second and that we want to know which gutter size is to be used.The gutter's drainage length is 8 m and the slope is 0.5%.When applying the Belgian standard the cross-sectional area of a half-round gutter should be at least 35 cm². If the French standard is used, this area has to be minimum 60 cm² and according to the European standard 79 cm².
As the differences are quite important, the question arises as to which method is the most appropriate,i.e.which method guarantees that a given flow rate can be discharged without oversizing the gutter or allowing the water to spill overthe front of the gutter. In order to sort this out the Belgian Building Research Institute decided to perform capacity tests on a set of eaves gutters, commonly used in Belgium, and to compare the measurement results with the results, calculated according to thesestandards.

2 Tests

As mentioned above, the tested gutterswere commonly used eaves gutters in Belgian practice:

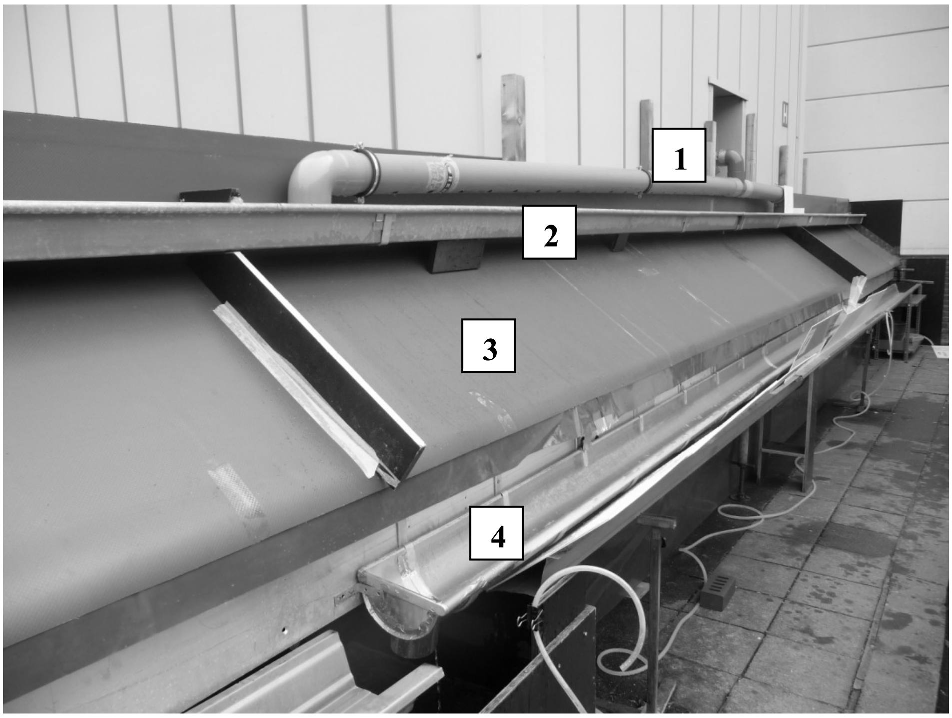
- *3 half-round eaves gutters*: 127, 153 and 192 mm wide at the top with a depth of respectively 72.5, 86.5 and 107 mm
- *2 eaves gutters of trapezoidal shape*: 80 and 150 mm wide at the bottom, a top width of 99 and 174 mm and a depth of 70 and 90 mm
- *1 rectangular gutter*: 120 mm wide and a depth of 75 mm

The tests werecarried out according to the test method as described in Annex A of the European standard EN 12056-3. For this purpose the following test rig was built (see figure1):

- Water was supplied, equally distributed, to an open canal that spilled over onto the top of a roof with an inclination of 37°,

[1]The European standard allows the use of measured capacities besides calculated ones.
[2]The information in this article is based on the version of 1988 of the French standard as these tables are currently still in use in practice. In the renewedversion of 2013, the standard continues to apply the old method for gutters with slope and refers to the European standard for level gutters.

- The water running off the roof was collected by the gutter to be tested.



1 : Water supply
2 : Open canal
3 : Roof with an inclination of 37°
4 : Gutter to be tested

Figure 1 Test rig

The flow rate was measured every second with an ultrasonic flowmeter.
The gutter capacity was determined by gradually increasing the flow rate untilthe water level in the gutter was just below spill-over level. This flow rate, maintained constant for at least 5 minutes, was the capacity of the gutter without overflowing.
The length of each gutter was 50 times its depth.First, all gutters were tested freely-discharging, i.e. discharging through one open end without the presence of an opening in the bottom. Afterwards, the gutters were tested in combination with an outlet - provided by the manufacturer- in the bottom near one of the closedgutter ends.
All outlets were sharp-edged with the exception of one funnel outlet having a wide opening at the half-round gutter side and ending at the downspout side in a plain drop outlet with an internal diameter of 100 mm: see Figure 2.
The capacity measurements were carried out for 4 different slopes towards the discharge opening: 0%, 0.2%, 0.5% and 1%.

Figure 2 Sharp-edged outlets and funnel outlet

3 Results and discussion

The results of the capacity calculations according to the standards and the results of the measurements are given in Table 4and Table 5and Figure 3, Figure 4 and Figure 5.

Table 4 Overview of Capacity Test Results of Half-Round Gutters

Half-RoundGutters		Capacity (l/s)						
		Calculatedcapacities			Measuredcapacities			
GutterSlope (%)	GutterLength (m)	NBN 306	NF DTU 60.11.P3	EN 12056-3	Free discharge	Outlet80 mm	Outlet 100 mm	Funnel outlet 100 mm
Half-Round: 127 mm wide at top, depth of 72.5 mm								
0	3.63	/	/	1.72	1.75	1.62	1.82	/
0.2		3.07	1.75	1.72	2.04	1.77	1.98	/
0.5		4.85	2.76	1.72	2.21	2.17	2.37	/
1		6.85	3.91	1.72	2.42	2.48	2.63	/
Half-Round: 153 mm wide at top, depth of 86.5 mm								
0	4.33	/	/	2.72	2.66	2.50	2.60	2.71
0.2		4.86	2.95	2.72	2.95	2.69	2.79	2.77
0.5		7.68	4.66	2.72	3.29	2.99	3.11	3.15
1		10.87	6.59	2.72	3.93	3.45	3.65	3.71
Half-Round: 192 mm wide at top, depth of 107 mm								
0	5.35	/	/	4.68	3.63	3.51	3.82	/
0.2		8.35	5.43	4.68	4.25	3.87	4.25	/
0.5		13.21	8.58	4.68	4.89	4.00	5.09	/
1		18.68	12.13	4.68	5.49	4.00	5.55	/

Table 5 Overview of Capacity Test Results of Flat-Soled Gutters

Flat-SoledFutters		Capacity (l/s)						
		Calculatedcapacities			Measuredcapacities			
GutterSlope (%)	GutterLength (m)	NBN 306	NF DTU 60.11.P3	EN 12056-3	Free discharge	Outlet60 mm	Outlet80 mm	Outlet 100 mm
Trapezoidal: 80 mm wide at the bottom, 99 mm at the top, depth of 70 mm								
0	3.50	/	/	1.67	1.45	1.38	/	/
0.2		2.18	1.19	1.67	1.53	1.51	/	/
0.5		3.45	1.88	1.67	1.88	1.71	/	/
1		4.88	2.66	1.67	2.12	1.88	/	/
Rectangular: 120 mm wide , depth of 75 mm								
0	3.75	/	/	2.44	2.32	/	2.13	2.26
0.2		3.48	2.02	2.44	2.43	/	2.26	2.38
0.5		5.50	3.19	2.44	2.66	/	2.57	2.63
1		7.77	4.51	2.44	3.07	/	2.82	2.96
Trapezoidal: 150 mm wide at the bottom, 174 mm at the top, depth of 90 mm								
0	4.50	/	/	4.39	3.77	/	3.45	4.02
0.2		6.31	3.95	4.39	4.48	/	3.61	4.69
0.5		9.97	6.25	4.39	5.02	/	3.76	5.28
1		14.11	8.84	4.39	5.54	/	3.77	5.54

In these tables and figures the measurement results are the values as indicated by the flow meter. When the measurement results are used in the design of the rainwater drainage system, all capacities that were measured by the flow meter should be diminished by 10% as recommended in EN 12056-3.

When comparing the measured freely-discharging capacities with the calculated values, it is obvious that the Belgian standard greatly overestimates the capacity of the gutters in all cases, as can be seen inTable 4 and Table 5, as well as in Figure 3, Figure 4 and Figure 5, where the results are shown graphically for the rectangular and trapezoidal gutters.Thus, dimensioning with the aid of this standard increases the risk that gutters will spill over.

For slopes departing from 0.5%, gutter capacity according to the French standard is overestimated to some extent, while for slopes below 0.5% the capacity is slightly underestimated.

In general, the calculated results in accordance with the European standard give the best estimate of the real capacity. However, when slopes are 0% or 0.2%, i.e. level gutters according to EN 12056-3, the gutters' capacity is often somewhat overestimated. This could mean that the safety factor of 0.9 as applied in this method (see § 1) should be slightly diminished in case this standard would be reviewed.

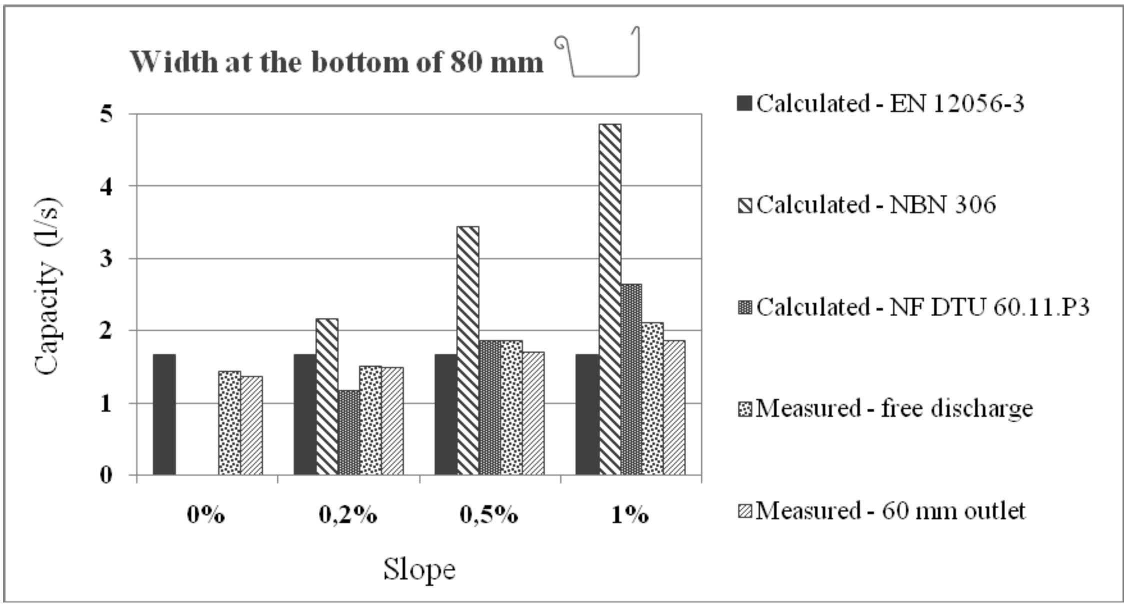


Figure 3 Calculated and measured capacity for a trapezoidal gutter, 80 mm wide at the bottom

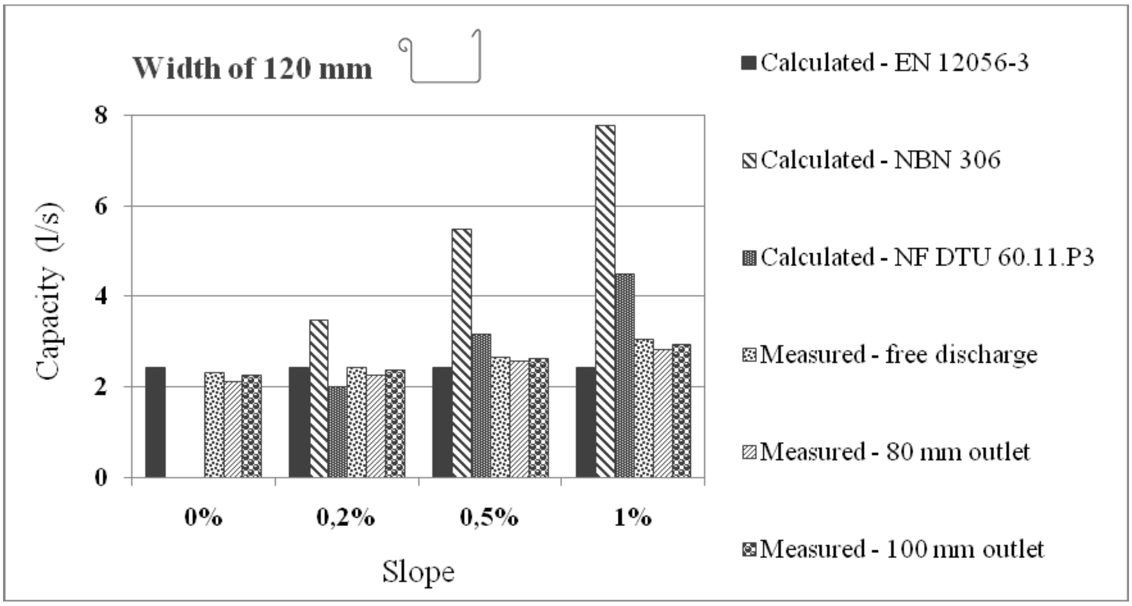


Figure 4 Calculated and measured results for a rectangular gutter, 120 mm wide

As expected, the capacity of a gutter, not freely-discharging, is influenced by the size of the discharge opening: while the 100 mm opening often approaches the situation of free discharge, the 80 mm opening generally restricts the capacity of the gutter (see Figure 4 and Figure 5).

Thus, when calculating the capacity of a gutter, the outlet capacity must always be taken into account.

The capacity of an outlet can be calculated by means of the formulae given in the European standard. In case of the smallest trapezoidal gutter, Figure 3 shows that the full capacity will never be reached because the bottom width of only 80 mm does not allow a manufactured opening larger than 60 mm.

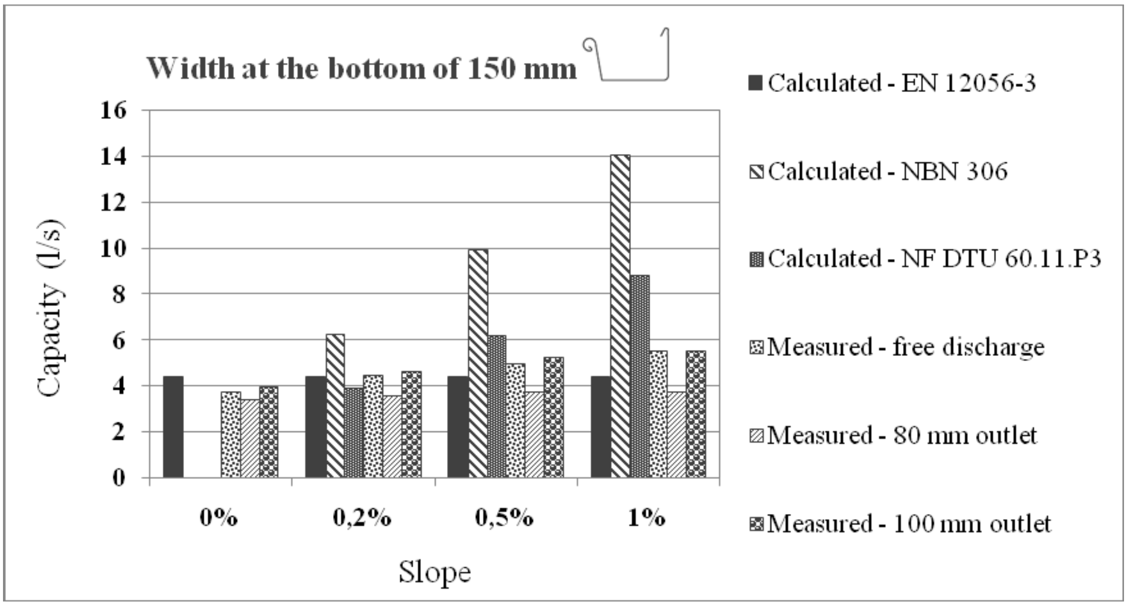


Figure 5 Calculated and measured results for a trapezoidal gutter, 150 mm wide at the bottom

4 Extra available measurements

In addition to the results discussed above, other measurements were performed on the gutters:

- In order to verify the capacity calculation of outlets, given in the European standard, the depth of the water flowwas measured at the outlet, as well as the maximum level upstream.
- Longer drainage lengths of gutter have been tested to verify the values of the capacity factor (F_L),a coefficient introduced in the European standard in order to correct the calculated capacity in case the drainage length of gutter is longer than 50 times the gutter depth
- Not only stop-end outlets, but also outlets installed in the middle of two equal lengths of gutter have been tested in orderto control the effect of the position of the outlet on the gutter capacity.

The results of these tests were not discussed in this article, but can be found in [6].

5 Conclusions

The most frequently used dimensioning methods for eaves gutters in Belgium arethe Belgian standard NBN 306, the previous version of the French standard NF DTU 60.11.P3 and the European standard EN 12056-3. The calculated capacity of gutters differ greatlybetween these 3 methods.
Capacity measurements of freelly-discharging eaves gutters have shown that among these methods the best results are obtained using the European standard.
In practicegutters are normally not open ended so that the capacity is influenced by the outlets, often availablein several sizes. Nearly always the largest size should be chosen to approach the situation of free discharge from the gutter. Smaller sizes usuallycause a bottleneck effect which means the full capacity of gutter can’t be used.

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7 Presentation of authors

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Studies on retention of seal water function of siphonic drainage system for garbage disposal

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Abstract

In Japan, the garbage disposal system for apartment buildings, is superior both in terms of hygiene and usability. The annual number of apartment buildings completed in 1998 was only about 250, which grew to be 45,000 in 2004, and is continuing to increase. As discharge from disposals has high contents of solid matter, in some cases the minimum flow rate of 0.6 m/s stipulated by the current Japanese drainage design standards is not sufficient. If disposals are equipped with siphonic drainage system that makes possible the placement of small diameter drainage pipes with no slope, so they can make significant contribution to flexible use of sanitary fixtures.1),2) This study mainly focused on the retention of seal water function in cases of using air admittance valves or self seal traps. We made actual-scale piping models using U-PVC pipes (φ20mm) and 4 m horizontal piping, and experimented and discussed the retention of seal water function and flow characteristics using an air admittance valve and a self sealing trap. This study can contribute to understand about the efficacy of an air admittance valve and a self sealing trap.

Keywords

Drainage system, siphon, siphonic drainage system, garbage disposal, seal water.

1 Introduction

The garbage disposal system for apartment buildings, is superior both in terms of hygiene and usability. The annual number of apartment buildings completed in 1998 was only about 250, which grew to be 45,000 in 2004, and is continuing to increase. As discharge from disposals has high contents of solid matter, in some cases the minimum flow rate of 0.6 m/s stipulated by the current Japanese drainage design standards is not sufficient. If disposals are equipped with siphonic drainage system that makes possible the placement of small diameter drainage pipes with no slope, so they can make significant contribution to flexible use of sanitary fixtures.
Two issues need to be resolved to realize incorporation of siphonic drainage system into the existing disposals: 1) securement of performance of conveyance and, 2) retention of seal water in traps after discharge. As for the performance of conveyance, some field tests have been conducted and problems dealt with.[3)] On the other hand, not much consideration has been given to the issue of retention of seal water in traps.
In this study, the authors have focused on the retention of seal water in siphonic drainage system with disposals, and tested the validity of air admittance valve and self-sealing trap which functions without water.

2 Experiments on flow characteristics

2.1 Purpose

Experiments were conducted on flow characteristics and seal loss using piping where an S trap, an air admittance valve, and a disposal were connected at the inlet section, and the effect of siphonage on seal loss in trap was investigated.

2.2 Outline

(1) Experimental device
The experimental device is shown in Figure 1, and external appearance and specifications of construction elements in Figure 2. A hammer-mill type disposal was used as a test disposal. This is equipped with a program whereby operation is automatically terminated when no garbage is detected in the shredding chamber. The reason for using this unit as a test disposal is that it is less likely to be influenced by the different usages of various users compared with other units that must be switched off by users. It also has superior performance of conveyance as it can store water in the shred chamber temporarily and discharge shredding garbage in a follow-up flush. Though this disposal is also equipped with an automatic water supply function, water was supplied manually in the experiments to vary water supply flow rate.
U-PVC pipes (φ20mm) with horizontal pipe length of 4 m and outflow heads of 2 m were used. Pressure was measured near the inflow and the outflow sections, and at the measuring tank. The S trap was placed at the inflow section. It was combined with an air admittance valve.

(2) Experimental conditions
Experimental conditions are shown in Table 1, and flow conditions of the experiments in Figure 3. Two types of discharge: clean water and water containing garbage. And two types of piping, one with S trap and the other with S trap and an air admittance valve were used. There were six discharge flow rates. Washing with stored water: 10 L, 20 L.

Washing with running water: 4, 6, 8, 10 L/min. To simplify the experimental procedures, simulated kitchen garbage consisting of white rice (200 g), carrot (45 g) and egg shell (5 g) that roughly amounted to standard garbage in a regular home kitchen. Each measurement lasted 2 minutes.

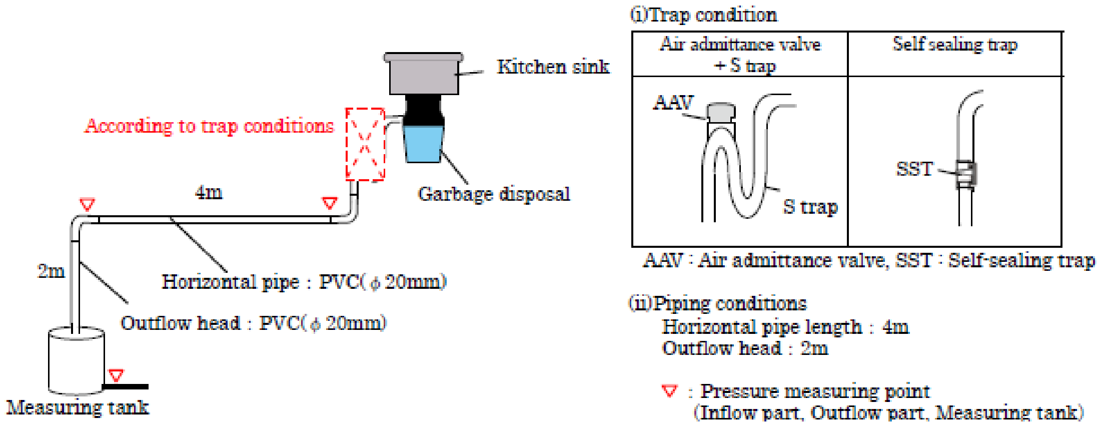


Figure 1 Experimental device

(i)Garbage disposal

Type of solid breaking down	Hammer-mill type
Type of water supply	Automatic
Shredding chamber volume	1.4L

(ii)S trap

Type・Material	S trap・Polypropylene
Diameter	Inlet leg: φ35mm Outlet leg: φ20mm
Depth of seal water	5cm
Ratio of leg's cross sectional area	0.326

(iii)Air admittance valve (AAV)

Type	Air admittance valve
Material	ABS
Vent flow rate※	$3.86\times10^{-3}m^3/s$
Resistance ciefficient※	8.41

※The valve at -500pa

(iv)Self sealing trap (SST)

Type		Self sealing trap
Material	Body part	ABS
	Membrane	Silicon
Diameter		φ20mm

Figure 2 External appearance and specifications of construction elements

Table 1 Experimental conditions

Type of trap	Type of drainage	Discharge rate	
With AAV Without AAV※	Clean drainage ・ Disposal drainage (Simulated kitchen garbage)	Stored water [L]	10 ・ 20
Self sealing trap		Running water [L/min]	4 ・ 6 ・ 8 ・ 10

※S trap have also been installed with AAV

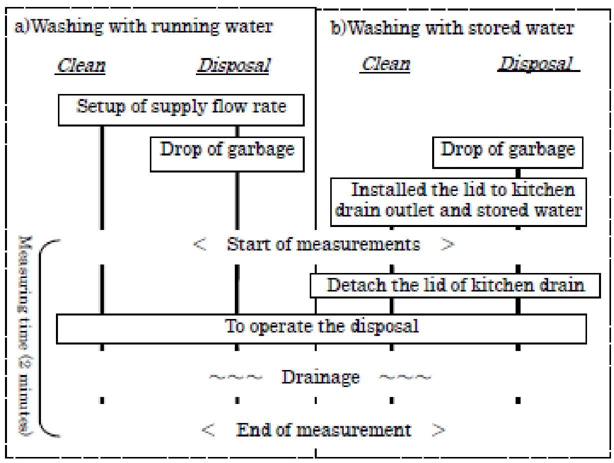


Figure 3 Flow of experiments

2.3 Results and discussion

2.3.1 When Air Admittance Valve Was Connected

(1) Fluctuations in pressure and flow velocity in pipe

The occurrence of siphonage was confirmed in all experimental conditions. The fluctuations of pressure and flow velocity in pipes in washing with running water (10 L/min.) are shown in Figure 4, and those in stored water (10 L) in Figure 5.

In washing with running water, intermittent flow was predominant without much variation in flow phases as the water discharged contained a large amount of air bubbles regardless of the presence of air admittance valve. In washing with stored water, the flow phase was mainly fill flow, and again, without much variation regardless of the presence of the valve. When garbage was discharged in washing with running water, water turned clean after 30 to 40 seconds as all the garbage had been disposed of.

(2) Maximum negative pressure and maximum flow velocity

Maximum negative pressures (siphonic negative pressure) and maximum flow velocities in each experimental condition are shown in Figure 6 and 7. Discharging water mixed with garbage, generated lower pressures than discharging clean water when air admittance valve is connected. Also maximum negative pressures in washing with stored water were lower when the valve was connected, but in washing with running water, there was little difference. This may be attributed to the limited effects of air-intake from the valve in washing with running water in which intermittent flow was predominant as siphonage occurred cyclically with or without the air admittance valve.

Similarly, maximum flow velocities in discharging with water mixed with garbage were lower than discharging with clean water when the valve was connected. While the presence of the valve made flow velocities lower in washing with stored water, it did not affect velocities in washing with running water.

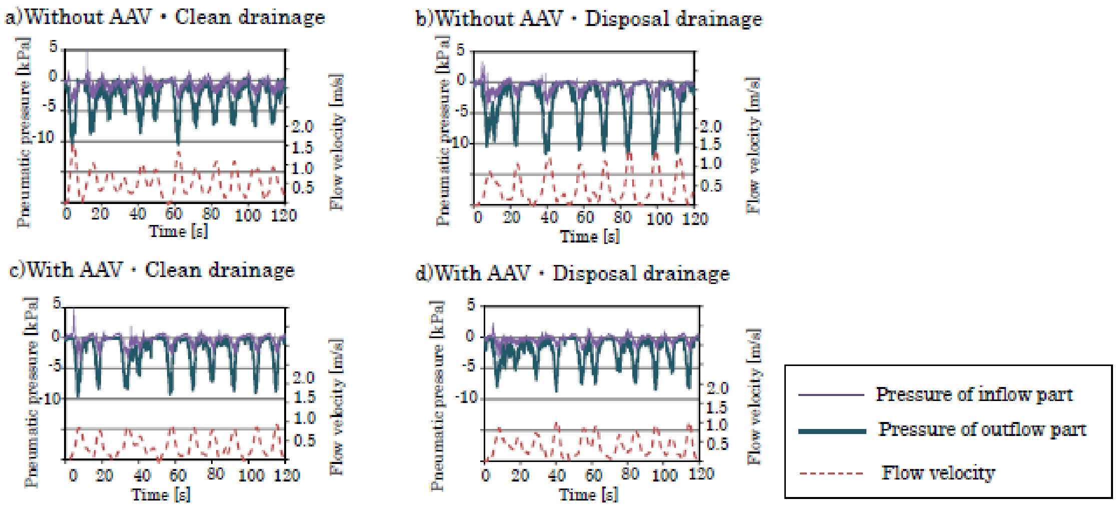


Figure 4 Fluctuations of pressure and flow velocity with running water at 10 L/min.

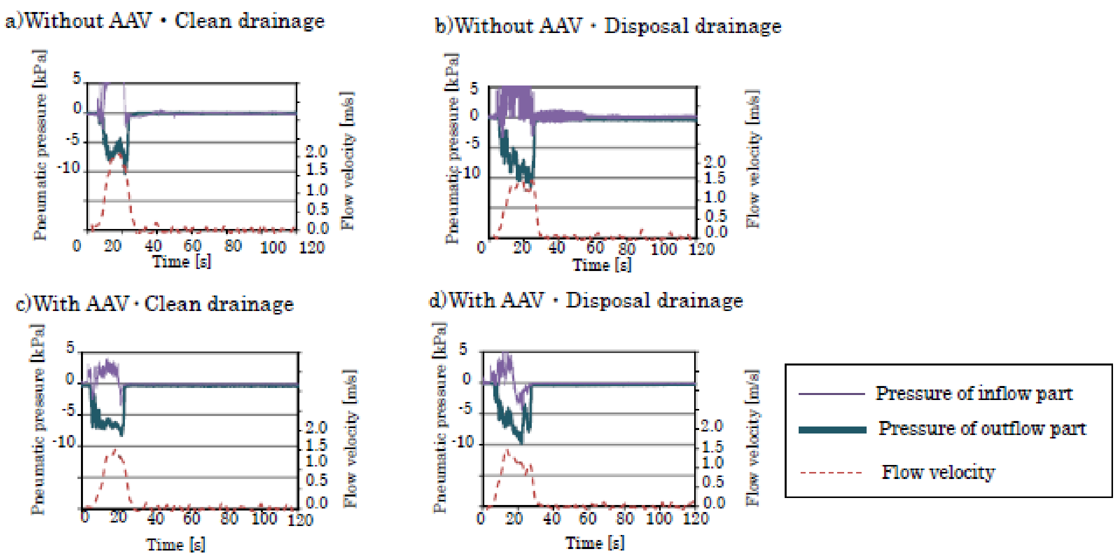


Figure 5 Fluctuations of pressure and flow velocity with stored water at 10 L

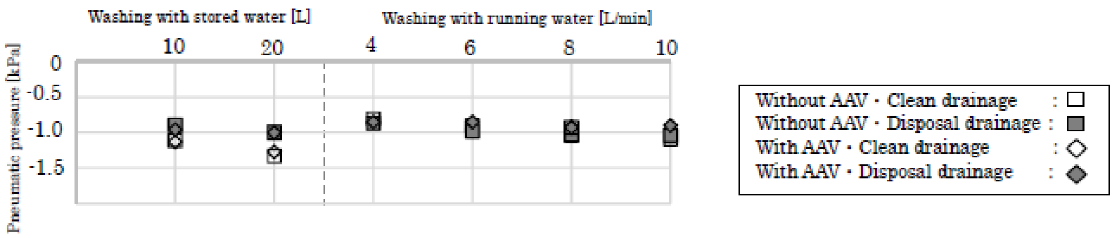


Figure 6 Maximum negative pressure with air admittance valve

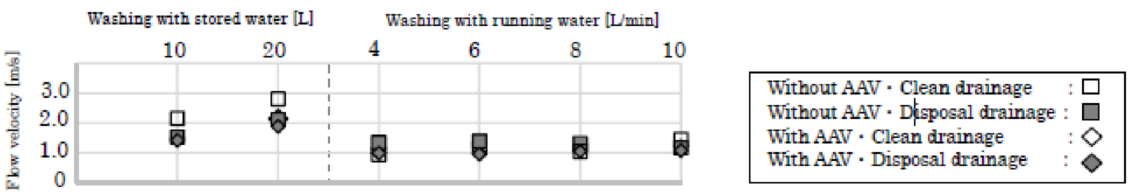


Figure 7 Maximum flow velocity with air admittance valve

(3) Seal loss and residue

Results of seal loss and residue in each experimental conditions are shown in figure 8. Seal loss occurred in all conditions when the air admittance valve was not connected. However, in washing with running water, seal loss triggered by water remained in the disposal or sink occurred after discharge was made. No seal loss occurred when the valve was connected, except for washing with stored water (20 L). This seems to give support to the efficacy of the air admittance valve in retaining seal water.

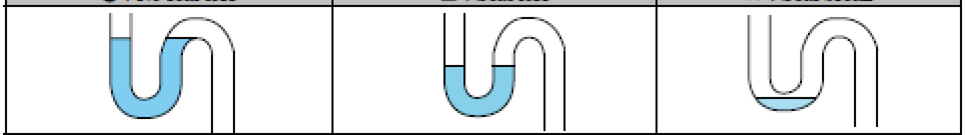
In washing with running water, little residue remained in the pipe as discharge generated by flushing from the disposal and siphonage continued until the end of measuring time. On the other hand, residue was seen in trap and pipes in washing with stored water as the water in the sink was lost before the disposal could make a follow-up flush.

Type of drainage	Type of flowing	Discharge rate	Without AAV			With AAV		
			Seal loss					
			1st	2nd	3rd	1st	2nd	3rd
Clean drainage	Stored water[L]	10	×	×	×	●	●	●
		20	▲	▲	×	●	▲	▲
	Running water [L/min]	4	▲	▲	▲	●	●	●
		6	▲	▲	▲	●	●	●
		8	●	▲	▲	●	●	●
		10	▲	▲	▲	●	●	●
Disposal drainage	Stored water[L]	10	×	×	▲	●	●	●
		20	×	×	×	▲	▲	▲
	Running water [L/min]	4	▲	×	▲	●	●	●
		6	▲	×	×	●	●	●
		8	×	×	×	●	●	●
		10	×	×	×	●	●	●

: When there is residue in trap or pipe

(i)Legend of seal water conditions

● : No seal loss	▲ : Seal loss	× : Seal break
There is no seal loss.	There are seal loss, but no seal break.	The water level of seal water is dip below.



(ii)Illustration of residue in trap or pipe

No residue	Residue in trap or pipe

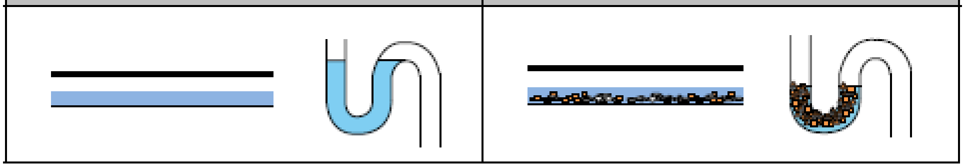


Figure 8 Seal loss and residue in each experimental conditions

(4) Relationship between vent flow rate and maximum negative pressure
The average values of maximum vent flow rate and negative pressure in each experimental condition are shown in Table 3. Assuming the maximum air flow was laminar with low-Reynolds number and achieved in the center of pipe, average flow velocity was calculated as one half of the maximum velocity from Hagen-Poiseuille equation. The maximum vent flow rate tended to be larger in discharge with garbage than in discharge with clean water in all experimental conditions.
Pressure in pipe and vent flow rate with both clean water and with garbage in washing with stored water (20 L) and with running water (8 L/min.) are shown in Figure 9. In stored water, vent flow rate tended to be larger as siphonic negative pressure increased. As washing with stored water is a continuous discharge, positive pressure was retained near the inlet section of trap from the beginning of said discharge. In running water, vent flow rated tended to be smaller as siphonic negative pressure increased. This may be due to the shortened time of negative pressure as siphonic cycles with intermittent flow became shorter as discharge rate increased. Totally, the air admittance valve functioned effectively and negative pressure was attenuated.

Table 3 Maximum air flow rate and maximum negative pressure

a)Clean drainage

Flow rate		Max. Air flow rate $[10^{-4}m^3/s]$	Max. Negative pressure [Pa]
Stored water [L]	10	3.92	11,485
	20	4.74	13,350
Running water [L/min]	4	4.21	10,120
	6	3.95	11,810
	8	2.95	11,690
	10	2.97	12,100

b)Disposal drainage

Flow rate		Max. Air flow rate $[10^{-4}m^3/s]$	Max. Negative pressure [Pa]
Stored water [L]	10	5.15	13,182
	20	4.99	12,367
Running water [L/min]	4	4.49	8,290
	6	4.80	8,610
	8	3.39	9,370
	10	3.73	9,030

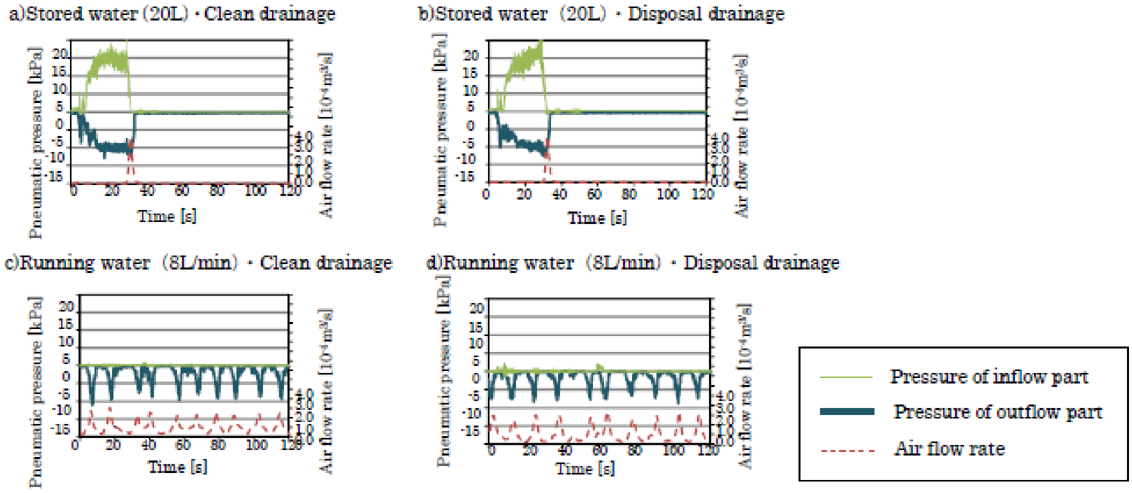


Figure 9 Fluctuations in pressure in pipe and air flow rate

2.3.2 When self-sealing trap was conected

(1) Fluctuations in Pressure and Flow Velocity in Pipe

Siphonage occurred in all experimental conditions. Fluctuations in pressure and flow velocity in pipe in washing with running water at the discharge rate of 10 L/min. are shown in Figure 10, and those in washing with stored water at 10 L in Figure 11.

The flow phase was the same as when the air admittance valve was connected with intermittent flow containing air bubbles in running water and fill flow in stored water. However, both pressure and flow velocity tended to be slightly larger than when the air admittance valve was connected. This may be attributable to the fact that the self-sealing trap has lower partial resistance than the air admittance valve with S trap.

(2) Maximum Negative Pressure and Maximum Flow Velocity

Maximum negative pressures and maximum flow velocities in each experimental condition are shown in Figure 12 and Figure 13 respectively. There was no noteworthy tendency in maximum negative pressure and maximum flow velocity when discharge with clean water and discharge with garbage were compared. Maximum negative pressure and maximum flow velocity were larger than when air admittance valve was connected.

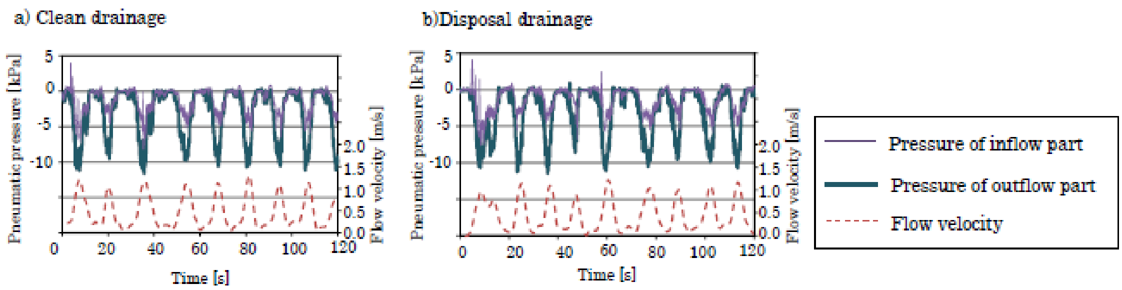


Figure 10 Fluctuations in pressure and flow velocity in pipe in running water

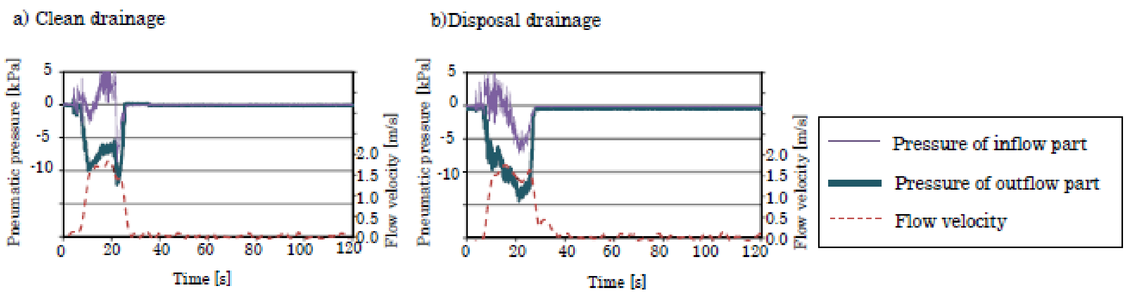


Figure 11 Fluctuations in pressure and flow velocity in pipe in stored water

(3) Residue
The conditions of residue in pipe and membrane of self-sealing trap after discharge was made are shown in Figure 14. A little residue was seen in pipe in some cases at the discharge rate of 4 L/min. in washing with running water. This is due to the fact that some residue in the shredding chamber of the disposal was not initially discharged completely and flowed out after discharge was made.
More residue was seen in stored water. This was because no discharge was made after the disposal stopped operating, and indicates the importance of follow-up flush.
(4) Vibration noise caused by the membrane of self-sealing trap
Noises due to vibrations of the membrane of self-sealing trap were generated. They grew larger in volume as the discharge flow rates increased. However the onset of the noises coincided with the time the disposal started operating, and the noises themselves were never larger than the disposal's shredding or flushing noises. Further examination seems necessary in view of the application of self-sealing trap.

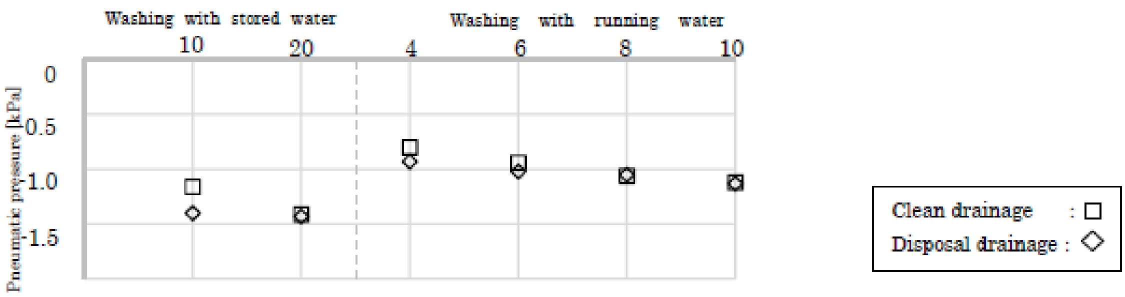


Figure 12 Maximum negative pressure with self-sealing trap

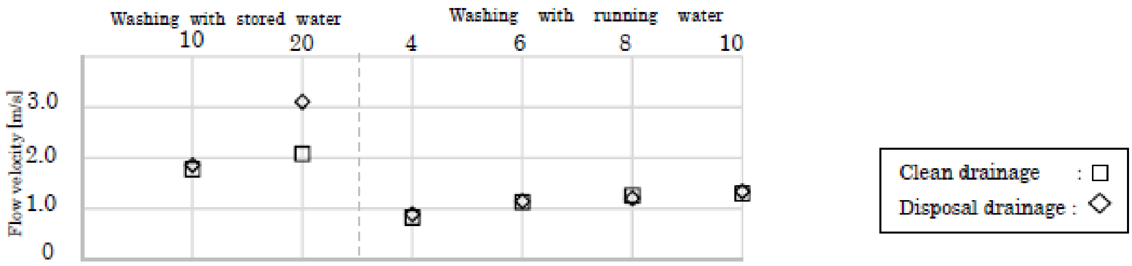


Figure 13 Maximum flow velocity with self-sealing trap

Type of drainage	Discharge rate	1st	2nd	3rd
Stored water [L]	10	×	×	×
	20	×	×	×
Running [L/min]	4	△	△	○
	6	○	○	○
	8	○	○	○
	10	○	○	○

There is residue : ×
There is little residue : △
No residue : ○

: When there are a little residue in membrane of the self-sealing trap

Figure 14 Residue in pipe and membrane of self-sealing trap

3 Conclusion

The results of this study can be summarized as follows:
1) When air admittance valve was connected
- No significant effects of air admittance valve on maximum negative pressure, flow velocity in pipe and flow phases were observed in disposal discharge.
- Connection of air admittance valve was found to reduce seal loss, and is therefore effective.
2) When self-sealing trap was connected
- No significant effects of self-sealing trap on maximum negative pressure, flow velocity in pipe and flow phases were observed in disposal discharge.
- Self-sealing trap was found to increase negative pressure and flow velocity in pipe in greater degree than air admittance valve.
- Further verification is required as to the nature of vibration noise generated from the membrane of self-sealing trap at the time of discharge.
The present study has raised the following issues to be addressed in the future: To verification of the difference in the type of air admittance valves, and noise from membrane of self-sealing trap.

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Performance evaluation method of self-sealing trap

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Abstract

Drainage gas blocking devices that are used globally are equipped with water sealed trap to date from 18th century. However, this trap is possibility of seal break by the evaporation, induced siphonage etc. Self-sealing trap with membrane has been recently developed in Great Britain and widely used. Because this trap is non-water seal water, there is seal break. A type of self-sealing trap was also developed in Japan, accredited by BCJ evaluation and provided as an environmental standard of Building Institute of Japan (AIJES-B0003).

In this paper the authors evaluate the position of water-sealed trap in drainage system, shed light on its characteristics, and discuss the structure, characteristics, performance evaluation methods of self-sealing trap and the results of tests on major performance indicators.

Keywords

Drainage system, trap, self-sealing trap, self-sealing valve, performance evaluation.

1 The position of water sealed trap in drainage system

1.1 Drainage system and trap

Water discharge depends on the force of gravity in building drainage system in the same way as in the sewer system except for drainage piping of sump pit on the ground floor. The discharge flow in pipe is typically non-fill flow with water and air flowing alongside. When water is not flowing in pipe, air that contains drainage gas moves in the opposite direction to discharge flow (toward stack ventilation pipe) and could gain entry into rooms through fixture outlets. Even when discharged water is flowing in the pipe, air containing drainage gas may enter indoors if positive pneumatic pressure is present. Drainage gas contains some toxic substances that may contaminate indoor air and present health hazard. In order to prevent this from happening, traps are routinely placed at various points along the piping as a gas-blocking device. Traps may be used not only by themselves but also incorporated into drainage catch basins and interceptors. Traps are designed to create seal water, and normally called seal water traps.

Systems using the force of gravity and traps were created in the 16^{th} ~ 17^{th} century, and incorporated into building drainage system in the late 1800s. It had gone through many stages of improvement and systematization, and was standardized as modern drainage system in the first half of 20^{th} century. During its long history some mechanical traps using floats were developed but soon went into disuse because of frequent malfunction and lack of durability. As a result, design standards around the globe began to endorse seal water trap, and minimum seal depth was designated as the standard for seal water trap performance. However, in America and Japan, maximum seal depth was stipulated as well. “Seal depth” stipulated in SHASE-S 206[1] is referred to as “depth of drainage trap” in Building Standards Act[2].

1.2 Trap mechanism and prevention of seal break

Seal water of trap blocks drainage gas from entering the room. Seal water is what is left of the discharged water from fixtures, and whenever a fixture is used, a part of water discharged remains in trap as seal water. A seal water trap is considered a superior gas-blocking device as it has a relatively simple structure and is not prone to mechanical failure. However, seal water could be lost or broken. A trap consists of two adjacent water sealing sections (an inlet leg and an outlet leg) and connecting part (see Figure 1). Seal depth is defined as the vertical distance from the upper section of the contact between two legs to the lowest section of the outlet leg. When discharge is made from a fixture, water normally fills the trap. But there are cases where a trap may not be filled when discharge is made or seal may be broken when discharge is not made. If seal is broken, that is, if the level of seal water gets lower than the dip level, drainage gas can enter the room. Therefore, prevention of seal break constitutes an important design condition in a drainage system with seat water trap.

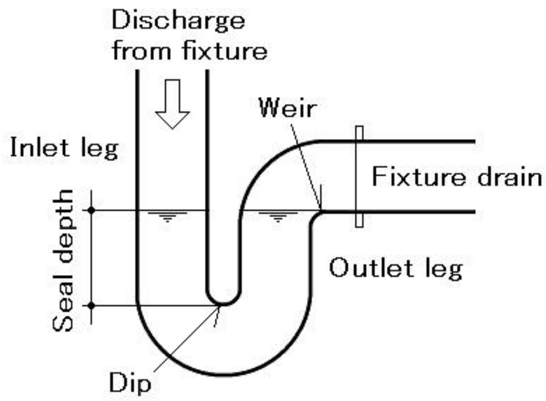

Figure 1 Basic structure and name of each part of trap

1.3 Seal loss / Seal break

Evaporation, induced siphonage, self-siphonage, and capillary phenomenon are typically cited as seal loss / seal break phenomena though self-siphonage is not technically a seal loss / seal break phenomenon as it would occur during fixture discharge and deplete water that should have remained in the trap otherwise. Capillary phenomenon can also be ignored as it is unlikely to occur with smooth material currently used in traps. Therefore, evaporation and induced siphonage remain major concerns that need to be addressed in designing a trap.

1.3.1 Evaporation

Evaporation is inevitable when discharge is not made as the seal water surfaces in the both legs of a trap are in contact with air. The amount of evaporation depends on temperature and humidity of air, wind velocity and the structure of a trap. Theoretically evaporation at normal temperature / humidity amounts to 0.154 mm/day[3], but evaporation of 0.3 ~ 0.7 mm has been known to occur experimentally[4]. If amount of evaporation was 0.7 mm and seal water depth 20 mm, seal break would occur in about a month (29 days). Here seal break caused by evaporation is referred to as evaporation seal break. No preventive measures against evaporation seal break have been incorporated in designing a trap. Practically either water must be discharged or added as seen fit to prevent seal break. It should be noted that the problem of evaporation seal break has been completely ignored in designing trap when in reality it cannot be avoided in the use of seal water trap.

1.3.2 Induced siphonage

Induced siphonage is triggered by the fluctuation of pneumatic pressure inside piping that is caused by discharge flow. Pneumatic pressure varies depending on drainage characteristics such as discharge flow rate and the position of drainage pipe. As the water sealing section of a trap has a U-shape, seal water fluctuates in response to pneumatic pressure exerted from the outlet side. It is a dynamic vibration response phenomenon accompanied by a resonance phenomenon. If a resonance phenomenon occurred, a large seal water fluctuation / loss would result for a given pneumatic pressure. Seal water loss occurs when seal water level goes above the outlet leg while seal water fluctuates. From this viewpoint, the negative pressure of influence is larger than positive pressure. However, seal water loss does occur as a result of vibrating seal water

when pneumatic pressure fluctuates toward the positive side. If seal water loss progresses, or if it occurs in combination with evaporation, the possibility of a seal break increases. Such a seal break is referred to as pressure seal break here. Drainage gas can enter the room if the water level inside an outlet leg instantaneously goes lower than the dip level while pneumatic pressure fluctuates on the positive side. When pneumatic pressure fluctuates on the negative side, and a part of the seal water surface in the inlet leg instantaneously goes below the dip level, air in the room may flow into the drainage pipe. This type of seal break is called instantaneous seal break. In contrast, a phenomenon that occurs when seal water level is lower than the dip level and drainage gas constantly keeps entering the room is called steady seal break.
As instantaneous seal break and steady seal break that are triggered by positive pneumatic pressure present problems, prevention of such pressure seal break constitutes a major issue in designing a drainage system. The crux of prevention is how to reduce pneumatic pressure, and it is done by the placement of ventilation pipes and determination of pipe diameter based on permissible flow rate. SHASE-S 218[5] stipulates ±400 Pa for permissible pneumatic pressure that sets a standard for permissible flow rate. As for pneumatic pressure resistance performance of a trap, minimum seal depth only is stipulated. Seal depth is specified as 50 mm in both Building Standards Act and SHASE-S 206. In terms of the static relationship between pneumatic pressure and seal water fluctuation, pneumatic pressure of -400 Pa is equivalent of 40.8 mm difference in seal water level between the legs. The remaining seal water depth in this case would be 29.6 mm if the both legs had the same diameters and seal depth was 50 mm. Therefore, seal water depth (remaining seal water depth) of about 30 mm should be maintained if a proper drainage system designing method was adopted on the basis of the static correspondence of pneumatic pressure to seal water fluctuation. However, in reality the relationship of the two is a dynamic vibration response phenomenon, the remaining seal water level may get lower, and seal break occur. If the remaining seal water level is small, the possibility of seal break due to evaporation increases. No designing method has yet been developed to nullify the possibility of pressure seal break.

1.4 Characteristics and evaluation of seal water trap

Seal water trap has been held in high regard as a valuable device and used extensively worldwide because 1) it can block drainage gas as long as seal water is retained, 2) is simple and works automatically without power, 3) is mechanically hard to fail and requires little maintenance, and 4) has been in use for over two hundred years. However, seal break can occur resulting in contamination of indoor air. Pressure seal break can be prevented by technical improvements of drainage system designing methods, but nothing can be done to stop evaporation seal break.
Therefore, 100% fail-safe drainage gas blocking devices must be installed in drainage fixtures in places such as hospitals and laboratories where no air contamination is permissible. Improvements of the current seal water traps or development of new mechanism is highly expected.

2 Characteristics and current status of self-sealing trap

Seal water trap has some disadvantages as it cannot avoid neither evaporation seal break nor pressure seal break. Break-free traps can be made possible either through improving current seal water traps or by developing traps without requiring seal water. No improvements on current seal water traps have been made so far. In the past, no-seal-water trap such as the ones using floats and flappers had been developed, and some similar traps are being developed today. But they cannot be highly recommended as they have been found unreliable as a drainage gas-blocking device and prone to malfunction.

A self-sealing waste valve was developed in Great Britain in the 1990s. As it had the same functions as a trap, it was begun to be called self-sealing trap in Japan. The main body of a self-sealing trap is made of silicon membrane (self-closing membrane). The outlet end of the membrane is closed and opens when discharge flow comes in from the inlet section (see Figure 2). As it is closed when water is not flowing or pneumatic pressure is the same or larger than atmospheric pressure, drainage gas cannot pass through. Constructed in such a way that discharged water can flow smoothly, but drainage gas cannot pass, it is considered a type of trap (gas blocking device). However, no water is sealed inside. No seal water means no seal break, which makes it quite an efficient trap. Since self-sealing trap not only blocks drainage gas but also prevents back flow of discharged water, it can be used as fixtures to indirect discharge. Also having an air intake function, it serves as a small inlet valve (air admittance valve).

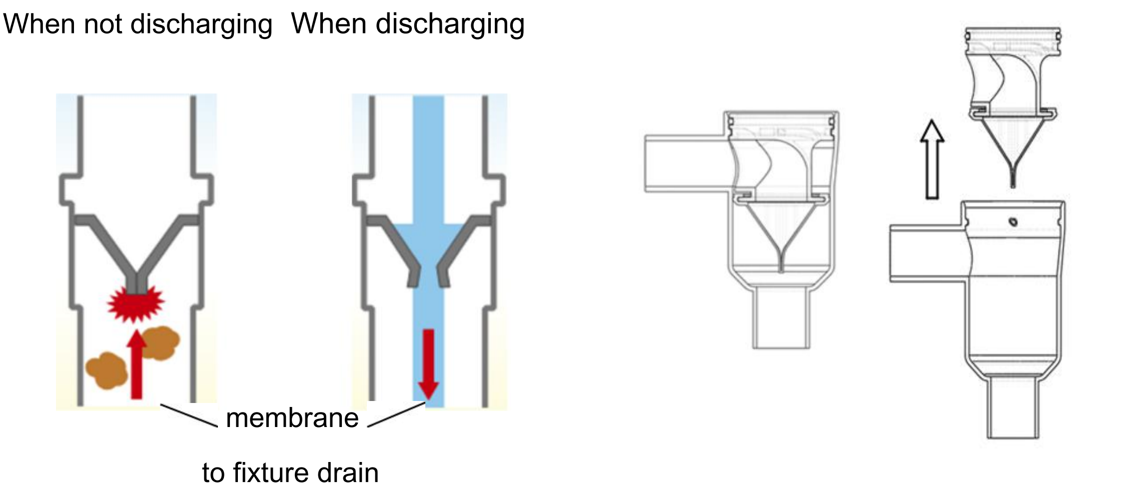

Figure 2 Self-sealing trap (Self-sealing waste valve) for lavatory and wash-basin

In Great Britain, self-sealing trap has been used in miscellaneous drainage fixtures such as wash-basins and bathtubs as well as in WC. Its performance has been given a high regard and authoritative design technique literature [6] describes its design standards. British self-sealing trap was introduced to Japan in 2010, and its applications to lavatory, wash-basin, floor drain of bathroom, bathtubs, and washing machine have been given BCJ evaluation by the Building Center of Japan. Rubber made self-sealing traps had been in use for air-conditioning drain, but their performance in blocking gas was not satisfactory. But their applications had been allowed relatively freely as air-conditioning drain was outside the scope of water supply and drainage system design standards and no restrictions were placed on them neither legally nor performance-wise. Superior silicon self-sealing trap for air-conditioning drain, wash-basins was developed in 2012. In 2015 self-sealing trap for floor drain was developed and self-sealing trap for wash-basin was given BCJ evaluation. Furthermore, in 2016, “no-seal water trap” whose main body was constituted of self-sealing trap was described in the attachment to the environment standards of Building Institute of Japan; AIJES-B0003[7].

Technical standards, in the nature of things, should be performance standards. But in reality, regulations concerning trap in SHASE-S 206, National Plumbing Code (NPC)[8], and other building standards are all structural standards. AIJES-B0003 was the first performance standards to describe trap and it is expected that other technical standards will follow suit.

3 Performance Evaluation of Self-Sealing Trap

Self-sealing trap can be applied to various sanitary fixtures in the water supply and drainage field such as wash-basins, bathtubs, WC, discharge pan for washing machine and floor drains), and air conditioning drainage. We will discuss performance evaluation methods of self-sealing trap for wash-basins below. The functions, characteristics and criteria will be listed and application to floor drain and air-conditioning explained.

A British design technology literature[6] states under the section "Testing of waste valves", "Because devices do not depend on a water seal in a trap, many of the guidelines related to prevention of seal loss contained in the previous pages need not be applied". Also under the section "Standards", "As these valves are not covered by British Standard, it is important that they carry performance certification by a third party approvals body acceptable to Building Regulations, eg WILAS or BBA". As for performance evaluation of self-sealing trap, there is a technical paper[9] on the subject.

Referring to the literatures [8] and [9], we have discussed the performance parameters and characteristics that should be incorporated into self-sealing trap, and test methods and judging criteria for each function.

3.1 Performance Parameters and Characteristics

The performance parameters required in self-sealing trap can be broken down into basic performance items and general performance items necessary for fixtures and devices. The characteristics of self-sealing trap also need to be clarified for designing trap.

3.1.1 Basic performance parameters

A good self-sealing trap should be capable of smoothly discharging water and impurities (foreign substances), and effectively blocking drainage gas. Its basic performance parameters are as follows.

1) Drainage / low noise: Discharge from fixtures must be done smoothly and without making much noise.
2) Minimum drainage passage: This is to make sure even low volume water is discharged completely.
3) Impurities discharge (self-cleaning function): Impurities (foreign substances) in discharged water from fixture should be cleared smoothly.
4) Hair draining: Hair should be drained without getting caught. If hair is caught in the membrane, airtightness may be undermined.
5) Positive pressure resistance: Airtight performance when pneumatic pressure is positive.
6) small pressure resistance: Airtight performance when pneumatic pressure is slightly positive.
7) Minimum operational negative pressure: Minimum negative pressure required to open the membrane.

3.1.2 General performance parameters

1) Water tightness, 2) Heat resistance, 3) Heat-cycle resistance, 4) Thermal shock resistance 1, 5) Thermal shock resistance 2 (JIS), 6) Hot water resistance, 7) Freeze resistance, 8) Chemical resistance, 9) Chemical repetition resistance, 10) Operation resistance, 11) Fall resistance

3.1.3 Characteristics

1) Discharge characteristics / coefficient of resistance: The characteristics of discharge flow rate and coefficient of resistance. Coefficient of resistance is for reference only.
2) Air intake characteristics / coefficient of resistance: Though these are not the functions of a gas blocking device, a self-sealing trap has a function of vent valve when pneumatic pressure is negative. The relationship with intake air flow rate against negative pressure and characteristics of ventilation resistance. Air intake characteristics and coefficient of resistance are for reference only.
3) Backflow prevention: This is not a function of a gas blocking device, but a self-sealing trap works as a check valve.

4 Performance tests and judging criteria

Major performance tests and judging criteria for basic performance parameters are shown below.

1) Drainage / low noise: Drainage performance (drainage time: T[s]) and low noise performance ((judgment of noise level L_{Aeq}[dB])
   Standard: T ≦ 30s, $L_{Aeq} \leq 50$dB
2) Minimum discharge volume performance (passage minimum volume: W[mL]).
   Standard: W ≤ 2mL
3) Impurities discharge (self-cleaning function): Foreign substances used in the test
   Standard: Table 1
4) Hair draining: Pseudo hair used in the test
   Standard: Table 2
5) Positive pressure resistance: Judging criteria for the test pressure P_o[Pa], and pressure difference ΔP[Pa] between when the membrane is tightly closed and when it is open.
   Standard: P_o = 600 Pa (for 60s), ΔP ≤ 30Pa
6) Small pressure resistance: Judging criteria for the test pressure P_o[Pa], and pressure difference ΔP[Pa] between when the membrane is tightly closed and when it is open.
   Standard: P_o = 10 Pa (for 60s), ΔP ≤ 2Pa
7) Minimum operational negative pressure: Tests were conducted when the membrane was open, closed, moist, and dry.

Table 1 Typical foreign substances

Substances	Quantity	Mixing water etc.
pseudo hair	length:10cm, weight: 1.5g length:20cm, weight: 1.5g	water: 4.5L
sand	particle diameter: 1-2mm, weight: 10g	water: 4.5L
potato starch	weight: 50g	hot-water: 2L (40℃) + water: 2.5L

laundry starch	weight: 100g	water: 4.5L
soap powder	weight: 50g	water: 4.5L

Table 2 Pseudo hair in test

Fixture	Type of usage	Length and number of hair
wash basin	shampoo	10cm and 21, 30cm and 21
	hairdressing	10cm and 5. 30cm and 5
lavatory	-	10cm and 3, 30cm and3

Table 3 shows the list of the performance test methods and judging criteria for each item of basic and general performance parameters and characteristics.

Table 3 List of the performance test methods and judging criteria for each item of basic and general performance parameters and characteristics

Performance	Parameters	Judging criteria
Basic performance	Drainage / low noise	Drainage time ≤30s Noise level L_{Aeq} ≤50dB
	Minimum discharge volume	Drain by minimum volume: 2mL
	Impurities discharge (self-cleaning function)	Noremainsofimpurities(foreign substances)
	Hair draining	Pseudo hair should not be caught.
	Positive pressure resistance	Pressure difference between when the membrane is tightly closed and when it is open under the test pressure: 600Pa ≤ 30Pa
	Small pressure resistance	Pressure difference between when the membrane is tightly closed and when it is open under the test pressure: 600Pa ≤ 2Pa
General performance	Minimum operational negative pressure	Operate ≤ negative pressure: -900Pa
	Water tightness	There should be no leakage.
	Heat resistance	There are no leakage and abnormalities.
	Heat-cycle resistance	There are no leakage and abnormalities.
	Thermal shock resistance	There are no leakage and abnormalities.
	Thermal shock resistance (JIS)	There are no leakage and abnormalities.
	Hot water resistance	There are no abnormalities.
	Freeze resistance	There are no leakage and abnormalities.
	Chemical resistance	There are no cracking, leakage and abnormalities.
	Chemical repetition resistance	There are no leakage and abnormalities.
	Operation resistance	There are no leakage and abnormalities under sinusoidal wave pressure (amplitude: 10Pa, 3000,000 periodic time)
	Fall resistance	There are no abnormalities.
Characteristics	Discharge characteristics / coefficient of resistance	0.6 ≤ Discharge-flow ratio of with trap to without tap
	Air intake characteristics / coefficient of resistance	–-
	Backflow prevention	Do not flow backwards.

5 Conclusion

Self-sealing trap is currently the only no-water-sealing trap with effective gas blocking functions. In this paper, the position and characteristics of water seal trap were described and the characteristics and performance test methods for self-sealing trap clarified. It is expected that further improvements on the performance of self-sealing trap will be made and other types of non-water-sealing trap developed in the future.

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7 Presentation of authors

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Field evaluation of housing units with low flush toilet (4,8 l/flush) installed -water consumption monitoring and damage verification in the drainage system performance

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Abstract

The need to reduce water consumption in Brazilian cities has promoted the development of more efficient sanitary appliances, particularly low flush toilets. This paper aims to present the results of the field phase of a Brazilian Study Performance Evaluation of Building Water and Drainage System with Low Flush Toilets (4,8Lpf). This study takes into consideration that the conditions of the piping installation of building drainage system in Brazil are critical: low slope and diameter of 100mm. For this evaluation, the study was conduct in twos phases. The first phase was performed by evaluating in the laboratory 20 toilets with 4,8L/flush. It were performed all the tests defined in: NBR15097:2011, NBR15491:2010, ASMEA112.19.2:2013 and soybean paste transport test according to USA study of PERC - Plumbing Efficiency Research Coalition - "*The Drainline Transport of Solid Waste in Buildings*". Seven toilets were considered approved in all laboratory tests, which represents 35% of the total toilets tested. The second phase - the field monitoring phase - was conducted during 8 months and consisted of the verification of the water consumption reduction in ten houses, when 6,8Lpf toilets was replaced by 4,8Lpf toilets. In this phase was also verified the occurrences of blockages in the horizontal pipes of the building drainage system. The results showed that not all models of toilets monitored have resulted in reduction in water consumption and the reduction of the flush volume may have caused negative effects in the performance of the building drainage system, checked through real time video.

Keywords:

Low flush toilet (4,8L/flush), water consumption, drainage system performance.

1 Introduction

Studies have been conducted in many countries in order to evaluate the reduction of water consumption in toilets to less than 6,8Lpf. However, the conditions of the building drainage system in Brazil are critical (ø100mm and slope 1%).
The performance of the sanitary appliance is important, but the system performance as a whole is also important. The operation of building drainage system is essential for the performance of buildings and, with the use of water saving equipment increasing, the volume of water is reducing, which affects the transport of solid and causes clogging in the pipe of the drainage and sewage system.
In order to increase knowledge on this subject, this paper aims to present the results of field phase of a Brazilian Study Performance Evaluation of Building Water and Drainage System with Low Flush Toilets (4,8Lpf).

2 Solid transport studies

In 1997, the Brazilian Program of Quality and Productivity in Habitat (PBQP-H) of the Federal Government encouraged studies to reduce water consumption in toilets with the purpose of promoting the efficient use of water in buildings.
A study to evaluate the possibility of reducing the water consumption in toilets to 6,8Lpf, conducted between 1998 and 2002, showed that this volume would be more efficient, because it would avoid the double discharges and thus save bigger volume of water (OLIVEIRA, 2002). This study was divided into two phases. The laboratory phase was developed at the USP Polytechnic School with the assistance of the Stevens Institute of Technology (New Jersey/USA) and evaluated the performance of toilets in different conditions. The field phase was held in a CDHU housing development (Development Company Housing and Urban State of São Paulo) and evaluated the performance of toilets in real conditions (Gonçalves et. al, 2000).
It was established the water consumption of toilets of 6,8Lpf should be adopted gradually by manufacturers until 2002 (OLIVEIRA, 2002). Thus, consumption of 12Lpf (admitted until 2002) changed to 6,8Lpf (after 2002), this volume is established in the current Brazilian Standard (NBR 15097, 2011).
The first phase of a study of the Plumbing Efficiency Research Coalition (PERC, 2012) verified the effects of the adoption of different variables including slope of the building drainage pipe (1 and 2%) and discharge volumes (3,0, 4,8 and 6,0Lpf). The discharges were simulated by using a device called surge injector, which provides constant volume of discharge, reducing the variation that the toilet could present. Although this study was not conclusive, reports clogging problems with 3,0Lpf discharges and shows that the performance of 6,0Lpf discharges can be better than 4,8Lpf discharges to clean up the pipe. The transport of solid in this study was evaluated in the laboratory with an acrylic pipe 41 meters in length, which simulates the building drainage system, soybean paste media and toilet paper media.
In the same study it was also possible to verify that 3,0Lpf discharges require at least 4 times more successive discharges to remove the entire media pipe that 6,0Lpf discharges. This indicates that a toilet with a lower discharge volume is not necessarily economic, since it requires more discharges to have performance compatible with the 6,0Lpf toilet.
The study indicates that to 3,0Lpf discharges, 26 discharges were required to remove the media, while for 6,0Lpf and 4,8Lpf discharges were required 8 and 12 discharges,

respectively. For 3,0Lpf toilet, 78L were used for pipe cleaning and the 6,0Lpf and 4,8Lpf toilets used, respectively, 48L and 57,6L.
Another difference shown in this study is the impact of slope of the drainage pipe system. A toilet may require up to two times more discharges to remove the media from the drainage pipe system when the slopes change from 2 to 1%.
The second phase of the PERC Study (2016) mainly analyzes the effects of two variables: 3,8Lpf discharges and cross section of pipe building drainage system of ø75mm. The results showed that the reduction of the discharge volume from 4,8Lpf to 3,8Lpf causes a reduction in system performance. Figure 1 shows the average to flush out (AFO) all media from the pipe (41 meters) for different discharges.

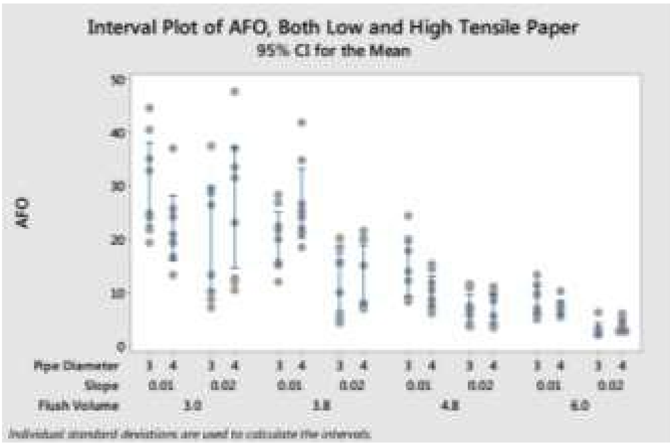

Figure 1 Discharge averages for pipe cleaning - tests with high tensile toilet paper
Source: PERC (2016)

In Japan, since 2011 are used toilets of 4,0Lpf (KOBAYASHI, N. and OTSUKA, M., 2012). However, the authors emphasize that the decrease in volume can result in problems in the transport of solids in the pipe drainage system. The study showed, through experiments, as the performance of drainage system is affected by the use of various water-saving toilets. The study used a tower with nine storeys and a height of 25m to simulate the drainage system of high-rise buildings. Through laboratory tests concluded that the transport distance becomes longer as the drainage load becomes smaller. In a real usage situation, when a full flush was applied followed by a partial flush, the average transport distance of paper was longer than 10 meters (paper standard reference was 8.7 meters).

3 Evaluation of drainage system performance with 4,8Lpf toilet

This paper aims to present the results of the field phase of a study on Performance Evaluation of Building Water and Drainage System with Low Flush Toilets (4,8L/flush) in Brazilian type of installation.
The study had the laboratory phase before the field phase. The objective of the first phase was characterized, in the laboratory, 4,8Lpf toilets in the conditions of building installation used in Brazil and evaluate the transport of solid criteria in order to determine if the reduction in the discharge volume negatively affects the performance of building drainage system.
The field phase was carried out in order to verify, in real installation conditions, if the reduction of water consumption in toilets would cause problems to the inhabitants.
Figure 2 shows a schematic step-by-step of the study. After a literature review, the

laboratory phase was conducted (characterization of the toilet bowl and characterization of the flush gravity tank). The toilets approved in all tests were considered fit to be installed in the field (field phase).

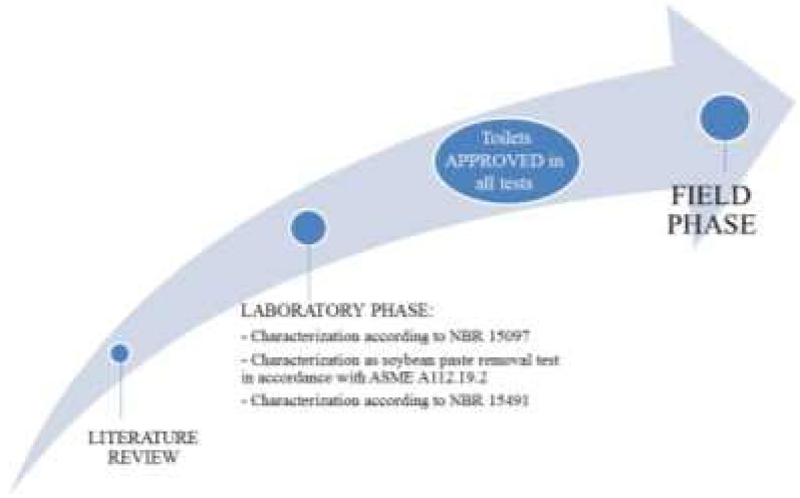

Figure 2 Scheme of the full study

3.1 Laboratory phase

In the laboratory phase were carried out all tests required by the Brazilian standards NBR 15097 (ABNT, 2011) and NBR 15491 (ABNT, 2010) and the soybean paste removal test according to ASME A112.19.2 (2013), as shown in Table 2. The transport of soybean paste, according to PERC (2012), was not used to approve or fail toilets in laboratory phase.

Table 1 Tests performed and reference documents

REFERENCE DOCUMENT	TESTS PERFORMED
ABNT NBR 15097:2011	Water consumption test; splashing water; trap seal restoration test; surface wash test; granule and ball test; mixed media test; spheres removal; drain line transport characterization test.
ABNT NBR 15491:2010:	Filling time; overflow test for gravity flush tanks; Tightness float tap; Tightness gravity flush tank; Tightness of the float; Drive effort; Resistance to the drive mechanism; Resistance to the use; Resistance to static charge.
ASME A112.19.2: 2013	Waste extraction test

The tests that evaluate the performance of the toilets are designed to verify that the product meets the desired functions by users and by the system:

- The removal tests verify that the toilet has ability to remove waste from the toilet itself. If the product does not meet any of these requirements it is possible that, in the field, the toilet presents clogging;
- The transport of solid test verifies the ability of the toilet to transport the waste along the drainage pipe to avoid clogging;
- The surface wash test verifies that the toilet makes proper cleaning of its interior;
- The trap seal restoration test checks if the toilet does self siphonage and recompose the minimum trap seal;
- Tightness tests are performed to verify that the product presents leaks;
- The filling time tests, drive effort and overflow capacity are requirements related to

user comfort;
- Use resistance tests, tightness of the float and resistance of drive mechanism evaluate the product's ability to resist use;
- The static load resistance test is related to user safety.

Figure 3 shows the results of the water consumption test. Note that all tested toilets used 4.8±0,4Lpf.
The results show that all toilets are able to remove a minimum of polypropylene spheres required by the Brazilian Standard (80 spheres) by the toilet itself, but four toilets do not carry the minimum distance (10,0m) required by the Brazilian standard NBR 15097 (ABNT, 2011), as showed in Figure 4. This indicates that the major problem encountered in reducing the discharge volume can be the removal of solids from drainage and sewage system. There were toilet failed in the tightness gravity flush tank requirement, trap seal restoration test, surface wash test and mixed media test.
The waste extraction test was performed in 13 of the 20 initial toilets (only approved previously). Of these, nine were considered approved and four failed. The waste extraction test is a more critical test than other media removal tests. 31% of the toilets evaluated in this requirement failed.
At the end of the laboratory phase, seven toilets were considered approved in all laboratory tests, which represents 35% of the toilets. However, manufacturers decided to continue with five toilets for field phase, each one of different model.

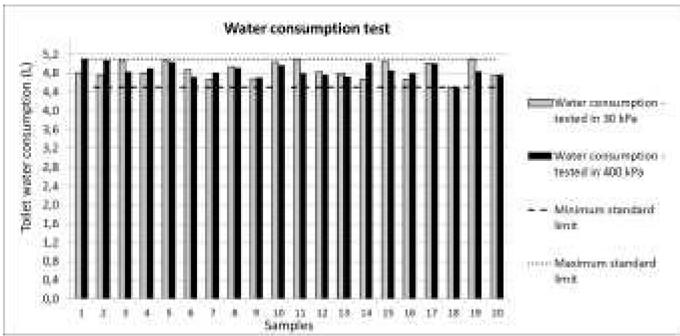

Figure 3 Results of water consumption test

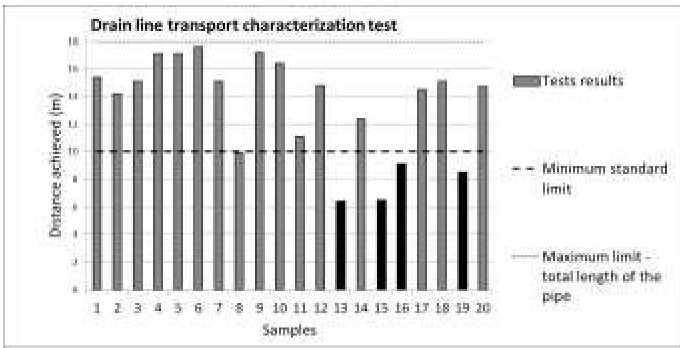

Figure 4 Results of drain line transport characterization test

3.2 Field phase

The field phase consists of the monitoring of toilets water consumption of ten houses and the monitoring the occurrence of clogging on the drainage system through real time video.
The field phase site is located in the Housing Development Victoria (Osasco/SP -

Brazil), designed to low-income population. The chosen housing development consists of twelve town houses (six houses on the ground floor and six on the first floor). Figure 5 shows the top view of the housing development and Figure 6 shows other view of the housing development.
Despite the housing development has twelve houses, residents of houses nº09 and nº23 did not allow monitoring. Therefore, the field phase was conducted in ten houses (Figure 7).

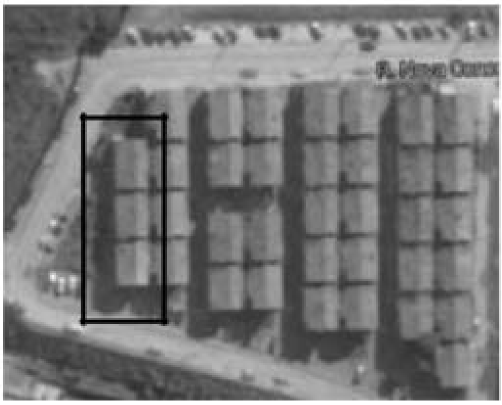

Figure 5 Top view of housing developement monitored

Figure 6 View of the housing development

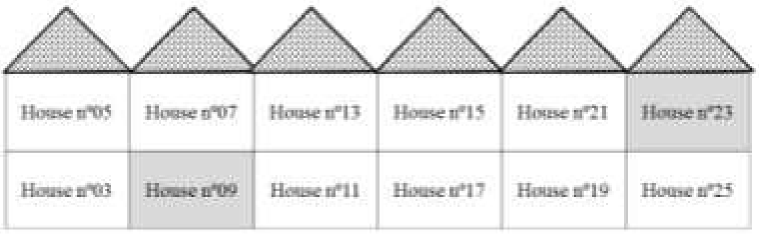

Figure 7 Scheme of positioning of the houses in the housing development - houses in gray represent those not involved in the monitoring of water consumption

This housing development was selected because the critical characteristics that features: beginning of sewage system and final section pipe with low slope and without any extra contribution. These characteristics are shown in Figure 8. The sewer pipe of each house have flow direction from 1 to 2 (detail in Figure 8).

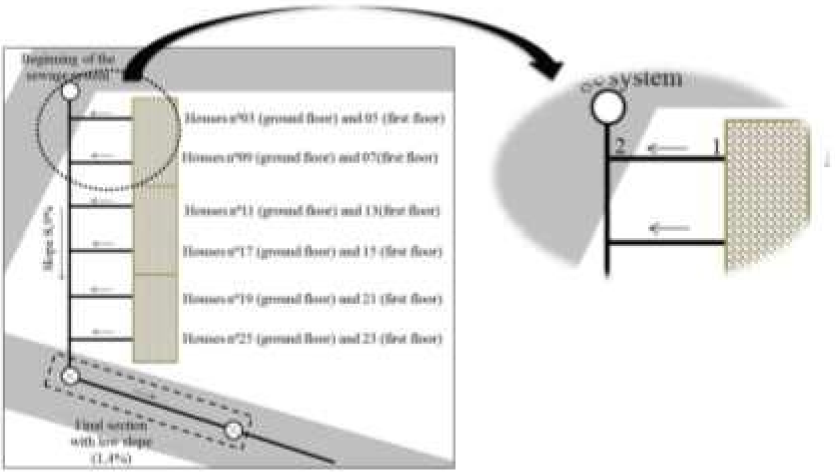

Figure 8 Scheme of sewage system of monitored houses (top view scheme)

It was realized a geometric survey of houses to define the toilet model more appropriate for each bathroom to avoid installation problems. With the measurements taken on site it was set up a database with the floor plan of each bathroom. Figure 9 shows an example of attempts to choose the toilet model for the house nº17. Note that the toilet model nº20 can not be installed in this house, because the toilet bowl size does not allow the installation.

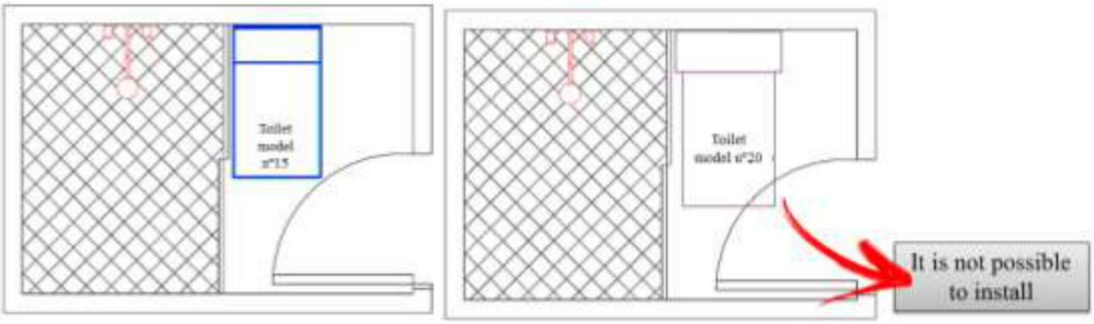

Figure 9 Example of attempts to choose the toilet model for the house nº17

As five toilet models were considered suitable for field phase and the inhabitants of ten houses agreed to participate in the study, each toilet model was installed in two houses. We chose to install the same toilet model in the floor unit and the unit on top of this, thus reducing the number of variables that can interfere in the evaluation.

Questionnaires to characterize the habits of inhabitants was applied initially. It was possible to understand the routine of the inhabitants, including the pick period use of the bathroom and period of the day when the house is empty. It is possible to analyze in more detail the water consumption data and identify possible error of measurement equipment.

For monitoring the water consumption from toilets it was installed a water meter in each toilet (between the wall and the flexible supplying the flush tank). The accumulated data volume and flow are sent remotely via Internet every minute (Figure 10).

Initially, the ten houses were monitored with 6,8Lpf toilets that were installed. After one month of monitoring, the toilets were changed for 4,8Lpf toilets approved in the laboratory phase. Then, the monitoring occurred for over 7 months.

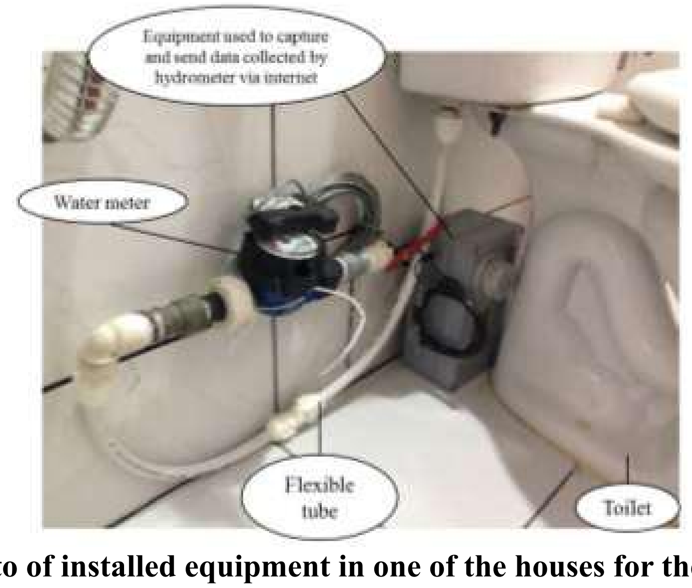

Figure 10 Photo of installed equipment in one of the houses for the monitoring of the toilet water consumption

The real time video system was used to verify possible initial damage in the sewage system and to check if after the installation of 4,8Lpf toilets occurs some damage or clogging the pipe. As shown in Figure 11, the camera is connected to a monitor that displays the image filmed live streaming.

Figure 11 System used for the real time video of the sewage system pipe

4 Results and discussion

4.1 Monitoring the functioning of the toilets

Throughout the field phase, satisfaction questionnaires were carried out to verify user satisfaction regarding the performance of the toilets. The results were positives.
In the first questionnaire any user reported malfunctions in toilets, such as clogging, odors in the house (no trap seal restoration) or need to use brush to clean the toilet bowl. Two residents of two different houses reported that it is rarely necessary the second discharge for removing the waste.
In the second questionnaire the following problems were found:

- House nº05: the discharge was too weak, not doing the proper wall washing and removal of waste. During the visit it was found that the flush button was badly regulated. The adjustment was made and resident satisfaction was checked on the next visit.
- House nº25: the resident noted that the total consumption of the residence significantly increased (on average 10m³ to 16m³/month). It was not found that this problem is being caused by the new toilet, because the house entrance water meter was "spinning" even without the use of any device, which indicates a possible leak.

Any other houses reported problems related to the new toilets in any subsequent verification by the end of the study.

4.2 Monitoring of water consumption

The monitoring of water consumption was performed for eight months. In the first

month were installed 6,8Lpf toilets, which were later replaced by 4,8Lpf toilets.
The average daily consumption of water from the toilets of 6,8Lpf was 16,6L/day/capita. Figure 12 shows the average water consumption values of the toilets per day per capita of all houses monitored when the 6,8Lpf toilets were installed.
Figure 13 shows the average values of toilets consumption per day per capita of all houses when the 4,8Lpf toilets were installed. The average water consumption of the toilets was 16,1L/day/capita.
When the averages water consumption of toilets are compared, It was not observed significant variation in the water consumption of toilets. However, when compare differents houses it can be observed that there are houses that have reduced the water consumption of toilet and there are houses that this volume increased. Figure 14 shows the consumption before and after the toilets replacement.

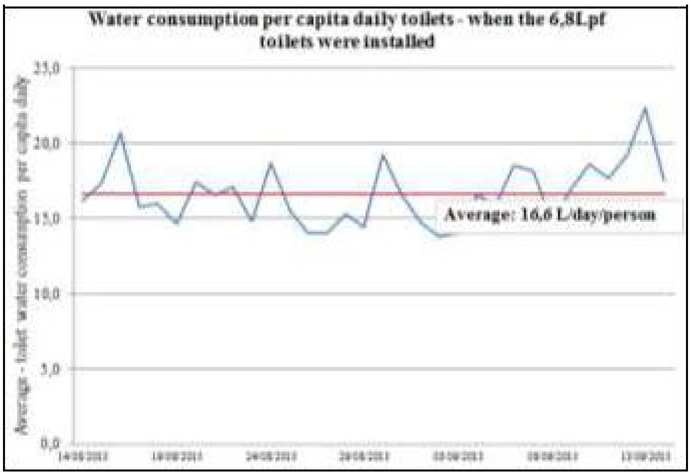

Figure 12 Water consumption per capita daily toilets – when the 6,8Lpf toilets were installed

Figure 13 Water consumption per capita daily toilets – when the 4,8Lpf toilets were installed

House	Water consumption per capita daily toilets (L)	
	When the 6,8Lpf toilets were installed	When the 4,8Lpf toilets were installed
3	17,5	11,3
5	12,0	10,0
7	12,6	8,5
13	12,5	18,4
15	20,8	22,8
17	14,7	19,4
19	11,5	11,5
21	21,0	16,5
25	27,0	26,1
Average	16,6	16,1

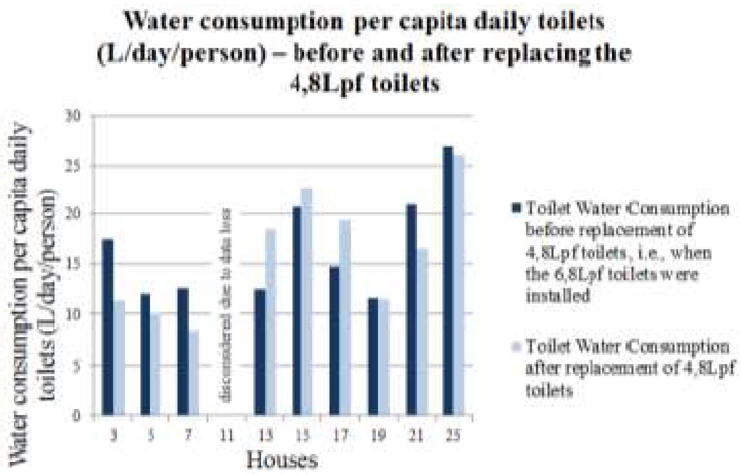

Figure 14 Water consumption per capita daily toilets – before and after replacing the 4,8Lpf toilets

4.3 Monitoring the occurrence of clogging on the sewage system through real time video

Five real time videos were realized during the field phase to check for possible clogging caused by reduced water volume. Items from 4.3.1 to 4.3.5 detail each one. At all times, the steps were as follows (Figure 15):

– Entry manhole nº1 direction manhole nº2;
– Entry manhole nº2 direction manhole nº1;
– Entry manhole nº2 direction manhole nº3;
– Entry manhole nº3 direction manhole nº2.

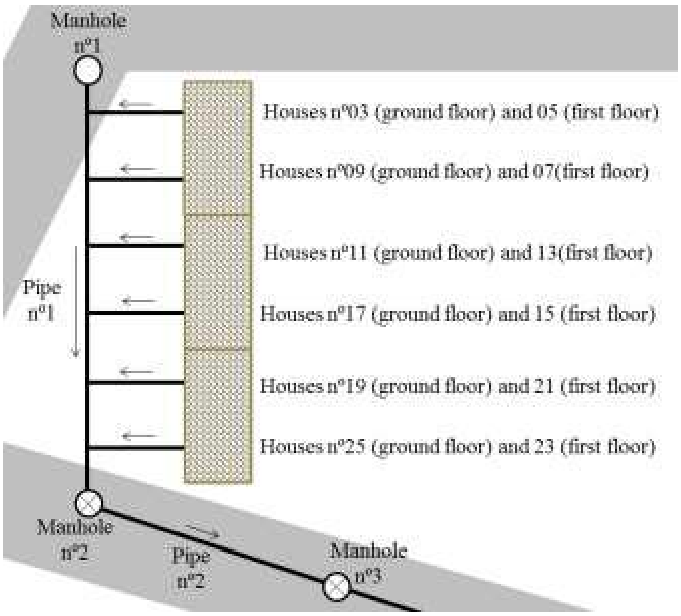

Figure 15 Detail of the video sections of sewage system

4.3.1 First real time video
The first real time video was realized initially, before the replacement of 4,8Lpf toilets.

It was performed after cleaning the pipe in order to verify pre-existing damages. It was observed that the pipe did not have damages.

4.3.2 Second real time video

In the second real time video, it was identified an obstruction 15 meters form the Manhole nº2 direction Manhole nº3 (Figure 16).

Figure 16 Detail of obstruction observed on the second real time video

4.3.3 Third real time video

In the third real time video, it was identified points of solids accumulation in both stretches near the Manhole nº2 (Figure 17 and 18).

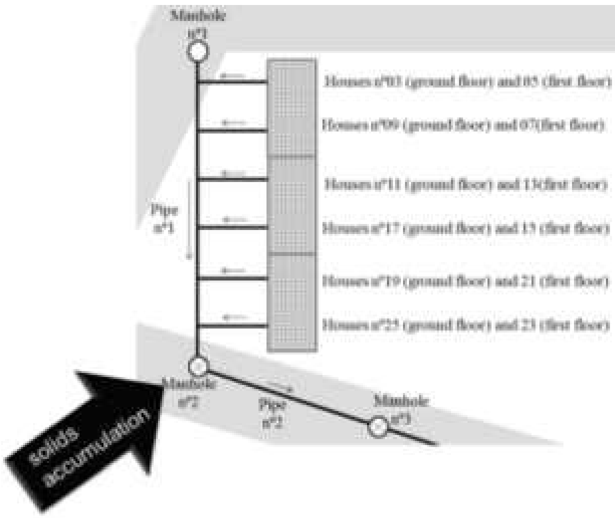

Figure 17 Detail of third real time video

Figure 18 Solids accumulation near the Manhole nº2

4.3.4 Fourth real time video

At the fourth real time video the following problems were found:

- In pipe nº1: Solid accumulation near the Manhole nº2.
- In pipe nº2: Solid accumulation near Manhole nº3.

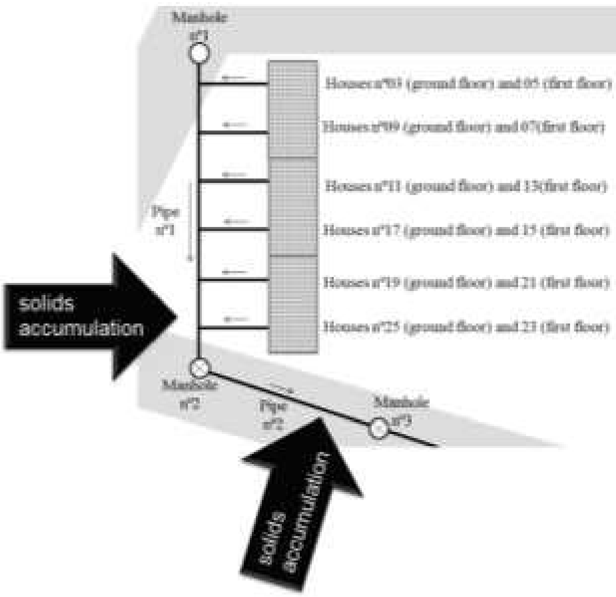

Figure 19 Detail of fouth real time video

4.3.5 Fifth real time video

In the fifth real time video, the accumulation of solids remained checked. Solids accumulation points were identified near the Manhole nº2 and nº03, as observed in the previous shooting.

These accumulations may have been caused by the lower volume of water used by toilets.

5 Conclusions

The results showed that there are toilet models that have reduced water consumption and the reduction of the flush volume may have caused negative effects in the performance of the sewage system, checked in real time video.

No problems were reported by the inhabitant about the 4,8Lpf toilets. However, it was found accumulation of solids in some parts of the sewage system. It is not possible to conclude that the reduction of the volume discharge causes an effect reduction in total water consumption for the users. It is necessary to deepen the study, with toilets that showed effective reduction in water consumption in the field phase to verify that the problems encountered are due to some toilets or the smaller volume.

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7 Presentation of Authors

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Hydro-technical assessment of public sewer system of the Kosice-city and practical experience from operation and creation of the general development plan for the combined sewer system

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Abstract

This article describes the hydro-technical assessment of public sewer system of the Kosice-city through the real measured rainfall events and real measured flow rates in sewer system. These data was also used for simulation of hydro-technical ratios and results from simulation outputs were also compared with real measured data.

Keywords

Sewer systems, hydrotechnical assessment, surface runoff, simulation.

1 Introduction

The main purpose of the hydrotechnical assessment was reconnaissance of the sewersystem of Košice-city - clarification and verification of building and technical solutions for combined sewer system and verification of building and technical solution for storm water overflow chamber.
Basic data of the sewer system in Košice-city:
- Altitude: approx.from 185 m a.s.l. to 348 m a.s.l.
- Combined sewer system- CSS (gravity system)
- CSS length: 438.2 km
- The number of storm water overflow chambers: 26
- District of Košice – Krásna (Separate major collector)
- Number of connected inhabitants: 226615 (year 2014)
- WWTP Kokšov Bakša - $Q_{real.24}$ = 780 l/s (year 2014)
- Recipient: river Hornád

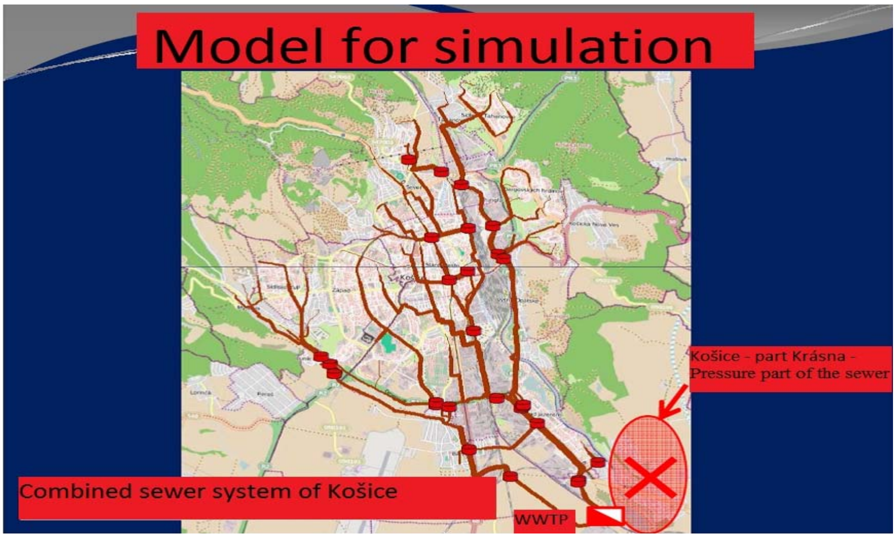

Figure 1 Locations of research points at the campus of the Technical University in Kosice (TUKE) [1]

2 Measurements and data acquisition for simulation

For the simulation was used the simulation software – Mike Urban. In simulation wasconsidered main parts of the sewersystem of Košicecity: A, B, B1, D, and major feeders. Total length of assessed public sewer system was 112.19 km. Diameters of assessed sewer system was from DN 600 mm to DN 4 000 mm. Shape of the considered profileswere: round, ovoid, muzzle.Material of the considered sewer system: reinforced concrete, earthenware, PVC (different roughness).

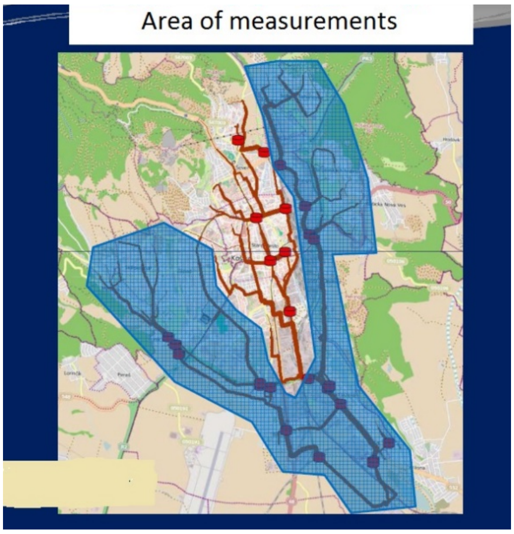

Figure 2 Area of measurements for research

2.1 Devices for measurements

For measurements were placed for 3 months next devices:

1. **the rain gauges** (for research was available data from raingauge placed in campus of the Technical University of Košice)

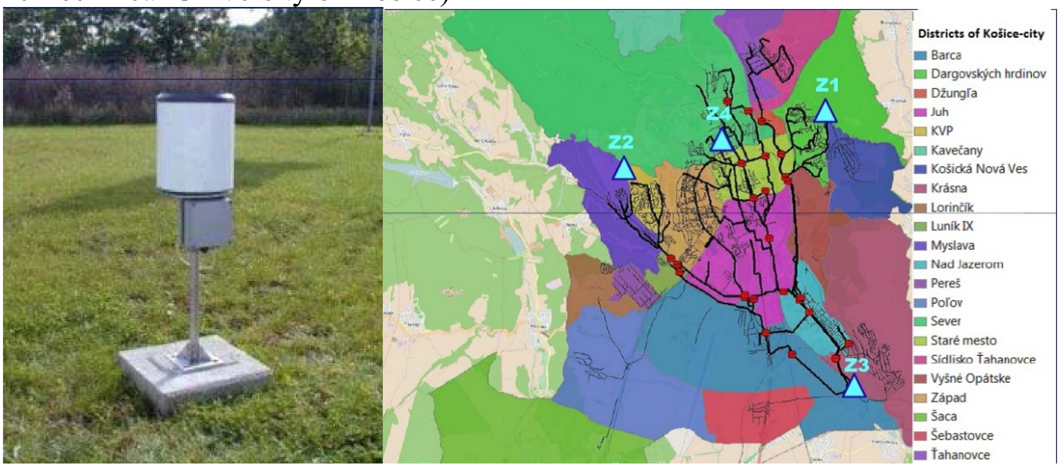

Figure 3 Rain gauge and its locations

2. **the flow meters**

Figure 4 Flow meter placed in sewer systemand its locations

3. **the water level meters**

Figure 5 Water level meter placed in sewer system and its locations

2.2 Calibration of model for simulation and measurements

As an input data was usedthe real measured values from rainfall events to the model. The aim of research is comparing the measured flow rate values in measurement points in the timeframe againstoutputresults from the model simulation.

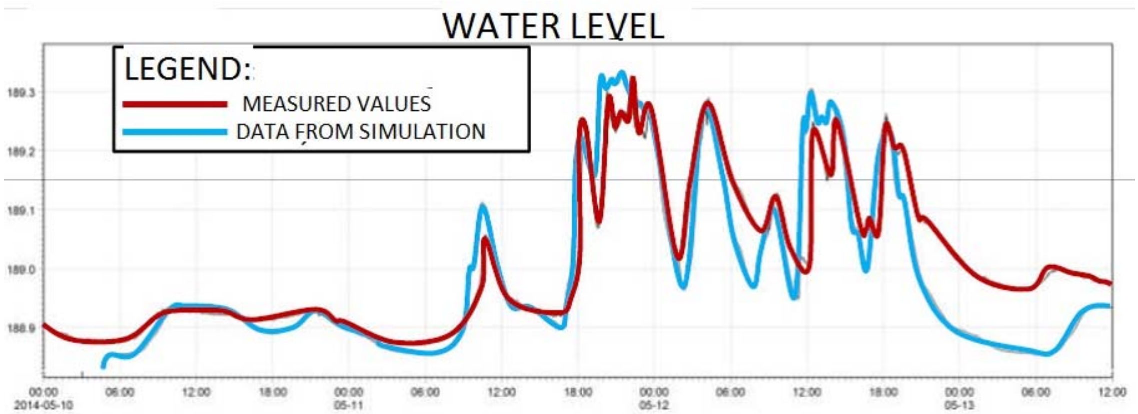

Figure 6 Calibration of model - Comparing water levels

Input data was selected:

As a specified design rainfall was used rainfall with intensity Q_{15} = 165 l/s/ha, corresponding to the periodicity p = 0.5 (repetition time once every two years) and also specified real rainfall with intensity Q_{15} = 244 l/s/ha, corresponding to the periodicity p = 0.1 (repetition time once every 10 years).

As main outputsdata from the model and also the main variables under consideration, for the selected parts of sewer system are:

1) Maximum flow [$l.s^{-1}$]
2) Pipe filling [%]
3) The rest capacity of the pipeline [$l.s^{-1}$]
4) Flooded shafts

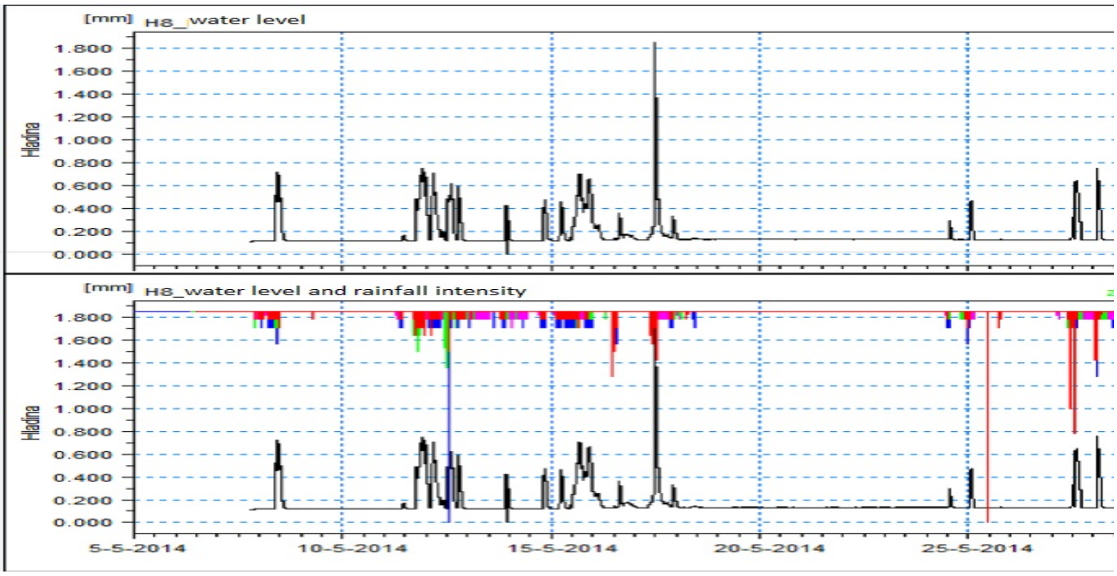

Figure 7 Illustration of measured data from the water level device with comparison with data from rain gauge

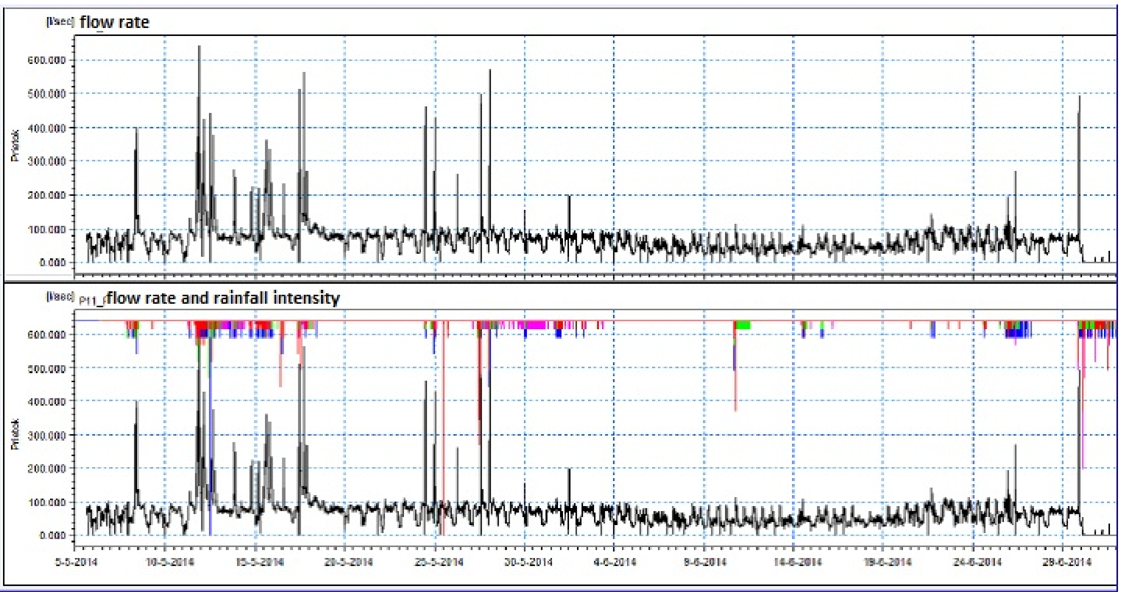

Figure 8 Illustration of measured data from flow rate devicewith comparison with data from rain gauge

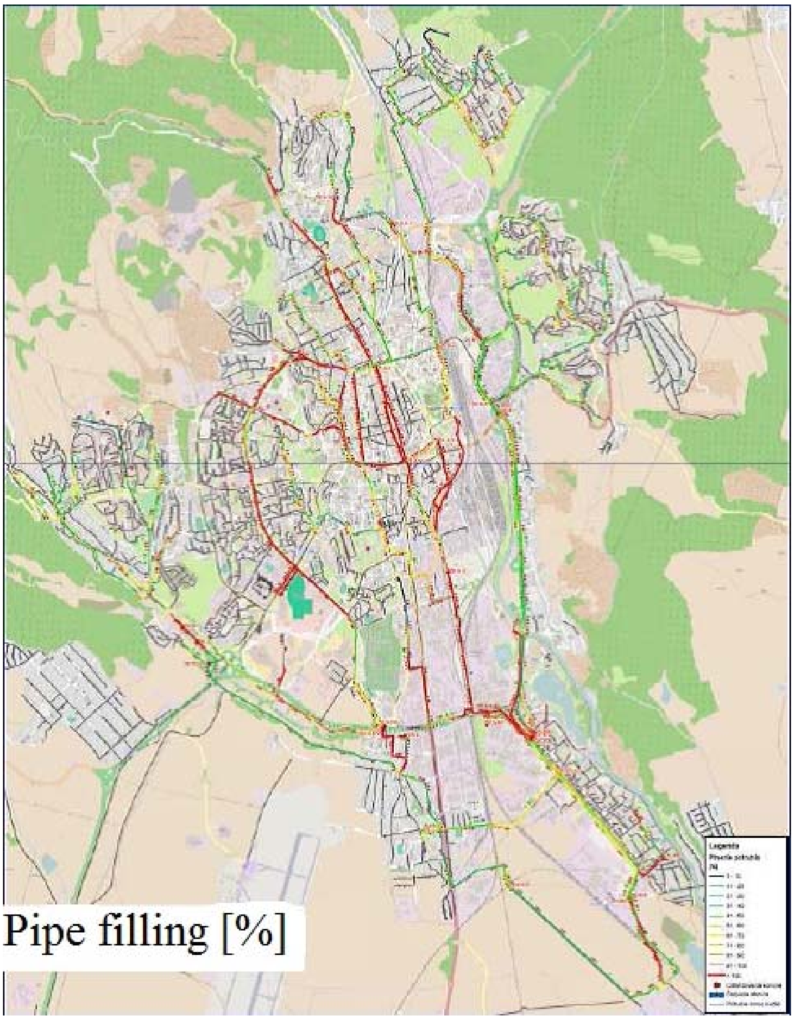

Figure 9 Pipe filling in % during measurements

3 Conclusion

Hydrotechnical assessment of public sewer system of the Košice-city provide us data about real flow rates and water levels in extisting public combined sewer system.Measurements show also some specific and extreme flow rates into the combined sewer system of Košice what represent abnormality and next research will be focused on source of this abnormal flow rates.Hydrotechnical assessmentprovide us also important information for reconstruction of overflows (in most cases there is no need to raise the spillway edge)and practical experience from operation for creation of the general development plan.

4 Acknowledgments

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6 Presentation of Authors

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Experimental study on the influence factors of the ventilation for three kinds of drainage systems

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Abstract

By using constant flow method, investigate the relationship between the air ventilation and positive air pressure in three different drainage systems, single stack drainage system with smooth PVC-U pipe and cyclone joint, single stack drainage system with smooth PVC-U pipe and specific cyclone joint and special single stack drainage system with inner spiral pipe and specific cyclone joint. Combining the relationship between the air ventilation and flow rate and the relationship between the air ventilation and the positive air pressure, analyze the influence factors that may effect on the air ventilation. The results shows that the positive air pressure is the main factor, and it is mainly affected by the combined action of free water droplets, shear stress of gas-liquid interface and water nappes. While the ventilation rate would be enslaved to the patency degree of the air passageway.

Keywords

Constant flow drainage, air ventilation, negative air pressure.

Comparing to specific vent stack drainage system, single stack drainage system has little air passageway in its pipe system, and its air cycling depends on stack vent at the top of the vertical pipe. The water nappes would hinder the airflow in the pipe and the negative air pressure is hard to relieve, so the air pressure is easy to be broken the limits when comparing with specific vent stack drainage system [1,2].

In order to get a good air passageway in the single stack drainagesystem, the system getsdeveloped constantly. Especially the system with special cyclone joint, it could relieve the effect of the water nappes effectively and its drainage capacity improves a lot [3,4].

Heriot-Watt University's Drainage Research Group (DRG) did so much researches on the influence factors of air ventilation and found that there are two main factors which effect on the air flow: the interface shear stress produced by the viscidity between the water film flow and the air and the air friction that the free water drops encounter during falling.

D P Campbell and K D MacLeod pointed out a mathematic model[6] as follows:

$$\frac{\Delta P \pi D_c^2}{4} = \tau \pi D_c L + \frac{1}{2} C_d S \rho V_{REL}^2 \qquad (1)$$

Where, ΔPisthe air pressure difference between the two air fracture surfaces, Pa; $D_c$isfree diameter of wet stack, m; $\tau$is the interfaceshear stress between the water film flow and the air, N/m^2; ρ is the density of air, Kg/ m^3; $C_d$is the air resistance coefficient of the free water drops; $V_{REL}$is the relative velocity between the free water drops and the air, m/s; L is the length of the water film, m; S is the projected area of the free water droplet on the vertical.

The mathematic model explains the reasons that the air flows under the water film flow. While, it cannot fit well with the air ventilation at the upper level of the vertical pipe and when the water droplet does not meet the so-called terminal velocity.

By using constant flow method, we did experimental research on three different drainage systems, single stack drainage system (with smooth PVC-U pipe and downstream sweep junction, short as system I), single stack drainage system with specific cyclone joint (PVC-U pipe, short as system II) and special single stack drainage system (with inner spiral pipe and special cyclone joint, short as system III) to find the influence factors that effect on the air ventilation at the upper level of the vertical pipe.

1 Experiment method

1.1 Experimental pipe system

This test took place at China National Engineering Research Center for Human Settlements- Wanke Building Research Center's high-rise building equipment R & D center and testing tower. The system I uses de110 PVC-U pipes as vertical stacks and de110 PVC-U pipes as horizontal cross pipes. Each level of horizontal pipes is connected to the vertical stacks via downstream sweep junction, and the main horizontal pipe is connected to the vertical stacks via two 45° elbow connectors.

The system IIuses a specific cyclone joint to connect the vertical pipe and horizontal pipes and the other construction is just the same as the SSS. While the system IIIuses a specific cyclone joint to connect the vertical pipe and horizontal pipes and the vertical pipe is one kind of inner spiral pipe with 12 ribs. The average height of the ribs is 3.54mm. The other construction is just the same as the system I. Seen as the Figure 1.

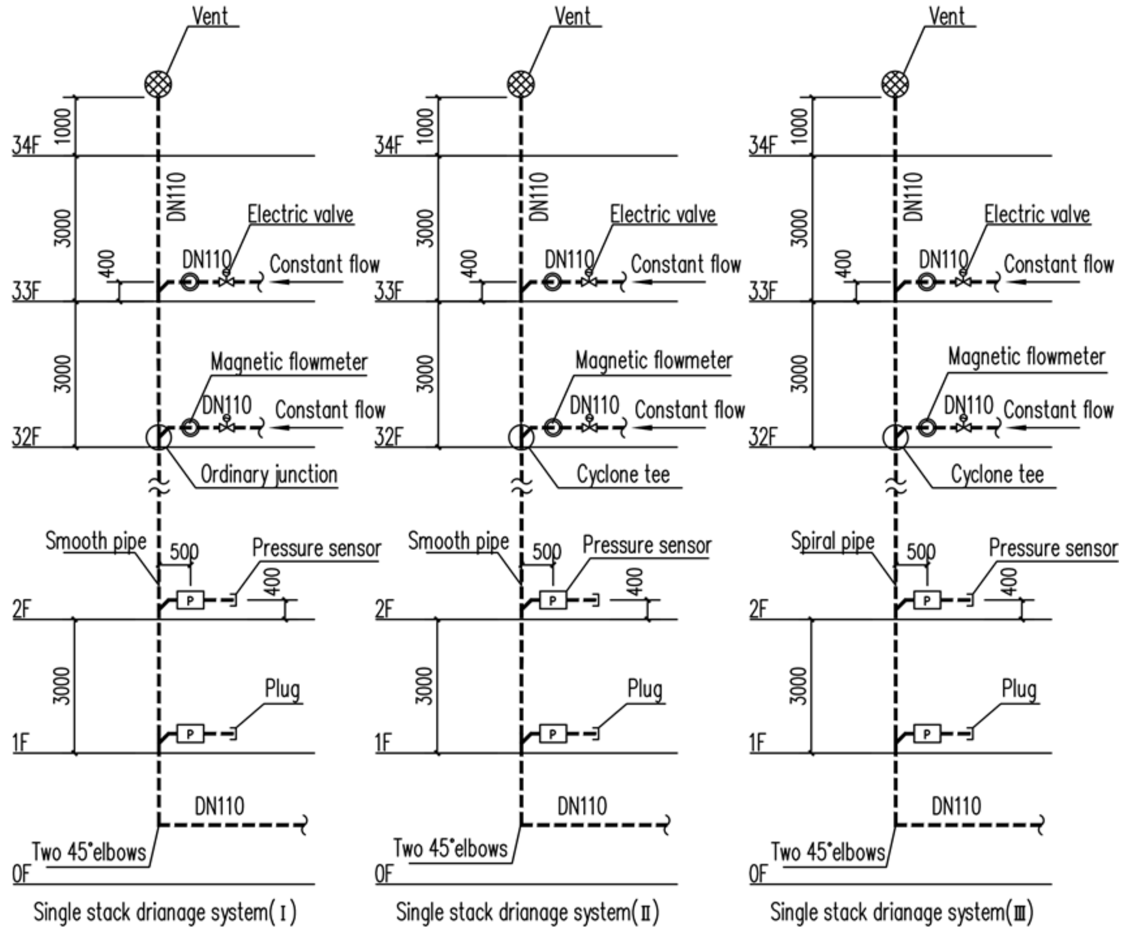

Figure 1 Test systems for the three drainage systems

1.2 Testing equipment and instruments

Pressure sensors are installed on the horizontal branches on every level expect of the drainage levels, with a direct distance of 500mm from the vertical stacks.The pressure sensor is American GE DruckPTX610 which ranges 1.5 through 10000Pa and it features is ±0.08% with a data acquisition cycle of 20ms.

The drainage device of constant method concludes an electric control valve which can be long-range controlled and an electromagnetic flowmeter with high precision. The flowmeter ranges from 0.3 through 12 m/s and its accuracy is ±0.5%. The drainage devices are installed on the floor of 32 and 33. The max flush flow rate is 2.5L/s and when the flow rate is not enough open another drainage device just beneath it.

The special cyclone joint used in this research is one kind of cyclone joint with central guide. The joint is made up of two parts. The upper one is an expansion period with no guide vane inside, and it only guides the flow from horizontal branches to the vertical pipe. The lower one is funnel-shaped with 6 guide vanes inside to enhance the rotational flow.

2 Testing results and analyzing

2.1 Testing results

We did experimental researches on these three drainage systems with constant flow method and get the data of negative air pressure and the ventilation flow rate at the top of the vertical pipe. The testing results could be seen at Table 1.

Table 1 The results of the experiment under different drainage flow rates

Drainage flow rate L/s	System I		System II		System III	
	Psmin/Pa	Ventilation L/s	Psmin/Pa	Ventilation L/s	Psmin/Pa	Ventilation L/s
0.5	-43	31	-68	41.4	-15	14.5
1	-107	46	-142	52.8	-39	20.3
1.5	-193	54	-209	56.8	-64	22.5
2	-366	60	-225	51.8	-92	24.6
2.5	-810	65	-258	46.9	-114	26.9
3	-1210	76	-361	43.9	-116	28.0
3.5	——	——	-350	41.4	-133	28.8
4	-1426	77	-455	40.8	-158	29.9
4.5	——	——	-910	41.1	-179	30.1
5	-1994	77	-1193	41.5	-218	30.0

Seen as Table 1, the negative air pressure rises with the increase of the water flow rate in each drainage systems. The ventilation flow rate rises to a steady level in system I and system III, while the ventilation in system II increase at the beginning and then decrease to a steady level, see Figure 2.

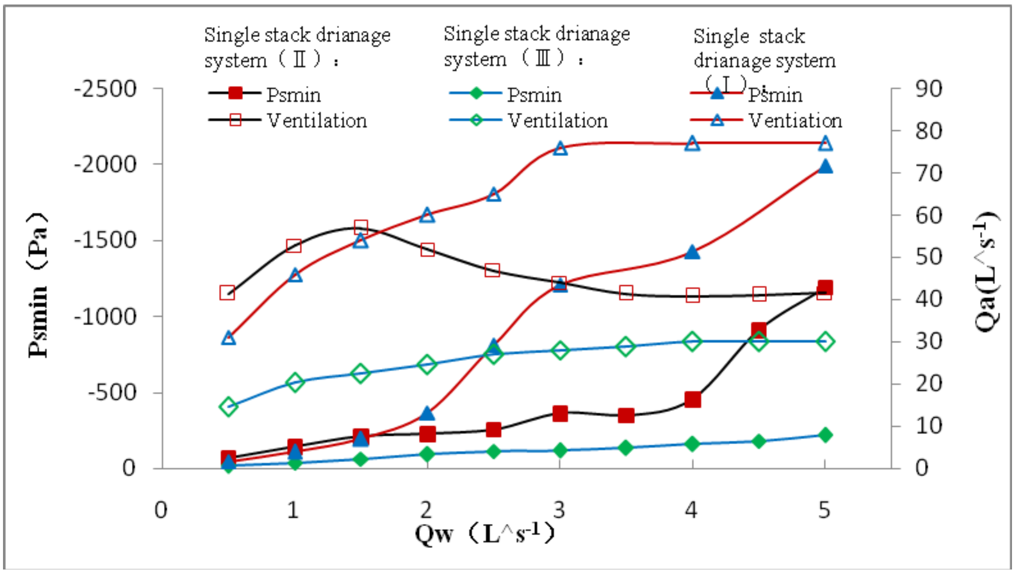

Figure 2 The trends of negative air pressure and air ventilation according to the drainage flow rate

Seen as Figure 2, when the water flow rate is less than 1.5L/s, the air ventilation and

negative air pressure have the same order: system I>system III . While the water flow rate is between 1.5L/s to 3.0L/s, the fluctuation of the air ventilation and negative air pressure is different. The air ventilation and the negative air pressure arise with the increasing water flow rate in system I and system III. While in system II the air ventilation decreases and the negative air pressure arises with the increasing water flow rate.
As figure 2 shows, the air ventilation in each systems would be steady at last and the order to be steady is: system I, system IIand system III. The corresponding water flow rate is 3.0L/s, 3.5L/s and 4.0L/s respectively. We could find in table 1, when the air ventilation in system I gets steady, the negative air pressure is -1210Pa and it is far beyond the critical value, -400Pa. When the air ventilation in system IIand system III gets steady, the negative air pressure is -350Pa and -158Pa respectively, which is not beyond the critical value. We find that the steady ventilation of single stack drainage system with specific cyclone joint (41L/s) and special single stack system (30L/s) decrease 47% or 61% when comparing with the single stack system(77L/s).

2.2 Analysis

For there is no steady water film at the top of vertical pipe in system I, we need to optimize the mathematic model that D P Campbell and K D Macleod proposed combining with the characteristics of the water flow. As tosystem I, when the water flow goes through from the horizontal branch, it will crash to the pipe wall opposite because of the gravity and then produce the water nappes. After crashed with the pipe wall, some water will diffuse around the wall and become the original water film. Some water will become little free water drops because of the crash. The water adhering the wall accelerates under the acting force of gravity, the friction of the pipe and the friction between the air and water. The thickness of the water film gets thinner and some of the water film will get atomized and disperse into the air passageway.The free fluid level of the water film is not parallel with the air stream direction in the process, so we need to bring in a new coefficient, K_1. The water drops would bear the air friction and devote to the air pressure of the system. Besides, the process that the air goes through the water nappes could simplify to the process that air goes through a sloping panel and it could be ignored. Thus, the formula 1 could be:

$$\frac{\Delta P \pi D_c^2}{4} = K_1 \bar{\tau} \pi D_c L + \frac{1}{2} C_d S \rho \bar{V}_{REL}^2 + \Sigma \frac{1}{2} C_d' S' \rho \bar{V}_a^2 \qquad (2)$$

Where, K_1 is a coefficient representing the water flow rate of the horizontal pipe and drainage level. S' is a coefficient representing the water flow rate. K_1 and S' would arise with the increasing water flow rate. Although, the air would bear the frictional resistance of the pipe, it is small respectively and we ignore it during analysis.
When the water flow rate is less than 1.5L/s, the thickness of the water film is thin in system I and system II. It is influenced by the frictional resistance of the pipe wall, the average air-water shear stress is small, and the terminal velocity is small, respectively.As to system I, water will atomize to little free drops though the waternappe phenomenon is not strong. As to system II, although the specific cyclone joint could eliminate the effect of the water nappes, the thickness of the water film is not thin enough, water disperses when goes through the lower section of the joint for the little and centralized gravity and become a lot of free water drops after crashing with the joint. The system III has a

smaller terminal velocity because that it has a bigger resistance friction for the inner spiral pipe and a smaller terminal velocity comparing with the smooth pipe under the same water rate, and its' average water-air shear stress is smaller. With the increasing inertia of the water adhering the wall, the amount of the free water drops caused by the crashing with the joint is much lower when comparing with the system I. When the friction of the nappes and the water-air shear stress is both small, the negative air pressure is mostly caused by the friction of the free water drops. At the same time, there is a positive correlation between the air ventilation and the negative air pressure in the system for the clear air path.

When the water flow rate is between 1.5L/s and 3.0L/s, the water nappe phenomenon is much more clear and has a bigger air friction at first. Then the terminal velocity will get bigger as the same as the water-air shear stress. At last, the thickness of the water film in the acceleration section would get thickened and it would effect on the inertia, thus effect on the amount of the free water drops. The three factors mentioned before exist among the three systems. With the increasing drainage water flow rate, the friction of the water film would get bigger observably and become the main factor that effect on the negative air pressure in the pipe system, and the negative air pressure get bigger at the same time.

For system I, it has a clear air path except for the section of the water nappes and the air could get in clearly. As to the system I, except for the air path gets smaller topically for the water nappes, because that the cyclone action would be smaller in the smooth pipe system, then the water stemming occurs for the angles of the special joint's vane and the cyclone water do not match. The air ventilation gets smaller for the unclear air path. The adhering water in the system III could keep up the cyclone movement for the inner spiral pipe, so when the water goes through the cyclone joint the water stemming phenomenon is much small relatively, the air path is clear and the air ventilation could increase with the increasing negative air pressure.

When the water flow rate is bigger than 3.0L/s, the air ventilation gets steady in the three systems. Under the combined action of pipe wall and the air, the terminal velocity could not increase unboundedly. When the water flow rate is bigger relatively, the terminal velocity would get steady for given system, the water-air shear stress could not change significantly. Then the water nappes become the main factor for the negative air pressure increase further. While the water nappes will effect on the air path, the air movement could become steady at the same time.

3 Conclusion

The negative pressure of system I is effected by the free water drops, shear stress between the water and air and the water nappes. When the flow rate is low, the negative pressure is mostly effected by the amount of the free water drops, then the shear stress between the water and air when under the media level flow rate, and the water nappes when the flow rate is big.

The special cyclone joint could release the effect of the water nappes, make the water rotating, and release the effect of the incoming water from the branch pipe. While to the vertical pipe, the structure of the special cyclone joint could effect on the development of the free water drops, the amount of the free water drops and the thickness of the water film. Besides, the combine of the smooth pipe and the special cyclone could devote to development of the plug, and effect on the ventilation.

The shear stress between the water and the air is related to the terminal velocity. The using of the special cyclone joint and the inner spiral pipe helps to release the terminal velocity, release the speed of the development of the water film, and release the shear stress between the water and the air.

4 Presentations of Authors

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Study on a hybrid drainage system compatible with commercial building conversion

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Abstract

In Japan, commercial buildings in central cities nowadays are not only for accommodating company offices; various types of potential tenants would also be attracted to run their businesses in such buildings. In that case, the challenge would be how to accommodate water supply spaces, including securing gradients of horizontal drainpipes as well as incorporating presentable appearances into an architectural space, and this means that choosing locations for such spaces would be restricted when relying on a gravity type drainage system. In response, the Architectural Institute of Japan formulated Design Guidelines for Mechanical and Siphonic Drainage Systems, AIJES-B0003-2016, to initiate activities to promote force-feed type drainage systems.

In the study, for providing compatibility with free design of a water supply space by drainage facility technology, a hybrid drainage system that adopts both force-feed type and gravity type drainage methods was employed, and the performance and effectiveness of the hybrid drainage system was verified in the case of designing and introducing the same to an actual building. The building used for the verification is a commercial building located in Osaka City, Japan, which is occupied mainly with offices. The building has 37 storeys above ground, including a target floor that has been renovated to accommodate clinics. The result of proposing, installing and using the force-feed/gravity-type drainage system in the actual building for approximately six months confirms the operation of said drainage system without any problem to or any complaint about the drainage performance thereof, as well as confirming the effectiveness thereof. This report describes further details of the study.

Keywords

Hybrid drainage system, conversion.

1 Background and objectives of the study

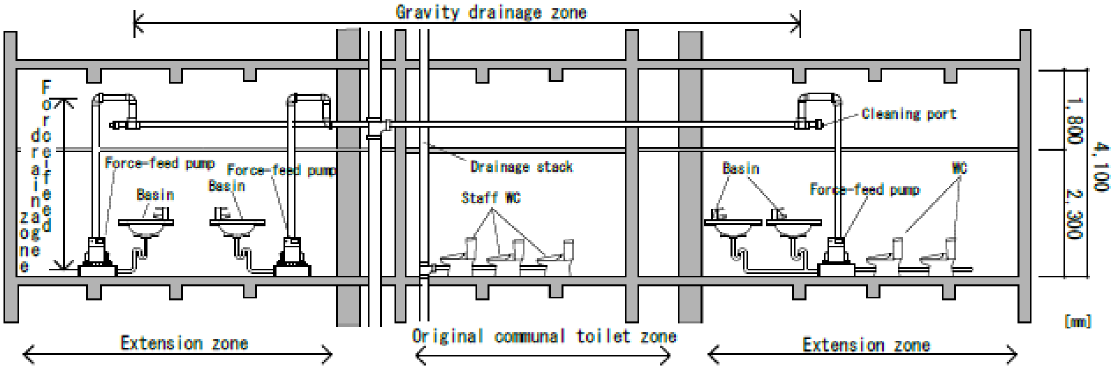
There is a need for the facilitation of 'commercial building conversion' according to the type of tenant business and the intended use thereof. Such conversion, however, entails a problem; locations for providing water supply spaces are limited, in an architectural sense, by the conditions that in each water supply space, the horizontal drainpipe that connects sanitary fixtures to the drainage stack needs to be provided with an appropriate pipe slope, and that the space needs to be created under the floor to accommodate the piping.

In order to address these conditions, the study proposes a hybrid drainage system (conversion-compatible drainage system) that employs both force-feed type and gravity type drainage mechanisms, applies the hybrid drainage system to an actual example of conversion of a super high-rise commercial building to examine the performance of said hybrid system, and verifies the effectiveness of the same. The following three points are discussed in this report.

a) Planning and overview of the conversion-compatible drainage system
b) Evaluation of the influence and effectiveness of the conversion-compatible drainage system on the horizontal drainpipe
c) Evaluation of the influence and effectiveness of the conversion-compatible drainage system on the drainage stack

2 Overview of the drainage system compatible with commercial building conversion

Figure 1 is a conceptual diagram of converting an office building to accommodate gynaecology clinics that are provided with small water supply spaces. The diagram shows that the small water supply spaces (zones) are added to the original communal toilet zone. The conversion-compatible drainage system works in such a manner that (1) in each zone, wastewater is drained from toilets, basins, washing machines, etc. which are installed in booths; (2) the wastewater first goes into the force-feed drainage pump unit; (3) the wastewater is then pumped up through the drainage stack (force-feed drainpipe); (4) the wastewater is led into the horizontal drainpipe which is installed in the ceiling; and (5) the wastewater is finally led into the drainage stack. This system makes it possible to add many water supply spaces to the existing communal toilet space. In the past, the author proposed a very similar hybrid drainage system for apartment houses.4) This study examines the applicability of the hybrid drainage system to commercial dwellings.



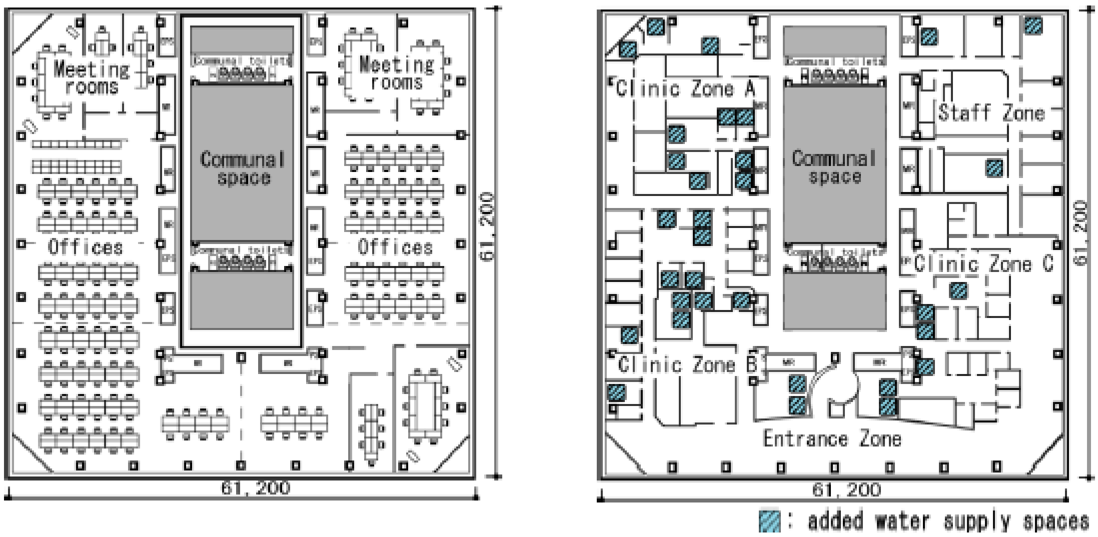
Fiugre 1 Concept of the hybrid system compatible with commercial building conversion

3 Applied example overview

Table 1 outlines the building to which the proposed conversion-compatible drainage system was applied. The building has 37 storeys above ground, and accommodates mainly commercial facilities and offices. The target floor for conversion is the 15th floor. Figure 2 (1) is the floor plan of the 15th floor with offices before being renovated, and Figure 2 (2) is the floor plan of the same floor after the renovation to facilitate gynaecology clinics. Figure 3 outlines the conversion-compatible drainage system. On the target floor, i.e., the 15th floor, 34 force-feed pump units of various types are installed (see Photo 1 for the typical appearance of the pump units, and Fig. 4 for the pump capacity curves by type), and it is configured such that wastewater from various sanitary fixtures (toilets, washing machines, etc.) is drained above the floor. Each force-feed pump unit is connected to a force-feed drainpipe with a pipe diameter of 25A, 40A, 50A or 65A according to the pump capacity, and the inflow part in the upper section of the force-feed drainpipe is connected to a horizontal drainpipe with a pipe diameter of 100A via a joint part which is shaped so as to prevent backflow. Wastewater from each sanitary fixture flows through the abovementioned piping and into a drainage stack with a pipe diameter of 100A. The wastewater then flows through a house drain with a pipe diameter of 100A in the 8th floor offset section, while being combined with wastewater from other floors, and is eventually discharged to the outside. Incidentally, the force-feed pump units are provided with a vent pipe having a pipe diameter of 20A or 32A, and the stacks are provided with a vent pipe having a diameter of 50A or 100A.

Table 1 The building

Location	Kita Ward, Osaka City
Intended use	Commercial facilities / offices / hotels, etc.
Building area	15,597.79m^2
Floor area	294,775.31m^2
Structure	S/SRC/SR
No. of storeys / height	37 floors including 3 basement floors, height 175.3m, target floor 15F



(1) Before (offices) (2) After (gynaecology clinics)

Figure 2 Floor plan of 15F before and after the conversion

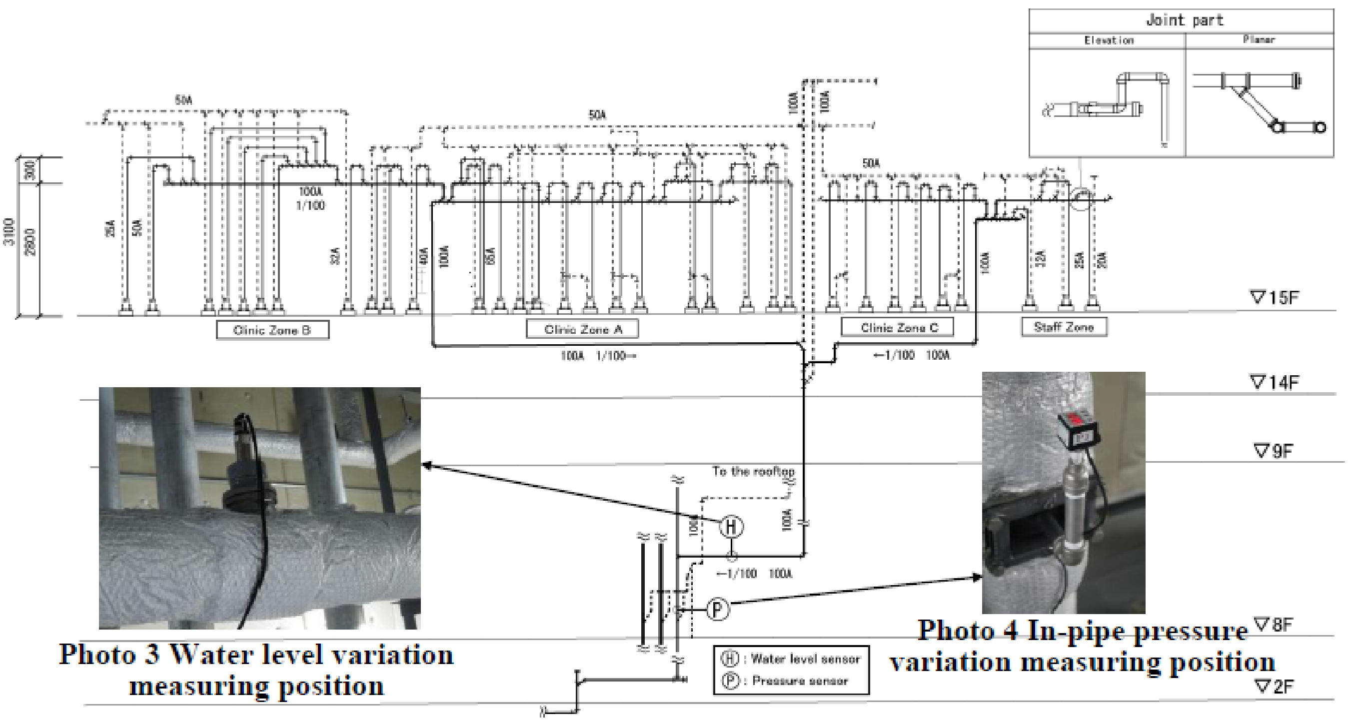


Photo 3 Water level variation measuring position

Photo 4 In-pipe pressure variation measuring position

Figure 3 System diagram of the conversion-compatible drainage system

Photo1 Force-feed pump unit

Force-feed pump	Specifications		No. of pumps installed
(I)	Type	Sewage/wastewater drainage system	1
	Pump capacity	175L/min	
	Tank capacity	200L	
	Head	12m(120kPa)	
(II)	Type	Sewage/wastewater drainage system	4
	Pump capacity	50L/min	
	Tank capacity	20L	
	Head	12m(120kPa)	
(III)	Type	Wastewater-only tank-less force-feed drainage system	25
	Pump capacity	35L/min	
	Head	6m(60kPa)	
(IV)	Type	Sewage/wastewater tank-less drainage system	4
	Pump capacity	35L/min	
	Head	6m(60kPa)	

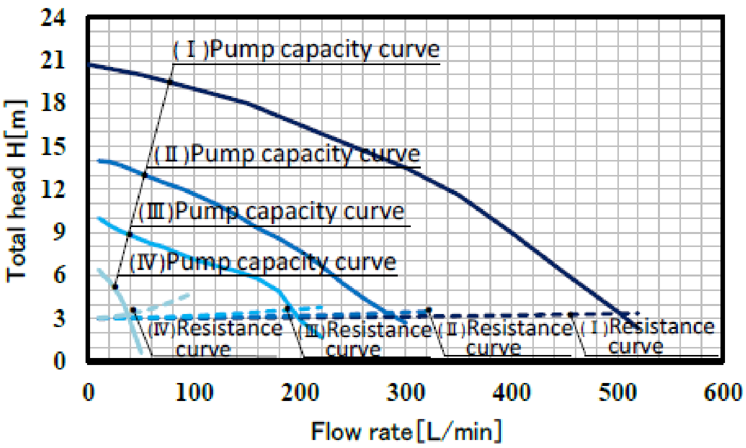


Figure 4 Force-feed pump units - overview

4 Drainage load estimation and discussion

4.1 Laboratory experiment

Prior to the actual drainage load estimation, a horizontal drainpipe model was set up in the laboratory, using the same diameter and material as a real horizontal drainpipe, as shown in Photo 2 and Fig. 5. Drainage loads of 0.1[L/s] to 5.0[L/s] were applied from the upstream of the model, and the variation of water level was measured with a water level sensor approximately 6000mm downstream from the inflow point, where the flow of wastewater normally becomes steady. Flow rates of drainage loads read on flowmeters disposed at application ports and measured water level variations were used to translate the relationship between the water level and the drainage load flow rate into a graph, as shown in Fig. 6, and actual measured water level variations were substituted in the relational expression of the water level and the drainage load flow rate to estimate drainage load variations. A correlation was observed between the water level and the drainage load flow rate, and it was confirmed that the values obtained by the relational expression and by the Manning's equation corresponded well to each other.

Photo 2 Experimental horizontal drainpipe system in the laboratory

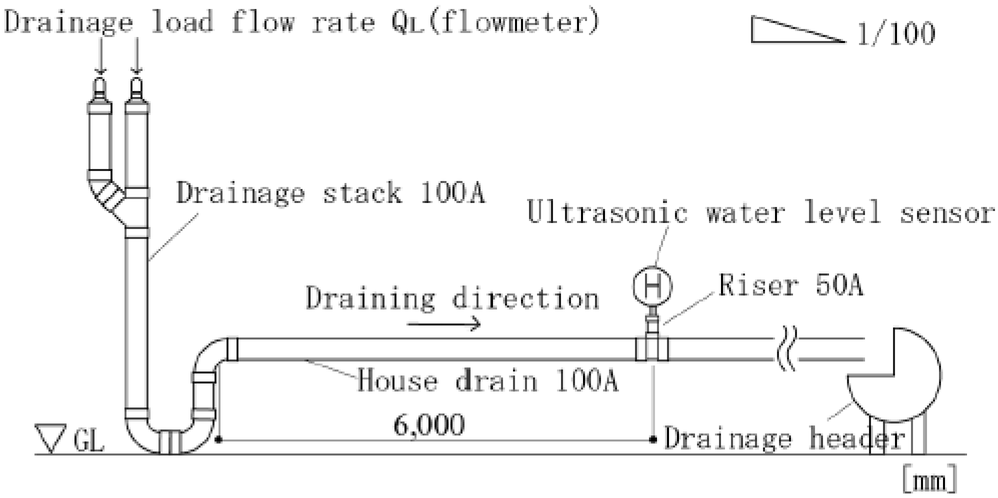


Figure 5 Experimental horizontal drainpipe system in the laboratory

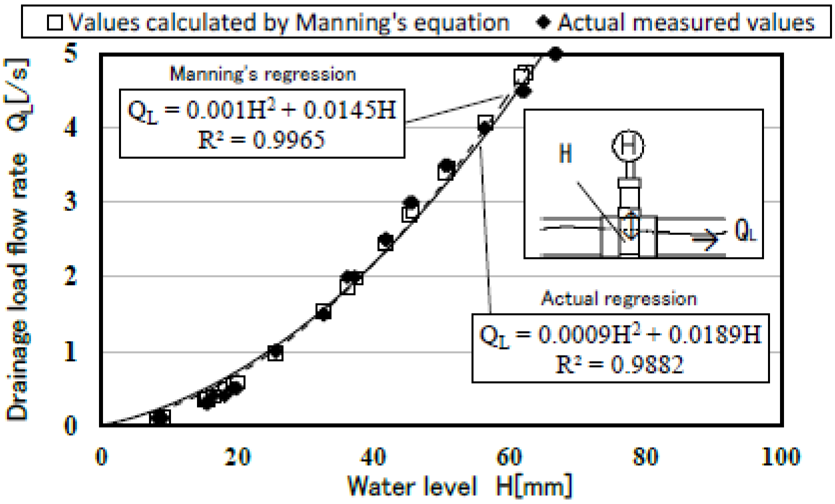


Figure 6 Water level variations in the horizontal drainpipe and drainage load

4.2 Drainage load estimation using real piping

A period of approximately eight months from 13 July 2015 to 21 February 2016 was set for the research that was carried out on the actual building.

As shown in Figure 3, an ultrasonic water level sensor H (see Photo 3) was disposed at a position H along the house drain in the 8th floor offset section, and Figure 6 was used to estimate a drainage load flow rate from a water level variation measured with the sensor. Figure 7 shows an example of the variation of water level in waveform as measured with time in the house drain in the 8th floor offset section. When looking at the waveform in detail, some wastewater may have been drained with detergent foam, due to the use of a washing machine for example, and in that case, the detergent foam was disregarded and only the actual wastewater was taken into the observation. With this adjustment, the variation of drainage load flow rate was calculated from the variation of water level, each day for eight months, and the obtained values were sorted into weekday average and maximum values, and Saturday average and maximum values, which are shown in Figure 8. According to Figure 8 (1), the weekday maximum is approximately 2.5[L/s] and Figure 8 (2) shows that the Saturday maximum is approximately 2.3[L/s]. Both diagrams also indicate the allowable flow rates specified by SHASE-S206 for house drains with diameters of 75A and 100A. When comparing the weekday diagram with the Saturday diagram, the weekday diagram shows that the variation of the drainage load flow rate is slightly bigger than that shown in the Saturday diagram. This is assumed to be because the maximum number of times that wastewater was drained with time on weekdays was high, i.e., the sanitary fixtures were used more often on weekdays than on Saturdays, resulting in generating higher drainage load flow rates. As in Figure 4, more (III) type force-feed pumps were used than the other types in the piping shown in Figure 3, and the flow rate of wastewater drained by the (III) type was measured approximately 190[L/min] (3.2[L/s]) at the point of flowing into the horizontal drainpipe, while the actual measured drain load was 2.5[L/s] at maximum. It is presumed that the flow rate of the wastewater drained from the 15th floor decreased by approximately 20% by the time it reached the 8th floor. Meanwhile, Figure 9 shows the transition of the daily maximum of drainage load flow rate during the measuring period. The maximum actual measured value is approximately 44% of 5.6[L/s], which is the allowable flow rate specified by

SHASE-S 206 for horizontal drainpipes with a pipe diameter of 100A (pipe slope 1/100). This confirms that the conversion-compatible drainage system is applicable with the use of drainage stacks and offsets with pipe diameters that are consistent with existing designs, thus, not requiring diameter expansion, and that the pipe diameter of 100A could be reduced by one size to 75A, since the flow rate of drainage load generated in the conversion-compatible drainage system is considerably below the SHASE-specified flow rate thresholds.

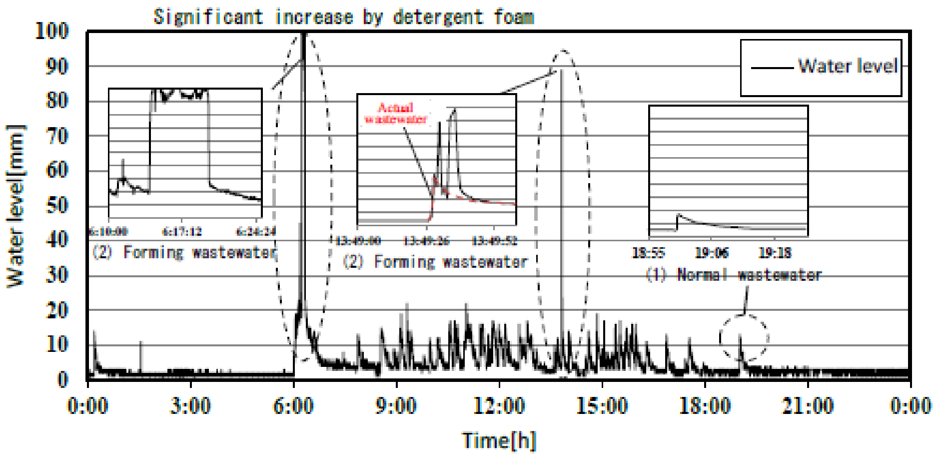
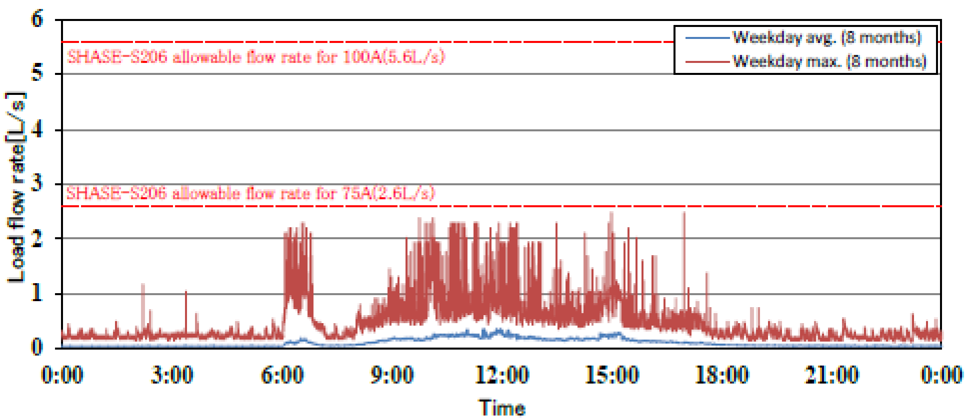
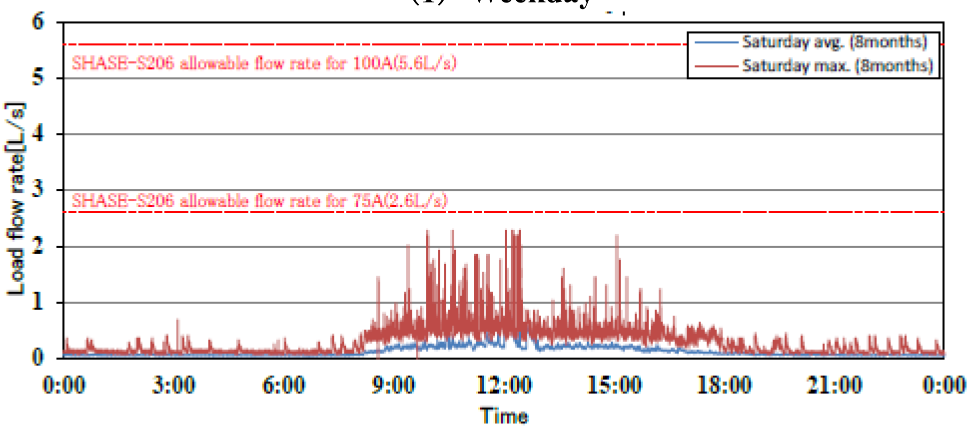


Figure 7 Water level variations in the house drain in the offset section - example



(1) Weekday



(2) Saturday

Figure 8 Drainage load flow rate per time zone (2015/7/14-2016/2/21)

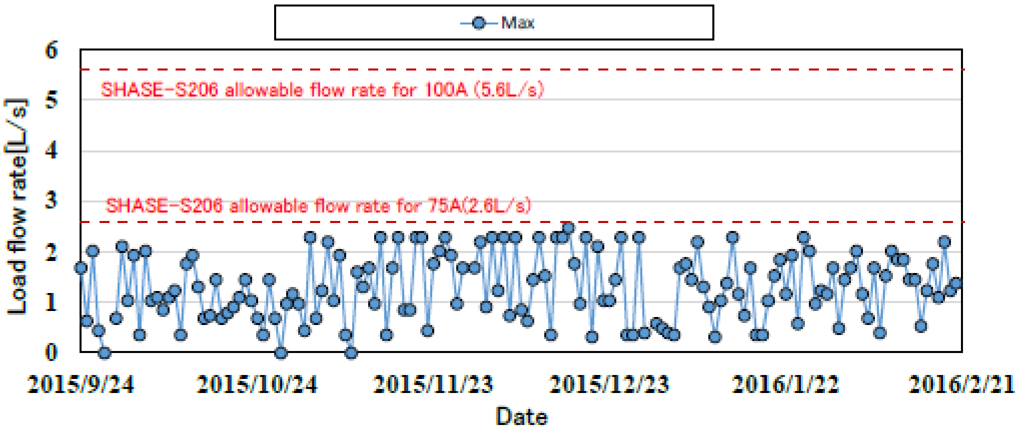


Figure 9 Transition of the maximum drainage load flow rate during the measuring period (2015/9/24-2016/2/21)

4.3 Variation of pressure in the drainage stack

A pressure sensor (see Photo 4) was attached to the drainage stack, as shown in Figure 3, and the variation of pressure in the drainage stack was measured. Incidentally, all the measuring instruments were set to measure at 1-second intervals.
Figure 10 shows the average variation of in-pipe pressure per time zone on weekdays and on Saturdays, respectively. The diagram confirms that the time zone in which pressure is generated significantly in the drainage stack is between 9.00 and 18.00, and that the in-pipe pressure fluctuates along with the drainage load estimated by the variation of water level in the same time zone. This suggests that although wastewater from other floors also flows into the drainage stack, the wastewater from the clinics on the 15th floor is the one that causes an impact on the drainage stack. Figure 11 shows how the maximum and minimum values of the in-pipe pressure fluctuate from day to day. The diagram indicates that the maximum value of negative pressure is approximately -300Pa, and the maximum value of positive pressure is approximately 180Pa. That is, the variation of the in-pipe pressure is approximately 75% or less of the SHASE-S218-specified threshold of ±400Pa, and therefore, the conversion-compatible drainage system could be operated safely without any concerns.

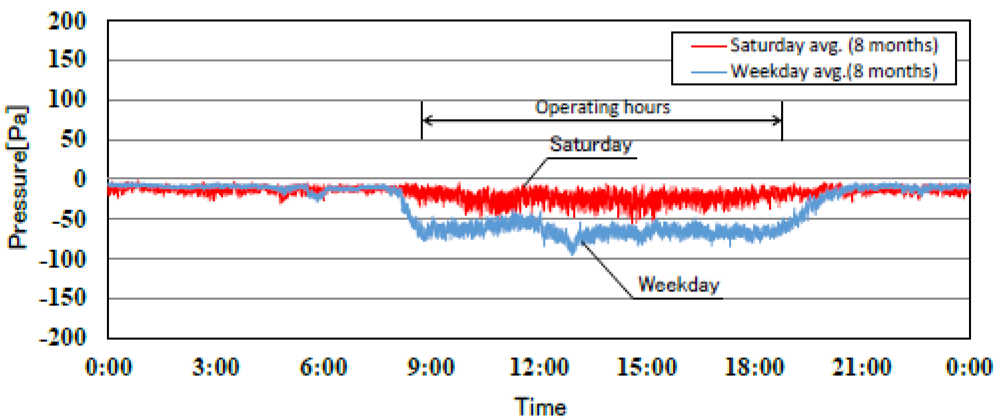


Figure 10 Average in-pipe pressure variation per time zone (2015/9/24-2016/2/21)

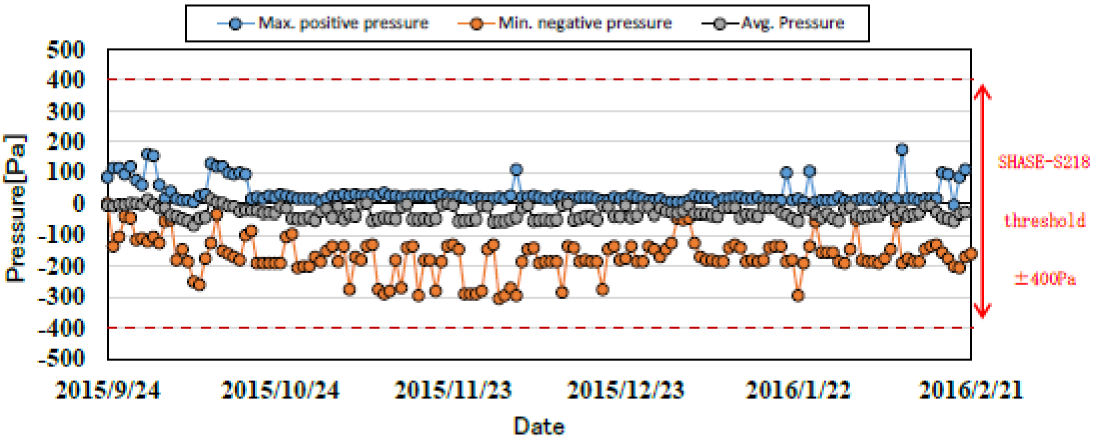


Figure 11 Variations of average, maximum and minimum pressure values during the measuring period (2015/9/24-2016/2/21)

5 Conclusion

The study proposed a conversion-compatible drainage system, which combines the use of force-feed type and gravity type drainage systems, and a verification experiment was carried out on an actual building for eight months. As a result, it was confirmed that the proposed system could be operated without hindering the drainage performance, and therefore, said system was effective. The findings are as follows.

1) The variation of drainage load in the horizontal drainpipe of the proposed system is approximately 45% of the allowable value specified by SHASE-S 206, and the pipe diameter of said drainpipe could be reduced.
2) The variation of pressure in the drainage stack is 75% or less of the threshold specified by SHASE-S218.
3) On the basis of the above, the proposed conversion-compatible drainage system has been verified to be effective.

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7 Presentations of Authors

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A study of design manuals for large-scale central kitchen facilities at schools

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Abstract

Health, safety and reliability are important in the kitchen. Requirements for hygiene and food safety are laid down in the Hazzard Analysis and Critical Control Point (HACCP) system. Planning has aimed to manage harm factors: biological, chemical and physical influences of the production environment and the process of manufacture. The Biness Continuity Plan (BCP) s important to implement so as not to hinder implementation, even at the time of a large-scale disaster such as the Great East Japan Earthquake. The prevention of food poisoning has become an important issue in relation to hygiene and cooking today. Few studies of building facilities and food handling in the kitchen have been undertaken and no study has been made of design manuals for engineers in respect of the overall kitchen facilities. This study examines the rearrangement of the design item, which is treated as a first step in the compilation of a design manual for large-scale kitchen facilities. This study demonstrates the following:

(1) Securing the infrastructure (in particular, energy source multiplexing of cooking apparatus and robust structures) is important in restoring the kitchen to normal at the time of a natural disaster.

(2) How to use kitchen apparatus is necessary for energy saving. In consideration of an electricity stoppage during peak periods, the introduction of a gas-type kitchen apparatus is a possible solution.

(3) A mutual grasp of the situation by both school and kitchen center is required.

(4) Regarding the business method for construction and management, the most appropriate method should be examined and decided at facility and local government levels.

(5) Thorough hygiene management is necessary through the monitoring of each process in the kitchen from the receipt of goods to the serving of meals, as laid down in the HACCP.

(6) The maintaining of a constant temperature and humidity and the prevention of secondary pollution in the kitchen through the adoption of the dry system.

(7) Hygiene management through the identification of pollution areas. Prevention of pollution generally is important and the prevention of pollution at the intersection of the work flow line is particularly necessary.

Keywords

Kitchen center, HACCP, BCP.

1 Introduction

An indoor environment of safety, hygiene and reliability are important when designing the kitchen. And it is demanded to offer hygienic food by “Hazard Analysis and Critical Control Point (named as HACCP)” system. The plan is aimed at managing three harm factors, those are “biologic hazard”, “chemical hazard” and “physical hazard” through the production of food. In the case of disaster such as the Great East Japan Earthquake, it is necessary to accept the establishment of the business continuity in a plan beforehand.
The issue of hygiene in food preparation and the avoidance of foods poisoning has become a social issue today. In contrast, there are few studies of building facilities which aimed at a planning solution for food handling in the kitchen.
In this study, it is intended that rearranging design items such as the layout of the kitchen instrumentation and the movement of food, is the first step in making a design manual for large-scale kitchen facilities.

2 Importance of BCP in the kitchen

2.1 Summary of BCP

When a large-scale disaster or accident occurs, a company and an administrative organization continuing lunch business, the thing that is reopened in time as short as possible even if work is stopped are required. Therefore it is important that an emergency action plan is devised beforehand.
Establishing the priority of duties beforehand in the kitchen facilities, and preparing for a backup system. Because it performs the quick safety confirmation of the member of duties for business continuation at the time of the disaster, and it is necessary to find the personnel required, it is necessary to decide the method beforehand. The robustness of the building and certain installation of instruments are required measures to prevent destruction.

2.2 The function pursued in the BCP kitchen

2.2.1 Securing of the infrastructure
It is desirable to secure electricity by the multiplexing of the power supply. For an available power supply, there are always three of commercial power, the good use of emergency generator and the gas cogeneration system. The commercial power and gas cogeneration systems are used normally, and there is not the thing that the gas cogeneration system stops if gas supply is done at the time of the emergency. When the commercial electricity supply is stopped, the emergency generator is operated. Even in normal circumstances, even as for the emergency, the power supply is enabled by putting these three together. In this case the base load is anticipated at the time of a design, and it is necessary to apply which power supply depending on electricity demand.
Because city gas has high utilization as an energy source to all types of kitchen apparatuses, in the securing of city gas supply it must be continued even at the time of a

disaster by making the gas gaining over in facilities a moderate pressure gas fitting superior in quake resistance.
The securing of a water supply is important to life in the emergency. The large-scale kitchen facilities need cisterns to greatly receive the supplied water that is set to avoid suspension of the water supply. The tank for the middle water is installed for securing of water of the restroom mainly. The urgent drainage tank is installed to retain filthy water and general drainage when the sewer was cut apart at the time of a disaster.

2.2.2 Heat source multiplexing of the cooking apparatus
It is necessary to set up the heating cooking machines by the electricity type and the gas type about as risk management of the use of energy. A large quantity of food is cooked efficiently, and the quick supply of food is possible. In addition, this system can be fitted, which can reduce the worry of energy stoppage at the time of emergency.
Combination of gas and electric power is tied to reduce the peak load of electricity in shortening the cooking time. This is the best mix of energy in the kitchen.

2.2.3 Building structure
Correspondence such as resistance to earthquake, it is necessary to introduce the seismic isolator, liquefaction measures and subsidence measures, to improve the quake resistance of a ceiling and to strengthen the windowpane facing the outside.
The seismic isolator comprised of laminated rubber and oil bumper is established under the foundations of building, and reduce the shaking of the building. By improvement of the ground, prevention of the liquefaction and the subsidence are planned.
The earthquake-resistant ceiling can prevent the fall by establishing the gap with the brace and wall. The glass in the outside windows by putting a film is prevented from scattering, and the prevention of the second disaster is enabled.

3 The main point of the design of the school kitchen center

3.1 A school meal and energy saving

It is strongly urged that the annual energy consumption of all buildings be reduced. The kind of heat source is chosen to reduce a CO_2 discharge in the kitchen center, and the introduction of the apparatus reducing energy consumed is important. It is tied to energy saving to devise how to use kitchen apparatus, for examples include in adjusting appropriate heat that accepted ingredients with the turn pot.

3.2 School meal and power saving and peak cut

There are two peak periods of electricity consumption in the kitchen. The first occurs throughout the cooking time in the morning, and the second occurs at the time of washing the tableware for example in the afternoon and sterilization. For the equalization of power consumption, there is a method to exchange the heat source of the kitchen apparatus with a gas type from an electric expression. The gas is used positively in the large-scale facilities. For the reduction of the energy consumption by the ventilation, the method collecting exhaust air and heat by the cooking in the whole ceiling and ventilating is adopted. This is called a "substituted ventilation ceiling system", and the air conditioning load is greatly reduced.

3.3 A school meal and earthquake disaster correspondence

In consideration of the case where the disasters such as earthquakes occurred, the kitchen center must do the earthquake-resistant fixation of the kitchen apparatus or measures of the prevention of fall. At the time of the disaster outbreak, it is assumed that the school facilities become the disaster prevention base. For refugees gathering there, the kitchen center may be assumed a role to supply meals.Then, it is necessary to examine a plan preparing for routinely including the securing of examination and storage product of the distribution of boiled rice.

3.3 School meal and allergic correspondence

The allergic cause and symptom diverge into many branches, but correspondence with the lunch may be required. There are how many students have an allergic predisposition, and it is necessary for the fact how much allergic predisposition each person is to be grasped beforehand.
What is performed thoroughly is important to the manufacturing management to confirm whether an allergy material does not get mixed with ingredients to use for a target student in the kitchen center, and not to get mixed in the process cooking. The setting of the allergy-response room is necessary, and each school and kitchen center cooperates mutually again and acts for situation grasp and examines the kitchen center, if necessary, how much allergy correspondence room is necessary. An important point is that allergy correspondence has limitation as far as there is not it of the unreasonableness without being going to offer lunch to all children with an allergy.

4 A business method

There are two business methods on establishing a kitchen center, and maintaining it. The first is the method where local public entity having jurisdiction over a school builds it.The second method is to make use of utilization of vitality in the private sector in and keeps private power alive, there is a PFI method. A PFI method includes a BTO (Build-Transfer and-Operate) type and BOT (Build-Operate-and-Transfer) type. In establishing a kitchen center, a business method is chosen on the basis of examination including the business cost from this.

5 The first example

5.1 Summary of facilities

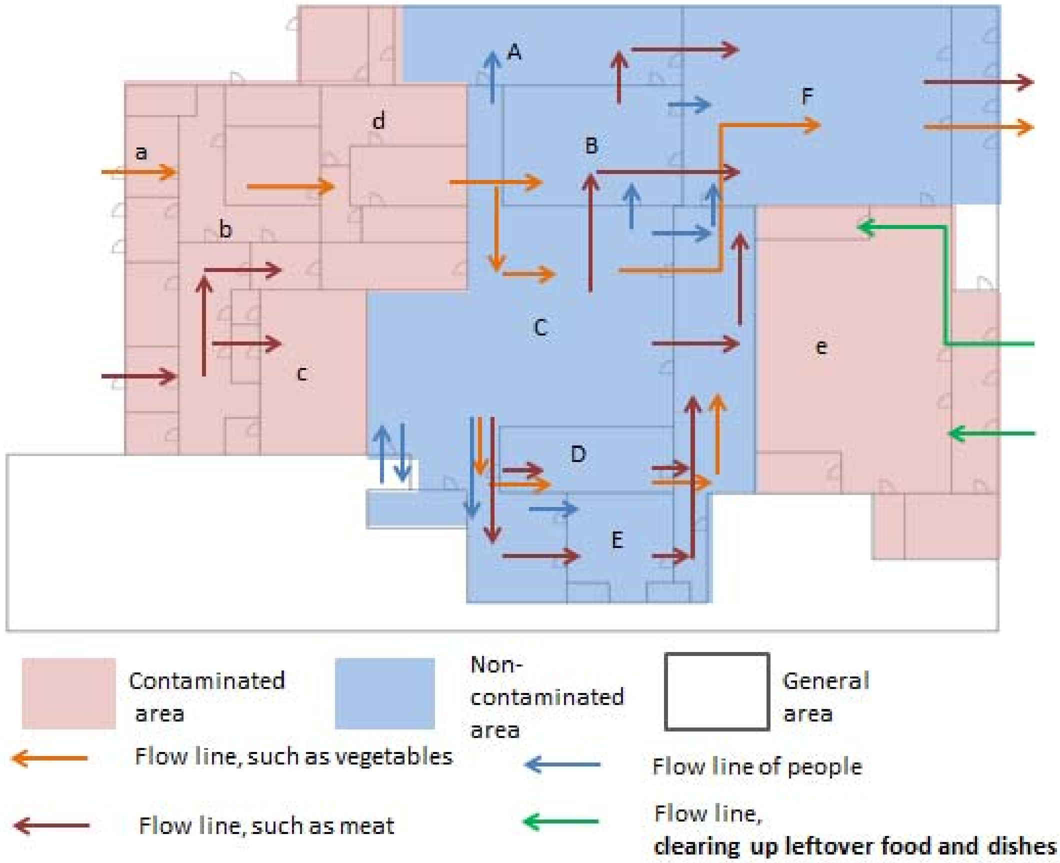
I show the summary of “T” facilities in table 1. It is located in Tachikawa city of Tokyo, establishment date is on April 1, 2013, lot area is 8,800m2, the deferred floor space is 4,605m2, the floor is produced for dry method, ability for cooking is 7,000 meals/day, and the number of the meals for allergy is up to 100 meals. The object is 12 elementary schools in the city.

Table 1 Equipment outline of “T” kitchen center

Kitchen name	“T” kitchen center
Location	Tachikawa city in Tokyo district
Established date	1/April/2013
Lot area	8800 m2
Floor space	4605 m2
Each room area	Food reception:82m2, Acceptance :138m2,
	Pretreatment:352m2, Cooking:807m2,
	Distribution box store:288m2, Washing:519m2
Cooking ability	7000 meals/day, forallergy consumers (100 meals/day)
Object schools	12 primary schools

5.2 Examination of the work line

I show the first-floor ground plan of T facilities and a work line in figure 1. As a characteristic of the hygiene management, a layout and a dry floor system based on HACCP are used. When food is processed and is made, the factor to cause harm on a process is analyzed and is management technique to manage the part most efficiently continually, and to ensure the security. Monitoring is performed by receipt of goods, a check, lower processing, cooking, each process of the serving meals, and a harm outbreak point is predicted, and, in the important management point, the mixture of the alien substance is prevented in what is decided beforehand. A reliable lunch can in this way be offered. In addition, a pollution area and the non-pollution area are distributed definitely, and the intersection pollution is prevented, and workers can raise the effectiveness and safety of work.



a	Food reception
b	Acceptance room
c	Pretreatment room (1)
d	Pretreatment room (2)
e	Cleaning room for tableware and

A	Rice cooking room
B	Grilled and fried room
C	Cooking room
D	Allergy room
E	Marinating room
F	Container room

Figure 1 Plan (1F.) and flow line of foods and works at "T" kitchen center

5.3 The environmental characteristics in the kitchen

Because a ceiling is expensive, a cooking worker feels space in the cookhouse, and work efficiency improves. The temperature and humidity of the wide space are maintained appropriately. In addition, the food residual substance is utilized as a biomass energy source. Because this is an inflection of the renewable energy, it becomes the facilities in consideration for the green environment.

5.4 Cooking in the kitchen

In cooking, it is usually common for large quantities to use a rotary pot. There is intent for workers performing the cooking on the iron plate in this kitchen, so that students sense when the dish made by hand is delicious. The exclusive allergy-response room is established in this kitchen and, to a necessary student for individual treatment, provide an allergy correspondence meal. In addition, it is cooked using the rice which is gotten in an area in these facilities. The local government has an intention to be understood that local production for local consumption is important for a student.

5.5 Health and Safety in the kitchen

The hygiene management is thorough by clarifying a pollution area and a non-pollution area. In response to HACCP, hygiene management is carried out. Receipt of goods, a check, storage, lower processing, cooking, the monitoring by each process of the serving meals are carried out. Each process is carried out according to ingredients, and the intersection pollution is prevented. In addition, the secondary pollution is prevented by the water to jump up and down in the work by the introduction of the dry-type floor system, and healthfulness is found.

6 The second example

6.1 Facilities summary

I show facilities summary of the “A” kitchen center in Nagano city in table 2.It is established on April 2, 1970 and rebuilt on April 1, 2003. the plot area is 9,318 m2, the deferred floor space is 2,994 m2 with a dry floor method, and the ability for cooking is 8,346 meals/day, composed 3,802 meals/day for junior high schools and 4,554 meals/day for the elementary school.

Table 2 Equipment outline of “A” kitchen center

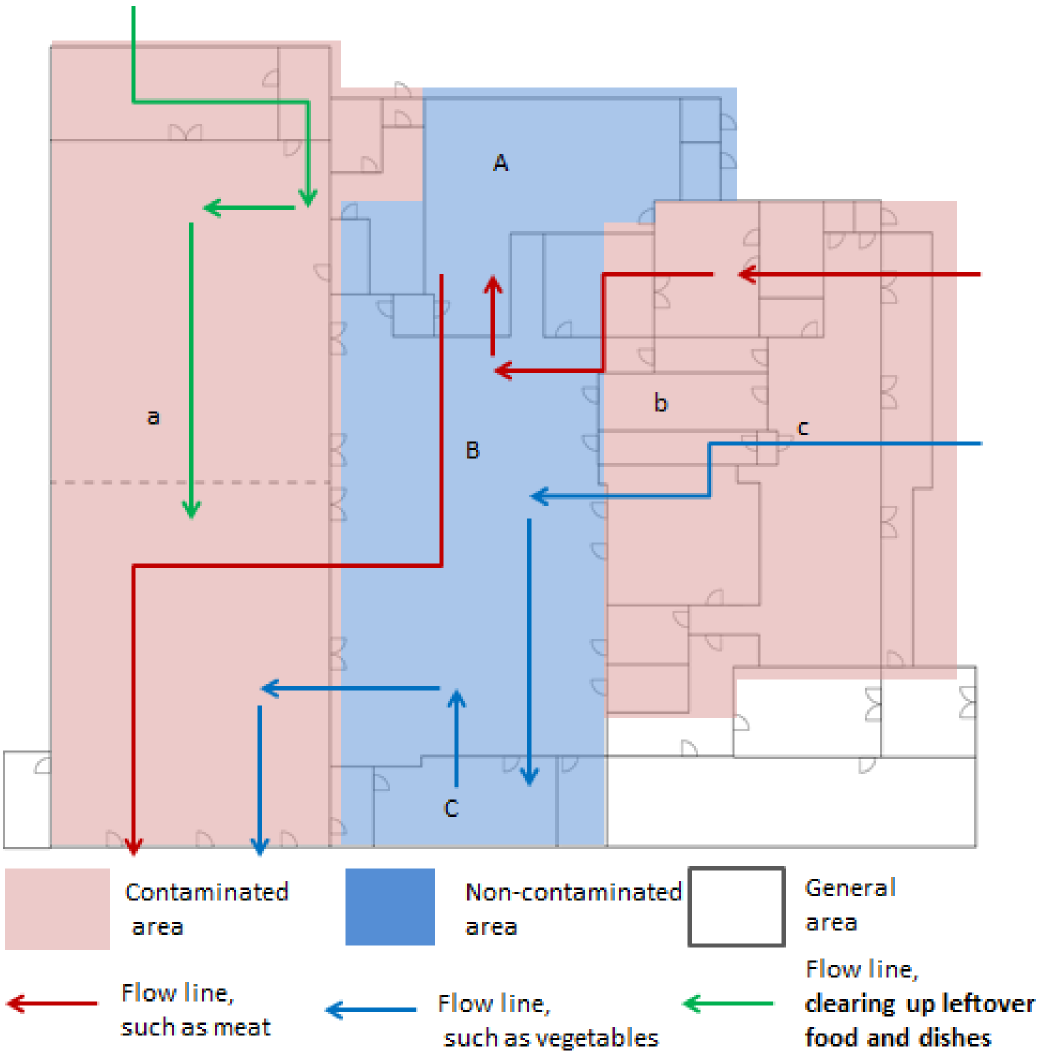
Kitchen name	“A” kitchen center
Location	Nagano city
Established date	2/April/1970, Rebuild in 1/April/2003
Lot area	9318m2
Floor space	2994m2
Cooking ability	8846 meals/day (primary schools:4554 meals/day, Junior high schools:3802meals/day)

6.2 Examination such as work lines

I show the first-floor simple ground plan of the “A” kitchen center and a work line in figure 2. Hygiene management is carried out by adopting a concept of HACCP. By receipt of goods, a check, storage, lower processing, cooking, the monitoring by each process of the serving meals, hygiene management is carried out. A pollution area and a non-pollution area are isolated definitely, and a line of goods flow becomes independent every ingredients and is prevented intersection pollution.

6.3 Facilities apparatus for heat source

I show the main facilities apparatus in Table 3. An absorption-type cool and warm water generator, steam boiler, cistern, a water tank, a gas heat pump air-conditioner to receive are main facilities apparatuses, and carry out air conditioning, the hot water supply of facilities.



a	Cleaning room
b	Medium processing room
c	Acceptance room

A	Grilled and fried room
B	Cooking room
C	Marinating room

Figure 2 Plan (1F.) and flow line of foods and works at "A" kitchen center

6.4 BCP in the "A" kitchen center

In this kitchen center, the seven following enforcement items are established as the first action correspondence at the time of the disasters.
(1)According to a deployment standard, the staff selected depending on the degree of the disaster gathers.
(2) They identify the neighboring damage situation as facilities and report it.
(3) They determine whether they can offer lunch and report it to the health lunch section of the city hall.
(4) They perform the communication to the staff who gathered by network.
(5) They perform the communication to electricity, gas, water supply company and confirm a policy of the restoration.
(6) They contact the maintenance check supplier of facilities and the kitchen apparatus and ask it for check adjustment and grasp the restoration possibility.
(7) They perform the communication to a supplier and confirm the right or wrong of the delivery of goods of the food and acceptance and information of a fact of the resumption.
These seven above-mentioned action plan prepared that can restore at a large-scale disaster immediately by coping.

6.5 The point that needs improvement

It is desirable to devise to make the height of the carrier of the truck and the high import tongue the same level. Because the facilities apparatus ages, it is desirable when there is an aim of the update number of years of the kitchen facilities apparatus. Because the kitchen was forced to allergic correspondence in these days, they changed the use of a storeroom to an allergic room temporarily and coped. It is desirable to make this the specialized room.

Table 3 Main facilities apparatus

(1) Absorption type refrigerator

Capacity	22.9 kVA
Refrigerating power	352 kW
Heating power	286 kW
Maximum pressure	0.8 MPa
Cooling characteristics	638 kW

(2) Steam boiler

Capacity	12.7 kW
Heat transfer area	7.44 m2
Steam flow	2,000 kg/h
Fuel consumption	113.6 Nm3/h
Maximum pressure	0.98 MPa

(3) Gas heat pump air-conditioner

Refrigerant	R407C
Cooling	56 kW
Heating	67 kW

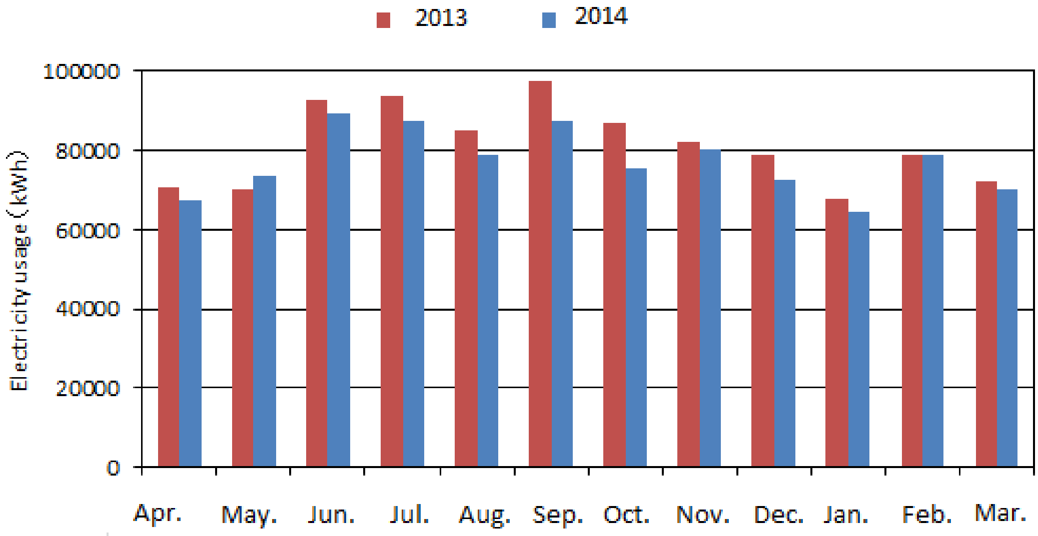


Figure 3 Monthly electricity usage of the past two years

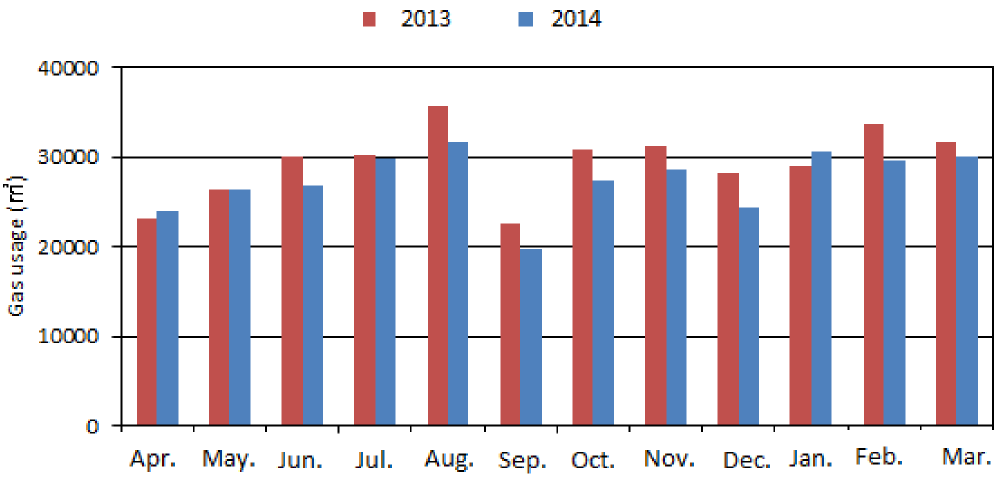


Figure 4 Monthly gas usage of the past two years

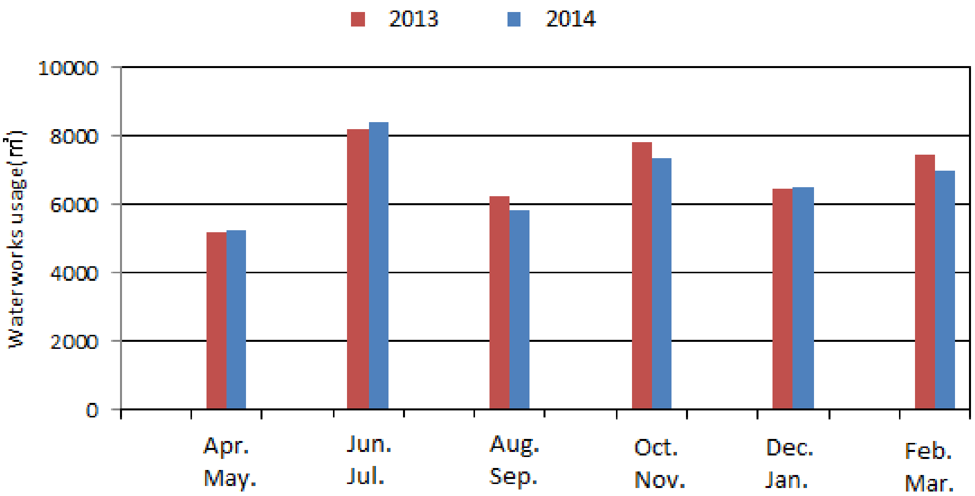


Figure 5 Monthly water usage of the past two years

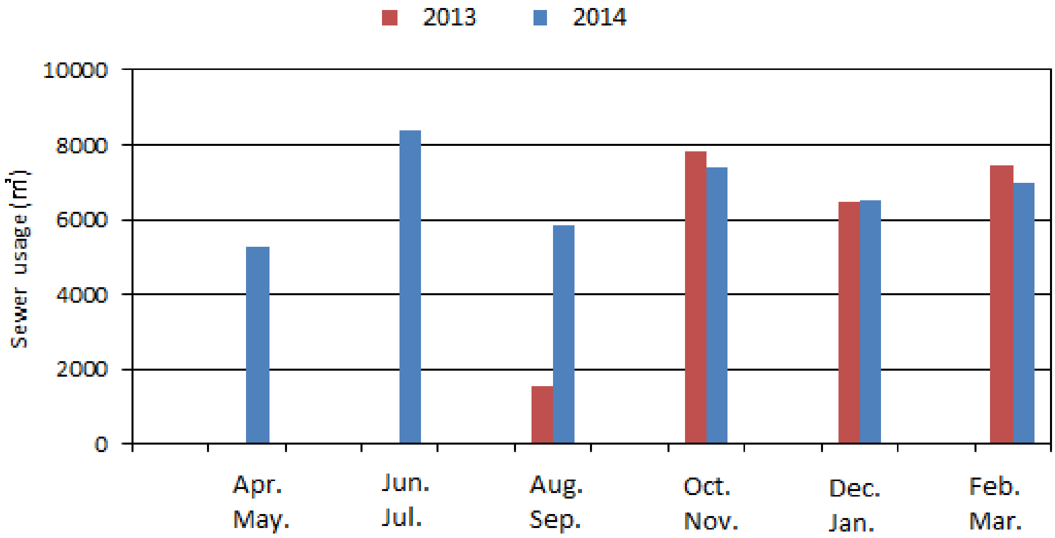


Figure 6 Monthly sewer usage of the past two years

6.6 Consumption data of electricity, gas, and water supplies

I show the electricity consumption according to the month for the past two years in figure 3. I understand to be less than last year except May. There is a difference in the amount of change monthly, but knows that energy-saving consciousness increases because approximately 10% of 2014 is less.
I show the gas consumption according to the month for the past two years in figure 4. Consumption becomes big from spring to the summer. There is little September over winter from autumn, but there are the some errors over March from October, but is constant.
I show the waterworks consumption according to the month for the past two years in figure 5. The peak understands that it is Jun, July and October, September. 2014 exceeds it over from April to Jun, but knows that energy-saving consciousness increases because approximately 5% of 2014 is less after it.
I show the sewer fee for use according to the month for the past two years in figure 6. By setting from September, 2013 from October is compared, but this knows that there is a peak of the consumption like waterworks in Jun, July, October and September.

7 Conclusion

I collect below the knowledge that this study provided.
(1)Securing of infrastructure, heat source multiplexing of the cooking apparatus, three of reinforcement measures of the structure are important mainly to restore at the time of a disaster immediately in BCP in the kitchen.
(2) Invention of how to use kitchen apparatus is necessary for the energy saving in the school meal. Methods to do a peak cut of the electricity usage include the gas-style introduction of the kitchen apparatus and a ceiling ventilation system. When I cope as a support place of the refuge base at the time of the disasters, the preparation to support the

distribution of boiled rice is necessary.
(3) About the allergic correspondence, mutual situation grasp in a school and the lunch center is the most important.
(4) About the business method, the company examines the most appropriate method in each local government or facilities to found and decides a business method.
(5) Thorough hygiene management is necessary by the monitoring by each process from receipt of goods to serving meals by a layout corresponding to HACCP.
(6) The adoption of the dry-type floor system is necessary. Making it constant and prevention of the secondary pollution of temperature, the humidity in the kitchen are necessary.

8 References

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3. About BCP:
   http://www.chusho.meti.go.jp/bcp/contents/level_c/bcpgl_01_1.html

9 Presentation of Authors

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Maintaining the function of a plumbing system after an earthquake

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Abstract

In Japan, earthquakes have caused various types of damage. Although the damage of building structures caused by the earthquake ground motion was insignificant, building equipment that acts as the lifeline of the building suffered great damage. The building equipment that had a low aseismic performance became apparent. Moreover, it became impossible to use the building because of the damaged building equipment, even though there was no damage to the building structure. More importantly, the plumbing system, which is necessary for the maintenance of human life and health should remain functional or should be able to obtain early functional recovery after large-scale earthquakes occur. In this study, with the purpose of maintaining the function and early functional restoration of a plumbing system at the time of earthquakes, a model of the plumbing system installed in existing buildings is created and evaluated for its aseismic performance using numerical analysis. In addition, further aseismic measures are used to confirm the effect for the weak point of the plumbing system in the evaluated building.

Keywords

Lifeline, plumbing system, water piping, numerical analysis, aseismic performance.

1 Introduction

During past earthquakes, the damage of building structures caused by the earthquake ground motion was insignificant. However, building equipment suffered great damage owing to the earthquake ground motion, and the low aseismic performance of the building equipment became apparent. The plumbing system has a water supply and drainage function that plays an important role in buildings from the point of view of maintaining human life and health. Therefore, the plumbing system differs from ordinary building services and utilities as it should easily maintain its functionality for immediate service following an earthquake. Moreover, intense earthquakes are expected to occur in the metropolitan area, where high-rise buildings are located. Therefore, it is necessary to ascertain the seismic risk and to improve the aseismic performance of plumbing systems.
The purpose of this study is to ascertain the seismic risk of building equipment by conducting aseismic performance evaluations of the plumbing system in high-rise buildings that need to maintain uninterrupted service. This study also aims to explore effective aseismic measures for the weak points of the plumbing system. Hence, a plumbing system model ware created at the Kogakuin University, Shinjuku campus for the purpose of this study.

2 Damage to plumbing systems caused by the great east japan earthquake

Several building equipment were damaged because of the Great East Japan earthquake of 2011. Figure 1 shows the damage reports of building equipment which cover the plumbing systems, air conditioning systems and electrical installations. The plumbing systems sustained the greatest damaged. In the plumbing system, the pipes sustained most of the damage, which highlights the fragility of the water supply. Moreover, the damage of plumbing system categorized according to the damage part, and the piping sustained the most of damaged in the plumbing system. The total damage percentage of the piping to plumbing system is around 56%.Therefore, the seismic performance of a plumbing system with a water supply, water treatment, and initial firefighting function should be improve.

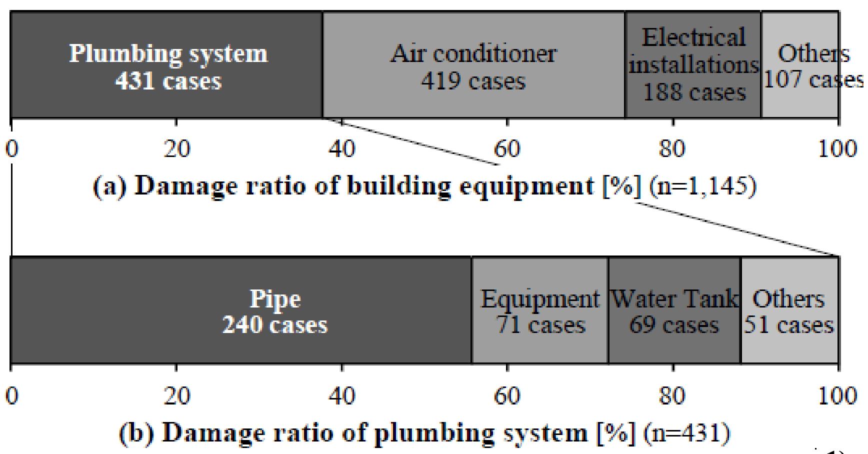

Figure 1 Damage ratio in the Great East Japan earthquake[1)]

3 Plumbing system model construction and details of input seismic wave

3.1 Construction of the plumbing system model

The evaluated building is a high-rise building with 29 floors above the ground and 6 floors below. Figure 2 shows the plumbing system diagram. The water supply system was used as the gravity tank system. Water was supplied to the receiver tank installed in the 6th basement to pump water up to the three gravity tanks installed on the 8th and 20th floors, and the penthouse. Water was then supplied to the plumbing fixture installed on each floor. The waste water on the ground floor was drained by gravity, and that in the basement was pumped by a sump pump after being collected in the sump pit. The sprinkler piping with an initial firefighting function was filled with water to the three systems by the pump installed in the sixth basement.
As shown in Table 1, the water supply piping in the evaluated building was made of stainless steel pipes and unplasticized polyvinyl chloride lining steel pipes for water supply. The drain piping was made of stainless steel pipes, and the sprinkler piping was made of carbon steel pipes for ordinary piping. The aseismic performance was examined using a pipe stress analysis software (AutoPIPE, Bentley Systems, Incorporated). Table 1 shows the tensile strength and allowable stress of the plumbing system.

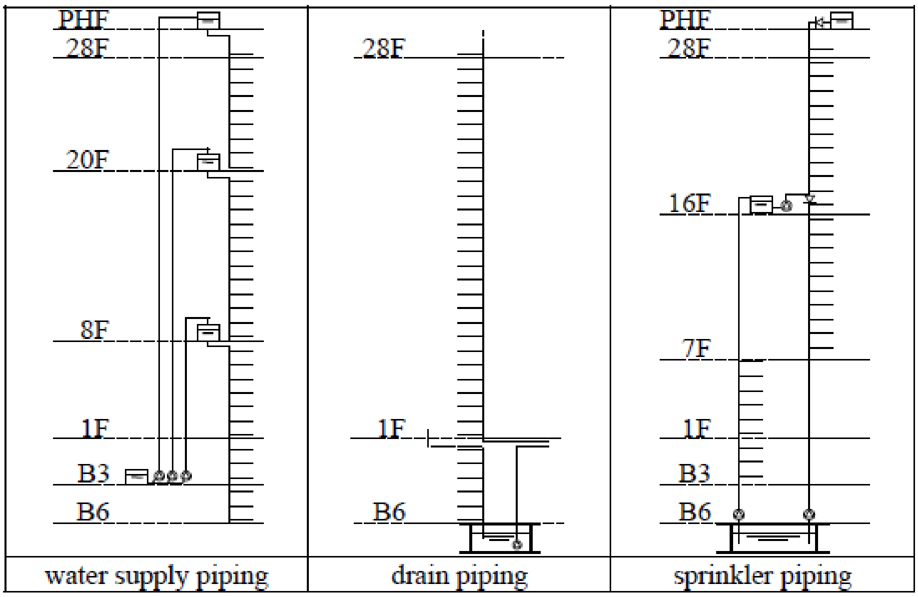

Figure 2 Riser of plumbing system

Table 1 Plumbing system of evaluated building

	piping material	joint	tensile strength *	allowable stress *
water supply piping	Stainless steel pipes	screw thread joint, flange joint, welding joint	520 N/mm^2	223 N/mm^2
	Unplasticized polyvinyl chloride lining steel pipes for water supply		290 N/mm^2	124 N/mm^2
drain piping	Stainless steel pipes		520 N/mm^2	223 N/mm^2
sprinkler piping	Carbon steel pipes for ordinary piping		290 N/mm^2	124 N/mm^2

The boundary condition for each element was set based on the investigation of the actual construction. Table 2 and Figure 3 show the boundary condition of each element in the vertical piping. The piping was rigidly jointed to the tank, pump (I), and upper and lower floor slabs (II). Moreover, the piping was pin-jointed to a U band, which was used to fix the vertical piping (III).

Table 2 Contact conditions of each element in the vertical piping

Symbol	Each element	Contact conditions
I	Tank・pump - piping	Rigid joint
II	upper and lower floor slabs - piping	Rigid joint
III	Fixed point of vertical piping (U band)	Pin joint

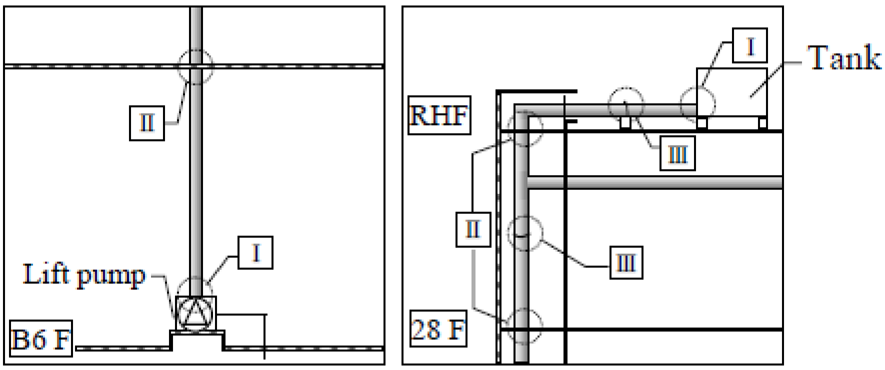

Figure 3 Model outline of vertical piping in numerical analysis

Table 3 and Figure 4 show the boundary condition of each element in the vertical piping. The piping was rigidly jointed to the fireproof compartment (A). The hanger bolts were rigidly jointed to the slab of the upper floor (B), and the hanger ring was pin-jointed to the piping (C). Moreover, the sprinkler head was pin-jointed to the ceiling board.

Table 3 Contact conditions of each element in the horizontal piping

Symbol	Each element	Contact conditions
A	Main water supply piping - fireproof compartments penetration・water supply piping - smoke control zone compartments penetration	Rigid joint
B	The slab of upper floor and hanger bolts	Rigid joint
C	Hanger ring	Pin joint
D	Joint with a ceiling	Pin joint

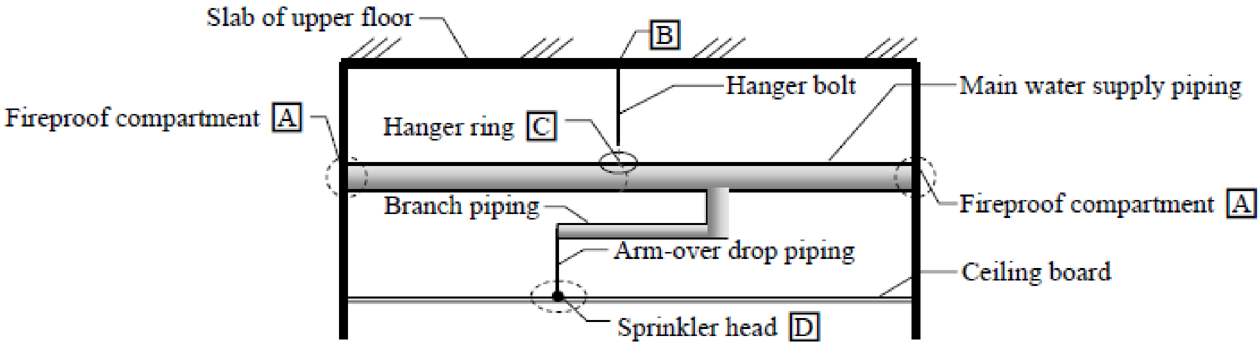

Figure 4 Model outline of horizontal piping in numerical analysis

3.2 Input seismic motion

Figure 5 shows the input wave used in the numerical analysis. The input wave was a random wave expected in the evaluated building for the Tokyo inland earthquake. The maximum acceleration of the Tokyo inland earthquake, which is bigger than that of a typical observed wave, is used to structure the high-rise building design. The response acceleration—a larger acceleration in north-south direction than that in the east–west direction—of each floor of the evaluated building in the Tokyo inland earthquake[2)3)] was then calculated. A random wave was used as the input wave in the north–south direction of the Tokyo inland earthquake.

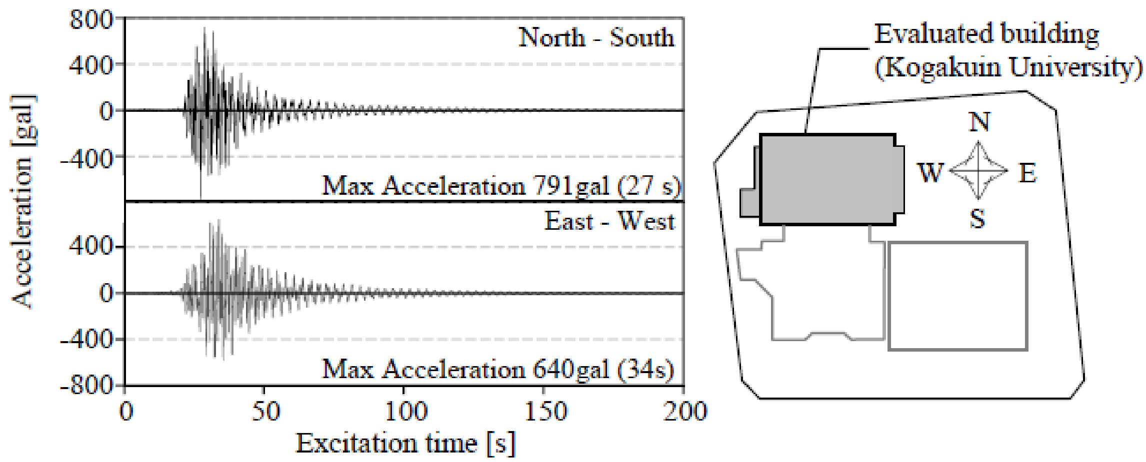

Figure 5 Input wave

4 Aseismic performance of plumbing system

4.1 Water supply piping result

Figure 6 shows the stress distribution of the water supply piping in the evaluated building obtained from the numerical analysis results. The stress distribution shows the maximum stress from the numerical analysis. The maximum stress (100 N/mm^2) occurred on the weld joint of the water supply piping in the roof floor, which corresponded to approximately 50% of the allowable stress (201 N/mm^2) for the stainless steel pipe welded joints. The numerical analysis results showed a high aseismic performance of the water supply piping.

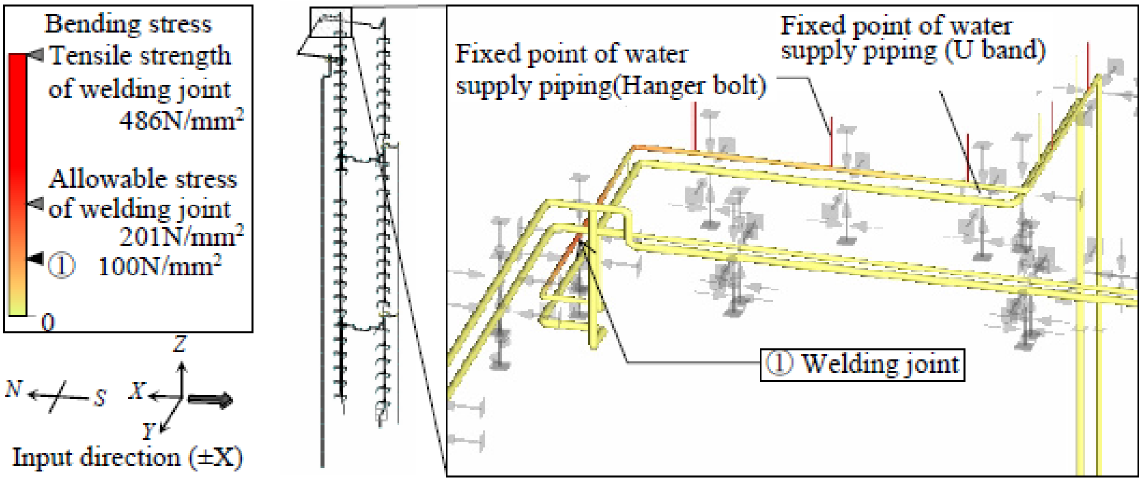

Figure 6 Stress distribution of the water supply piping

4.2 Drain piping result

Figure 7 shows the stress distribution of the drain piping in the evaluated building obtained from the numerical analysis results. The maximum stress (13 N/mm^2) occurred on the weld joint of the drain piping on the 7th floor, which corresponded to approximately 5% of the allowable stress (201 N/mm^2) for the stainless steel pipe welded joints. The numerical analysis results showed a high aseismic performance of the drain piping.

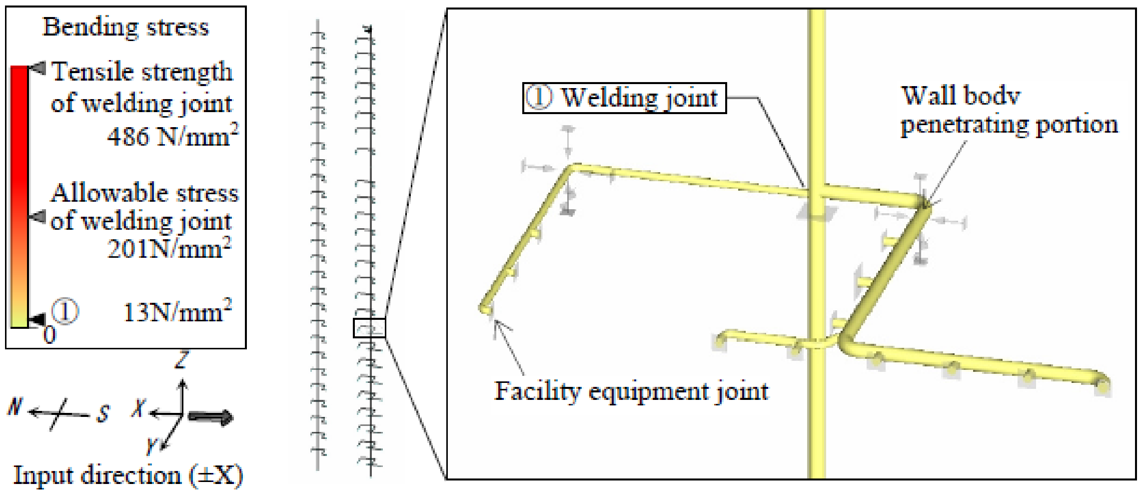

Figure 7 Stress distribution of drain piping

4.3 Sprinkler piping result

Figure 8 and Figure 9 show the stress distribution of the sprinkler piping in the evaluated building obtained from the numerical analysis results. The numerical analysis results of the vertical sprinkler piping show that the maximum stress (100 N/mm^2) occurred at the screw thread joint of the junction to the vertical and horizontal sprinkler piping. The

stress corresponded to approximately 10% of the allowable stress (112 N/mm^2) of the carbon steel pipes for ordinary piping screw thread joint. The numerical analysis results show that the vertical sprinkler piping exhibited high aseismic performance.
The numerical analysis results of the horizontal sprinkler piping show that the maximum stress (126 N/mm^2) occurred on the screw thread joint of the branch pipe. The stress corresponded to approximately 168% of the allowable stress (112 N/mm^2) of the carbon steel pipes for ordinary piping screw thread joint. The numerical analysis results demonstrated that the horizontal sprinkler piping is the weak point of the plumbing system in the evaluated building.

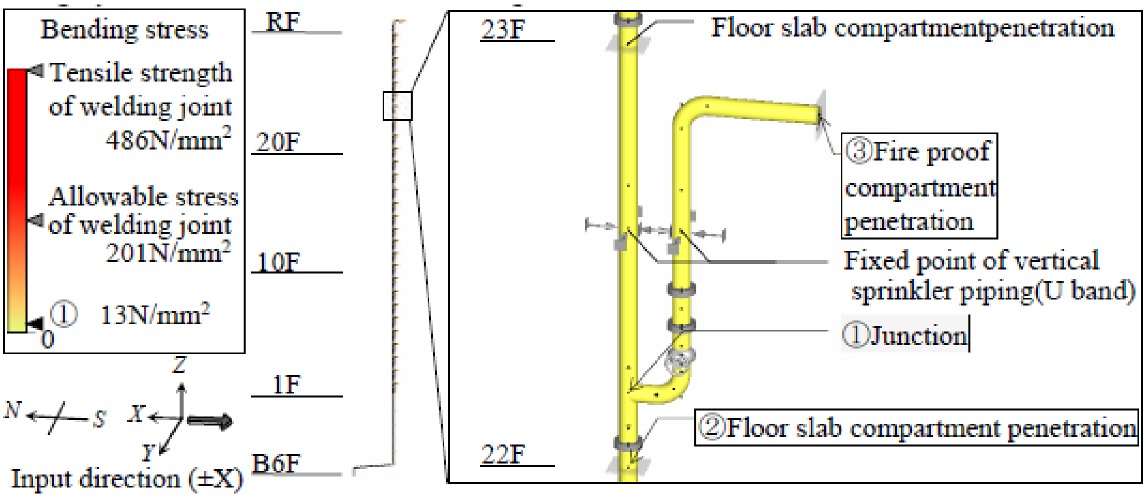

Figure 8 Stress distribution of vertical sprinkler piping

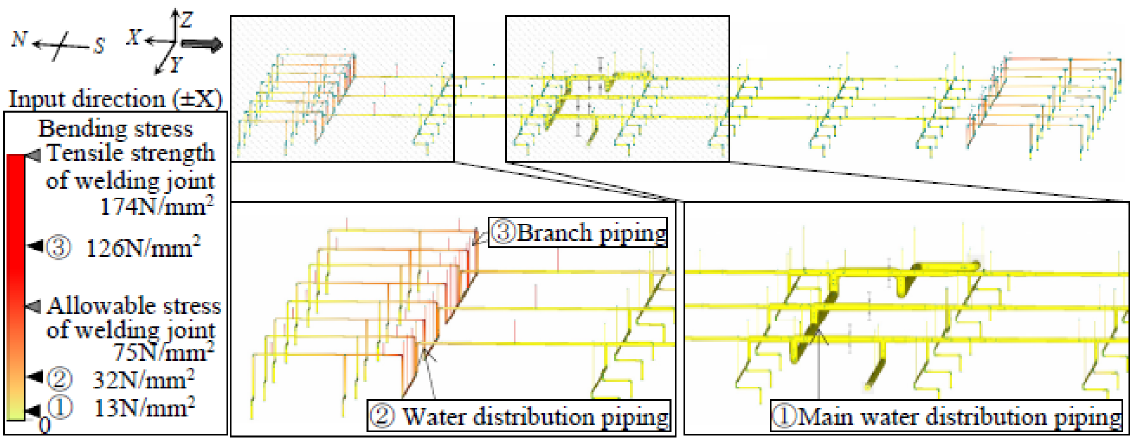

Figure 9 Stress distribution of horizontal sprinkler piping

5 Damage probability of plumbing system

5.1 Aseismic measures for weak points of plumbing system

The numerical analysis results for the plumbing system in the evaluated building showed that the allowable stress occurred on the horizontal sprinkler piping. Aseismic measures were employed to improve the aseismic performance. The braces described in Figure 10 were installed on the model used in this study to improve the aseismic performance in the horizontal sprinkler piping. The braces were rigidly jointed to the slab of the upper floor

(a) and hanger bolts of the lower floor (b). Eight braces were installed on the branch piping in the model used in this study following the locations of the existing hanger bolts. The numerical analysis results showed that stress in the horizontal sprinkler piping installed with braces was lower than that in the existing horizontal sprinkler piping, and the allowable stress as well.

Number brace[-]		2
Length of brace[mm]		H_l=800
Span of brace[mm]		L_l=400
Angle of brace [°]		θ_b=65
Symbol	**Each element**	**Contact conditions**
a	Slab of upper floor - brace	Rigid joint
b	Hanger bolts - brace	Rigid joint

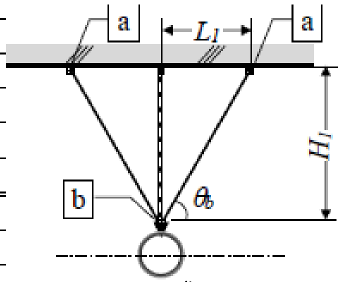

Figure 10 Conditions of model brace with numerical analysis [4)]

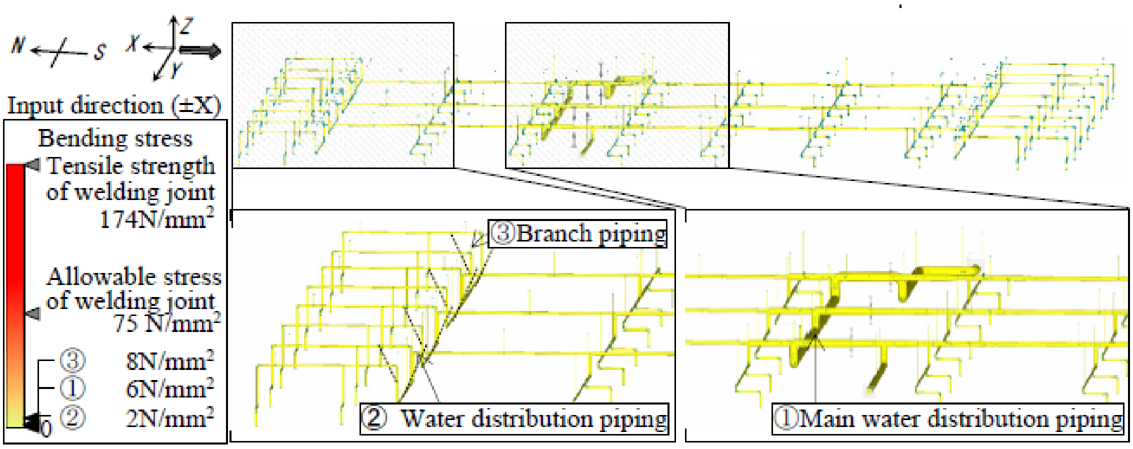

Figure 11 Stress distribution of brace installation in horizontal sprinkler piping

5.2 Damage probability and aseismic measures to verify the aseismic performance of plumbing system

The seismic risk of the plumbing system in the evaluated building was evaluated based on the damage probability**. Figure 12 shows the damage probability of the plumbing system. The damage probability of the water supply and drain piping was less than 10%. The maximum damage probability of the plumbing system was calculated at 85% in the horizontal sprinkler piping. In contrast, the damage probability of the horizontal sprinkler piping installed with braces was lower than that of the existing horizontal sprinkler piping, which showed that the aseismic performance of the horizontal sprinkler piping could be improved.

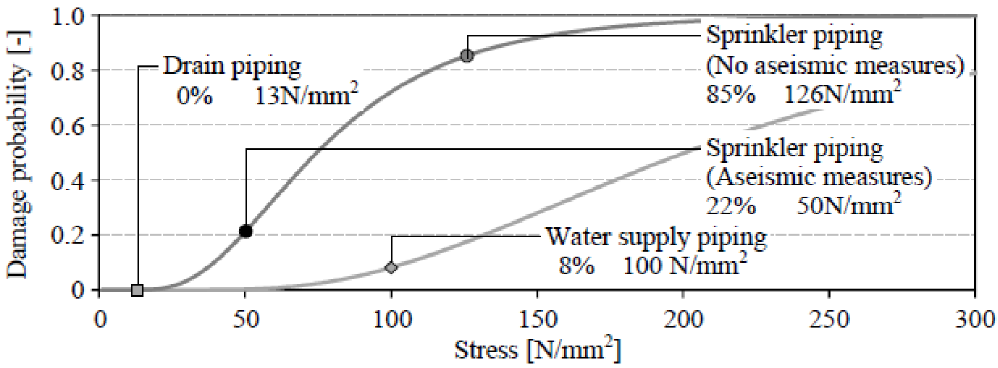

Figure 12 Damage probability of plumbing system

6 Conclusions

This study was conducted to evaluate the aseismic performance of the plumbing system in the evaluated building using numerical analysis.
The damage probability of the water supply and drain piping was less than 10%. Hence, the water supply and drain piping was found to exhibit sufficient aseismic performance. The damage probability of the sprinkler piping was 85%, which showed that the sprinkler piping was the weak point of the plumbing system. In contrast, the damage probability of horizontal sprinkler piping installed with braces is lower than that of the existing horizontal sprinkler piping, which means that the former could be used to improve the aseismic performance of horizontal sprinkler piping.

7 Acknowledgments

The present study was supported by the Research Center for Urban Disaster Mitigation of Kogakuin University and the Japan Society for the Promotion of Science KAKENHI grant number 24246094. The authors would like to thank Prof. Yoshiaki Hisada and Prof. Tetsuo Yamashita of Kogakuin University. The authors would like to thank Mr. Tetsuto Dokko for working with us to prepare the manuscript.

8 Note

* The strength of the joint portion of the piping was reduced compared to that of its straight portion. Therefore, the tensile strength and the allowable stress of the joint portion of the pipe were calculated by multiplying the joint efficiency. The joint efficiency of the screw thread and flange joints was 0.6. The joint efficiency of the welding joint was 0.9.
** The damage probability of the plumbing system was calculated using Eq. (1) as follows:

$$p_{fi}(x) = \int_0^{r_{mi}} \left(\left(\sqrt{2\pi} \cdot \sqrt{\varsigma_C^2 + \varsigma_R^2}\right) \cdot exp\left\{ \frac{-(ln x - ln \bar{C}_{mi})^2}{2\left(\sqrt{\varsigma_C^2 + \varsigma_R^2}\right)^2} \right\} \cdot x \right)^{-1} dx \tag{1}$$

$p_{fi}\,x$: Damage probability [-]

r_{mi} : The median of the earthquake motion, which acts on piping [N/mm^2]

C_{mi} : The median allowable stress of plumbing system [N/mm^2]

ς_C : The logarithmic standard deviation of the allowable stress of plumbing system (=0.3) [-]

ς_R : The logarithmic standard deviation of the stress of earthquake motion (=0.4) [-]

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10 Presentation of Authors

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Calculation procedure of siphonic roof drainage system

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Abstract

Siphonic roof drainage system is suitable for buildings with huge flat roofs, where the torrential rains could cause big overload on building construction. The main advantage of siphonic roof drainage system after siphon action starts is full bore flow and faster roof drainage in comparison with gravity drainage system. Siphonic drainage system is also material saving and place saving. The paper is focused on design methodology of siphon roof drainage system by German technical regulation VDI 3806 - Dachentwässerung with Druckströmung [1]. The calculation procedure is shown step by step on specific example. The calculation is made by hand and compared with calculation in KEIDEL SOFTWARE - DrainStar Siphonic Calculator [4].

Keywords

Siphonic drainage system, calculation procedure, design methodology.

1 Calculation by hand

1.1 Input data for calculation

Calculation is realized for hall measuring 44.0 m x 15.0 m. Hall roof is flat with a slope of 2 %. The building is situated in Bratislava (Figure 1).
For the correct design of siphonic roof drainage system, the rain volume flow (Q_r in l/s), which is fed into the drainage system, when the reference rainfall rate (r in l/(s*m^2)) occurs, is decisive. The reference rainfall rate determined by Slovak technical standard [2] is 0.030 l/(s*m^2).

1.2 Process of design the siphonic system

Dimensions design of siphonic system consists of following steps:

- calculation of rain volume flow Q_r (l/s) (1),
- calculation of number of roof runoffs n_v (-) (2),
- determining the flow path and sections of pipes l_i (m),
- calculation of available pressure in flow path p_{disp} (Pa) (3),
- determining preliminary pressure losses in sections of the pipes R_{pr} (Pa/m) (4),
- determining DN and flow velocity in sections of the pipes v_i (m/s),
- determining real pressure losses due to pipe friction R_i (Pa) and pressure losses due to local resistance Z_i (Pa) (6),
- calculating real pressure (vacuum) in sections of the pipes p_i (Pa),
- verification of design conditions.

1.3 Calculation of rain volume flow

The rain volume flow of water on the flat roof is calculated:

$$Q_{□} = r * C * A \text{ (l/s)} \quad (1)$$

$$Q_{□} = 0.030 * 1.0 * 660 \text{ (l/s)}$$

$$Q_{□} = 19.80 \text{ l/s}$$

where:

r – reference rainfall rate by Slovak standard is 3 00 l/(s*ha) = 0.030 l/(s*m^2) [2],

C – coefficient of drainage, by [2] C = 1,0,

A – surface area in m^2, on which rain will fall, (Figure 1).

$A = a * b = 44.0 * 15.0 = 660 \text{ m}^2$

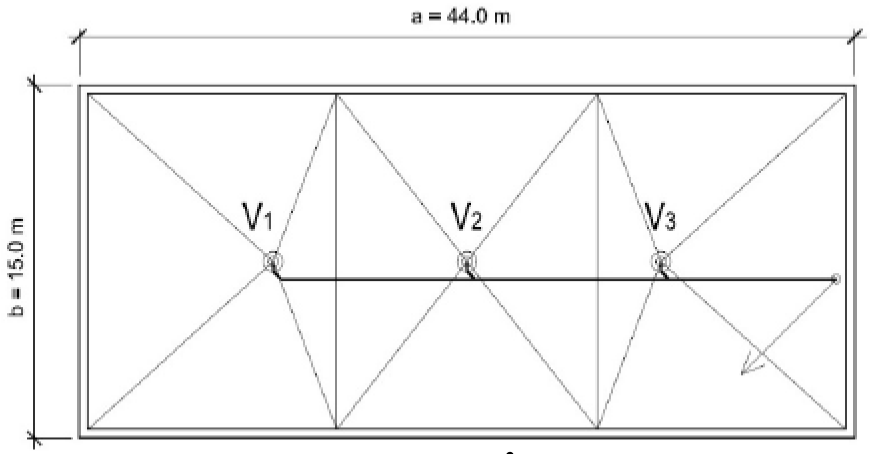


Figure 1 Ground plan of the hall, A = a*b (m^2) with placement the siphonic roof runoffs V1, V2 a V3.

1.4 Number of roof runoffs

When the rain volume flow of a roof surface Q_r (l/s) (1) is known, the necessary number of roof runoffs, rounded to the whole number, is designed:

$$n_v = \frac{Q_r}{V_v} \quad (ks) \tag{2}$$

$$n_v = \frac{19.80}{7.50} \ (ks)$$

$$n_v = 2.64 \text{ ks} \cong 3 \text{ ks}$$

where:
Q_r – calculated rain volume flow in l/s, by formula (1),
V_v – estimated capacity of roof runoff given by producer in l/s, it is considered the roof runoffs with drain capacity 7.50 l/s.

1.5 Available pressure in the flow path

The flow path with connection of all roof runoffs is designed after determining the number of roof runoffs and their positioning on the roof surface. Axial distance of roof runoffs should not exceed 20 m [1]. The scheme of the flow path is shown in Figure 2.

The available pressure p_{disp} (Pa) in flow path is calculated as:

$$\Delta p_{disp} = \Delta h_{disp} * \rho * g \ (Pa) \tag{3}$$

$$\Delta p_{disp} = 5.0 * 999.60 * 9.81 \ (Pa)$$

$$\Delta p_{disp} = 49{,}030.38 \text{ Pa} = 49.03 \text{ kPa} = 0.4903 \text{ bar} = 490.30 \text{ mbar}$$

where:

h_{disp} – available height (m), difference in level betwe en roof lining and the transition to gravity drainage system (Fig.2), hdisp = 5.0 m,

ρ – density of water at 10 °C is 999.60 kg/m ^{3},

g – gravity acceleration 9.81 m/s ^{2}.

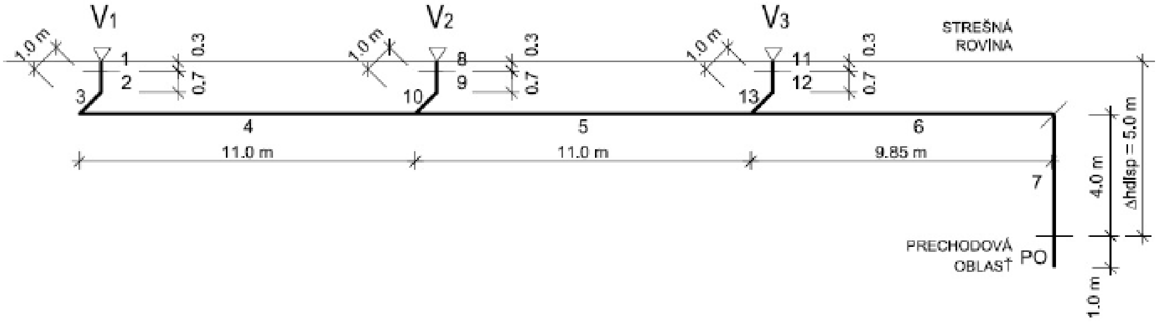


Figure 2 Scheme of the flow path with connection of all roof runoffs with determining the pipe sections

1.6 Preliminary pressure loss in pipes

The calculation of pressure losses begins in the most unfavourable (the longest) flow path, the other flow paths must be compared with the longest one. For the dimension design of all parts of the siphonic system it is necessary to know the preliminary pressure losses R_{pr} (Pa/m) in pipe 1 m long.

$$R_{pr} = \frac{\Delta p_{disp}}{1.2 * l_{tras}} \quad (Pa/m) \qquad (4)$$

$$R_{pr} = \frac{49{,}030.38}{1.2 * 37.85} \quad (Pa/m)$$

$$R_{pr} = 1{,}079{,}49 \text{ Pa/m} = 10.79 \text{ mbar/m}$$

where:
p_{disp} – available pressure in the pipe in Pa (3),
l_{tras} – total length of the flow path (pipes) in m (Tab. 1), l_{tras} = 37.85 m,
1.2 – coefficient, takes in consideration friction in the pipes as 20 % from l*R [1]

The dimension DN of each part of the siphonic system is designed by the design diagram (Fig.3) by calculated preliminary pressure loss R_{pr} (mbar/m) and calculated rain volume flow Q_{ri} (l/s) (1). Calculated rain volume flow Q_{ri} for each part of the pipe is in Tab. 1, it will be changing in addition to rain volume flow, which is going thru the part of the pipe. The dimension DN of the pipe is find out as the cross section of this calculated values. After determining the dimensions of the pipes the real pressure loss in pipe R_i (mbar/m) and the real water flow velocity v_i (m/s) is find out by the design diagram (Fig.3).
Design diagram and also the results form calculation software used mbar/m, therefore this unit will be used in further calculations.

1.7 The calculation of real pressure loss in pipes

Real pressure loss in every part of the pipe i, by the designed dimensions is calculated:

$$\Delta p_i = \sum(l_i * R_i + Z_i) \ (Pa/m) \tag{5}$$

where:
l_i – length of parts of the pipes (m),
R_i – real pressure loss in pipes (mbar/m) caused by f riction, taken from the design diagram suitable for used siphonic pipe material, (Tab. 1, column F),
Z_i – pressure loss caused by local resistance (mbar/m), calculated by formula (6).

$$Z_i = \sum \zeta \frac{{v_i}^2 * \rho}{2} \quad (Pa/m) \tag{6}$$

where:
$\sum\zeta_i$ – summary of locale resistance in considered part of the pipe (-),
v_i – real flow velocity in considered part of the pipe (m/s), taken from the design diagram (Fig. 3) (Tab. 1, column G),
ρ – density of water with temperature 10 °C is 999.6 0 kg/m^3.

Supposed internal pressure (depression), should by calculated for every part of the pipe i, (Tab. 1, column P), by formula:

$$p_i = \Delta h_i * \rho * g - \frac{{v_i}^2 * \rho}{2} - \sum(l_i * R_i + Z_i) \quad (Pa) \tag{7}$$

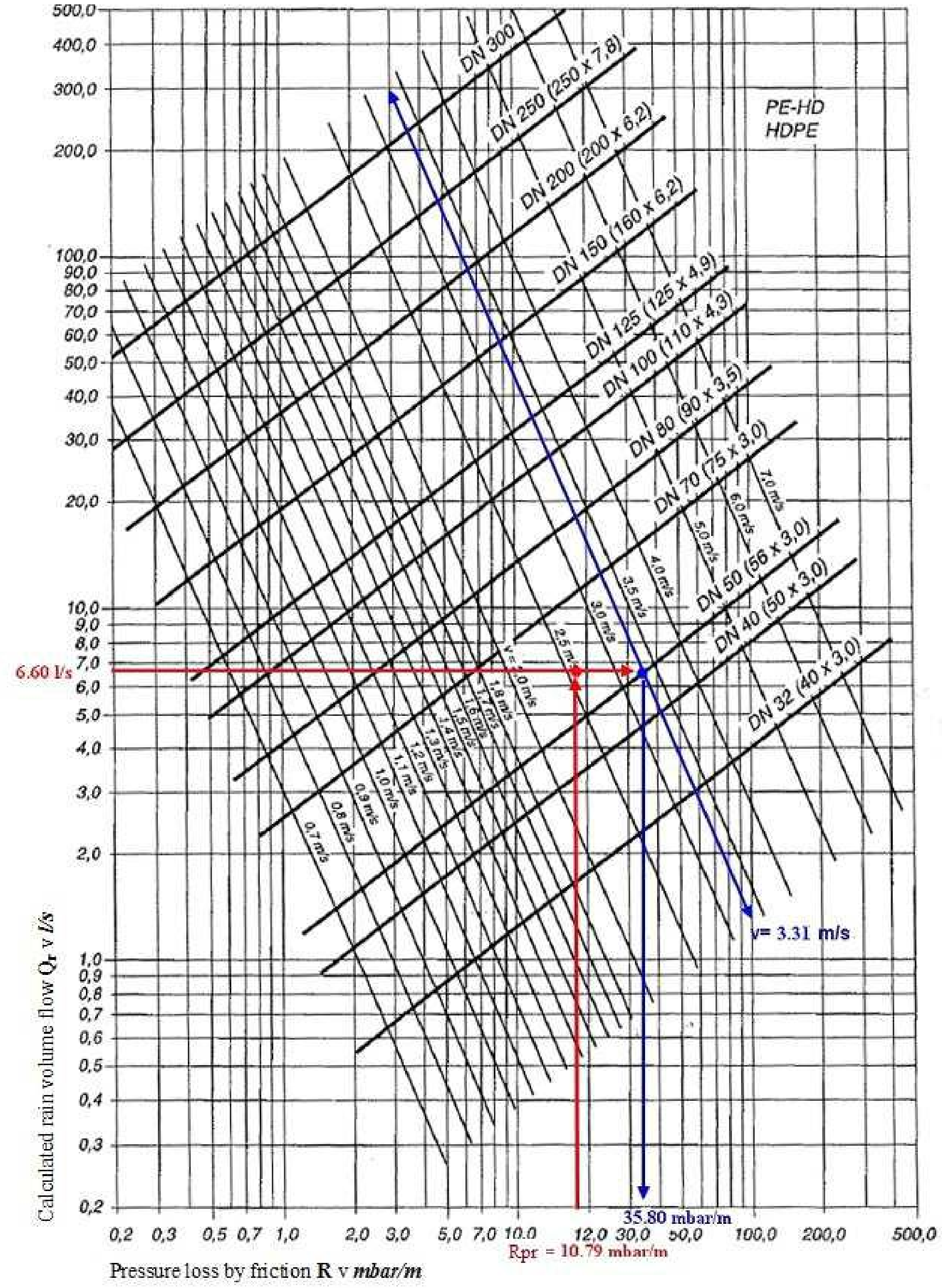


Figure 3 Design diagram of PE-HD pipe material, for determining dimensions DN, real pressure loss due to friction Ri (mbar/m) and flow velocity vi (m/s) in pipes [1]

1.8 Design conditions

There are some design conditions which must by followed for proper function of siphonic roof drainage system [1]:

1. Minimal flow velocity in pipes is considered as vi = 0,7 m/s, because of the self-cleaning effect in the pipes.
2. The numerical value of pressure in the pipe must not exceed 900 mbar, $p_i > -90$ kPa = -900 mbar. It should be also taken in consideration the lowest and the highest value of pressure given by the producer of the siphonic pipe system.

3. The dimensions of the pipes should be designed so that the summary of the pressure losses in every flow path p_i (5) should be as close as possible to available pressure p_{disp} (3) in siphonic system. This equation must be in force:

$$\Delta p_i \cong \Delta p_{disp} \tag{8}$$

4. The pressure difference in flow paths in row must not exceed the value 10 kPa = 100mbar.

1.9 Dimensioning parts of the pipes in each flow paths

The calculation of the most unfavourable (the longest) flow path is in Table 1.

Table 1 The most unfavourable (the longest) flow path 1-7

A	B	C	D	E	F	G	H	I
part i	**length l_i m**	**Qri l/s**	**DN -**	**mm -**	**R_i mbar/m**	**v_i m/s**	**Δh_{xi} m**	**$\sum\zeta_i$ -**
1	0.30	6.60	**40**	**50*3.0**	66.8	4.30	0.30	1.3
2	0.70	6.60	**50**	**56*3.0**	35.8	3.31	1.00	1.1
3	1.00	6.60	**70**	**75*3.0**	6.8	1.75	1.00	0.8
4	11.00	6.60	**70**	**75*3.0**	6.8	1.75	1.00	0.9
5	11.00	13.20	**80**	**90*3.5**	9.4	2.37	1.00	0.6
6	9.85	19.80	**80**	**90*3.5**	21.5	3.75	1.00	0.8
7	4.00	19.80	**80**	**90*3.5**	21.5	3.75	5.00	1.8
PO	1.00	19.80	**100**	**110*4.3**	7.4	2.38	6.00	0
l_{tras} ∑1-7=	37.85 m							

Continuation of Table 1

A	J	K	L	M	N	O	P
part i	**$(v^2 *\rho)/2$ mbar**	**l_i*R_i mbar**	**Z_i mbar**	**l_i*R_i + Z_i mbar**	**$\sum(l_i$*$R_i + Z_i)$ mbar**	**Δh_{xi}*ρ*g mbar**	**p_i mbar**
1	92.4	20.0	120.1	140.2	140.2	29.4	-203.2
2	54.8	25.1	60.2	85.3	225.5	98.1	-181.0
3	15.3	6.8	12.2	19.0	244.5	98.1	-166.5
4	15.3	74.8	13.8	88.6	333.1	98.1	-250.3
5	28.1	103.4	16.8	120.2	453.3	98.1	-383.3
6	70.3	211.8	56.2	268.0	721.3	98.1	-693.6
7	70.3	86.0	126.5	212.5	933.9	490.3	-513.8
PO	28.3	7.4	0.0	7.4	941.3	588.4	-352.9
			∑ p1-7	933.9			

Legend to Table 1:

li - length of parts of the pipe 1-7 in (m), are shown in (Fig. 2),
Qri - volume flow in the pipe (l/s), it comes from plan projection of considered building (Fig. 1) it is
taken 1/3 from whole volume flow from roof surface for one roof outlet,
DN - designed dimension of pipe for considered part of pipe, from design diagram (Fig. 3),
Ri - real pressure loss caused by pipe friction (mbar/m), from design diagram (Fig. 3),
vi - real velocity flow of water in pipe (m/s), from design diagram (Fig. 3),

Δh_{xi} - high difference between roof lining and considered part of pipe (m), $\sum\zeta_i$ - summary of local resistance in considered part of pipe (-), (Tab. 2), p_i - calculated value of pressure in the pipe (negative pressure), $\sum\Delta p_{1-7}$ - summary of pressure loss caused by friction and local resistance (l_i*R_i + Z_i) in parts 1,2,3,4,5,6 and 7 (mbar), part PO is not considered it is transition area, (Tab. 1, column M).

Table 2 Table of local resistance, belongs to Table 1

part	local resistance	ζ (-)	∑ζ (-)
1	roof runoff	1.00	1.30
	extension	0.30	
2	bend 45°	0.40	1.10
	bend 45°	0.40	
	extension	0.30	
3	bend 45°	0.40	0.80
	bend 45°	0.40	

part	local resistance	∑ζ (-)	∑ζ (-)
4	branch	0.60	0.90
	extension	0.30	
5	branch	0.60	0.60
6	bend 45°	0.40	0.80
	bend 45°	0.40	
7	transition	1.80	1.80

The Tab. 1 is evaluated by the given four condition:

1. Minimal volume flow in pipes is followed (Tab. 1, column G).
2. The condition of minimal numerical value of pressure in pipes is followed (Tab. 1, column P).
3. Summary of pressure losses in flow path p1-7 = 933.9 mbar (Tab. 1, column M) what is expressively higher than value of available pressure pdisp = 490.3 mbar (3),
   therefore it would be appropriate to make new dimension design by increasing the diameter of pipes to decrease the pipe friction in this flow path.
4. This condition can be considered after designing all flow paths.

New dimensions of the most unfavourable (the longest) flow path are shown in Tab. 3. By the changing the dimensions of parts of the pipe, it must be also change the value of local resistance ζ_i (-). The local resistances in flow path with new dimensions are not shown in the table, but the principle of their specification is the same as in the Tab. 2.

Table 3 The most unfavourable (the longest) flow path 1-7 with new dimensions

A	B	C	D	E	F	G	H	I
part i	**Length l_i m**	**Qri l/s**	**DN -**	**mm -**	**R_i mbar/m**	**v_i m/s**	**Δh_{xi} m**	**$\sum\zeta_i$ -**
1	0.30	6.60	**40**	**50*3.0**	66.8	4.30	0.30	1.3
2	0.70	6.60	**50**	**56*3.0**	34.1	3.31	1.00	1.1
3	1.00	6.60	**70**	**75*3.0**	6.3	1.80	1.00	1.1
4	11.00	6.60	**80**	**90*3.5**	2.4	1.20	1.00	0.9
5	11.00	13.20	**100**	**110*4.3**	3.4	1.60	1.00	0.6
6	9.85	19.80	**100**	**110*4.3**	7.4	2.40	1.00	0.8
7	4.00	19.80	**100**	**110*4.3**	7.4	2.40	5.00	1.8
PO	1.00	19.80	**100**	**110*4.3**	7.4	2.40	6.00	0
ltras ∑1-7 =	37.85 m							

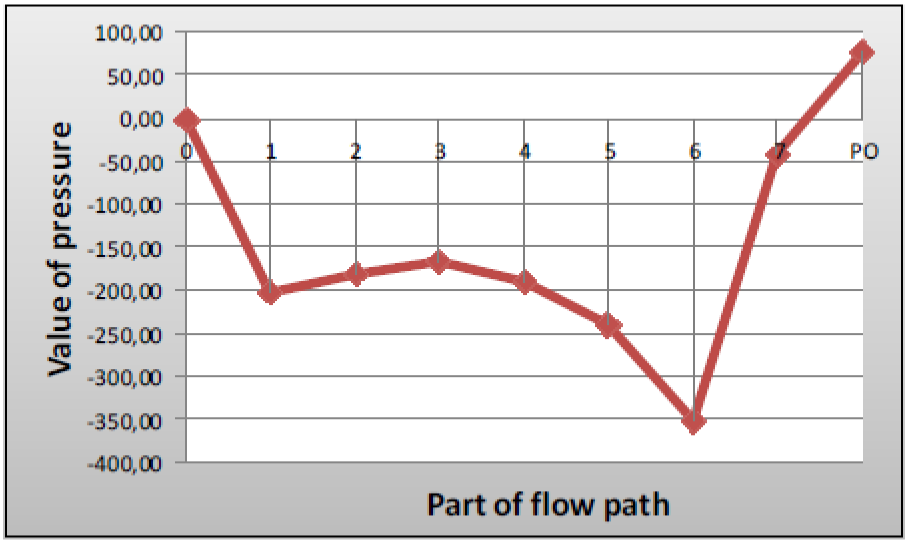
Continuation of Table 3

A	J	K	L	M	N	O	P
part i	**$(v^2 * \rho)/2$ mbar**	**$l_i * R_i$ mbar**	**Z_i mbar**	**$l_i * R_i + Z_i$ mbar**	**$\sum(l_i * R_i + Z_i)$ mbar**	**$\Delta h_{xi} * \rho * g$ mbar**	**p_i mbar**
1	92.4	20.0	120.1	140.2	140.2	29.4	-203.2
2	54.8	23.9	60.2	84.1	224.3	98.1	-181.0
3	16.2	6.3	17.8	24.1	248.4	98.1	-166.5
4	7.2	26.4	6.5	32.9	281.3	98.1	-190.4
5	12.8	37.4	7.7	45.1	326.3	98.1	-241.1
6	28.8	72.9	23.0	95.9	422.3	98.1	-353.0
7	28.8	29.6	51.8	81.4	503.7	490.3	-42.2
PO	28.8	7.4	0.0	7.4	511.1	588.4	77.3
			p_{1-7} =	503.7			

Evaluation of the Tab. 3 by design conditions:

- Minimal volume flow in pipes is followed (Tab. 3, column G).
- The condition of minimal numerical value of pressure in the pipes is followed (Tab. 3, column P).
- Summary of pressure losses in flow path p_{1-7} = 503.7 mbar (Tab. 3, column M) is approximately equal to available pressure p_{disp} = 490.3 mbar (3) and this condition is also complied.
- This condition can be considered after designing all flow paths.

Pressure behaviour in the flow path 1-7 is shown in the Graph 1.



Graph 1 Values of negative pressure in flow path 1-7 (parts 1,2,3,4,5,6,7-see Figure 4)

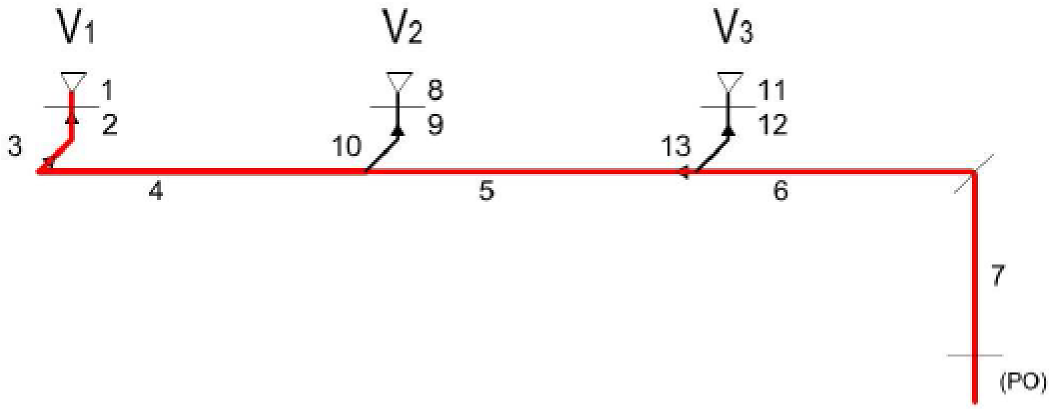


Figure 4 Flow path 1-7 (parts of pipe 1,2,3,4,5,6,7)

The calculation of flow paths 8-7 and 11-7 is not shown in the tables, the calculation principle and the evaluation of design conditions are the same as in the most unfavourable flow path 1-7.

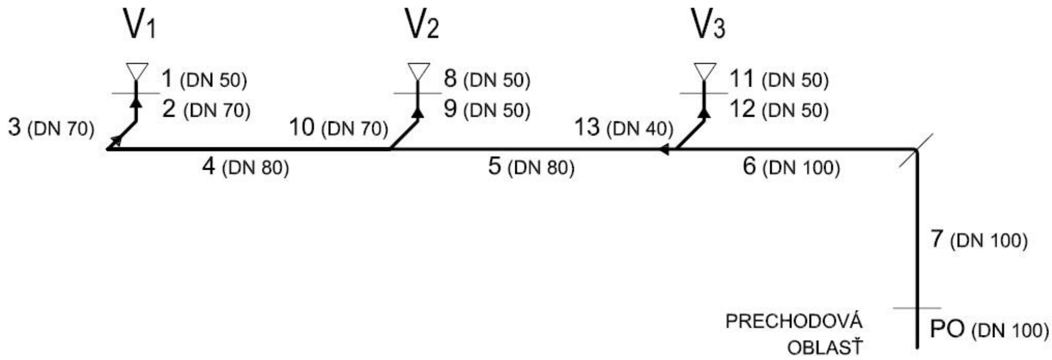


Fig. 5 Scheme of the siphonic system with calculated pipe dimensions

2 Calculation in drainstar siphonic calculator - KEIDEL Software

Calculation by the software is faster in comparison with calculation by hand. After inserting input data:

- reference rainfall rate and rainfall rate which occurs every one hundred years,
- shape of flow path,
- size of drainage area,
- total length of horizontal pipe,
- the length of vertical pipe and the length of transition area,
- roof runoff capacity,
- type of pipes material,

which are put in given tables, the program calculates the dimension of the pipes. Calculated parameters are shown in tables and the program also draw isometric scheme of the siphonic roof drainage system. It is possible to change dimensions and lengths of pipes in isometric scheme and modify whole system to our requirements. After changing some parts of isometric scheme the software highlights unsuitable parts of system, where the design conditions are not complied. It is necessary to know the basic principles and operating conditions of siphonic roof drainage system to be able to balance whole system. The example calculated by hand was also calculated in software. The calculated values of pressure (negative pressure) in parts are shown in Table 4 and the isometric scheme is shown in Figure 6.

Table 4 Calculated parameters from Drain Star siphonic calculator - KEIDEL[4]

Leg (TS) No.	Roof Segment No.	$\dot{V}_r$ l/s	DN mm	Length m	Δh_x m	$\Sigma \zeta$ Zeta	v m/s	Pressure Loss mbar	Pressure px mbar
1	1	6,6	50	0,30	0,30	1,30	4,3	138,67	-203,42
2		6,6	56	0,70	0,70	1,10	3,4	81,69	-178,77
3		6,6	75	1,00		1,10	1,8	22,48	-160,35
4		6,6	90	11,00		0,60	1,2	27,51	-179,72
5		13,2	110	11,00		0,60	1,7	40,55	-226,51
6		19,8	110	9,85		0,80	2,5	87,91	-331,51
7		19,8	110	4,00	4,00	1,80	2,5	81,09	-20,36
0		19,8	110	1,00	1,00	0,00	2,5	6,43	0,00
8	1	6,6	50	0,30	0,30	1,30	4,3	138,67	-203,42
9		6,6	56	0,70	0,70	1,10	3,4	81,69	-178,77
10		6,6	75	1,00		1,00	1,8	20,92	-158,79
11	1	6,6	50	0,30	0,30	1,30	4,3	138,67	-203,42
12		6,6	56	0,70	0,70	0,80	3,4	64,74	-161,83
13		6,6	56	1,00		1,00	3,4	84,42	-246,25

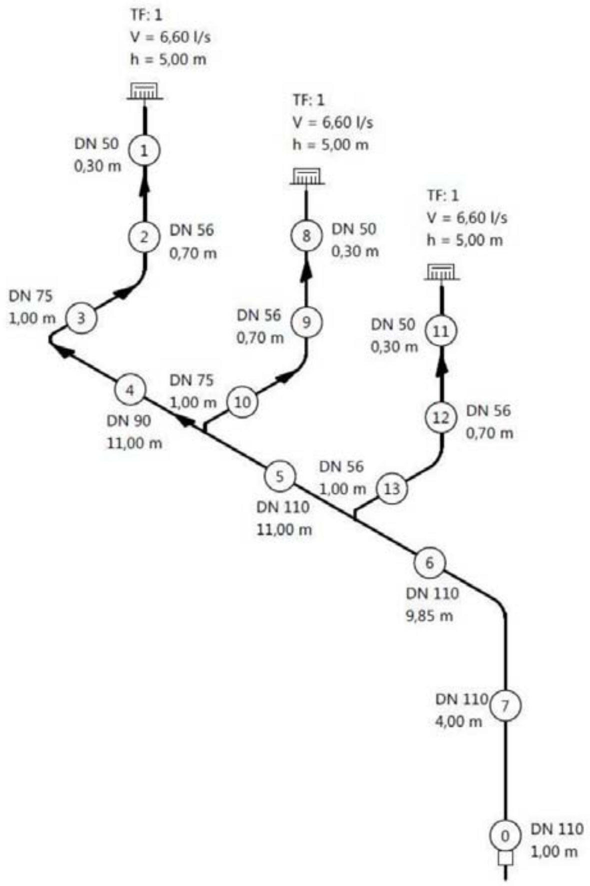


Figure 6 Isometric scheme from DrainStar siphonic calculator - KEIDEL[4]

3 Discussion

Comparison of dimensions in parts of the pipes calculated by hand and in the calculating software is summarised in Table 5.

Table 5 Comparison of calculated dimensions in parts of the pipes

Number of the part	Hand calculation	Software calculation
1	DN 40 (50*3.0)	DN 50
2	DN 50 (56*3.0)	DN 56
3	DN 70 (75*3.0)	DN 75
4	DN 80 (90*3.5)	DN 90
5	DN 100 (110*4.3)	DN 110
6	DN 100 (110*4.3)	DN 110
7	DN 100 (110*4.3)	DN 110
8	DN 40 (50*3.0)	DN 50
9	DN 50 (56*3.0)	DN 56
10	DN 75 (75*3.0)	DN 75
11	DN 40 (50*3.0)	DN 50
12	DN 50 (56*3.0)	DN 56
13	DN 50 (56*3.0)	DN 56

At the first glance it seems that the dimensions of parts of the pies are different. The difference is in writing the dimensions. By comparing the PE-HD pipes from different manufacturers, result was that the PE-HD pipes from manufactures has the same dimensions and wall thickness. Design diagram which was used in calculation by hand is from German technical regulation VDI 3806 and contain smaller range of pipes and have different writing in comparison with calculation software.
Looking at the calculation tables Tab. 1 (column M) and Tab. 4 (column PressureLoss) is easy to see, that pressure losses in parts are a little bit different. The difference is caused by interpolation in taking the values of pressure loss R_i and flow velocity v_i from design diagram. The differences are not so big to have an influence on dimension design. The design condition no. 3 (8) is the most important in the designing siphonic drainage system, but it still allows to variate the design and adapt it to our needs.

4 Conclusion

Calculation of siphonic drainage system by hand is difficult. By the high number of calculations, it is high risk of making mistakes. Therefore, calculation in the software is easier and also faster. Even though it is necessary to know the main design principles. In the designing siphonic roof drainage system is not only one right solution. There is more ways how to design the system to work properly, but the main design conditions must be followed all the time. Siphonic drainage system is easy to maintain, it does not need any given energy to work, the only think which need is right design. Not less important is also quality of installation and quality of pipeline joints, which must withstand higher flow velocity and mechanical stress.

5 Acknowledgement

My thanks belong to company KEIDEL SOFTWARE for free providing the Drain Star Siphonic Calculator for Department of Building Services, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, for study and educational purposes.

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Session D
Computer modelling

Opportunities and benefits of open BIM for water supply and drainage design

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Abstract

Building Information Modelling (BIM) is increasingly accepted by different specialists in construction process. Building water supply and drainage design is one of the many services that would be efficiently supported by BIM and became part of the integrated and collaborative design and engineering. This paper builds on experiences from other building services and overall integrated design approach to propose recommendations targeting challenges in water systems design. It describes the benefits of using BIM in water systems design, proposes ideas for integration of the design process with the design of other systems and presents design and implementation process changes needed for successful BIM implementation. Water and drainage systems are usually implemented from pre-fabricated elements, therefore application of BIM in this area also integrates design and construction activities with the broader supply chain context. The BIM approach could be efficiently used on small and large scale projects. The paper illustrates the opportunities of BIM on a single family house project.

Keywords

Building information modelling, small houses, MEP.

1 Introduction

Design and implementation of a contemporary building inevitably includes integration of several functional subsystems of the building where mechanical, electrical and plumbing (MEP) systems are just a few of them. Coordination of the systems during design stage and also in later stages like construction and facility management is complex and challenging. Traditionally, MEP and other systems are designed by domain specialists and also implemented by independent subcontractors, which adds to the complexity of the design coordination and integration. The systems like water supply, drainage, hot water and sprinklers ought to be properly placed in buildings where the space is limited and where they compete for space with heating, ventilation, air conditioning (HVAC), electricity and other systems. Therefore, there is high risk for clashes among the systems. From a life cycle perspective, MEP related activities affect the whole building life cycle from early design, through detailed design, engineering and construction and also heavily influence facility management. In each stage of the project, water and drainage systems pose different requirements. When considering design stage, design coordination and quantity take-off is of outmost importance. In engineering phase, engineering analysis like hydraulics calculations and static analysis of breaks in the continuity of constructive elements, like openings for MEP and HVAC in the reinforced concrete slabs, is necessary to perform. In construction phase, scheduling, coordination of subcontractors and supply chain management should be performed. Finally, during facility management the systems should be maintained and adjusted according to new requirements and needs of end users. Since MEP so much affects the construction project, the project participants from various backgrounds should work in a collaborative way. However, this also requires higher level of information exchange and cooperation in all stages of the project. On the other hand, better integration could considerably reduce the time required for design and construction coordination.

Additionally, industrialisation in construction is increasingly popular in recent years [1] aiming to achieve several improvements in the sector like higher productivity levels and better quality of construction products. Reports and case studies from different parts of the world have shown that prefabrication and on-site assembly are becoming common practice [2, 3]. Industrialization is trying to address the problems of low profit margins in comparison to other industries, and a shortage of skilled workers [4, 5]. Prefabrication of building components at a remote facility is shown to save space for material storage on site, assures better quality control of part production, reduces waste and enables reengineered and more efficient supply chain management.

Related to water and drainage systems, prefabrication of parts and on-site assembly is common practice. However, in scope of industrialised construction another level of prefabrication should be taken into consideration. Pipes and other installations are built into prefabricated components on a larger scale, like walls, already at the manufacturing facility. This creates new requirements for designers of those systems and increases requirements for design coordination among design specialists. Even more, designs of MEP should be coordinated together with load bearing construction and other building components very early in the project. Such building components allow development of customised building systems which are very flexible and could satisfy a range of end users and assembly processes could be standardised [6].

Next to industrialized construction, integration and interoperability have for several years been a very important topic in the construction industry in general. Research and development efforts in this area have resulted in building information modelling (BIM). The results of these developments lead to integration based on an extensible BIM platform. Building information modelling, integration of information and product driven manufacturing control have also been proposed in manufacturing in general [7] [8]. Collaborative approach in process planning and manufacturing has become increasingly customer centric.

2 BIM and design coordination

BIM is considered to be a process (modelling) and also to be a product (model).
According to Eastman, "Building information modelling (BIM) is a digital representation of the building process to facilitate exchange and interoperability of information in digital format" [9]. The main purpose of BIM should be to provide effective building information management throughout the whole building life cycle. It is expected that all stakeholders in the project would use BIM as a platform for exchange and coordination of information about the building. The National Building Information Model Standard (NBIMS) defines BIM as "a digital representation of physical and functional characteristics of a facility" [10]. From this point of view, most often BIM is considered as a virtual representation of the building, holding all information which is necessary to erect and maintain the building. However, considering BIM as a shared data model in a sense that the model is a description of a data structure instead of concrete "virtual building" would provide even better ground for collaboration [11]. This is because stakeholders are free to use any kind of tool, data repository, partial building information, etc. as long as they are able to exchange data using shared data model, meaning that they are able to store information in a standardised format.
With regard to the lifecycle, the industry accepted BIM as a common approach that should deliver substantial gains. The literature review on BIM [12] discovered that the literature is overwhelmingly positive with regard to the potentials of BIM. Large innovative projects such as ROADCON [13], STRATCon [14] or InPro [15] are aiming for completely transforming the AEC industry from traditional paper-based working and project delivery into model-based collaborative work.
In contrast to large scale projects, which are most often the target for BIM research, in this work we explored possibilities to apply BIM to small scale building project on a case of one family house. The main idea behind this work is to study possible BIM benefits in the area of water supply and drainage during design and engineering stage of the project, where small stakeholders with different disciplines and backgrounds should coordinate their work. We expect that small companies in construction sector working on small scale projects would also benefit from integration of information flows. Specifically, on such small projects there is not much space for changes, mistakes or reworks because projects are very short. Therefore, design and engineering coordination would be of outmost importance and has critical impact on construction phase and on the final product. Also, every decision affects use and maintenance of the building.
Using a case study approach, we explored possible benefits and implications of BIM based design coordination among small stakeholders with the focus on water supply systems. The second goal was observation of possible obstacles to introduction of BIM and collaborative way of working in small scale construction projects.

3 Expected benefits

BIM based construction affects the construction project significantly because of several features provided by building components and via fostering communication among stakeholders. Related to MEP design, tasks such as visualisation, construction simulation, clash detection, quantity take-off (QTO), engineering analysis and coordination of construction works are some of the more important areas of possible improvement.

3.1 Visualisation

Water supply and drainage systems are complex 3D structures which span across the whole building. System functionality cannot be split into localised parts of the system. Therefore, 2D based design in form of floorplans and cross-sections leads to problems in understanding and does not provide sufficient overview of the complete functional system. In BIM based approach, pipes and other equipment are represented with semantically rich 3D components and complete system can easily be visualised. This provides better understanding and decision making, contributes to higher flexibility during design stage and highly contributes to clash-detection. Visualisation of hidden infrastructure can also significantly improve facility management.

3.2 Clash-detection

Water supply and drainage system are not the only systems in the building. Hence, they have to compete for space with other systems like electricity, HVAC and other services. Usually, designers tend to reduce the space needed for all these systems. Since every system is designed by design specialists and domain experts independently, there is high probability of clashes. Beside 3D visual inspection, BIM tools provide automated procedures to detect clashes. When clashes are identified systems should be adapted and those changes must follow certain priorities as required by functional specifications. BIM provides holistic approach to understanding of functional systems, therefore decision making and implementation of changes should be easier. Early clash-detection can also help to optimise later stages of a project, like engineering design and construction. In this way, costs of rework and waste of material are reduced.

3.3 Functional analysis

When particular system is designed, domain experts carry out analysis of the system to check the performance and optimise the system in line with the agreed user requirements. For this purpose, each domain developed certain methods and tools to perform the analysis. However, changes in the overall building design or adjustments needed to remove the clashes, ask for changes in the design of particular system. Therefore, analysis should be performed several times. BIM based integration of domain models provide more efficient way for information exchange among stakeholders. In contrast to traditional approach where domain experts rely on initial calculations followed by quick expert opinions on changes because time for further analysis is too short, BIM based approach makes several iterations of analysis possible in a short time frame.

3.4 Quantity take-off

Estimation of quantities is very time consuming and error prone task when it is based on 2D drawings. Besides, change management and configuration management routines are highly resource demanding. BIM promises high improvements in both the quality of information as well as time savings during material quantity take-off. In BIM, every part of the building is represented with virtual architectural component, hence the model explicitly stores semantics about the building components. Because of that, schedules of needed materials can be extracted automatically. As a consequence, information about quantities are always up to date and reflect all the changes which occur during the project. BIM based cost estimates supported with 3D visualisation and quantity and cost estimation algorithms improve accuracy. Using 4D modelling, project managers can also better plan material logistics and procurement.

3.5 Project planning, tracking and oversight

Planning and tracking of on-site activities could be very demanding for building services because the systems comprise of large number of elements. However, 4D modelling which adds time dimension to 3D components, contributes to more accurate planning of on-site activities and also provides more effective project tracking, which enables postponed detailed scheduling and optimisations among different specialists working on construction site at the same time.

BIM based construction planning and project tracking also improves transparency of material needs at any specific time during project implementation. In this way, site managers get better insight into availability of materials on site and are able to proactively communicate urgent needs to suppliers or customise short-term plans according to available resources. Since piping systems are produced in off-site manufacturing processes and delivered to construction sites, supply chain management could be improved using BIM.

Visualisation of project progress and comparison of as-planned and as-built project status is important insight to project managers and site managers as well as to future owners about the overall project progress.

4 Case study: BIM modelling of water supply, wastewater, underfloor heating and ventilation duct subsystems for a family house

Our research case was a family house for which a BIM model was developed. Conceptually, the house has two attached parts, main part is a cube and attached part is a cuboid. House elevation has three levels (-1 - basement, 0 – ground floor, 1 – first floor). Besides the main constructive elements, the model (Figure 1) contains subsystems that facilitate water supply (green -hot, orange - circulation, blue - cold), wastewater (brown), underfloor heating (red) and central ventilation duct system (green). Planned source of heating is geothermal (earth soil) heat pump. Besides primary ventilation function, the duct system is also planned to assist the process of passive cooling without using the heat pump. In addition to that the external drainage systems was also modeled.

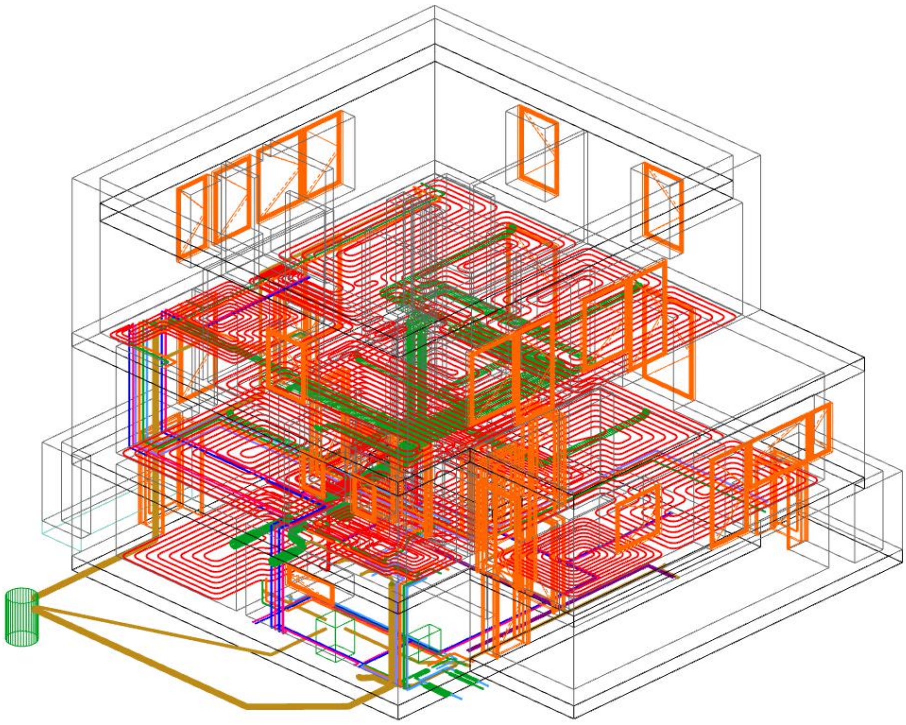

Figure 1 Subsystems that facilitate water supply

The BIM model was primarily created (using one of the available BIM modellers) to support and coordinate communication between investor and consultants in the early design phase:

1. Optimal organization of space in the utility room (bottom middle section in the model) where equipment for heat pump system, equipment for central ventilation duct system, laundry equipment (washing machine, dryer) and other equipment (closet, shower) are placed. The task was achieved with the combined use of the two typical BIM-tool features: visualisation and clash detection.
2. Quantification of underfloor piping network in model was used to compare with quantities (length of pipes) delivered by HVAC consultant. The result was queried from the BIM model using a BIM-tool's MEP module, which can be configured to perform quantity take-off and report sum of lengths of MEP elements.
3. Elevation checks of ventilation duct system against the height (18cm) of reinforced concrete slab. The ventilation duct system is planned to be used also for passive cooling. For that reason, the supply and return ducts were designed to be placed inside of the reinforced concrete slabs (between the rebar). It is believed that ducting the air through concrete slab will reduce the effect of air condensation in supply ducts during the cooling period because of great thermal mass or heat capacity of concrete. Diameter of ducts was therefore optimized to 65mm. The elevation checking task was completed with visualisation and clash detection inside of the BIM tool we used for modelling.
4. Optimization of space in vertical mechanical shaft (from basement to 1st floor) where all supply and return ducts are placed, together with electrical and communication cables, chimney for a fireplace, laundry chute and vertical drainage pipe. The shaft's width (distance from the wall) and length (parallel to

wall) was dimensioned as minimal as needed using visualisation and clash detection functionality of the BIM modeller.

5. Conceptual optimization of wastewater pipeline from the wall opening to the external wastewater shaft on the parcel and further down to the public wastewater collection system. Elevation of the shaft was determined in the BIM model using 3D view functionality.
6. Quantification of external drainage system where the volume of excavations for drainage and quantity of drainage gravel was better planned with the BIM model. The quantification was completed with the zone functionality in the BIM tool.
7. Position of rainwater collection tank outside of the house and its influence was easier to analyse in the context of the surrounding environment (garage, yard, parking places, elevations of electrical main supply cable, main water supply pipeline, walk paths, etc.). The BIM tool was a great help for simulation of different possible locations for the rainwater container in 3D space.

5 Discussion and conclusions

Presented case study implemented design and on-site coordination using BIM approach in the area of MEP. The case study shows some direct gains from using BIM approach and collaborative working practices. The use case for application of BIM modelling for HVAC and MEP subsystems for a family house proved that there are definitive practical gains in efficiency and coordination related to exchange of information between investor and involved consultants. It was possible to design piping systems for water supply, wastewater, underfloor heating and ventilation duct subsystems for the family house.

In this case study, information manager was introduced to coordinate BIM activities and help stakeholders in learning and using the technology. Rising motivation for small stakeholders to actively participate in the BIM based working could be achieved using new contractual policies which would take into account new types of profit distribution according to gains resulted from BIM use. However, especially on small projects, an alternative approach could also be an introduction of information manager which plays mediator role among the stakeholders. Such mediator stays in close contact with all the participants and works closely with each team of domain specialists. In this way, learning curve for each stakeholder is less steep and each company can start collaborative work process using simple methods and BIM.

BIM based working connected all stakeholders linked to the MEP related activities into collaborative working process, where BIM was gradually developed and used for decision making, planning and tracking of construction activities. The major difficulty identified in this project was transition to collaborative way of working, since the stakeholders had to change their habits and organisational culture. It was evident that technical challenges could be resolved and domain specific work methods adapted with less difficulty. Collaboration requires better understanding of other domains and also higher levels of trust among the stakeholders.

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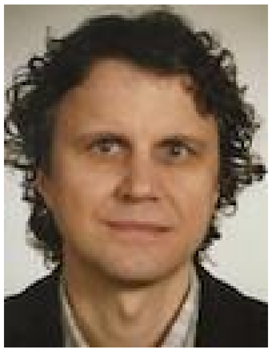

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Verification on the simulation technique for the estimation of water supply loads in the toilets of an office building

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Abstract

The authors have developed a dynamic calculation method for the cold and hot water supply loads: the instantaneous flow rates, hourly and daily consumption by the time series through the day, in the different types of buildings by the Monte Carlo simulation technique. The buildings that have been the subject are apartment houses, office buildings, hotels, restaurants, etc. The results of these studies have been reported at the international symposium of CIB-W062, and the calculation method has been confirmed to be very useful for the estimation of the cold and hot water supply loads by comparison with the measured values. However, the suggested models of using the fixtures must be modified depending on the characteristics of the buildings. Therefore, in this paper, we apply the data which have been measured as the hourly water consumption at each usage by BEMS in the own office building: the T-building. Based on the analysis of the data measured throughout the year, it creates the usage models of toilet bowls. We show the water supply loads which are calculated by the developer simulation program that has been named the MSWC (Murakawa's Simulation for Water Consumption).The calculated results are compared with the measured values, and the accuracy is confirmed. Also, it is discussed for the effect of water conservation when the water-saving toilet bowls are installed in the T-building.

Keywords

Office building, water supply loads, simulation technique, water-saving, toilet bowls.

1 Introduction

The water-saving fixtures has been processing in the buildings, the existing standard values of water consumption for plumbing design have been pointed out that these values deviates significantly from the actual situation. Therefore, it is required to propose the design method for plumbing designers based on the actual situation.
The authors have studied about the water consumption in residential buildings and non-residential buildings, and have proposed the new calculation method to estimate the cold and hot water supply loads: the instantaneous flow rates, hourly and daily water supply loads by making an application of the Monte Carlo simulation technique, which have been reported at the international symposium of CIB-W062 [1~7, 10. 11].
In this paper, the authors show the water consumption that has been measured at each water usage by BEMS (Building Energy Measurement System). And, based on the analysis of the hourly and daily data measured through the year, the authors set up the models to estimate the water supply loads, and show the calculation results by the developed simulation program that has been named the MSWC (Murakawa's Simulation for Water Consumption). The calculated results are compared with the measured values in the toilets flushing systems, and the accuracy is confirmed. Also, the authors discuss the effect of water conservation when the water-saving toilet bowls are installed in the T-building.

2 Outline of the subject building

The outline of the T-building is shown in Table 1. The T-building is an own office building located in Tokyo. The building is a relatively large. The total floor area is 29,747m^2 which have a convenience store, cafeteria and café for the employees. The employed enrollment is assumed about 1,900 people, and the ratio of the male and female is about 4:1.

Table 1 Overview of the subject building

Building name	T- building
Building application	Office
Ownership form	Own Building
Completion	October 2014
Total floor area	29,747 m^2
Office area	24,269 m^2
Ratio of effective office area	81.6 %
Number of seats	2,347 seats
Employed enrollment	1,900 people (assumed value)
Gender ratio	Male : Female = 4 : 1
Construction	S and CFT structure
Scale	The ground 7th Floor, penthouse second floor
Water supply system	Receiving tank and booster pomp system, Rainwater harvesting system
Number of plumbing fixtures	Male's water closet : 41
	Urinal : 47
	Female's water closet (with device of imitative sounds) : 39
	Washbasin : 56
	Small washbasin for brushing teeth : 21
	Sink for cleaning : 16

The personnel density for the office area is about 0.07 [people/m^2], which is lower than 0.1~0.2 [people/m^2] used as a design reference. All the female water closets in the toilets are equipped with the device of imitative sounds in order to prevent the waste of flushing water.

Figure 1 shows the water supply systems and measurement points of water consumption. The water supply system is a receiving tank and booster pumps. As the source of water for the toilet flushing systems, tap water and rain water are used. The flushing water in the toilets of each floor is supplied from the storage tank for using of rain water. The water for air conditioning is supplied from the gravity tank by the booster pumps.

The sum of the measurement points is 11 points, which are the point of the water service pipe: M1, the tap water supply pipe to the storage tank of rain water: M2, to the toilet flushing systems: M3, to the air-conditioner: M4 and cooling towers: M5~M7, to the convenience store: M8, cafeteria: M9~M10, and Café:M11. In addition to the points of M1~M11, the tap water consumption for watering to plants on-site is measured monthly because of declaration to the sewage works in order to reduce the discharge fee.

On the analysis of these measurement data, the consumption of the other tap water for office systems and rain water which are not measured directly is grasped by the recorded data in front and behind systems. The data have been recorded with a cubic meter per hour as one unit. The annual consumption from 2005 to 2013, the daily consumption in 2013, and the hourly consumption of the representative week from January to October in 2013 are analyzed in this paper.

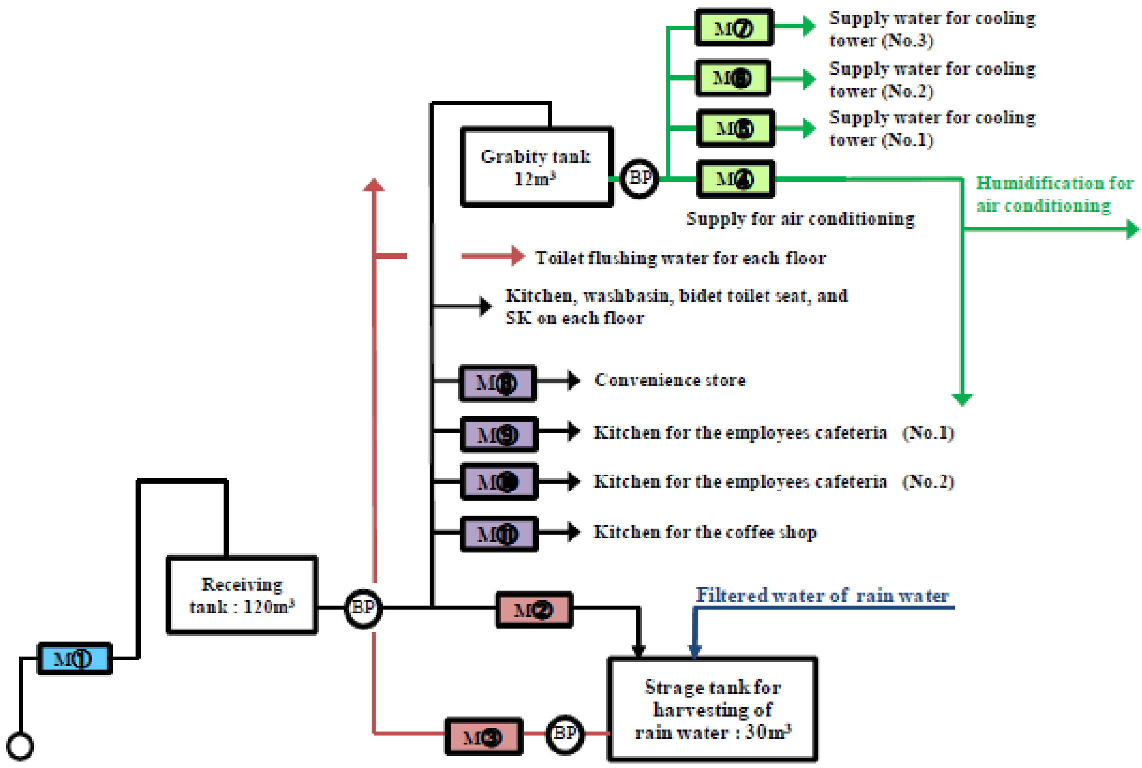


Figure 1 Water supply systems and measurement points

3 Water consumption in each usage of water supply systems

Figure 2 shows the monthly water consumption in each usage of nine years from 2005 to 2013. As for the total water consumption in the T-building of which includes the water uses of the air-conditioning systems in summer, the values for each month during nine years have remained between 2,500 m^3 and 4,000 m^3. However, since 2009, the water consumption per month shows a slightly decreasing trend such as between 2,000 m^3 and 3,500 m^3.

As for the water usage systems, the consumption volumes in the toilet flushing systems have remained between 1,000 m^3 and 1,500 m^3. Among the toilet flushing systems, the consumption of rain water indicates between 50 m^3 and 300 m^3. And, the values of water consumption do not change significantly in the nine years after completion.

The water consumption in the air-conditioning systems is influenced by the make-up water to the cooling towers, and shows the values between 700 m^3 and 1,200 m^3 in summer from July to September. The consumption in the interim period shows small values such as 300m^3 or less including zero.

The water consumption in the kitchen systems and the tap water systems in the office has remained between 400 m^3 and 1,200 m^3, and between 500 m^3 and 900 m^3, respectively from 2005 to 2008. Since 2009, both of the systems have shown the values between 200 m^3 and 800 m^3, and between 300 m^3 and 500 m^3, respectively. These values show a similar tendency as the reduction in the total water consumption of the T-building, because it may be considered that the decrease of an employed enrollment and the decrease of the number of food that had been provided were affected.

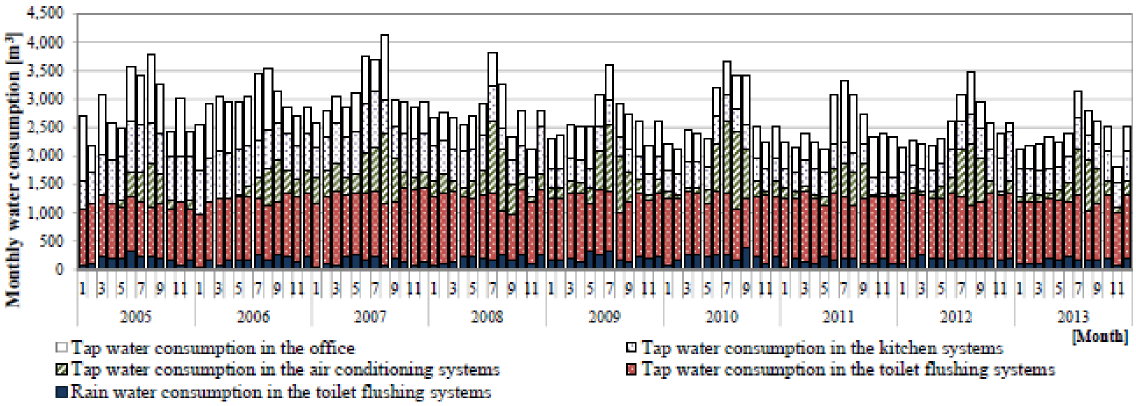


Figure 2 Monthly water consumption for each usage of water supply systems

Table 2 shows the average values of water consumption per total floor area, and per people based on the integrated value through the 365 days in 2013 and the integrated value of 240 days in 2013 that was extracted as the weekday of working. In addition, the table shows the percentage of each usage of the water supply systems for the average value of the total water consumption in the T-building.

It should be noted that the water consumption per people shown in Table 2 is the values that were calculated by dividing with the employed enrollment assumed 1,900 people.

The following in this paper shows the analyzed results based on the data of 2013.
As for the total consumption in the T-building, the average values per unit through the 365 days of the year and the 240 days of being works are shown with the values of 2.66 [L/m^2/day], 41.7 [L/people/day] and 3.79 [L/m^2/day], 59.3 [L/people/day], respectively. According to the standards of design for building service, the amount of water consumption per people per day except for the kitchen and cooling tower in an office building is shown as 60~100 liters. The average consumption per unit in working day indicates approximately 1.4 times for the annual average value. If the average value of 240 days in the T-building including the kitchen, air-conditioning, etc. is compared to the standard value, it can be said that the reference value is fairly large.
Within each water supply system, the tap water consumption for the toilet flushing systems shows the maximum percentage: 43.2 % for the 365 days data and 44.9 % for the 240 days data. The total consumption of the tap and rain water in the toilet flushing systems accounts for about half of the whole consumption in the T-building. The average water consumption in the kitchen systems of the working day divided by the 900 meals which are assumed as the average number of provided foods per day: it has the range of 800~1,000 meals per day, shows about 25.1 [L/meal/day].

Table 2 Statistics of water consumption per unit

		Tap water systems in the office			Kitchen systems			Air conditioning systems			Toilet flushing systems						Total value		
											Tap water			Rain water					
		Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value	Max.	95% value	Ave. value
Water consumption per total floor area [L/m²/day]	Annual value (365days)	2.89	1.37	0.46	1.14	0.91	0.51	1.95	1.24	0.37	2.15	1.98	1.15	1.61	0.67	0.17	5.72	5.18	2.66
	Value of working day (240days)	2.32	1.45	0.67	1.14	0.94	0.76	1.95	1.35	0.43	2.15	2.02	1.7	1.61	0.87	0.23	5.72	5.28	3.79
Water consumption per people [L/people/day]	Annual value (365days)	45.26	21.47	7.26	17.9	14.21	8	30.53	19.37	5.72	33.68	31.05	18.02	25.26	10.53	2.66	89.47	81.05	41.66
	Value of working day (240days)	36.32	22.63	10.42	17.9	14.74	11.9	30.53	21.08	6.79	33.68	31.61	26.68	25.26	13.68	3.52	89.47	82.63	59.31
Percentage for the total average value [%]	Annual value (365days)	17.3			19.2			13.9			43.2			6.4			100		
	Value of working day (240days)	17.7			20.1			11.3			44.9			6.1			100		

4 Daily and hourly water consumption in the toilet flushing systems

The typical examples of daily water consumption for a week of January, April, July and October 2013 are shown in Figure 3. The daily consumption on a weekday in every month shows about 55~60 [m^3/day]. However, the water consumption on Saturday and Sunday of the day off shows less than 10 [m^3/day].
Figure 4 shows the typical examples of hourly water consumption in a week. The hourly values of water consumption fluctuate with the unit of a cubic meter because of the smallest measurement unit set up by the BEMS. From these hourly fluctuations, it is possible to grasp the tendency of workers behavior of water uses. The volumes of 3.0~4.0 [m^3/hour] are used in early morning of the time zone of 7:00~8:00 because the office starts work at 8:30. Until around the time zone of 14:00, the water consumption in the toilet flushing systems shows the peak values of 5.0~6.0 [m^3/hour]. After then, the values reduce at the time zone of 18:00.

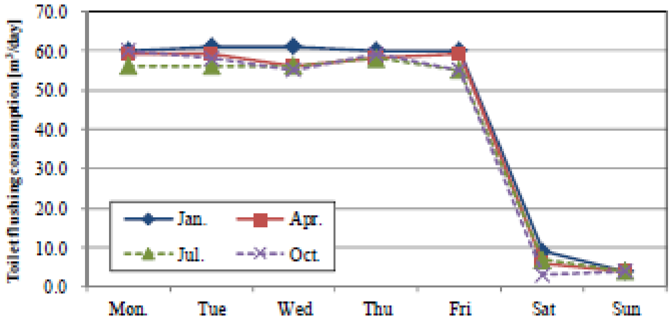


Figure 3 Daily water consumption in the toilet flushing systems

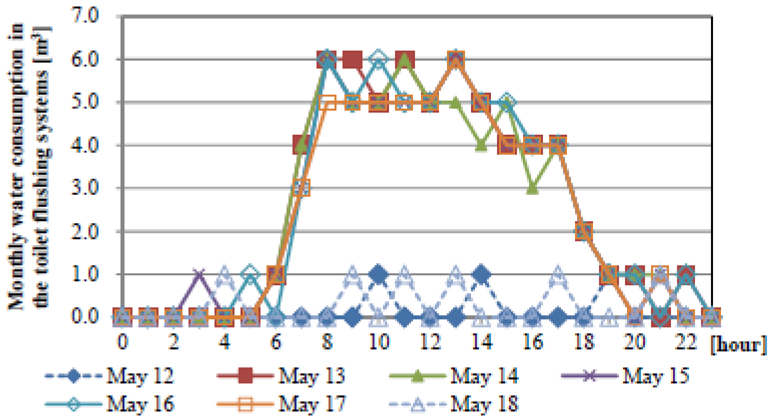


Figure 4 Hourly water consumption in the toilet flushing systems

As the water consumption in the holidays on Saturday and Sunday has occurred slightly by the holiday attendances, the measurement values of 1.0 [m^3] are caused in the some hourly time zones.

Table 3 shows the average values of water consumption per day on weekday, Saturday and Sunday in a representative week in each month from January to October, 2013. The average values of weekday in each month are in the range of 56~60 [m^3/day], and significant difference is not observed. As the total average values, the weekday, Saturday and Sunday show the values of 58.0, 6.0 and 4.1 [m^3/day], respectively. The water consumption on Saturday and Sunday for the weekday value represents about 1/10 and 1/14 times, respectively.

Table 3 Average water consumption in the toilet flushing systems on weekdays and holidays

Average water consumption in the toilet flushing systems in weekdays and holydays [m^3/day]		Weekdays	Saturday	Sunday
Jan. 2013		60.40	9.00	4.00
Feb. 2013		59.80	8.00	5.00
Mar. 2013		56.60	5.00	5.00
Apr. 2013		58.20	6.00	4.00
May. 2013		58.60	6.00	3.00
Jun. 2013		56.20	6.00	3.00
Jul. 2013		56.20	7.00	4.00
Aug. 2013		57.60	4.00	4.00
Sep. 2013		59.40	6.00	5.00
Oct. 2013		57.40	3.00	4.00
Total	Average value	58.04	6.00	4.10
	Standard deviation	1.95	1.67	0.70

5 Estimation of the water consumption in the toilet flushing systems

The authors have developed the calculation method of the cold and hot water consumption for the plumbing design in the buildings such as collective housing, office building, city and business hotel, restaurant, etc. In this chapter, we show the calculation results of water consumption in the time series and compare with the measurement results in order to verify the dynamic calculation method. In addition, we estimate the instantaneous flow rates and the water consumption in each fixture usage that have not been recorded by the BEMS.

5.1 Setting of the calculation models

Figure 5 shows the model of the occupied ratios to the number of workers in the T-building. The ratios in the time series were analyzed based on the average model that was shown in the previous studies [6, 10], because the start time of work in the T-building has become as fast as 30 minutes composed with the general office buildings.

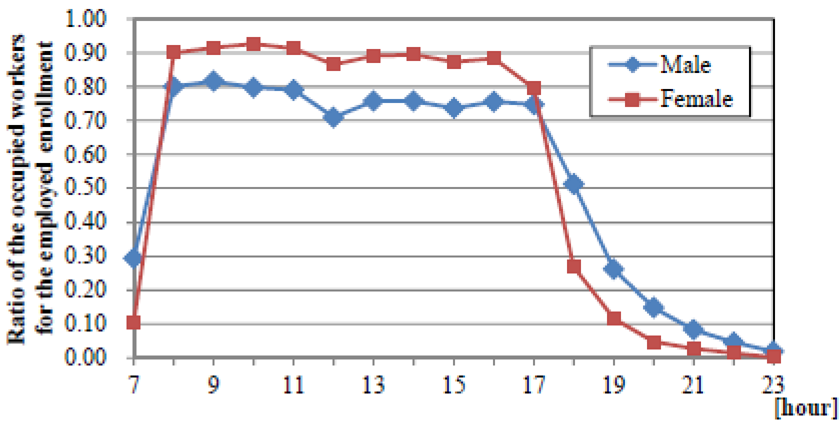


Figure 5 Model of the occupied ratio of workers for the employed enrollment

Figure 6 shows the frequencies of fixture usage per people per hour. Based on the measurement values for the hourly fluctuations of water consumption, the frequencies were adjusted by multiplying 0.9 to 1.25 times in the values of the previous reports [6, 10]. The calculation models of water consumption for the toilet flushing systems are shown in Table 4. Based on the types of fixtures that are actually installed in the T-building, the flushing water volumes of the water closet and urinal have been assumed with the type of 10 liter and 4 liter, respectively.

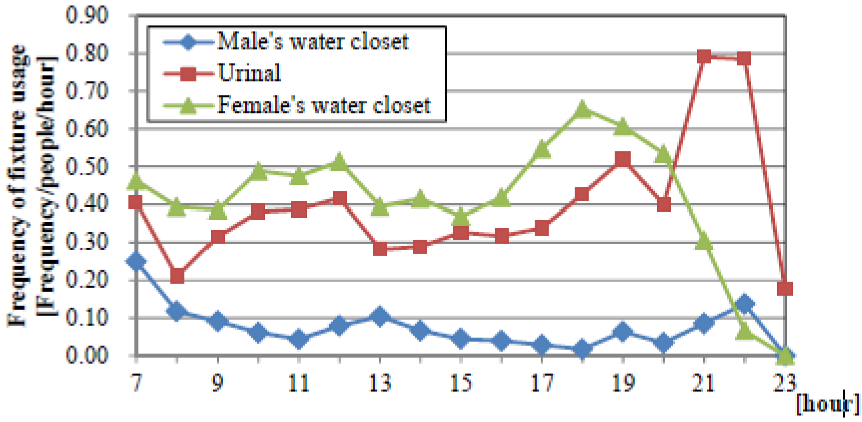


Figure 6 Models of hourly frequencies of fixture usage

Table 4 Calculation models of water supply loads

		Male		Female
		Water closet [10L]	Urinal [4L]	Water closet [10L]
Arrival model	Arribal interval distribution	Exponential distribution , random arrival		
	Arrival ratio [people/min]	Setting in each time zone of one hour		
	Number of fixtures	41	47	39
Occupancy model	Dulation time of occupancy [sec]	260	37	110
	Distribution	Erl.3	Erl.7	Erl.3
Water volume model	Dulation time of water discharge [sec]	6	20	6
	Distribution	Exp.	Erl.10	Exp.
	Flow rate [L/min]	100	12	100
	Distribution	Erl.6	Erl.10	Erl.6
Fixture operation model	Frequency of fixture operation	1.60	1.00	1.30

As for the average number of the operations of flush valve for an occupancy per toilet booth, male's and female's water closet were adopte d 1.6 and 1.3 times, respectively. In the case of female's water closet, the average operation frequency is smaller than the male's water closet because of setting the device of imitative sounds.

5.2 Verification for the calculation results by the simulation method

5.2.1 Instantaneous water supply loads

Figure 7 shows the instantaneous water supply loads per 5 seconds, 10 seconds and 60 seconds as the value of failure factor 0.2 % that were calculated for each one hour. Each of these values was determined by the statistical processing based on the simulation results by 100 trials per hour. The basic data for the statistical processing were used the average values of 5, 10 and 60 seconds calculated by the simulation of 0.1 second intervals.

The peak flow rates appear at the time zone of the lunch break and the morning of starting work regardless to take the average value of time interval. However, the peak flow rates per 5 seconds or 10 seconds have occurred a significant difference compared with the 60 seconds values because the water closet with flush valve is caused a large flushing flow rate per operation in a short discharge time.

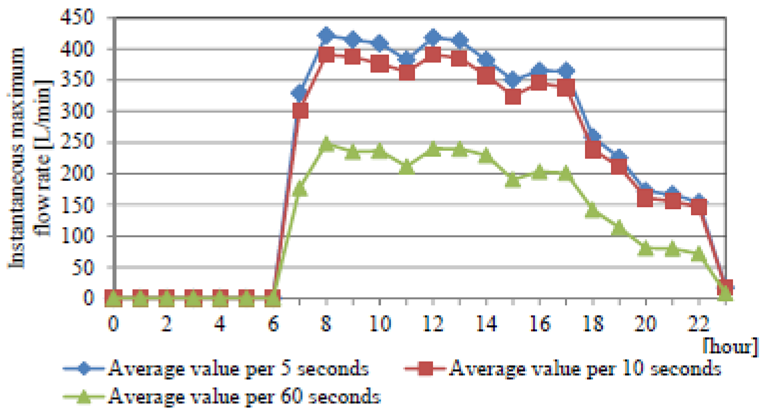


Figure 7 Instantaneous maximum water supply lords by the simulation

As the estimated values of the instantaneous flow rates in the time zone of the lunch break, the maximum values and the values of each failure factor per 5, 10 and 60 seconds are shown in Table 5.

Table 5 Statistics of the instantaneous maximum water supply loads

	maximum	Failure factor					
		0.1%	0.2%	1.0%	5.0%	10.0%	50.0%
Average value per 5 seconds	708.6	452.4	418.4	336.1	242.8	197.6	66.2
Average value per 10 seconds	625.4	421.4	390.6	310.9	229.3	188.9	71.2
Average value per 60 seconds	398.8	252.0	239.8	202.4	161.2	143.2	85.4

5.2.2 Comparison with the simulation and measurement results as for the hourly and daily water supply loads

As for the hourly water consumption, it is possible to compare with the measurement and simulation values. Figure 8 shows the hourly water consumption of the maximum and cumulative probability 95 % and 50 % values by simulation in addition to the average values of measurement in weekday.

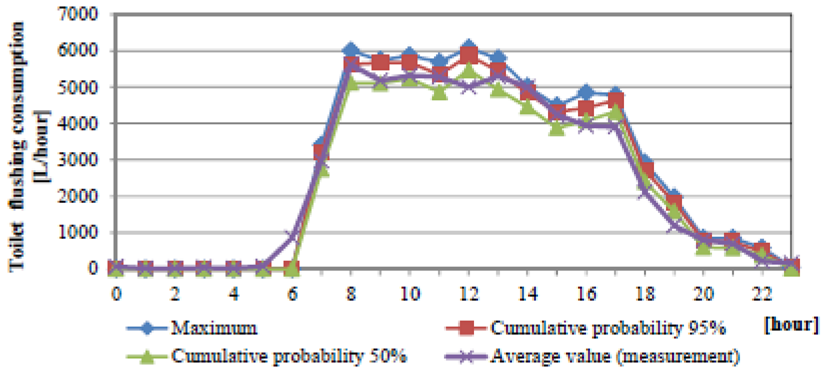


Figure 8 Hourly water supply loads by the simulation and measurement

The measurement average values and the simulation values of cumulative probability 50 % are fairly approximate in each of the time zone except in the morning of 6:00~7:00. The difference in the early morning is appeared by the simulation model which was built in the time zones from 7:00 to 24:00.

Figure 9 shows the frequency distribution and cumulative probability distribution for the daily water consumption which was calculated by the 100 trials of an example of the simulation.

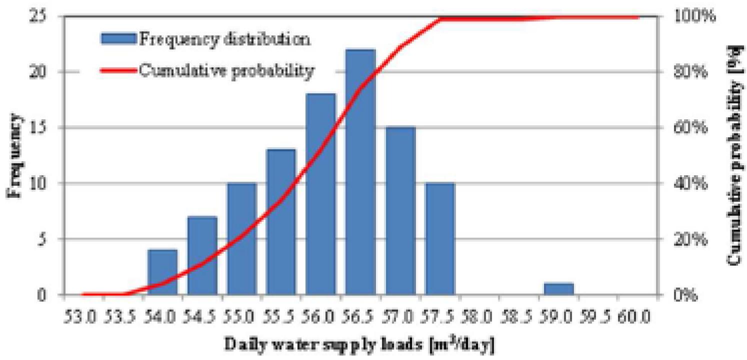


Figure 9 Daily water supply loads by the simulation

In the case of T-building, the average water consumption per day is slightly greater than the simulation value of cumulative probability 50 %. The reason for the difference is considered that the water consumption from 1 to 2 [m^3] in the time zone of 24:00~7:00 is excluded from the results of simulation.

5.2.3 Estimation of water supply loads in each fixture usage of the T-building

Table 6 shows the simulation results in each fixture usage and the whole of toilet flushing systems as the estimation of water supply loads in the T-building. The values of failure factor 0.2 % for flow rates per 5 seconds are shown as the maximum instantaneous water supply loads. The total instantaneous load of the toilet flushing systems is much smaller than the sum of the values for each fixture usage because the peak load of each fixture appears in different time zone. The instantaneous water supply load [L/min] for the whole fixtures shows about five times if compared with the hourly average water supply load [L/min] calculated in the time zone from 8:00 to 18:00. The daily loads per people in the time zone of working from 8:00 to 18:00 are estimated with the assumed average numbers of male and female to stay at work in the T-building as shown in Table 6.

Table 6 Calculation results for the water supply loads

		Male		Female	Toilet flushing consumption
		Water closet	Urinal	Water closet	
Instantaneous water supply loads [L/min] Average value of 5 seconds	F.factor 0.2%	321.1	100.0	322.4	418.4
Hourly water supply loads [L/hour]	Maximum	2,960	2,087	3,275	6,073
	95 probability	2,726	2,015	2,692	5,864
	50 probability	2,276	1,888	2,136	5,468
Daily water supply loads (24hours) [m^3/day]	Maximum	16.9	19.7	22.5	58.7
	95 probability	16.7	19.6	22.4	57.2
	50 probability	15.5	19.2	21.2	55.9
	Average value	15.6	18.5	21.2	55.8
Daily water supply loads (8:00 am～6:00 pm) [m^3/10 hours]	Maximum	14.4	17.1	21.6	52.3
	95 probability	14.0	16.9	21.4	51.2
	50 probability	12.9	16.6	20.4	49.9
	Average value	12.9	16.6	20.4	49.9
Daily water supply loads per people (8:00 am～6:00 pm) [L/people/10 hours]	Maximum	12.4	14.7	64.3	34.8
	95 probability	12.0	14.5	63.7	34.1
	50 probability	11.1	14.2	60.7	33.3
	Average value	11.1	14.2	60.7	33.2
	Assumed actual headcount in the office : 1,501 Number of male : 1,165 (occupied ratio : 0.767) Number of female : 336 (occupied ratio : 0.886)				

6 Effect of installing the water-saving fixtures in the toilet flushing systems

6.1 Setting up the simulation models for water-saving

The toilet flushing systems in the T-building had been designed with the water-saving fixtures at the time that was built. However, it has been progressed for further watersaving. Therefore, it is discussed the reduction effect of water consumption, when the water-saving fixtures considered presently to be appropriate are installed in the T-building.

Table 7 shows the specification of the three types of water-saving for each water closet and urinal. Also, the three kinds of model that are combined with each water closet and urinal are shown in Table 7. They are called as the standard model of water-saving, watersaving model and super water-saving model in this paper.

Table 7 Specification of water-saving water closet and urinal

	Water consumption	Duration time of water discharge	Flow rate	Standard water-saving model	Water-saving model	Super water-saving model
Water closet (Standard water-saving type)	8 L/one time	4.8 sec	100 L/min	○		
Water closet (Water-saving type)	6 L/one time	18 sec	20 L/min		○	
Water closet (Super water-saving type)	4.8 L/one time	24 sec	12 L/min			○
Urinal (Standard water-saving type)	3 L/one time	15 sec	12 L/min	○		
Urinal (Water-saving type)	2 L/one time	10 sec	12 L/min		○	
Urinal (Super water-saving type)	1.2 L/one time	6 sec	12 L/min			○

6.2 Estimation of the water supply loads

Figure 10 shows the instantaneous water supply loads for the three kinds of water-saving models and the model of the T-building as the values of failure factor 0.2 % and per 5 seconds.

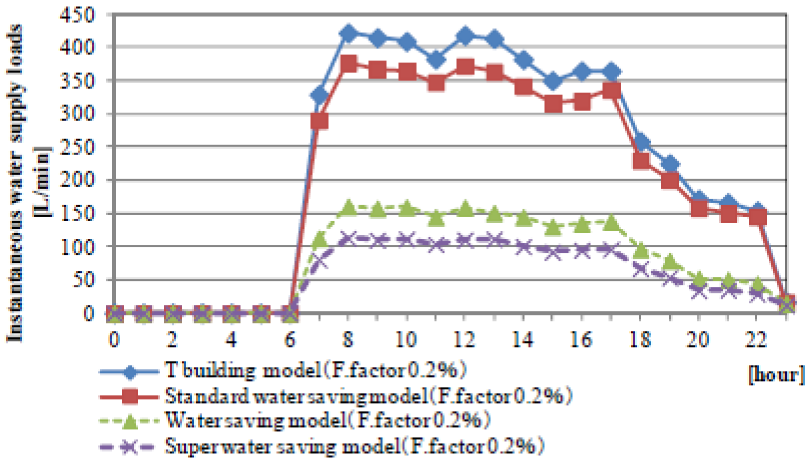


Figure 10 Instantaneous water supply loads (5 seconds value)

The instantaneous water supply loads of the T-building are slightly larger in comparison with the standard type of water-saving. However, the values of T-building have a fairly large difference if compared to the water-saving type and super water-saving type.
Figure 11 shows the hourly water supply loads of the four models as the values of cumulative probability 50 %. In the 10 hours from 8:00 to 18:00 of working time zone, there is a difference of a cubic meter or more per hour between the T-building model and the standard model. Also, it has approximately same difference between the standard model and the water saving model.
As shown in Table 8, the daily water supply loads of the standard model, water-saving model and super water-saving model are reduced about 21 %, 44 % and 58 % for the T-building model, respectively.

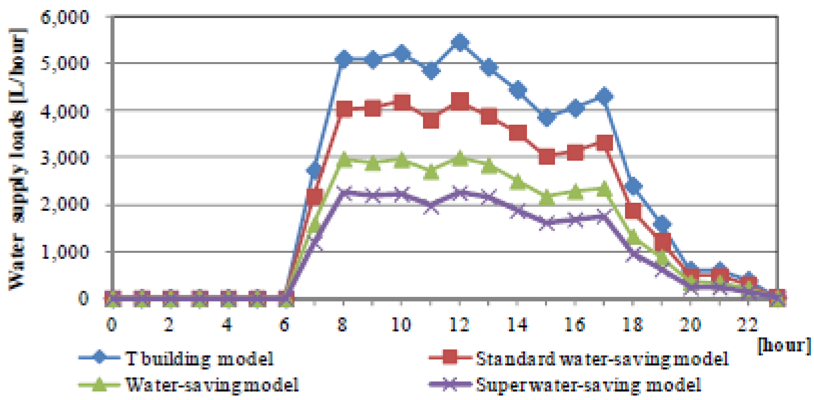
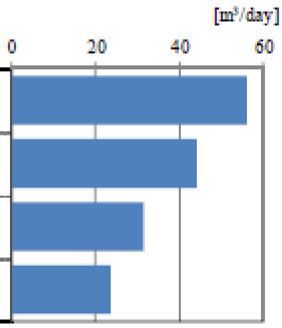


Figure 11 Hourly water supply loads in the case of cumulative probability 50%

Table 8 Daily water supply loads in the case of cumulative probability 50%

	Daily water supply loads [m^3/day]	Reduction rate of water consumption
T building model (Cumulative probability 50%)	55.9	100%
Standard water-saving model (Cumulative probability 50%)	43.9	-21%
Water-saving model (Cumulative probability 50%)	31.4	-44%
Super water-saving model (Cumulative probability 50%)	23.3	-58%



On the effect of installing the water-saving fixtures, Table 9 shows the comparison of the instantaneous water supply loads which were calculated by the four models described above and by the two conventional methods which were currently used as the Hunter's Curve and the new water supply fixture unit. In addition, the table shows the water supply pipe diameter that was determined by the instantaneous water supply loads.

Table 9 Comparison of water supply pipe size by t he simulation and existing methods described in "SHASE-S 206"

	Instantaneous maximum flow rate (L/min)	Type of pipe	Pipe size	Average velocity of water
T buiiding model	421.8	Stainless steel pipe (SUS304)	75 mm	2.0 m/s
Standard water-saving model	376.6		75 mm	2.0 m/s
Water-saving model	160.6		50 mm	2.0 m/s
Super water-saving model	112.8		40 mm	2.0 m/s
Method of described in "SHASE-S 206"-1 ※	807		100 mm	2.0 m/s
Method of described in "SHASE-S 206"-2 ※	600		80 mm	2.0 m/s

1※: Hunter's curve using water supply fixture unit
2※: Convenient method using new loading unit

The four estimated instantaneous water supply loads calculated by the MSWC program are shown as the statistic processing values by failure facto 0.2 % based on the group of average flow rates per 5 seconds. The diameter of water supply pipe using stainless steel pipe for the toilet flushing systems was determined in the average velocity of flow rate so as not to exceed 2 [m/second]. The instantaneous water supply loads by the existing conventional methods show fairly large values. The diameter of water supply pipe determined by the Hunter's Curve show the largest value.
It should be noted that the capacity of the booster pump water supply system that has been installed in the toilet flushing systems of the T-building is as follow:

500 [L/min]×600 [kPa]×5 [kW] : It intends to have parallel running with two pumps.

Therefore, the actually designed value in the T-building can be said to be approximated to the estimated instantaneous maximum load that was calculated by the simulation model.

7 Conclusions

The authors have shown the usefulness of the dynamic calculation method for water supply loads based on the simulation model that has been set by the hourly measurement data in an office building. The clarified contents are as follows:

1. The water consumption in each water supply system of the T-building was clarified for nine years after the completion. In recent years, it was grasped that the water consumption in the office building is decreasing.
2. From these analyzes, the water consumption per total floor area, and per people of the employed enrollment was shown in each water supply system. These measured values were found to be considerably smaller than in conventional design values.
3. Based on the hourly water consumption of the toilet flushing systems in the T-building, the simulation model applied for T-building was set in place of the standard model that has been proposed in previous research papers.
4. The instantaneous, hourly and daily water supply loads of the toilet flushing systems in the T-building were clarified based on the simulation results. The calculated hourly and daily water supply loads were revealed to approximate the measured values.
5. Three kinds of water-saving simulation model were set in order to verify the effect of introducing water-saving toilet bowls. According to the calculation results, it was revealed that the moderate model: 6Lwater closet and 2L urinal can save water about 44 % compared to the present conditions.
6. Further, according to the comparison of the calculated instantaneous loads, it was found that the diameter of water supply pipe can be fairly reduced with the introduction of water-saving toilet bowls.

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9 Presentation of Authors

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 method for cold and hot water consumption in buildings that is referred to as the MSWC program.

Verification of calculation method using Monte Carlo method for water supply demands: The water consumption of an office building

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Abstract

In Japan there are 4 kinds of calculation methods for water supply demands prescribed by SHASE-S 206(The Society of Heating, Air-Conditioning, and Sanitary Engineers of Japan Standard) and 2 kinds prescribed by the design standard of MLIT (Ministry of Land, Infrastructure, Transport and Tourism) for the office buildings. However, these methods were found to produce overestimated values because water savings of sanitary fixtures have progressed in recent years. In order to address this problem, MSWC (Murakawa's Simulation for Water Consumption) using Monte Carlo method enables to calculate water consumption dynamically. Therefore, we examined MSWC about the water consumption of an office building. Actual water consumption data was collected from the office building with 6 stories above ground and one below. Values calculated by all of the 6 kinds of conventional calculation methods and the MSWC were compared with the measured values. Compare to the measured values，the values calculated by the conventional calculation methods were much bigger than measured values, while the value based on the MSWC method was very close to the measured values.

Keywords

Water supply demand, calculating method, office building, Monte Carlo method.

1 Introduction

In Japan six water load calculation methods have been in use for design the office building: two based on the design standard of Ministry of Land, Infrastructure, Transport and Tourism [1] (referred to as the design standard below) and four based on the procedures of the Society of Heating, Air- Conditioning and Sanitary Engineers of Japan SHASE-S 206 [2] (referred to as SHASE-S 206 below). However those standards were established in the 1970s to the 1980s, and there is a risk of overestimating water supply load if the calculation methods based on them are applied to the present day sanitary systems with rapidly growing water saving features. On the other hand, MSWC (Murakawa's Simulation for Water Consumption), a tool to dynamically calculate various water usages in buildings by applying them to probability models has been developed by Murakawa et. al.

In the previous study [3],[4],[5], actual water consumption and the number of occupants in an office building in Tokyo were measured to examine and analyze water usage surrounding sanitary fixtures. We compared measured values and values obtained using each water load calculation method, and confirmed that the conventional methods overestimated water supply load and that the calculations made by MSWC were highly accurate.

In this study, we measured water consumption and the number of occupants in an office building, and compared and analyzed daily water consumption (referred to as Qday below) and instant peak flow rate (referred to as Qmax below) in order to further examine the validity of MSWC.

2 Water consumption measurement

2.1 Purpose

Water consumption was measured in an office building to collect basic data, and examine the validity of MSWC and the conventional water load calculation methods.

2.2 Outline of water supply system

Data were collected in a 7-story (6 floors above ground and 1 below) office building (referred to as T-building) with the total floor area of 2384.4 m^2 in Tokyo. Figure 1 shows the water supply lines, the locations of ultrasonic flow meters, and the type of the tenants on each floor. Water was supplied by the increase-pressure water supply system.

2.3 Method of Measurement

Ultrasonic flow meters were placed in the water supply main near the outlet of the pump (A), in the water supply main between the floors 3 and 4 (B), 4 and 5 (C), and 5 and 6 (D) from Wednesday, August 5 to Thursday, August 6, and on Thursday, November 12, 2015, and water flow rate was measured every second.

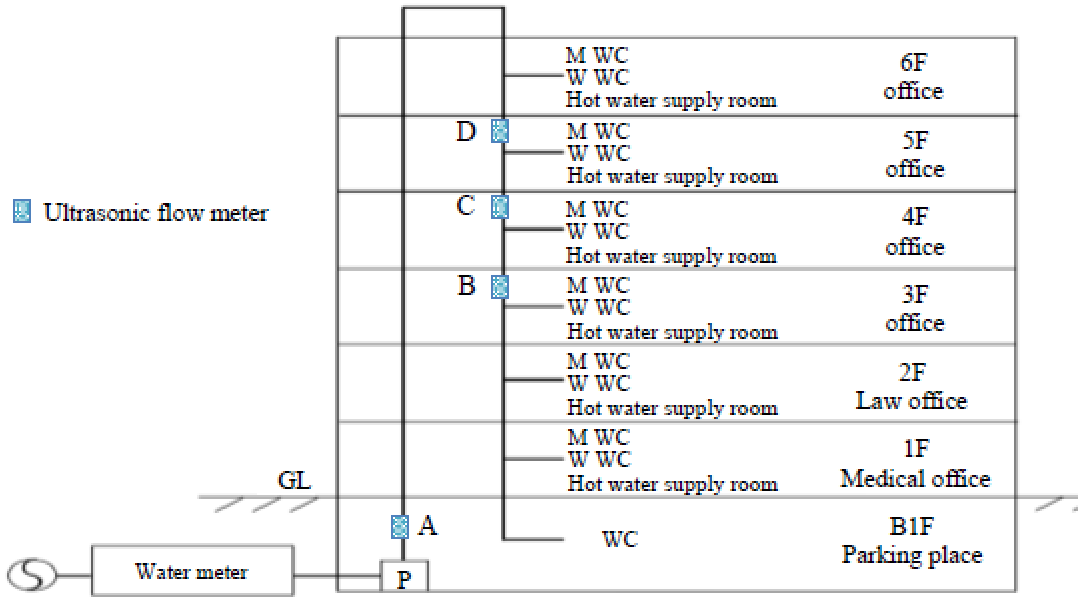

Figure 1 Water supply system diagram

2.4 Results

Oday and Omax on each floor obtained from calculation based on the measured data by ultrasonic flow meters during the measuring period: August 5 ~ 6, and November 12, 2015 are shown in Table 1. In Chapter 7, data obtained on August 6, when Qday calculated from the ultrasonic flow meter data were the largest were used.

Table 1 Oday and Omax on each floor

Period	Classification	Whole building	6F	5F	4F	B1F~3F
8/5 (Wed.)	Qday[L/day]	9,361	1,434	2,357	2,017	3,552
	Qmax[L/min]	86.7	28.6	66.2	85.3	69.5
8/6 (Thu.)	Qday [L/day]	9,701	1,558	2,649	1,827	3,667
	Qmax[L/min]	79.0	45.4	73.3	52.9	70.7
11/12 (Thu.)	Qday [L/day]	9,493	1,574	2,438	2,182	3,298
	Qmax[L/min]	67.1	38.1	58.4	53.7	67.1
Ave.	Qday[L/day]	9,518	1,522	2,481	2,009	3,506
	Qmax[L/min]	77.6	37.4	66.0	64.0	69.1

3 Counting the number of occupants

3.1 Purpose

In order to determine the number of occupants present in the rooms in T-building during the measurement period, the occupants of T-building were asked to fill out questionnaires and their presence in the rooms every 30 minutes on the days measurements were made were investigated. To further validate the accuracy of the questionnaires, security cameras were used.

3.2 Method

3.2.1 Counting the Number of Occupants by Questionnaire

The number of occupants in the rooms by gender was counted every 30 minutes during the measurement period: Wednesday, August 5 to Friday, August 7; Wednesday, November 11 to Friday, November 13, 2015.

3.2.2 Monitoring People In and Out of Building

People entering and exiting T-building were monitored by security cameras placed at the front and back entrances during the measurement period: Wednesday, November 11 to Friday, November 13, 2015; and the number of people was counted by gender every 5 minutes.

3.3 Results

The number of occupants registered for T-building is shown in Table 2. The movements of people obtained by questionnaire on Thursday, November 12 are shown in Figure 2, and an example of the fluctuation of occupants captured by a security camera on Thursday, November 12 in Figure 3. The maximum numbers of occupants by gender calculated from the data obtained from questionnaires and security cameras are shown in Table 3. Though the fluctuation of occupants was seen both in questionnaire and on security cameras, the female maximum number of occupants monitored on security cameras was about 1.3 times greater than that counted by questionnaire. This may be due to the fact that there were visitors who had not been reflected in the questionnaire.

Table 2 The number of occupants registered for T-building

Floor	Tenants	Aug.		Nov.	
		Male	Female	Male	Female
6F	office	20	6	22	4
5F		53	19	55	19
4F		38	14	36	14
3F		53	10	51	12
1-2F	Law office Medical office	17	7	17	7
Entirety	-	181	56	181	56

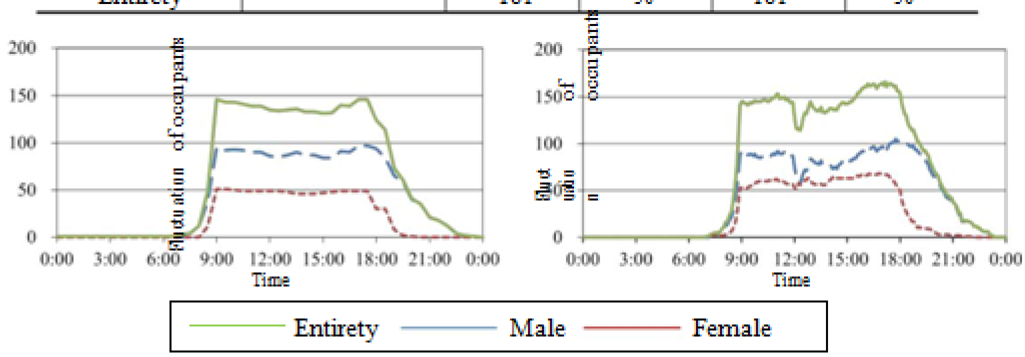

Figure 2 Questionnaire **Figure 3 A security camera**

Table 3 The maximum numbers of occupants

Period	Questionnaire		Security Camera	
	Male	Female	Male	Female
8/5(Wed.)	136	52	-	-
8/6(Thu.)	142	52	-	-
8/7(Fri.)	134	53	-	-
Aug.(Ave.)	137	52	-	-
11/11(Wed.)	112	52	111	61
11/12(Thu.)	97	51	105	68
11/13(Fri.)	103	50	96	66
Nov.(Ave.)	104	51	104	65

4 Measurement of WC flush time and flush volume

4.1 Purpose

Average flush time and average flush volume are two of the simulation conditions set forth in MSWC. Therefore WC flush time and flush volume were measured to calculate average flush time and average volume in WC in T-building.

4.2 Method

Single WC was flushed several times and the fluctuation of flow rate was measured with an ultrasonic flow meter.

4.3 Results

Average flush time and average flush volume calculated from five measurements are shown in Table 4. Averages were used for MSWC calculations. As a result, average flush time was 17.2 seconds and average flush volume 49.8 L/min. (Table 4)

Table 4 Average flush time and average flush volume

Count	water supply discharge time [s]	water supply discharge [L]	Average water supply discharge volume [L/min]
1st	17	13.8	48.5
2nd	20	14.1	42.4
3rd	16	14.4	54.0
4th	15	14.4	57.5
5th	18	14.0	46.7
Ave.	17.2	14.1	49.8

5 Conventional water load calculation method

5.1 Outline

The conventional water load calculation methods described in the design standards and SHASE-S 206 are listed in Table 5. Calculations were made based on two methods in the design standards and four methods in SHASE-S 206. Calculations based on the design standards included those utilizing units derived from the number of occupants in the rooms(referred to as NOR below) and water used in each sanitary fixture (referred to as Actual Basic Unit(ABU) below) in addition to the number of people obtained by multiplying effective area by personnel density (0.2 person/m^2) (referred to as Personnel/Area(P/A) below), which is used in the personnel method; and those based on flow rates of sanitary fixtures and faucets (referred to as Conventional Basic Unit(CBU) below), which is used in the fixture method.

Table 5 Conventional water load calculation method

Calculation method		Abbr.	Possible calculated water supply demand
Facilities design criteria of MLIT[1]	Calculation method based on personnel	PM	Q_{day}
	Calculation method based on sanitary fixture	FM	Q_{max}
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	

5.2 Results

Qday and Qmax obtained from calculations for all floors, B1 to 3rd floor, 4th floor, 5th floor and 6th floor are shown in Table 6. Actual basic unit was smaller than conventional basic unit in both the personnel method and fixture method. There was a difference of 21,280 L/day in Qday for all floors in the personnel method.

Table 6 Qday and Qmax obtained from calculations

Water consumption		MLIT				SHASE-S206			
		PM		FM		WFM	NWM	PFM	SLM
		P/A	NOR	CBU	ABU				
Whole building	Qday[L/day]	38,080	16,800	21,120	16,554	-	-	-	-
	Qmax[L/min]	238	105	220	172	474	390	1,094	370
B1F～3F	Qday[L/day]	18,880	6,960	11,040	8,650	-	-	-	-
	Qmax[L/min]	118	43.6	103	90.0	280	290	702	380
4F	Qday[L/day]	6,480	3331	3,360	2,635	-	-	-	-
	Qmax[L/min]	41	20.8	35	27.4	175	210	355	257
5F	Qday[L/day]	6,480	5,330	3,360	2,635	-	-	-	-
	Qmax[L/min]	41	33.3	35	27.4	175	210	355	257
6F	Qday[L/day]	6,240	1,396	3,360	2,635	-	-	-	-
	Qmax[L/min]	39	8.7	35	27.4	175	210	355	267

6 Water load calculation based on MSWC

6.1 Outline

The simulation conditions in T-building are shown in Table 7. The number of sanitary fixtures in the building, average flush time, average flush volume, and simulation conditions such as the target number were entered to calculate water load. Also presence rate was calculated from the number of occupants and registrants in the questionnaire, and used as a simulation condition.

Table 7 Simulation conditions in T-building

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	10	3	1	3
Average water supply discharge time (second/use)	17.2	5	6	17.2	11
Distribution form phase of average water supply discharge volume	6	10	10	6	10
Average water supply discharge volume[L/min]	49.8	30	5	49.8	5
Distribution form phase of occupancy time	3	7	2	3	2
Average occupancy time (second/person)	260	37	12	110	17
Increase of usage with multiple use taken into account	1.37	1	1	1.17	1
No. of people, house, room					
Fixture usage rate (Ratio of water to hot water)	1	1	1	1	1

6.2 Method

6.2.1 Calculation Based on Personnel/Area

The number of fixtures on the target floor was entered. Then personnel/area was inputted into the target number, and a simulation was performed for all floors, B1 to 3rd floor, 4th floor, 5th floor, and 6th floor. The male-female ratio in personnel/area was set to 7:3.

6.2.2 Calculation Based on the Number of Occupants

The number of registrants on each floor of T-building in August was entered as the target number, and simulations were performed for all floors, B1 to 3rd floor, 4th floor, 5th floor, and 6th floor. The actual number of female occupants multiplied by 1.3 was used as the number of female occupants in this simulation.

6.3 Results

The results of simulations in MSWC are shown in Table 8. Except some cases, the simulation results based on personnel/area were larger than those based on the number of occupants, which confirmed that there was a difference of 8,713 L/day for all floors.

Table 8 Results of simulations in MSWC

Water consumption		P/A	NOR
Whole building	Qday[L/day]	1,8382	9,669
	Qmax[L/min]	122.3	100.3
B1F～3F	Qday[L/day]	9,402	3,740
	Qmax[L/min]	104.5	72.9
4F	Qday[L/day]	3,436	2,298
	Qmax[L/min]	68.4	65.0
5F	Qday[L/day]	3,450	3,299
	Qmax[L/min]	68.8	70.8
6F	Qday[L/day]	3,001	1,336
	Qmax[L/min]	68.5	48.1

7 Comparison of each water load calculation method

The Comparison of Qday obtained by each method is shown in Figure 4, the ratio of Qday to actual measurements in Figure 5, the comparison of Qmax obtained by each method in Figure 6, and the ratio of Qmax to actual measurements in Figure 7 (actual measurements of Qday is referred to as QAday, the ratio of Qday to QAday as Rd, actual measurements of Qmax as QAmax, and the ratio of Qmax to QAmax as Rm below). In comparison of Qday, the total figure of each floor and the figures for all floors were used in MSWC. MSWC calculations for the number of occupants were the closest to actual measurements. Compared to the conventional design standards, the personnel method based on the number of occupants and the fixture method based on actual basic unit produced figures closer to actual measurements in Qday and Qmax for all floors. However, they were smaller than actual measurements in Qmax for each floor, indicating that the personnel method and fixture method in the conventional design standards are not reliable when making calculations based on only a few sanitary fixtures installed.

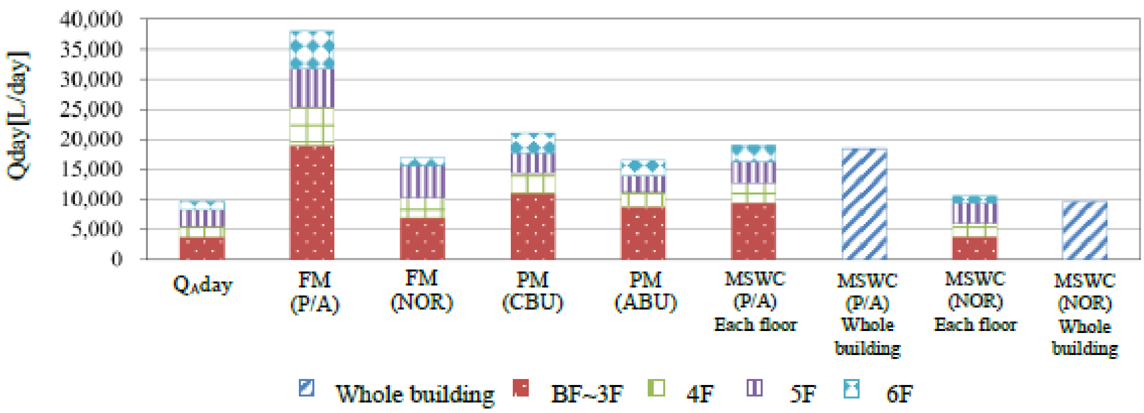

Figure 4 Comparison of Qday obtained by each method

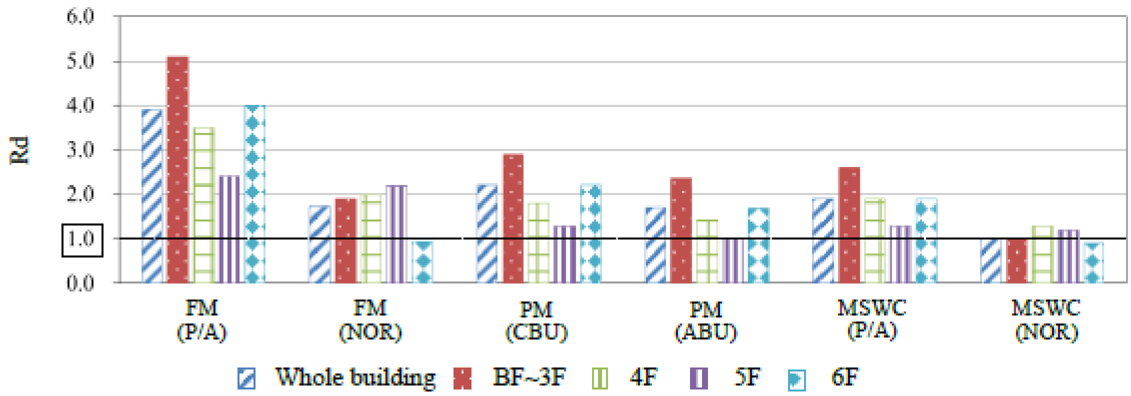

Figure 5 Ratio of Qday to actual measurements

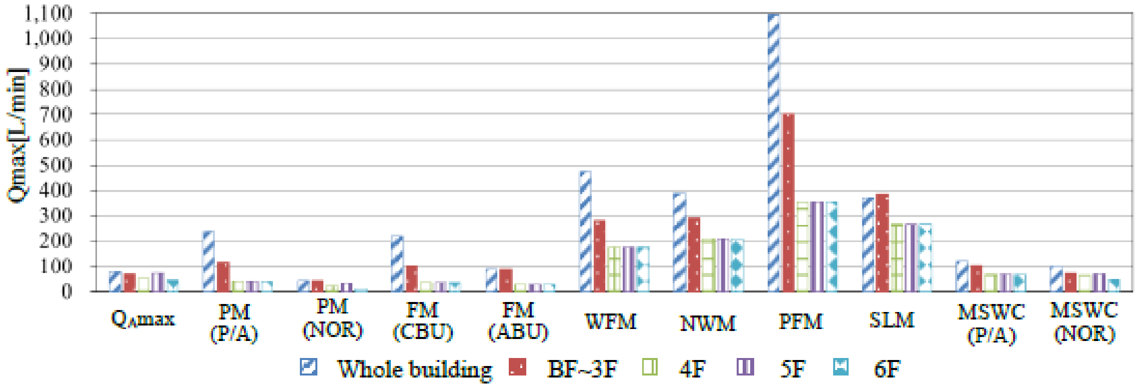

Figure 6 Comparison of Qmax obtained by each method

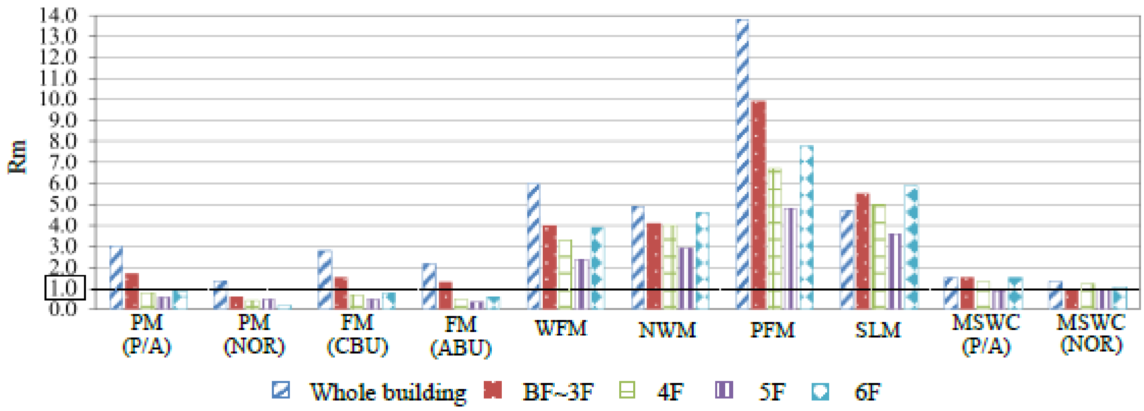

Figure 7 Ratio of Qmax to actual measurements

8 Conclusion

In this study, the accuracy of water load calculation based on the conventional method and MSWC simulation were compared and validated. The results were as follows:

The conventional water load calculation methods were found to overestimate water load except Qmax for each floor in the personnel method and fixture method. Qmax for all floors and Qday in the personnel and fixture methods using actual basic unit produced figures closer to actual measurements than the conventional methods did.

MSWC calculations for the number of occupants were the closest to actual measurements. It was confirmed that obtaining accurate number of people was important as the simulation based on personnel/area produced larger than actual measurements than the simulation based on the number of occupants.

To further refine and validate the accuracy of MSWC, our next step will be to compare the results of each water load calculation method with actual measurements based on detailed measurement of water consumption and counting of the number of people in buildings for multiple uses.

9 References

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10 Presentation of Authors

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Study on a simulation method for determining drainage characteristics and carrying performance of a water-saving toilet in relation to the horizontal drainpipe - Consideration of a calculation model using toilet paper

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Abstract

The purpose of the study is to propose a simulation method for determining the carrying performance of a water-saving toilet, and to verify the possible use of the method as a tool for aiding piping design.
At the International Symposium CIB W062 held in Brazil in 2014, a simulation method was proposed for determining fixture drainage characteristics in the horizontal drainpipe, which affect the carrying performance thereof, and in Beijing in 2015, a calculation model was proposed, enabling the prediction of carrying distances by using cylindrical waste substitutes (PVA sponges) and the matching of estimated values and actual measured values with high accuracy. The aim of this report is to extend the acquired knowledge and to verify the effectiveness of the proposed model when used under realistic conditions including the use of toilet paper as a waste substitute, and the experimental outcomes have confirmed that carrying distances can be calculated within a practically effective range.

Keywords

Toilet paper carrying simulation, waste carrying performance, water-saving toilet, horizontal drainpipe.

1 Background of the study

In recent years, technologies to reduce the burden on the environment have been actively developed as part of global warming prevention. Particularly in the field of water supply drainage and sanitary equipment and facilities, solutions for saving water with sanitary fixtures are sought, especially water-saving toilets, which have been the centre of attention worldwide. In response, the study aims to propose a simulation method for identifying fixture discharge characteristics and predicting waste carrying performance, when a toilet is installed to various horizontal drainpipe configurations, as well as to verify the effectiveness of the method. At the 40th International Symposium of CIB W062 held in Brazil in 2014, a simulation method was proposed for identifying fixture discharge characteristics in the horizontal drainpipe, which affect the waste carrying performance therein. At the 41st International Symposium of CIB W062 held in Beijing in 2015, a horizontal drainpipe simulation model was proposed for predicting waste carrying performance by using waste substitutes (PVA sponges), and the model enables the calculation of carrying performance with consideration of a realistic condition, such as the number of elbows used.

This report extends the knowledge acquired from the previous reports, thereby proposing a model for calculating a carrying distance by using toilet paper, which is an actually used material, and compares calculated values and actual measured values that are obtained when various pipe configurations are applied to the model. The report also intends to verify, on the basis of the comparison, the appropriateness of the simulation model, as well as the effectiveness thereof, as a design aid tool.

2 Experiment overview

2.1 Carrying performance experiment

Three types of JIS A 5207-approved water-saving toilets are used for the study; type I 8.0L, and type II 6.0L and 4.8L, as shown in Table 1. The toilets are each installed to a straight pipe (total pipe length L_P=18m) and a pipe with elbows equally spaced at 1m intervals (total pipe length L_P=18m (with 17 elbows)), as shown in Fig. 1, and various pipe configurations[3)] shown in Table 2, which are determined consistent with actual plans. Actual measured carrying distances and calculated carrying distances obtained by simulations are compared with each other, providing that the pipe diameter is 75A (inner diameter 78mm) and the pitch is 1/100.

Table 3 shows two types of experimental waste substitutes (toilet paper) which are used for measuring and calculating carrying distances during the carrying performance experiment. The amount of water absorbed by each waste substitute is measured immediately after the waste substitute has been drained out of the discharge port of the drainpipe, thus, still being in a soaked state.

The carrying distance of a waste substitute is measured with a tape measure, 15 seconds after the waste substitute is drained from an experimental toilet by using a full flush, from the draining core of the toilet to the tail end of the waste substitute in a stationary state.

Table 1 Discharge characteristics of experimental toilets

Normal amount of flushing water	Flushing method	Amount discharged W	Average draining time td	Ave. fixture discharge flow rate qd'	Max. fixture discharge flow rate $qmax'$
		[L]	[s]	[L/s]	[L/s]
4.8L	Washing doen (low cisten)	4.8	2.2	1.32	1.48
6.0L	Siphon jet (low cisten)	6.3	1.9	2.15	3.19
8.0L	Siphon (low cisten)	8.1	2.4	2.05	2.45

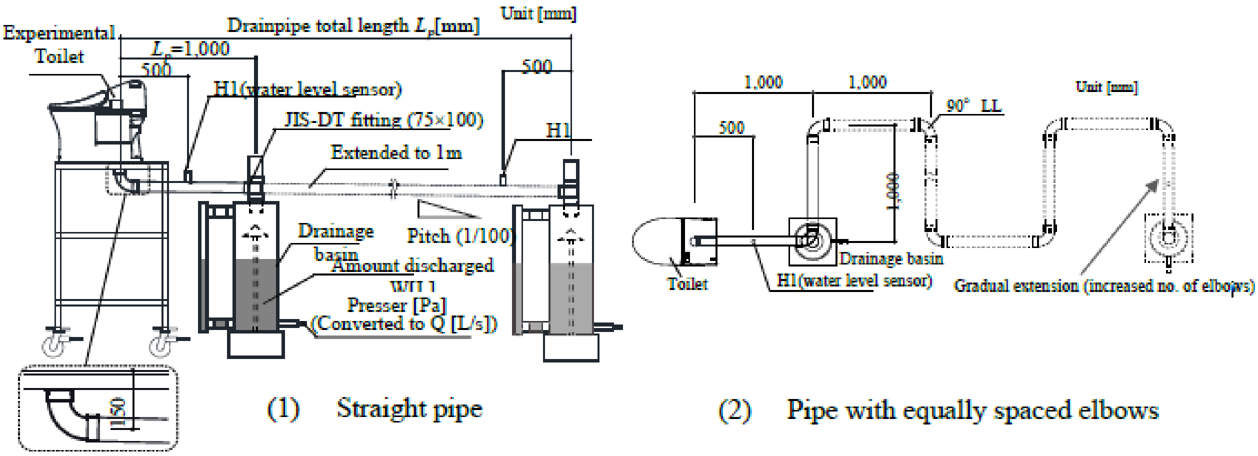
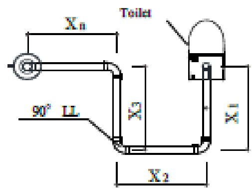


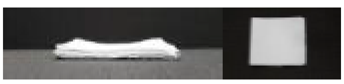
Figure 1 Experimental piping layouts

Table 2 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.

Table 3 Experimental waste substitutes

Type	Photo	Description
D		1-ply toilet paper 1m long 6 layered pieces Mass of water absorbed :168.93g Paper kinetic friction coeffient :0.02
BL†		1-ply toilet paper 0.9m long 4 layered pieces Mass of water absorbed :167.51g Paper kinetic friction coeffient :0.015

†) In accordance with Better Living standard BLE WC : 2013

2.2 Waste substitute kinetic friction coefficient μ' and the measuring method thereof

Fig. 2 and Photo 1 show how to measure the kinetic friction coefficient μ' of each

experimental waste substitute used in the study. The apparatus comprises an outer container for creating a pool of water, an inner container without a bottom sheet so as to allow a waste substitute (toilet paper) to make contact with the water surface, a piece of string for pulling the inner container, and a push pull gauge for measuring the pulling force (horizontal force F[N]). Toilet paper is placed in the inner container and the inner container is gently pulled to measure the horizontal force F and to subsequently calculate the kinetic friction coefficient μ' of the toilet paper. In the previous study, a PVA sponge soaked with plenty of water was left still before the sponge was gently pushed with a push pull gauge to measure the horizontal force. However, in the case where toilet paper soaked with water is left still after being drained down the drainpipe, the toilet paper may press some water out by its own weight, or pressing the toilet paper with a push pull gauge may distort the shape of the toilet paper, making the measurement difficult while keeping the toilet paper in a state as realistic as being drained down the drainpipe. In response, a new method for stably measuring the kinetic friction coefficient μ' of toilet paper has been formulated. In the measuring method, the horizontal force F is measured as F_0, which represents a state in which the inner container is submerged in the water without any toilet paper placed therein, and from F_0, F is measured as the total length of toilet paper in the inner container is increased from 0.5m to 7m by 0.5m at a time while the inner container is pulled horizontally. The average horizontal force F_{ave} is the average of the measured F values, as shown in Fig. 4, and F_{0ave} represents a state in which no toilet paper is placed in the inner container that is not pulled. The kinetic friction coefficient μ' of the toilet paper is calculated, using formula (2), from the value obtained by subtracting F_{0ave} from F_{ave}, and the normal force N_g[N] represented by formula (1). The mass ratio R_w of the toilet paper to the water is calculated by formula (3).
The mass of toilet paper, which is in the actual state of being discharged from the toilet and being drained along the horizontal drainpipe, is applied in the μ'-R_w relational expression to obtain μ' which can be used in the simulation.

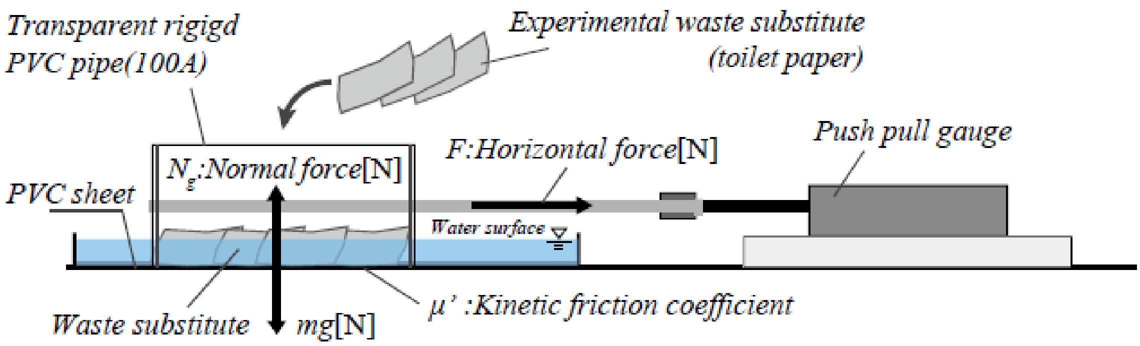


Figure 2 How to measure the kinetic friction coefficient μ'

Photo 1 Measuring the horizontal force with a push pull gauge

$$N_g = S_g \cdot V_c \cdot g \tag{1}$$

$$\mu' = \frac{F_{ave} - F_{0ave}}{N_g} \tag{2}$$

$$R_w = \frac{1.814\times10^{-3} N}{\rho_w \cdot S \cdot h_S} \tag{3}$$

Note) 1.814×10-3 indicates the weight of toilet paper [kg per meter].

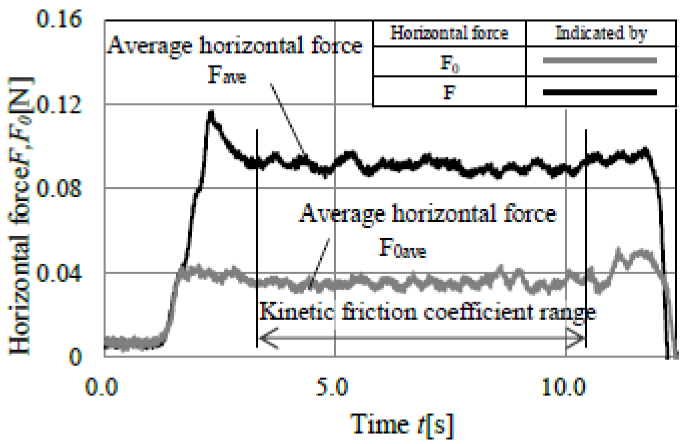


Figure 3 How to measure the kinetic friction coefficient μ'- example

3 Simulation overview

Fig. 4 illustrates a model for calculating the carrying value of a waste substitute used in the simulation. The previous study, in which PVA sponges were used as waste substitutes, proposed only a method for calculating flow resistance Fdrag[N] which is represented by formula (4) as a carrying force generated by a flow of water to a waste substitute. In this study where toilet paper is used, follow-up water catches up with toilet paper and causes a blockage, thus, creating a pool. Accordingly, the study adds impact force Fimpact[N] represented by formula (5), which is a force that is generated by follow-up water and collides against toilet paper from the upstream of the toilet paper, and pushing force Fpush[N] which is represented by formula (6) and is calculated from pooling water Vdam. Moreover, in the previous report in 2015, a method of calculating friction from gravity and buoyancy was proposed from a viewpoint that the resistance between a waste substitute and the bottom of a pipe varies according to the depth of water. Meanwhile, in the case of toilet paper soaked with water, the resistance thereof is not considered to be affected by water depth, and therefore, kinetic friction Fr[N] is represented by formula (8). Fig. 4 indicates carrying force Fw[N] represented by formula (7), which is the total of the values obtained by formulae (4), (5) and (6), and kinetic friction Fr[N] represented by formula (8).
The flow velocity in the pipe is calculated by continuity equation (9) and motion equation (10). A calculated flow velocity value and formulae (4)-(7) are used for calculating Fw, which is a force to carry toilet paper. Fr, which is kinetic friction, is then calculated by

formula (8). A speed variation in the toilet paper at each measuring time is calculated from the resultant force, and in repeated calculation, the carrying distance [m] is calculated at the time when the speed of the toilet paper Vs becomes 0m/s. Incidentally, μ' in formula (8) refers to the kinetic friction coefficient measured in 2.2.

Photo 2 shows how two different types of waste substitutes (toilet paper) are carried in the elbow section. In the bent and inclined part, the toilet paper is carried along the inclined water surface, and this is different from the case of using a PVA sponge as in the previous study. Accordingly, friction calculation is carried out with consideration of the variation of inclination created by additional centrifugal acceleration and the variation of acceleration in the normal direction in the elbow section. Fig. 5 is an illustration of a carrying calculation model.

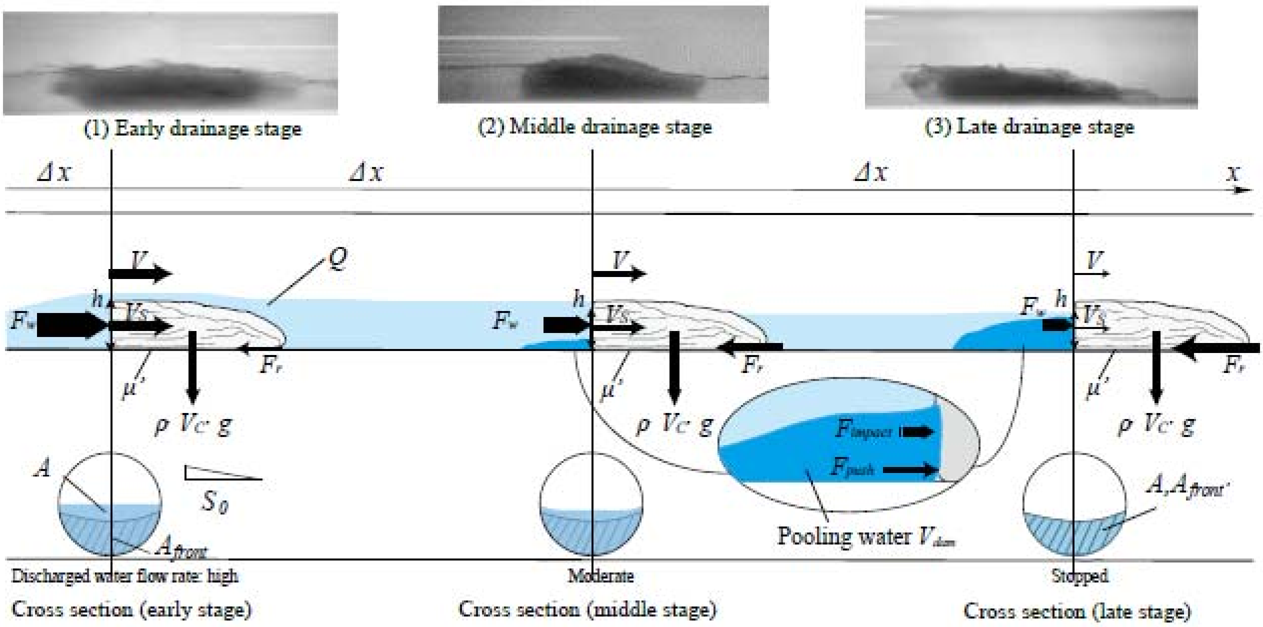


Figure 4 Toilet paper carrying calculation model

$$F_{drag} = C_d \cdot \frac{1}{2} \cdot \rho_w \cdot (V - V_s)^2 \cdot A \tag{4}$$

$$F_{impact} = \frac{1}{2} \rho_w \cdot (V - V_S)^2 \cdot A \tag{5}$$

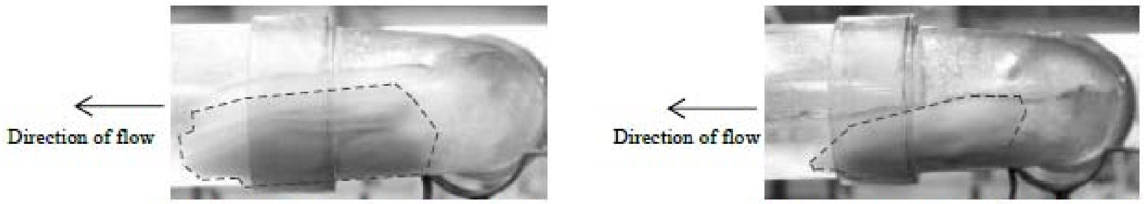
$$F_{push} = \rho_w \cdot V_{dam} \cdot g \cdot S_0 \tag{6}$$

$$F_w = F_{drag} + F_{impact} + F_{push} \tag{7}$$

$$F_r = \mu' \cdot g \cdot \rho_w \cdot V_c \cdot S_g \tag{8}$$

$$\partial A / \partial t + \partial Q / \partial x = 0 \tag{9}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A} + Agh\right) = gA\left(S_0 - \frac{n^2 V|V|}{R^{4/3}}\right) \tag{10}$$



(a) Experimental waste substitute D (b) Experimental waste substitute BL

Photo 2 The state of drained waste in the elbow

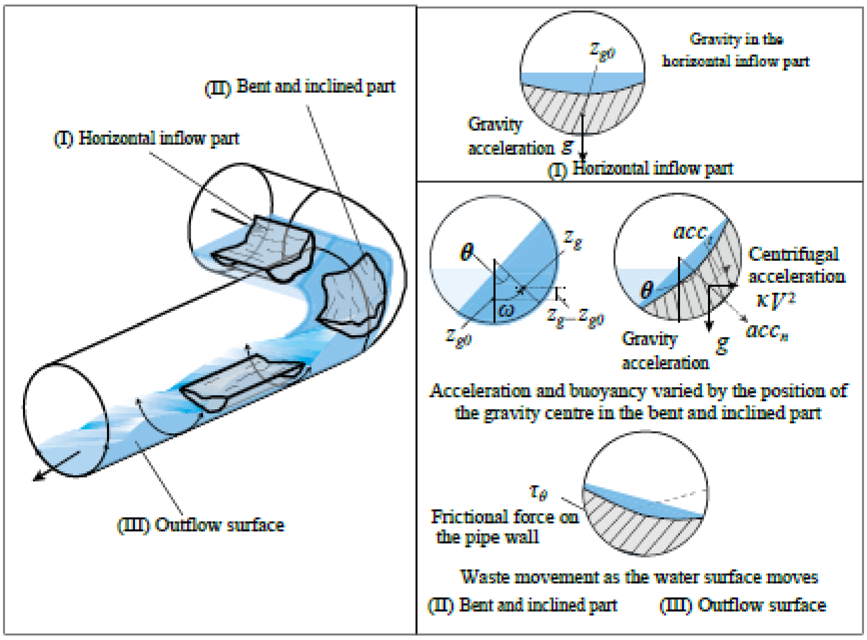


Figure 5 Toilet paper carrying model of the elbow section

[Reference symbols]

s_g : specific gravity, V_c : waste substitute volume [m^3], g : acceleration of gravity [m/s^2], m : waste substitute mass ($S_g \cdot V_c$)[kg], μ' : kinetic friction coefficient, F_{ave}, F_{pave} : average horizontal force [N], N_g : normal force ($m \cdot g$)[N], R_w : mass ratio N : toilet paper length [m] S : bottom area of container [m^2], h_s : water level in container [m], Q: discharged water flow rate [m^3/s], A: submerged area [m^2], t:time [sec], x: pipe axial length [m], h: water depth [m], R: hydraulic radius [m], S_0: pitch, V: flow velocity [m/s], n: Manning's coefficient of roughness (n=0.009)[s/m$^{1/3}$], F_w: carrying force [N], F_r: frictional force [N], C_d: resistance coefficient, ρ_w: water density [kg/m^3], V_s: waste substitute speed [m/s], A_{front}: representative area [m^2], V_{dam}: pool water amount [m^3], D:pipe diameter [m], P: wetted perimeter [m], 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$\cdot$m^2], ω : angular speed [rad/s], h_b: loss in the elbow, L_p: pipe length [m], θ: water surface angle [rad], L: angular momentum [kg$\cdot$m^2/s], r_g: gravity centre radius [m], τ_θ: wall surface frictional force

4 Results and discussion

4.1 Waste substitute kinetic friction coefficient μ'

Fig. 6 is a correlation diagram of the kinetic friction coefficient μ' and the mass ratio R_w calculated by formula (3). When the total length of a waste substitute (toilet paper) is 0.5-

1.5m, the waste substitute floats in the water, and for this reason, a total length of at least 2m was used in processing the relation formula. The diagram shows that there is a correlation between μ' and R_w although there is a slight variation. R_w was also measured by actually scooping water-soaked toilet paper out of the horizontal drainpipe after being drained from the toilet and carried along the horizontal drainpipe. The kinetic friction coefficient μ' was obtained within the variation range shown in the diagram, and in this study, calculations were carried out by using a μ' value of 0.02 for waste substitute D and a μ' value of 0.015 for waste substitute BL.

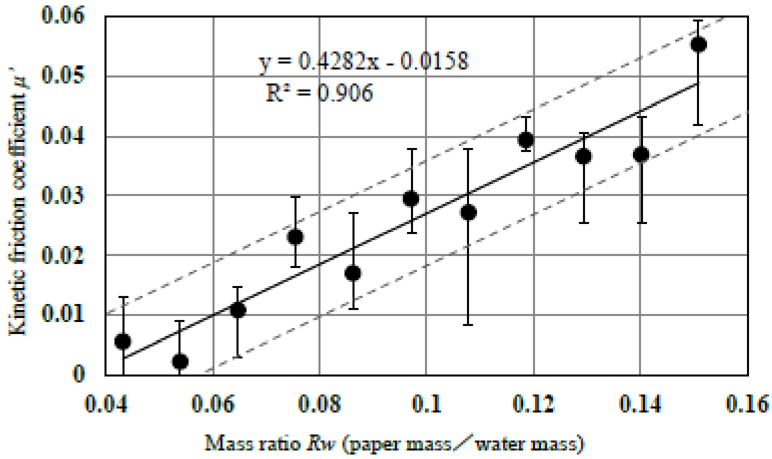
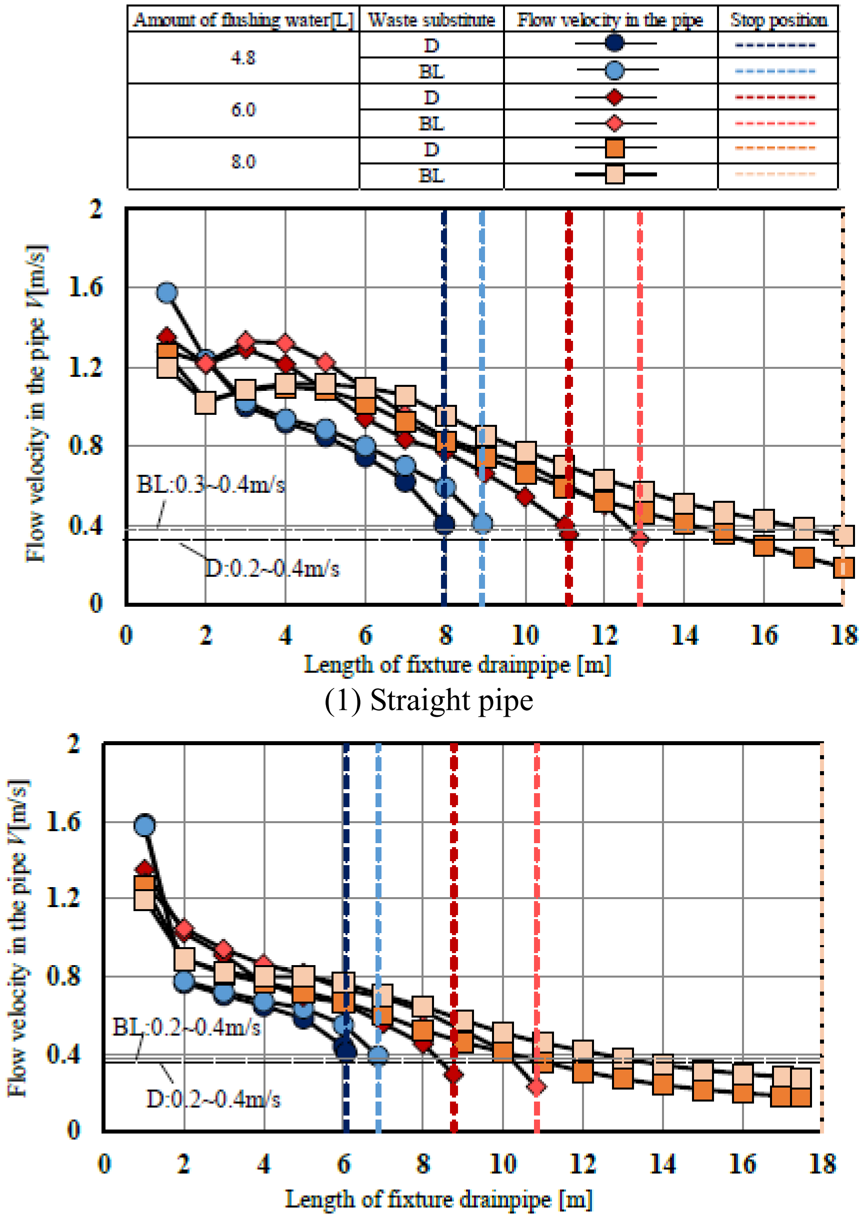


Figure 6 Correlation between mass ratio and kinetic friction coefficient

4.2 Limit flow velocity in the pipe in relation to the position of waste substitute

Fig. 7 shows the calculated value of flow velocity in the horizontal drainpipe in relation to the position of each waste substitute. In the case of the straight pipe, regardless of the amount of flushing water used, waste substitute D stopped when the flow velocity was approximately 0.3-0.4m/s (this is called 'limit flow velocity'), while waste substitute BL stopped at a limit flow velocity value of approximately 0.2-0.4m/s. in the case of the pipe with equally spaced elbows, both waste substitutes stopped at a limit flow velocity value of approximately 0.2-0.4m/s regardless of the amount of flushing water used. This means that a flow velocity value of at least 0.4m/s is required to carry toilet paper in the drainpipe, which is close to the actual draining condition.

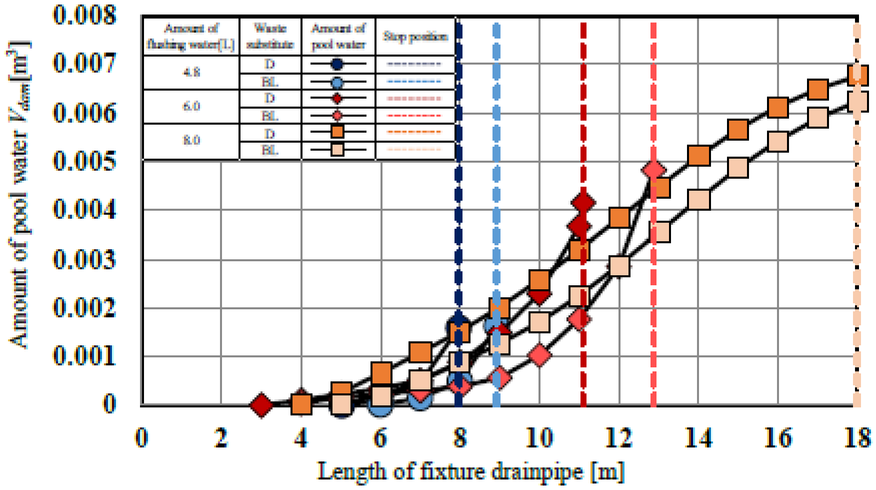


(1) Straight pipe

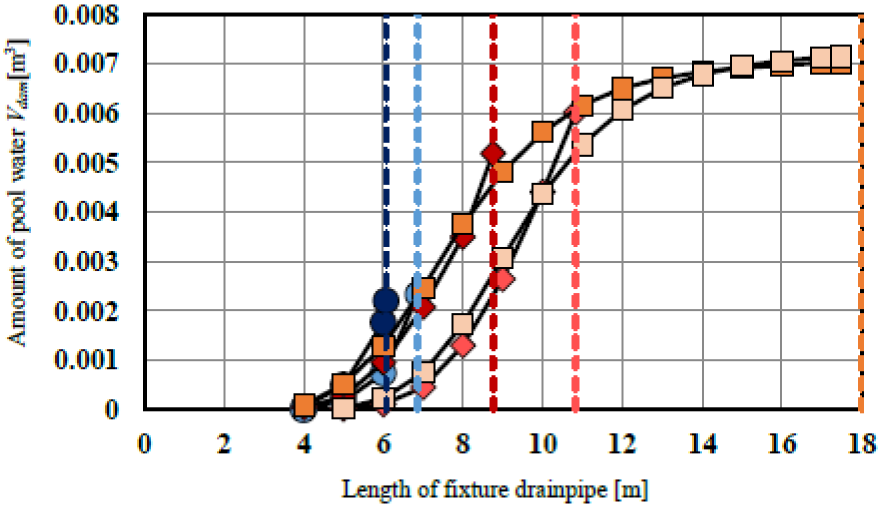
(2) Pipe with equally spaced elbows

Figure 7 Flow velocity in the pipe in relation to the position of each waste substitute

Fig. 8 shows V_{dam} values; calculated amounts of pooling water generated by the respective waste substitutes. In the case of the straight pipe, as shown in Fig. 8 (1), regardless of the type of waste substitute or the amount of flushing water, a pool of water begins to develop 4-6m along the pipe and continues to develop until the waste substitute stops. Meanwhile, in the case of the pipe with equally spaced elbows, as shown in Fig. 8 (2), when using 8.0L of flushing water, the increase of pooling water slows down as the carrying distance exceeds 10m, and the amount of pooling water becomes almost constant by the time the carrying distance exceeds 14m.



(1) Straight pipe

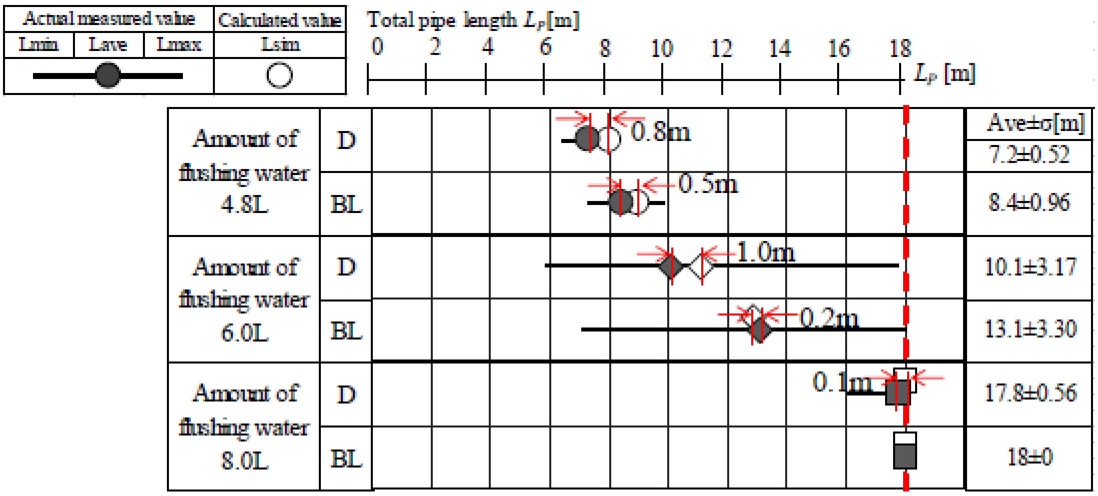


(2) Pipe with equally spaced elbows

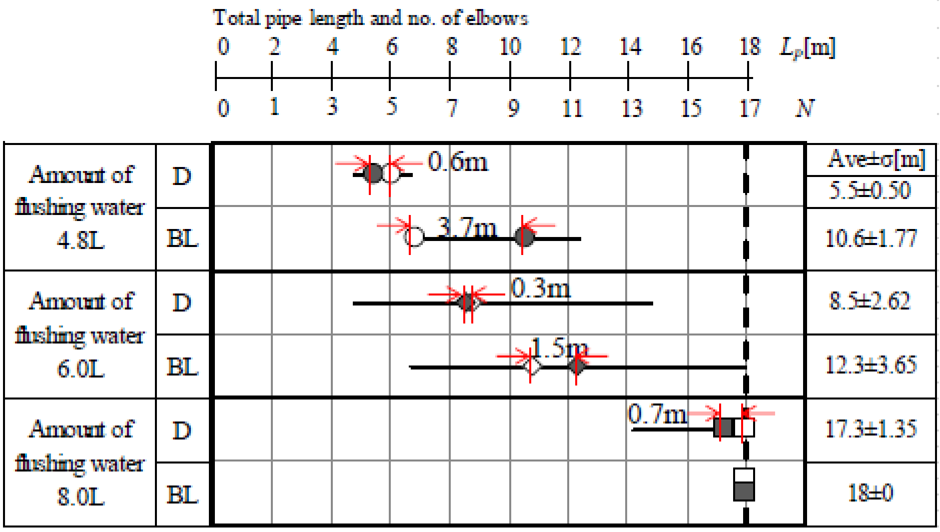
Figure 8 Amount of pool water

4.3 Comparison of carrying distances

Fig. 9 compares the actual measured and calculated carrying distances in each case of the waste substitutes. Moreover, in each case of the waste substitutes, the variation of actual measured carrying distance (between the maximum and minimum values), which was obtained by carrying out the distance measurement 10 times, and the value of 'average carrying distance ± standard deviation σ' are shown in Fig. 9. In the case of using the straight pipe with the 6.0L toilet connected thereto, as shown in Fig. 9 (1), the variation of the actual measured carrying distance of each waste substitute is quite significant. However, in the light of the average carrying distance, the actual measured value of waste substitute D is 10.1m and the calculated value thereof is 11.1m, creating an error of 1.0m. Meanwhile, the actual measured value of waste substitute BL is 13.1m and the calculated value thereof is 12.9m, creating an error of 0.2m. Accordingly, the actual measured value and the calculated value are roughly the same in both cases. Similarly, in the case of using 4.8L and 8.0L of flushing water, the error between the actual measured value and the calculated value is 1m or less in both D and BL cases. In the light of the standard deviation, the value is within the ±σ range in all patterns, except the case of using the 4.8L toilet and waste substitute D. When considering that there is no general shape of toilet paper when flowing in the drainpipe, these results indicate that very accurate predictions were made. In the case of using the pipe with equally spaced elbows, as shown in Fig. 9 (2), the difference between the actual measured and calculated carrying distances of waste substitute D is below 1m, regardless of the amount of flushing water used, which means that the actual measured and calculated carrying distances are more or less identical. However, in the case of waste substitute BL, the error between the actual measured and calculated carrying distances is 3.7m, when using 4.8L of flushing water, and 1.5m when using 6.0L of flushing water. Meanwhile, the value of the standard deviation is within the ±σ range in the cases of 6.0L and 8.0L of flushing water. This is understood that a large difference was created between the actual measured and calculated carrying distances by the state of toilet paper in relation to the condition of draining from the toilet and the shape of the toilet paper constantly changing as being drained through the elbows one by one.



(1) Straight pipe

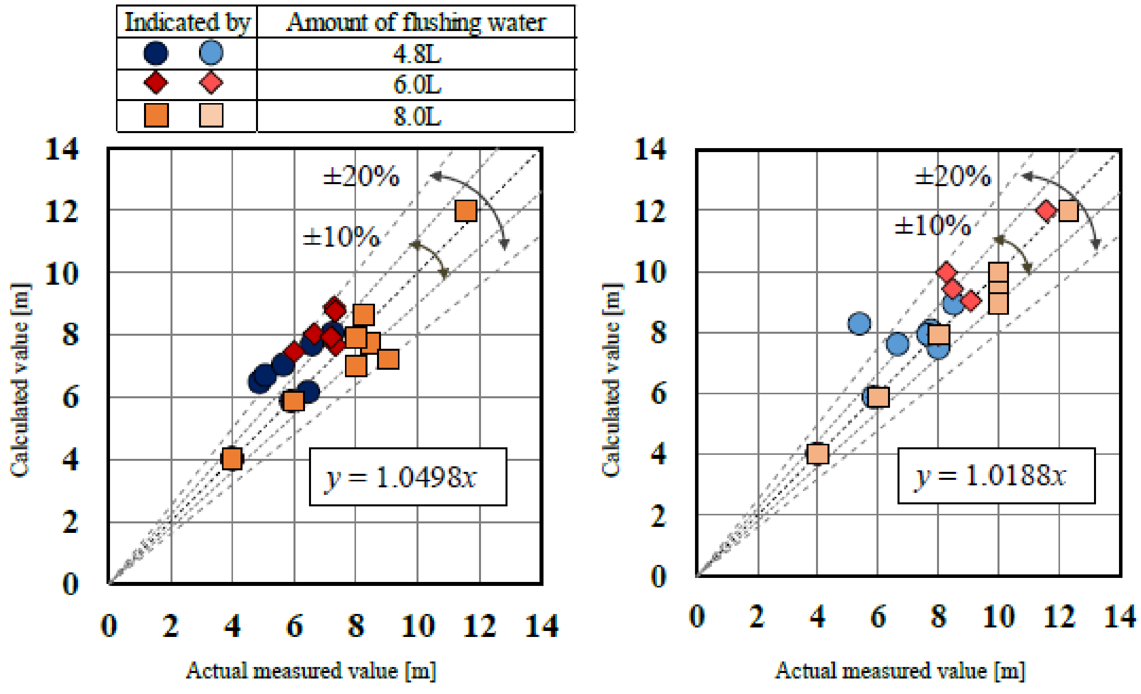


2） Pipe with equally spaced elbows

Figure 9 Comparison between actual measured and calculated waste carrying distances

❖ Actual measured value: each carrying distance was measured 10 times and the variation and average thereof were obtained.

Fig. 10 compares the actual measured distance and the calculated carrying distance in each case of the various realistically designed pipe configurations shown in Table 2. Fig. 10 (1) shows the case of waste substitute D that was drained using all the different amounts of flushing water, respectively, and similarly, Fig. 10 (2) shows the case of waste substitute BL. The error range of ±10-20% between the actual measured and calculated values is indicated with dotted lines and the results obtained using all the pipe configurations are plotted in each graph. In the case of draining waste substitute BL with 4.8L of flushing water, the error between the actual measured and calculated values is approximately 35% at most. However, with the other amounts of flushing water, the error is approximately 20% or less in both cases of waste substitutes D and BL. This error range is greater than the error range reported in the last year's report, which is 10% or less on the basis of the results of carrying distance prediction, using PVA sponges as waste substitutes. This is considered to be because the shape of toilet paper changes drastically in the elbow section of a toilet in which the water flow is at its peak, thus, causing a significant error between the actual measured and calculated values.



(1) Waste substitute D (2) Waste substitute BL

Figure 10 Comparison of carrying distances in various pipe configurations

5 Conclusions

In this report, a simulation method for predicting the carrying performance of a horizontal drainpipe was proposed, which uses toilet paper, a more realistic waste substitute than the substitute "sponge" waste used in the previous reports. Subsequently, the report has clarified the following.

1) In the straight pipe (total length 18m), the error between the actual measured and calculated carrying distances is 1.0m or less, and in the pipe with equally spaced elbows (total length 18, no. of elbows 17), the error is within the ±σ range. Therefore, it is possible to apply the carrying distance calculation with the above accuracy.
2) In the various realistically designed pipe configurations, the error between the actual measured and calculated carrying distances is approximately 20% or less Therefore, it is possible to apply the carrying distance calculation with the above accuracy.
3) The limit flow velocity required for draining toilet paper is approximately 0.2-0.4m/s, and this value is smaller than the minimum value of flow velocity in the pipe (0.6m/s) which is an index for designing SHASE-S206-compliant horizontal drainpipes.

6 Acknowledgments

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A numerical modeling of solid waste transport in main drain

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Abstract

The objective of the present work is to investigate the influence of variation of diameter and slope of a horizontal drain pipe on its self-cleaning performance. Specifically, computer simulations of solid transport inside the drain pipe of a water closet with 6 liters per flush are carried out. The fluid-solid interaction phenomena were modeled using a Lagrangean Particle-based computational fluid dynamics method, and four cases, with diameters of 78 and 100 mm and slope of 1 and 2 %, were considered. The computed results show that the dynamic can be divided in two phases. In the first, impulsive hydrodynamic force predominates and the reduction of the diameter seems to be advantageous because it increases the mean flow velocity and, consequently, the thrust on the solid. In the second phase, which predominate the forces due gravitational effect, the final velocity of the solid may be higher for large diameter in longer solid displacement. Moreover, the effects of the slope are more visible in the second phase.

Keywords

Building drainage system, waste transport, fluid-solid interaction, nonlinear hydrodynamics, simulation, particle method.

1 Introduction

Recently, the concerns about the self-cleaning performance of building drainage networks owing to the reductions of flow rate caused by adoption of water saving practices has motivated several experimental studies [1]. On the other hand, analytical or semi-empirical simplified approaches and numerical modeling on the issue have also been published [2]. However, as a highly nonlinear phenomenon that involves multiphase free-surface flows with complex fluid-solid interaction (FSI), more complete modeling for in-deep investigation of the system performance still remains a challenge. In this way, focusing on solid waste transport, the objective of this paper is to present a numerical modeling approach for the FSI problem in a drain pipe. For this purpose, a computational fluid dynamic method denominated Moving Particle Semi-implicit (MPS) is adopted herein. MPS method is a fully Lagrangian meshfree particle-based approach. Proposed by Koshizuka *et al.* [3] for the simulation of incompressible flow with free surface, it solves the governing equations of continuum by replacing the differential operators with algebraic operators derived from a particle interaction model based on a weight function. The method is very effective for the simulation of the flows that involve large deformation of free-surface, fragmentation and merging, moving or deformable solids boundaries, multi-body, multi-phase and multi-physics problems.

In the previous works of the present research, MPS has been used to investigate the transient flows inside a horizontal w.c. drain pipe and the effects of the diameter and slope of the pipe [4], as well as the drainage from a bathroom, located at the second floor, with a water closet, a shower and a wash basin considering typical flow rates of the appliances [5]. After that, a simplified modeling, in which sludge is considered as denser and more viscous fluid so that mixable multi-component flow model is adopted, has been carried out to assess the effects of the geometry of the elbow and slope at a stack's base on the waste transport performance [6].

In the present study, a further study on the complex FSI problem involving solid wastes is performed. For sake of simplicity, the solid wastes are assumed as rigid bodies with free motion and they are taken into account as a cluster of particles of which the relative velocities among them are zero. By integrating hydrodynamic loads on the surface of the solid, the motions of the bodies are determined. Beside the solid fluid interaction, a numerical model for solid-solid contact is also applied. Finally, considering the relatively low flow rate, the air entrapped inside the pipes and the pressure variation due to the entrapment is neglected. As cases of study of solid transport inside the drain pipe of a 6 liters water closet, a homogeneous cylindrical solid is considered and transient flows inside a horizontal pipe with 90^{o} elbows in its upstream are investigated. The effects of the diameter and slope of the horizontal pipe are also analyzed. As a result of the study, motion behaviors and displacements of the solid are obtained, which provides insights on the hydrodynamics of the waste solid transport.

2 Numerical method

2.1 Moving Particle Semi-implicit

Moving Particle Semi-implicit (MPS) method is a fully Lagrangian meshfree particle-based approach for the simulation of incompressible flow with free surface. It solves the governing equations of continuum by replacing the differential operators with algebraic

operators derived from a particle interaction model based on a weight function.
To solve the incompressible viscous flow, a semi-implicit algorithm is used. At first, predictions of the particle's velocity and position are carried out explicitly by using viscosity and external forces terms of the momentum conservation. The pressure of all particles is calculated by the Poisson equation for the pressure, which is solved implicitly. The RHS term of the Poisson equation is proportional to the deviation of particle number density, which is a parameter that is proportional to the density of the fluid in the vicinity of the particle. Finally, the velocity of the particles is updated by using the pressure gradient term of the momentum conservation and the new positions of the particles are obtained. More detailed description of the MPS method, including the numerical treatment of the boundary conditions, can be found in [3] and in the previous works of the authors [4,5,6].

2.2 Free solid modeling

For the numerical modeling of solids, three types are considered: fixed solid, solid with forced motion and a free floating solid. The velocity of the fixed and the forced motion solids are imposed as Dirichlet boundary conditions. On the other hand, the motion of the free floating solid are calculated based on forces and moments obtained from the integration of the pressure on the solid surface, i.e., the pressure of the wall particles. In the present study, based on Sueyoshi *et al.* [7], the center of gravity, the mass and the moment of inertia of each free floating solid are input parameters.

2.3 Collision among solids

The collision between two different rigid bodies is identified by monitoring the distance between their wall particles. When the distance between two wall particles, belonging to different solids is smaller than 1.225 l_o, where l_o is the initial distance between particles, collision is computed. The solid repulsion force resulting from the collision is then calculated by summing all the individual components of the force body from each particle. The individual components of the repulsion force are calculated based on a damped harmonic oscillator with linear spring force and damping force proportional to the relative velocity between colliding particles [8].

2.4 Validation of the numerical method

Regarding the validation of the numerical method, its ability to model the dynamics of the transient flow with surface was already been shown in the previous works [4,5,6]. The modeling free floating solids were also extensively validated in other studies such as Tsukamoto *et al.* [9].

3 Descriptions of the case

The configuration of the case consists of a horizontal pipe, which represents a drain pipe of a 6 liters water closet, with 2.5 meters in length. The drain pipe has a 90^o elbow in its upstream end and open downstream end, as shown in Figure 1.

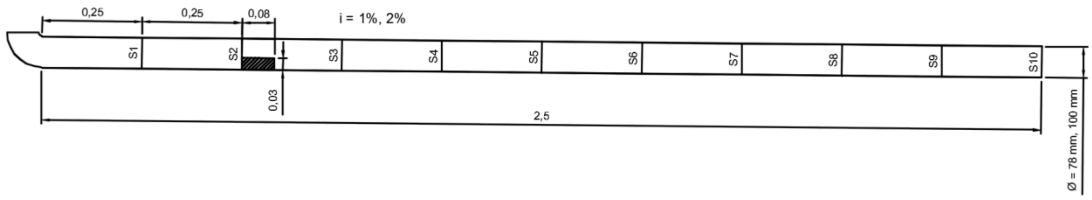


Figure 1 Configuration of the horizontal drain pipe of a 6 liters water closet

For sake of simplicity, the solid waste was modeled as a homogeneous circular cylinder. The cylindrical solid has 0.03 m in diameter and 0.082 m in length, and it is initially in rest inside the pipe with its axis parallel to the axis of the pipe. As the initial conditions for the simulation, the pipe is dry and cylindrical solid is located with its upstream face 0.5 m from the upstream section of the horizontal pipe. The density of the fluid is 1000 kg/m^{3}1010 kg/m^3. The mass of the cylindrical solid is 0.059 kg, homogeneously distributed with density equals to 1010 kg/m^3. As shown in Table 1, four conditions resulting from the combination of two diameters (78 mm and 100 mm) and two slopes (1% and 2%) have been considered in the study.

Table 1 Properties of the sludge

Case	Diameter (mm)	Slope (%)
TS10001	100	1
TS10002	100	2
TS07801	78	1
TS07802	78	2

Figure 2 shows the flow rate discharge as a function of time of the 6 liters water closet provided by Cheng *et al.* [4] and also used and [5].

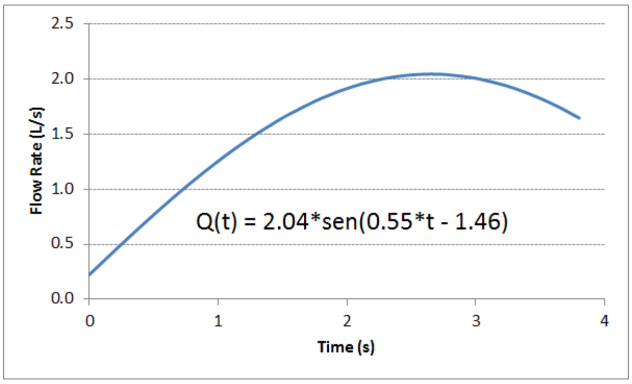


Figure 2 Water closet flush profile [4]

For all the cases simulated, the initial distance between particles (l_0) is 0.003 m, which leads to models with about 532 K particles for 78 mm diameter and 620 K particles for 100 mm diameter. The interaction between the solid and the pipe wall was models as a spring-mass system (harmonic oscillation without damping) with spring constant of 3809.8 N/m. A numerical friction coefficient of 0.22 Ns/m was also introduced to simulate the dynamic friction coefficient of 0.26. The time step adopted was 3 x 10^{-4} s, which leads to processing time of about 15 hours in the cases with 78 mm diameter and 16 hours for the cases with 100 mm diameter, for 5 seconds of simulation.

4 Results and discussions

Figure 3 gives a sequence of images obtained from the computational simulations of the solid transport by a discharge of 6 liters. In order to make easy the visualization, only section views of the initial part of the horizontal pipe and the dynamics of the first few seconds are shown. For the comparison of the results, some instants of time of the cases TS07801 and TS10001 are given, respectively, in the left and right columns of Figure 3.

Case TS07801 Case TS10001

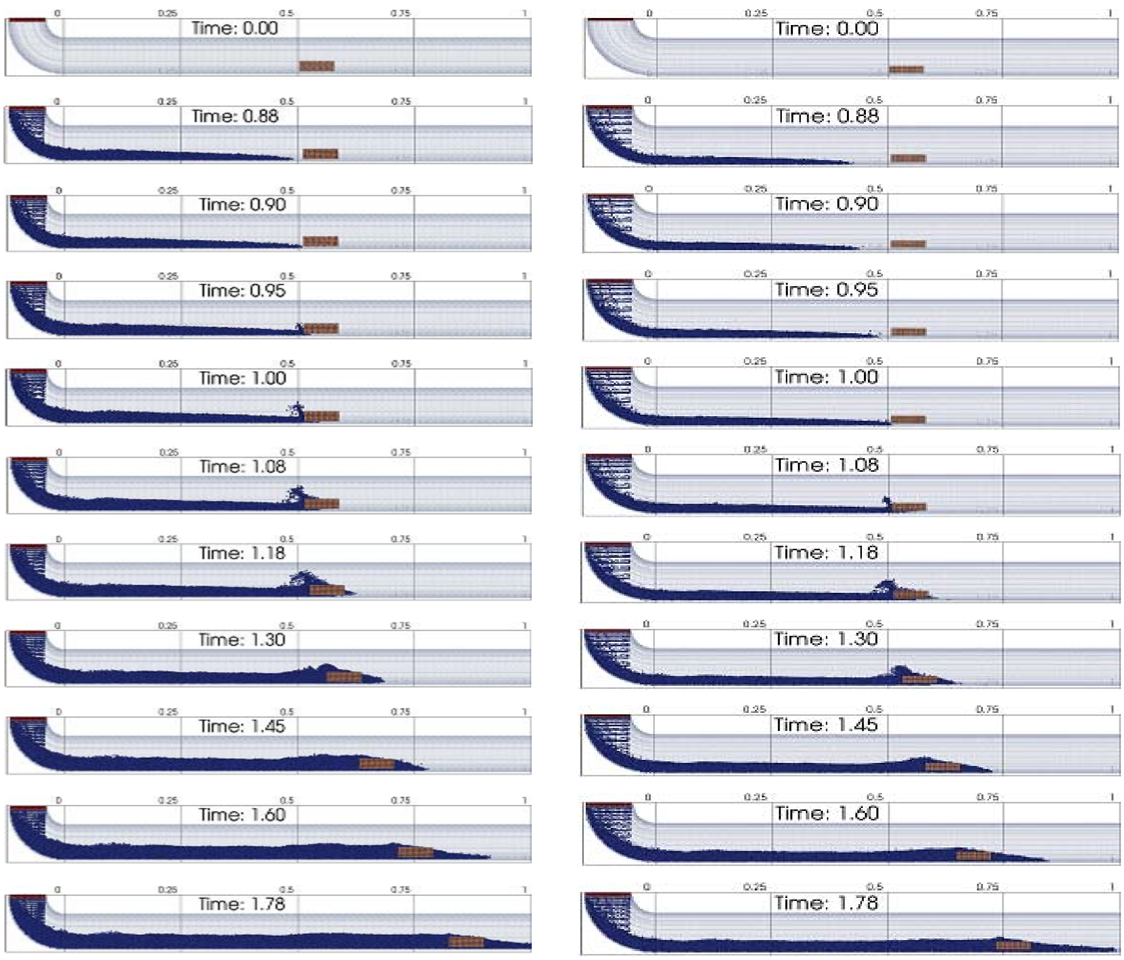


Figure 3 Sequence of images obtained from the simulations of the cases T07801 (left column) and T10001 (right column)

As mentioned before, at instant *t*=0.00 s, when the flush starts, the upstream face of the solid is 0.5 m from the initial section of the horizontal pipe. As the diameter of TS07801 is smaller than that of TS10001, for the same incoming flow rate, its average flow velocity is higher. Thus, while the incoming flow hits the solid around *t*=0.90 s in TS07801, in the case of TS10001 this occurs after *t*=0.95 s. In addition to this, the higher flow velocity of the case TS07801 also produced a larger hydrodynamic load on the solid, as a consequence, at least in the initial instants for the impact shown in Figure 3, a faster displacement of the solid in relation to TS10001 is observed. In other words, the computed results show that the reduction of diameter from 100 mm to 78 mm has a positive effect by increasing the flow velocity and, as a consequence, generating a large thrust on the solid so that it displaced faster in the initial phase of the solid transportation process.

From Figure 3, it is possible to observe that the initial phase, in which the impulsive hydrodynamic force is predominant, occurs in a relatively short interval, and it is associated to violent hydrodynamic impact and large deformation of the free surface. Within this interval, whose duration is about 0.5 to 0.7 s, the solid starts the motion. According to Figure 3, after the instant *t*=1.60 s, the geometry of the free surface remained practically unchanged, with the water level in upstream face of the solid higher than the downstream face. In this way, together with the hydrodynamic loads due to relative velocity between the flow and the solid, the thrust acting on the solid may have a significant contribution from the difference of the hydrostatic pressure between upstream and downstream faces of the solid.

The average flow velocities of the case TS07801 computed in the 10 sections S1 to S10 equally spaced in 0.25 m are shown in Figure 4. The time histories of the average velocities in the sections show a characteristic behavior of the fluid flow: after reaching a section, the flow velocity remains practically constant until the peak of flush passes completely trough the sections, when the velocity reduces remarkably, followed by a smooth decay to zero. The duration of the plateau is longer in the first section S1 and decreases gradually for subsequent sections. The energy loss in the fluid can also be observed by gradual reduction of the average velocity along the pipe, in the subsequent sections. In the case TS07801, the average velocity in the region of the plateau is about 0.93 to 0.62 m/s. On the other hand, the case TS10001, which shows the same behavior, the average velocity in the region of the plateau ranges from 0.72 to 0.58 m/s.

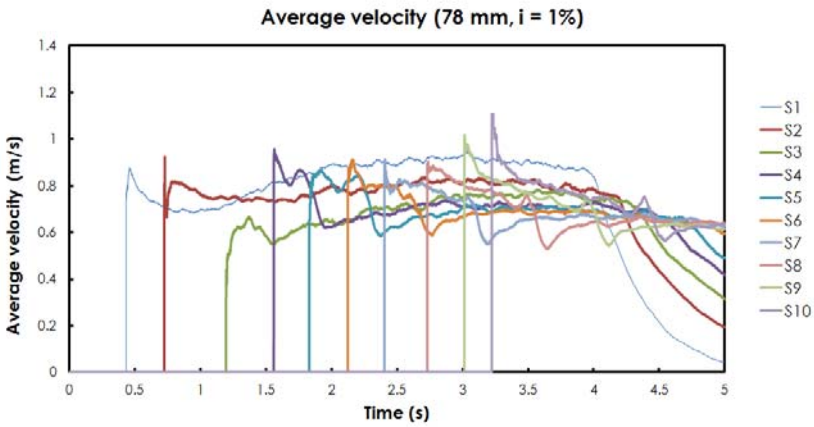


Figure 4 Computed time history of the average mean velocities in the sections of the pipe: diameter 78 mm, slope 1%

The computed positions of the solid as a function of time for the four cases computed in the present study are shown in Figure 5. From comparison among the results, it is clear that the motion patterns of the solid are significantly different for the pipes of 78 mm and 100 mm. For cases with 78 mm diameter (TS07801 and TS07802), in the initial phase of the solid motion, between 0.9 to 1.5 s, where the impulsive load is predominant, the solid starts to move and is accelerated to an almost constant velocity around 0.6 m/s. Then

from *t*=2.0 s, the effects of the pipe slope can be visualized. The motion of the solid becomes slightly faster when the slope is increased from 1% to 2%. This small but significant difference in velocity shows the effects of the gravitational force on the motion of the solid after the initial phase of impulsive loads. As a result, by *t*=4.5 s, the solid in the case TS07802, with 2% slope, reaches the downstream end of the pipe of 2.5 m in length shortly before the TS07801 case (1% slope).
On the other hand, for the cases with 100 mm diameter (TS10001 and TS10002), the curves of the position as function of time can be easily divided in two nearly linear segments: in the first, up to *t*=2.70 s, the gradient of the curve, i.e., the solid velocity, is slightly lower than that computed for 78 mm diameter. Nevertheless, by t=2.70 s, a small increase of the solid velocity occurs, and surpasses that computed for 78 mm diameter, so that the solid reaches earlier the downstream end of the pipe. Regarding the gravitational force due the variation of pipe slope, its effect is quite similar to the former two cases except they can be visualized in early stage of the solid motion.

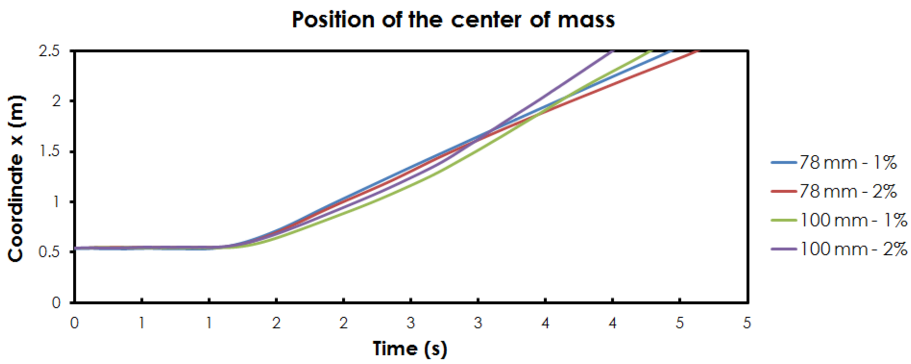
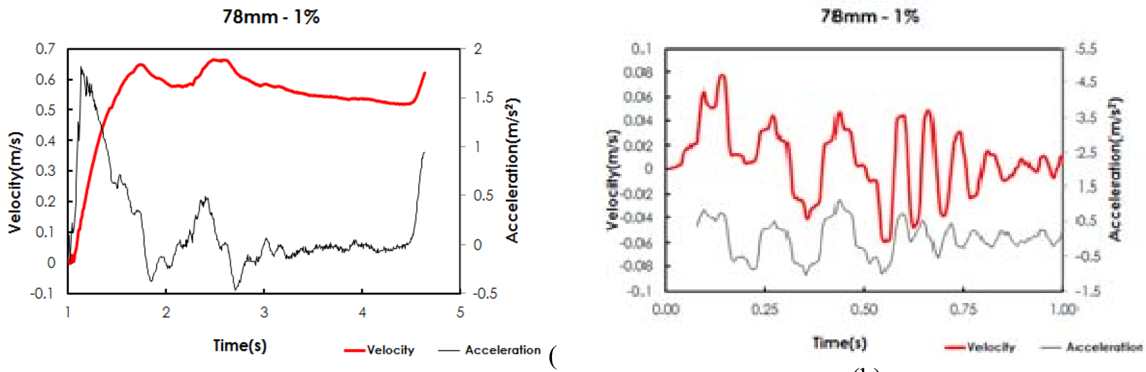


Figure 5 Computed time history of the positions of the cylindrical solid

This remarkable difference in the motion pattern due to the variation of the diameter can be explained by the contribution of several loads actuating on the solid. In the initial phase, the pipe with smaller diameter provides higher flow velocity, which results in larger impulsive thrust on the solid. However, this initial advantage is vanished later when the transient impulsive load ceases and other loads, much smaller in magnitude but permanents, such as gravitational force or friction between the solid and pipe wall, become dominants. Thus, due to lower energy loss by friction and other effects, the final velocity in larger diameter pipe may become higher for large displacements of the solid.
The time histories of the velocity and acceleration for the case TS07801 presented in Figure 6 provides a good insight about the complex hydrodynamic process of the solid transport. From the curve of the acceleration in longitudinal direction shown in Figure 6 (a), the abrupt rise up of the thrust due to the violent hydrodynamic impact reaches a peak and decays quickly to approximately zero at about *t*=2.00 s. After that, oscillations of the force associated to the dynamic variation of the relative velocity between the fluid and the solid marks the transition from impulsive to steady motion dominated by gravitational effects. Figure 6 (b) shows the time histories of velocity and accelerations of the solid in vertical direction. According to the computed results, the motion of the solid in vertical direction is negligible because in this case the density of the solid id slightly higher than the fluid density.



a) (b)

Figure 6 Computed time history of the velocity (red line) and acceleration (black line) of the cylindrical solid in the longitudinal direction of the pipe (a) and in the vertical direction (b). Case TS07801, diameter 78 mm and slope 1%

Figure 7 illustrates the computed pressure profiles on both upstream and downstream faces of the solid in the case T07801. Figure 7 (a) shows the compute result at *t*=1.00 when the impact just started, and Figure 7 (b) shows the result at *t*=1.85 s. It is important to point out that in both moments the pressure profiles are not linear, which means the presence of the hydrodynamic component. Thus, mainly for the first phase dominated by transient hydrodynamic impact loads, prediction using the simple assumption that consider only difference of the hydrostatic head between upstream and downstream faces of the solid to calculate the thrust will lead to questionable results.

(a) (b)

Figure 7 Computed pressure profile on the upstream and downstream faces of the solid at *t*=1.00 s (a) and *t*=1.85 s (b). Case TS07801, diameter 78 mm and slope 1%

5 Concluding remarks

In the present work, the influences of the variation in diameter and slope of a drain pipe on its solid waste transport performance was investigated through a particle-based numerical approach. Four cases of transport of the solid inside a drain pipe of a water closet with 6 liters flush considering pipe diameter of 78 mm and 100 mm and slope of 1% and 2% were taken into account. As a result, the computed results provide a very good insight about the complex FSI hydrodynamic process, which, for the duration considered in the present study, can be divided in two phases:

- The first one is dominated by very high impulsive hydrodynamic loads of relatively short duration when the incoming wave front hits the solid. Starting from the rest, the solid is suddenly accelerated in very short interval and very large free surface deformation may occur. As for a fixed flow rate the reduction of diameter increases the mean flow velocity, in this initial phase the reduction of diameter is advantageous because it will provide higher thrust for the solid.

- In the second phase, when the impulsive load decreased to nearly zero, the effects related to gravity, such as waves, hydrostatic heads, weight, friction between the solid and the pipe wall become relevant. According to the computed results, for longer distance displacements, the solid may reach higher final velocity in case of pipes with larger diameter. Similarly, as additional thrust due to gravity is provided by pipes with larger slope, slope effects are more relevant in the second phase.

As next step, more complex solid geometry, effects of the solid density and other solid proprieties should be considered, as well as the effects of the entrapping air.

6 Acknowledgments

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Application of building drainage solid transport modelling to village level: A case study of Marikuppam, India

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Abstract

Sanitation provision is a fundamental human need for survival. The use of engineering design to optimize sanitation provision appropriate to the means and resources available forms the basis of this work. Up-scaling is also an issue, with 2.6 billion people in the world without access to adequate sanitation and nearly 1 billion practicing open defecation, solutions need to provide appropriate means to remove waste at low cost and in a dignified and safe manner. Invariably this refers to sanitation provision in developing countries where poor infrastructure and inadequate social capital makes provision challenging.
The research presented in this paper seeks to use recognized methods associated traditionally with building drainage to expand its reach to a village level. A case study of a real village, Marikuppam in India, is used to illustrate and test the overall hypothesis.
Mixed methodologies were used to design, optimize and assess failure risk for the proposed installation. A steady state simplified sewerage model was used to do the initial design which was further modelling in DRAINET, a method of characteristics based numerical model traditionally used for above-ground building drainage systems. The input data for DRAINET was obtained from a detailed survey carried out on site, which included usage pattern and focus group data. A total of 106 properties were included in the design and the survey. Test runs were carried out for the whole site over a 12 hour period. All main pipe runs were 100mm and set to a gradient of 1:100.
Results from DRAINET modelling confirmed that the design operated during the day with little difficulty, however, there were areas of concern at the extremities of the site, confirming the importance of adjoining flows and the accumulation of water flow required to maintain drain self-cleansing velocity.

Keywords

Settlements, DRAINET, simplified sewerage, India, design.

1 Introduction

The UN sustainable development goals identify Water and Sanitation as essential elements to human development. Goal 6 of the UN Sustainable Development Goals (SDG) states the aspiration to 'ensure adequate water and sanitation for all'. The work specifically addresses the provision of improved sanitation'. The agreed target for UN SDG goal 6 states: 'By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations. The research described in this paper begins to explore the relationship between village level small bore piped sanitation systems and building drainage systems.

A mixed methodology approach involving steady state design, comprehensive usage data collection and numerical modelling has ensured that design of a simplified sewerage system is both real and relevant. Ultimately, the paper shows that a building drainage system model DRAINET can be modified and applied to up-scaling on-site sanitation provision to the village level in developing countries.

2 Background

Marikuppam Telugu Line is a community of 106 households in Kolar Gold Fields (KGF), Karnataka State, south India. (Figure 1) Gold was mined in the area for 2000 years. During the British Colonial period deep-shaft mining was introduced, increasing the extraction of gold ore. Mining is no longer economic and the mines have been abandoned, but many thousands of former mine workers still live in KGF. Most of them are from the Dalit (untouchable) communities. Among them are a Telugu speaking community who came to KGF from Andhra Pradesh during the colonial period. This community was assigned the job of night-soil collection and cesspit cleaning by hand, known as manual scavenging. In traditional Hindu culture, human excreta is considered to be the most 'defiling' of substances. Anyone doing tasks associated with excrement are considered spiritually and socially 'defiled' and are ostracised by others, even by those from other Dalit communities. This is the case for those from Marikuppam Telegu Line, the practice being so stigmatised that those who do it keep their occupation hidden, even from their families.


Figure 1 Satellite Image of Marikuppam Teluga Line and its location in India

In 1991 a group from Markuppam established ‘Safai Karmachari Andolan’ (SKA) *(Sanitation Workers Movement)*, now a nation-wide movement, to end the ‘inhuman practice’ of manual scavenging. With Mr Bezwada Wilson as its National Convenor enormous progress has been made in raising awareness of manual scavenging, nationally. The group has been at the forefront in securing the enactment of legislation that prohibits the practice of manual scavenging, and yet it continues.
A major step for the eradication of manual scavenging would be the introduction of low-cost sanitation technology, such as ‘simplified sewerage’ that does not require the manual emptying of filled cess pits or septic tanks – i.e. ‘dignified sanitation.
Marikuppam was identified as a pilot community for design of an appropriate sanitation system. Every family in the Marikuppam Telugu Line has been involved with manual scavenging, many still are, and 70% of households have no sanitation facilities. The communal latrine block, requires water for flushing, but there is no water available nearby. Consequently, the toilets are filled with faeces. Occasionally, water is supplied by tanker and manual scavengers are employed to clean the toilets, the contents being flushed into an open ditch beside a footpath. Many people prefer to practice open defaecation in the nearby bushes instead.

3 Methodology

This research employed a mixture of methodologies to design and optimise the simplified sewerage network. Methodologies ranged from computer design of network dimensions using an open access programme developed by Mara and Sleigh [1] to extensive water and sanitation usage survey data from the 106 households in the community, and numerical modelling of the entire site using a modified version of DRAINET [2]. A proposed design and optimisation methodology for a village-wide simplified sewerage system under ultra-low water usage criteria was developed.

3.1 On-site water usage data survey

Having accurate data concerning water usage and sanitation practices allows for the system to be modelled as exactly as possible. Through contacts in the community, a list of data requirements was sent. These were as follows:

- The availability of water – how much water each household has access to;
- Water usage – including quantities and patterns of water consumption;
- The number of people living in each household;
- The average diet of residents;
- Patterns of urination and defecation;
- Methods of anal cleansing.

3.1.1 Household survey

A survey was carried out to establish the number of occupants in each household, split by gender and age band. The entire population of 106 households was surveyed. Additional data was collected concerning the occupation of the householder, the highest level of education attained, whether they had an electricity connection and their sanitation facilities. The raw data collected can be found in Appendix B.

3.1.2 Water use survey

From the population, 15 households were randomly selected for a survey on water usage – 15 is the number recommended by Feuerstein [3] as a representative sample of 100 households. Four households were added to the survey because of their particular situations: one household with 12 members near the community toilet block, one where a disabled occupant had particular toilet needs, one which was the cleanest house observed, and one with a large number of livestock. In all households but one, only women were interviewed.

Households were asked what they used water for and how much water, measured in 18-litre pots, that they used for each task. Patterns of water use were also established by asking occupants when in the day that they would perform each activity. The day was divided into three-hour blocks to aid with the collection and reporting of the data. The raw data from this survey can be found in Appendix C.

3.1.3 Focus group discussions

Focus group discussions were also conducted to gain qualitative data about the general state of sanitation and health. Here the researchers asked about diet, sanitation practices, any health problems which residents had, menstrual hygiene and the disposal of infant excreta. Some additional information was gathered through general comments which survey participants made about sanitation and practices in the area. The questions asked and raw data collected can be found in Appendix D.

3.2 Steady state design

The design followed Mara et al steady state system approach based on maintaining tractive tension in the pipe to effect self-cleansing velocity. The layout is shown in Figure 2.

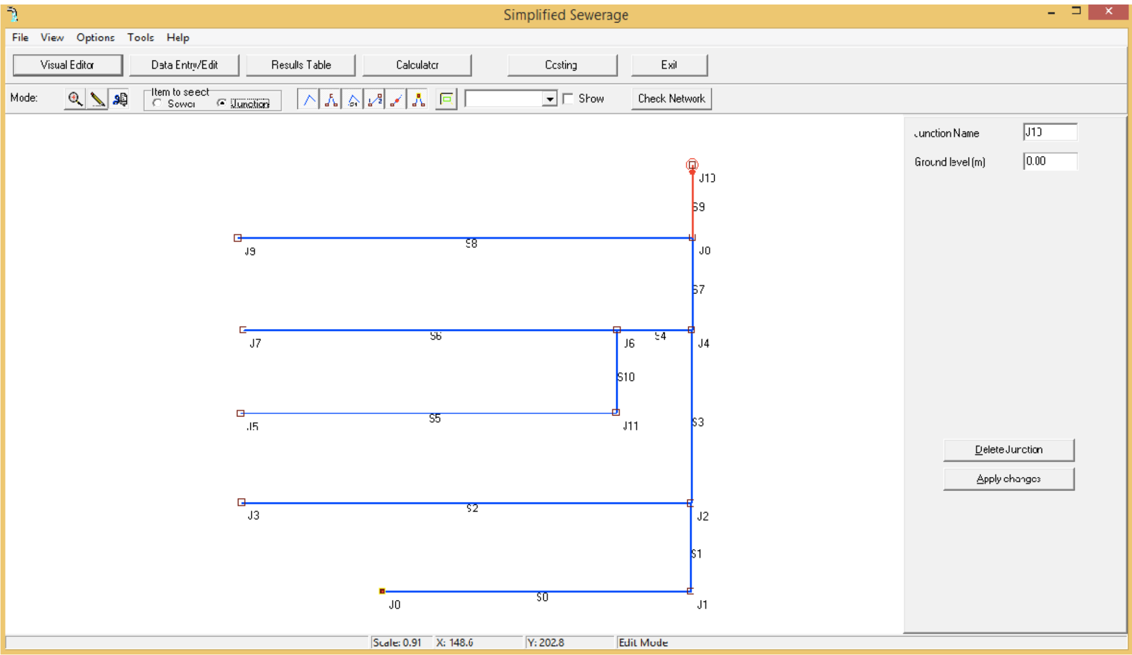

Figure 2 Steady state design layout

One limitation of using this methodology to determine parameters for the system is that the software is intended for use in situations where the level of detail known about the water usage is much lower than in this installation – the only input parameters related to water usage are the average water consumption per capita and the return rate.

3.3 Numerical modelling

In order to assess the risk of blockages occurring in the proposed system, the modelling software DAINET was used which was based on a flow velocity model developed at Heriot-Watt University [2] and modified for ultra-low water usage by Gormley [4]. The model uses the relationship between the velocity of the solid and the flow velocity [2] DRAINET uses the method of characteristics to model unsteady free surface flows by solving Saint Venant equations – a method first applied to small-diameter pipes by Swaffield and Galowin [2].

3.3.1 House type profiles

Gormley and Dickenson [5] detail a methodology for modelling large, complex systems using DRAINET. House types are divided into different 'scenarios', and these are modelled separately, then connected to represent the estate. A similar process has been followed to develop the methodology for modelling this system.

3.3.2 Deciding usage types

The population contains a wide range of household sizes – from one single occupant to a family of seventeen. It would be unrealistic to attempt to create a separate usage profile for each household size, and so five scenarios were chosen to represent a variety of households. Sizes were chosen based on the water use data available and the number of households of each size in the population. These were:

- House type A: 1 or 2 occupants
- House type B: 3 occupants
- House type C: 4, 5 or 6 occupants
- House type D: 7, 8 or 9 occupants
- House type E: 10 to 17 occupants

Offset versions of these profiles were created to reduce artificial inflation of the peak flow rates – the number of offset profiles was determined based on the number of households of that type in the population.

3.3.3 Water usage – quantities

The results from the water use survey were then divided up by which house type the households interviewed fell into. Within each house type, a mean was found for the number of litres or water used for each activity. Where the data showed that the majority of households in the group only performed a given water-consuming action once every two or three days, this was noted and used to influence the additional profiles created.

3.3.4 Water usage – patterns

A DRAINET simulation can be run for a maximum of 43200 seconds, or 12 hours. To account for this, the times used in the model were limited to between 7:00 and 19:00, with water usage outside these times being ignored – the data collected showed that the majority of water usage occurred within these 12 hours.

Within each house type, the most common three-hour window for each activity was found. Where there was a tie, a coin was flipped to determine which should be used. A random number generator was then used to determine in which minute of the three-hour window the water use would be placed. This time was then converted into the number of seconds, with 7:00 as the base point.

Generally, the different water uses were treated separately, with some exceptions – where the number generator produced results within five minutes of each other, this was assumed to be unrealistic and so another number was generated. It was also assumed that typically bathing would follow latrine use, and so these were placed consecutively.

3.3.5 Creating individual device profiles

Using DRAINET, discharge profiles were then created for each type of water use. Generally, these were based on the default profiles given in the program, adjusted for the specific quantities of water used. The profile for a two-litre pour flush was based on findings by Lehmann (2014) – ensuring accuracy for this profile was important because it is the discharge that brings solids into the system.

3.3.6 Creating 12-hour house profiles

Individual device profiles were added together to create each of the different 12-hour profiles. One-by-one, each device was connected to the end of a two-metre pipe and set to discharge at 0 seconds. A simulation was then run for 43200 seconds (12 hours) to allow for consistency in the time intervals for each. Flow profiles for individual devices were then copied to the relevant times in a blank 12-hour profile. This allowed for a profile for the flow rate at two metres from the entry point to be created for each house type.

Variations for each house type were also created. House types A and B did not generally undertake tasks such as laundry and household cleaning every day. For these, two profiles

were created, one with the task and one without. For other house types, offset profiles were created to simulate households waking and eating at different times.
Simulating rows of houses
Each row of the network was run separately, so as not to exceed the maximum number of pipes allowed by DRAINET. Houses on the end of rows and those with longer distances to the main pipe were selected as potential locations of problems. Solids were introduced to the system at these points so that solid transport could be assessed.

3.4 Generalised methodology

Figure 3 shows the general methodology employed for this mixed approach.
Data was collected in Marikuppam on the 18th and 19th of January 2016, following the process outlined above.

3.4.1 General demographics
The system will provide sanitation to 106 households of a variety of sizes. A total of 558 people are dispersed across households of sizes between one person and 17 people. The most common household sizes were those with four, five or six occupants.
Clean water in the area comes from three main sources. The public supply is piped from a borehole. This is available three times a week for an hour and a half, if power is available – power cuts in the state of Karnataka are frequent [6]. Households are charged Rs 20/- per month for access to this supply, and are permitted to fill six 18-litre pots at each opening. There is also a private tanker which supplies water from the borehole, at 2.5 Rupees per 18-litre pot. Bottled water is available from private suppliers for Rs 10/- per 20-litre container, which some households drink in preference to water from the borehole.

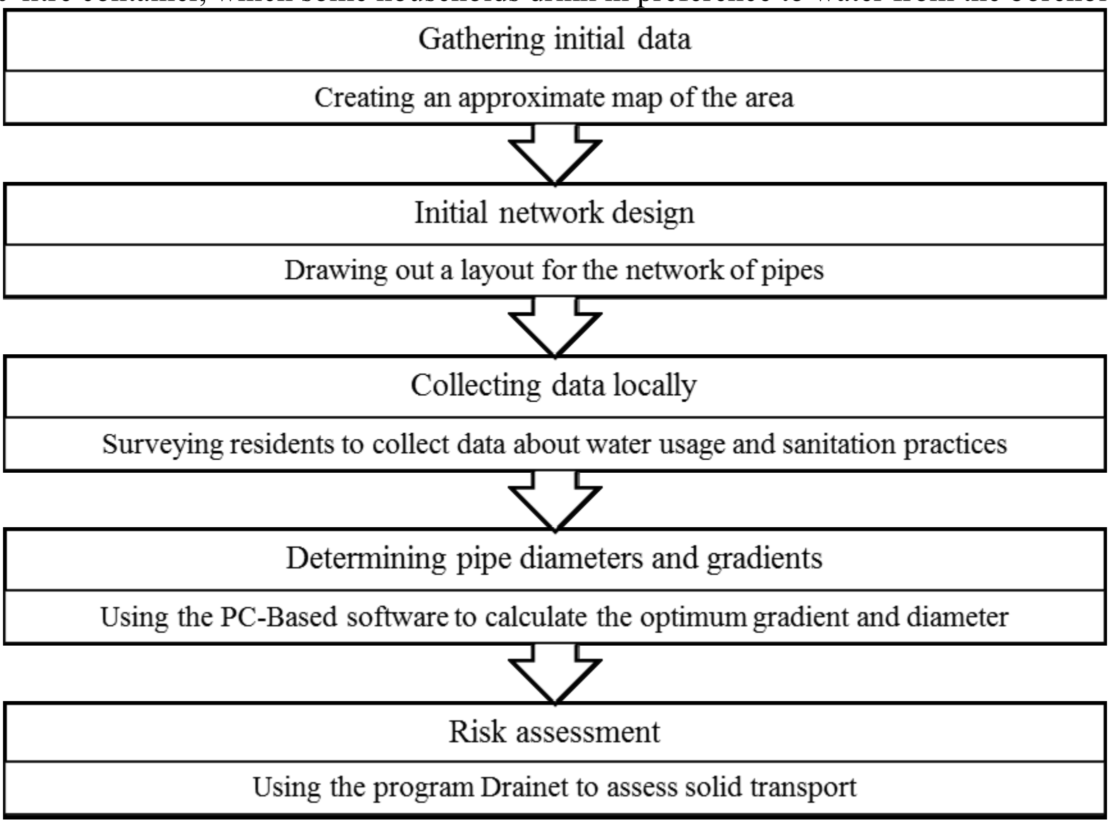

Figure 3 Flow chart showing the generalised methodology employed

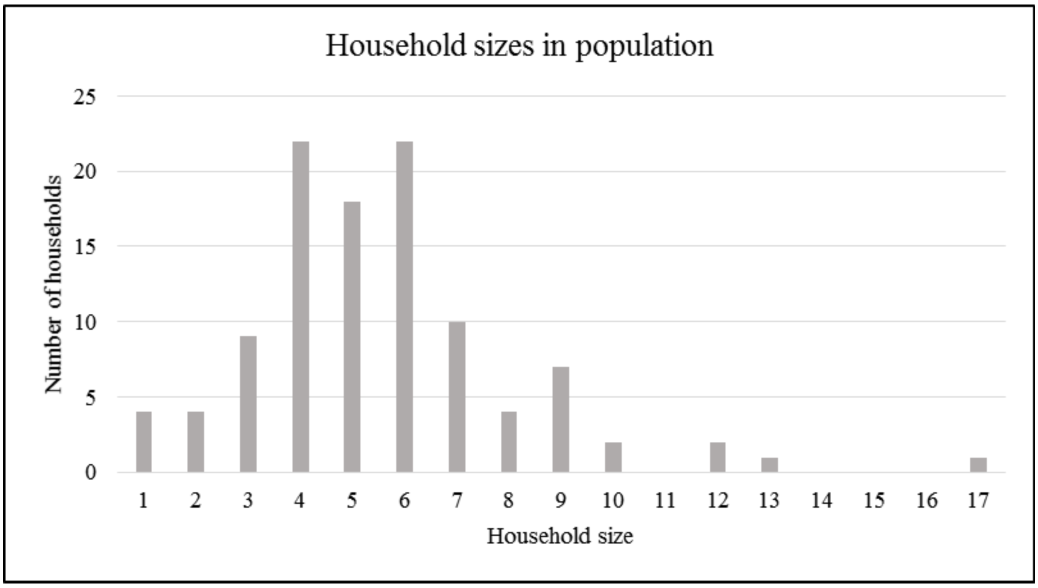

Figure 4 Household sizes in the population

The average water usage per person determined from the water use survey is around 50 litres per day per capita. However, this figure varied greatly from household to household, with figures from 10 to 97 litres per day per capita reported. This could be due to a variety of reasons. When calculating the average, the age of occupants was not taken into account – children and infants would likely use less water than adults, so this could have artificially lowered some figures. Another reason for this large discrepancy is that the household with the lowest water use consisted of just one person, who required the help of her neighbour for collecting water, and so was more conservative with her water consumption. The comparative wealth of some households could also influence their water consumption – if the public water supply is unavailable then the amount of water used directly correlates to the cost, encouraging poorer households to reduce their water consumption.

3.4.2 Water use

Eight main water uses were reported –

- drinking,
- cooking and food preparation,
- washing vessels and utensils,
- bathing,
- household cleaning,
- laundry,
- latrine use, and
- domestic animals.

Overall the largest single use of water for each house was laundry, with larger households generally washing clothes every day and smaller households washing clothes between one and four times a week. Bathing also used a large quantity of water, with most adults using between one and two 18-litre pots daily.

The return factor – the percentage of total water consumption which ends up in the sewer system - is typically assumed to be 80% or 85% [1]. However, in some households in this area the return rate is clearly much lower than this – one household interviewed reported that they used 360 litres per day just for taking care of their animals.

3.4.3 Water use graphs

Typical water usage graphs are presented in Figure 5 relating to the layout shown in Figure 6. The graph shows the peaks in water usage over the day – the line does not drop below 0.1 l/s because this is the initial flow rate required by DRAINET to allow for calculations to start.

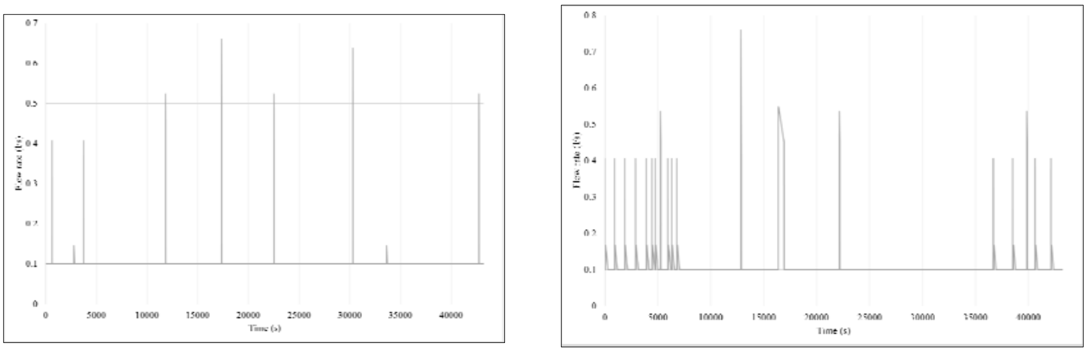

Figure 0 Water use hydrographs for two house types

The whole site with rows and collection drains are shown in Figure 6

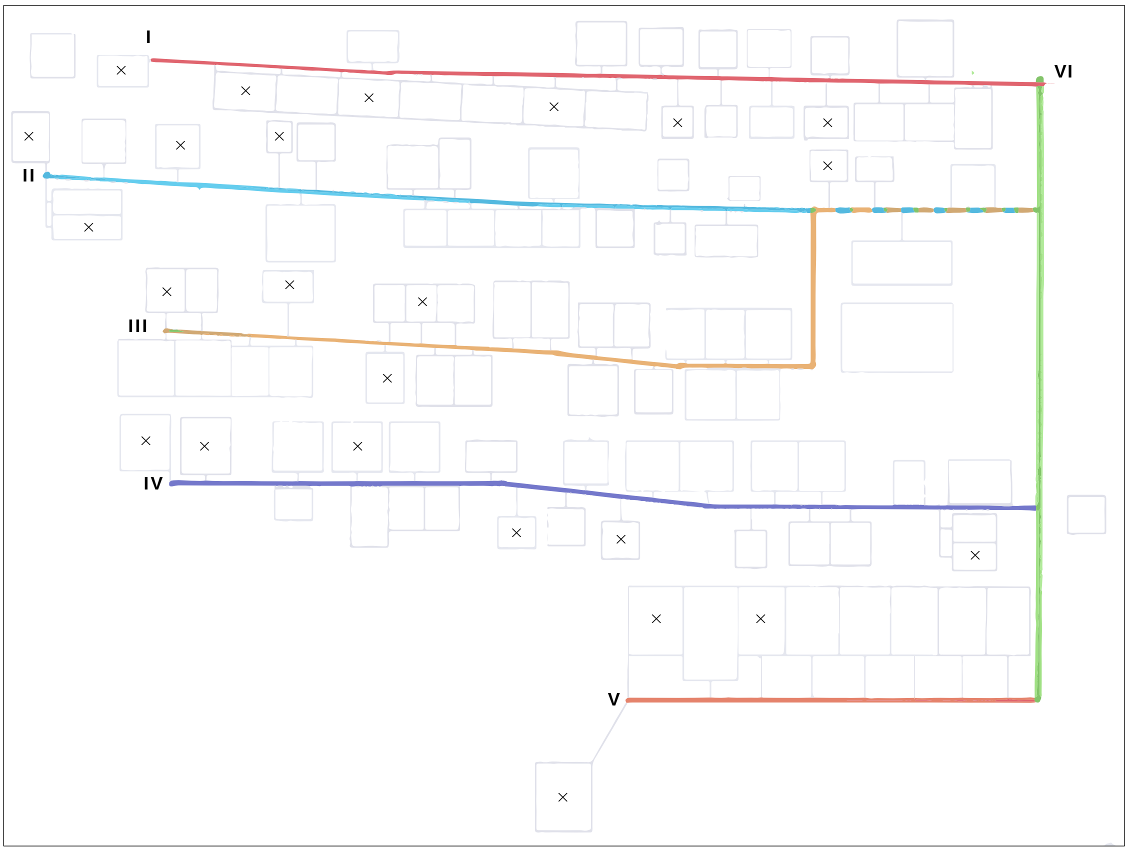

Figure 6 Layout for the whole installation (coloured lines indicate model sub-runs)

4 Results

Figure 7 shows the results for solid transport for one row, Row I. The flow profile for the row is also shown for completeness. The coloured lines indicate the travel of solids over the period of simulation. For this Row, the maximum length is 140 m so all solids have clearly passed on to the collection drain. A summary of solid travel times is shown in Table 1 also.

4.1 Discussion

In general, the modelling confirms that the usage patterns obtained from the usage survey are adequate to keep solids moving through the network and the system operating effectively.

Generally, solids did not reach the drain in the middle of the street after one flush, which corresponds with Lehmann's findings [7] using the same pipe diameter and gradient. However, over time, all solids reached the furthest end of the pipe. This was due not just to pour flushes but to water used for other purposes being discharged to the drain.

An important point clearly demonstrated by these results is that discharges other than flushes play a significant part in solid transport. This means that in order for the system to function effectively, waste water from other household activities must be deposited into the system. This could be achieved by either depositing waste water into the latrine, or by having a secondary drain in the bathroom for waste water, which people may prefer. This would have to be set up in a way so that the waste water would join with the discharge from the latrine as soon as possible, in order to maximise effectiveness.

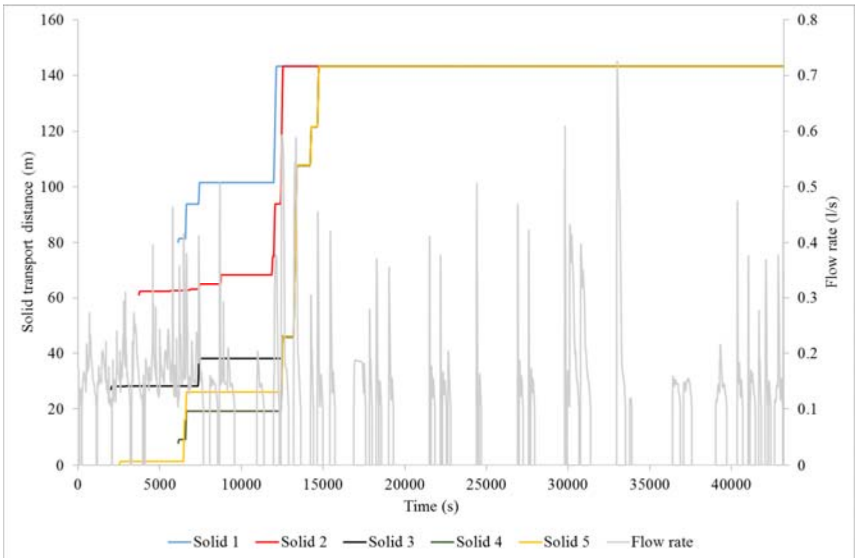

Figure 0 Results for Row I

Table 1 Average solid transport times

Row	Average solid transport time (s)	Average solid transport time (hh:mm)	Average solid speed (m/h)
I	12916	03:35	25.66
II	12695	03:32	31.99
III	12696	03:32	24.78
II and III	8211	02:17	29.71
IV	16617	04:37	22.62
V	12484	03:28	18.10
VI	8704	02:25	24.34

5 Conclusions

Using a multiple methodologies approach was an integral element of this system design. Whilst numerical modelling can accurately predict the transport of solids and associated risk of blockages in the system, problems can occur with people not interacting with the system as expected. In order for a project such as this to be successfully implemented, it is important to understand how people will use the system, and to use this to influence decisions throughout the system design. This is something which modelling alone cannot achieve.

The results of a survey undertaken in the area showed a need for improved sanitation, and confirmed that a simplified sewerage system would be suitable. Focus group discussions provided information on sanitation practices and the availability of water, and a household survey supplied detailed population data. A water use survey allowed an average per capita water use of 50 litres per day to be calculated, and for detailed usage patterns to be ascertained.

Modelling of the system using a modified version of DRAINET was conducted to gauge the risk of blockages occurring. Overall, the system performed well – all of the modelled solids reached the main pipe by the end of the twelve-hour period. This suggests that a simplified sewerage system would work effectively under the reported usage conditions, and so can provide a low-cost solution for the current problems with sanitation in Marikuppam.

The extensive modelling used to appraise the design was innovative in that such a large scale installation had never been modelled before over a full 12 hour period (representing one day). The research confirms that this type of modelling for the assessment of risk of failure has significant merit, however some further work is required to rationalize the process.

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7 Presentation of Authors

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Joy A Davidson and Angus Davidson have been working in international development for over 20 years. Joy has been mainly involved in sanitation and hygiene promotion. They are currently working closely with a grass-roots human rights NGO in India called 'Safai Karmachari Andolan', which exists to help manual scavengers take up alternative work. Through SKA's efforts the Government of India is asking the community of Marikuppam to identify sanitation solutions that are 'dignified'. Joy and Angus are advocates for SKA and have worked extensively with Heriot-Watt University to bring about change in Marikuppam village.

Computational solutions of aerosol generation rates for discharging water appliances

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Abstract

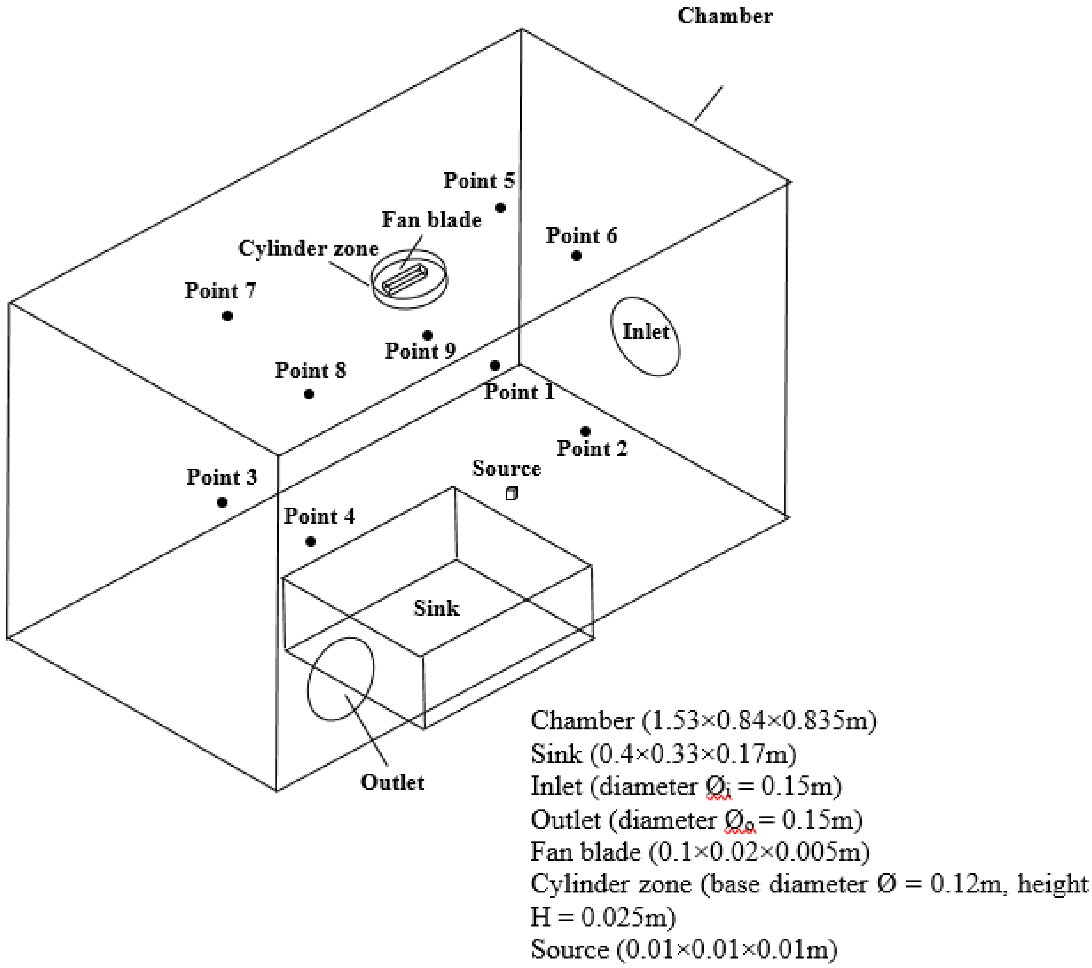
Aerosoliszation of water from discharging water appliances is a source for Legionellosis. This study investigates the aerosol generation rates of a discharging water appliance in a mechanically ventilated test chamber (size 1.53×0.84×0.835 m; with a water sink of size 0.4×0.33×0.17 m) using computational fluid dynamics (CFD). Aerosol volume fractions and concentrations in the chamber were computed to evaluate the aerosol counts in the air. The results showed that the simulated aerosol concentration in the immediate proximity of the central point in the chamber did not show significant difference from the experimental measurement values reported in the open literature. This paper hence demonstrates that CFD can be a useful aid in evaluating the aerosol generation rates of discharging water appliances.

Keywords

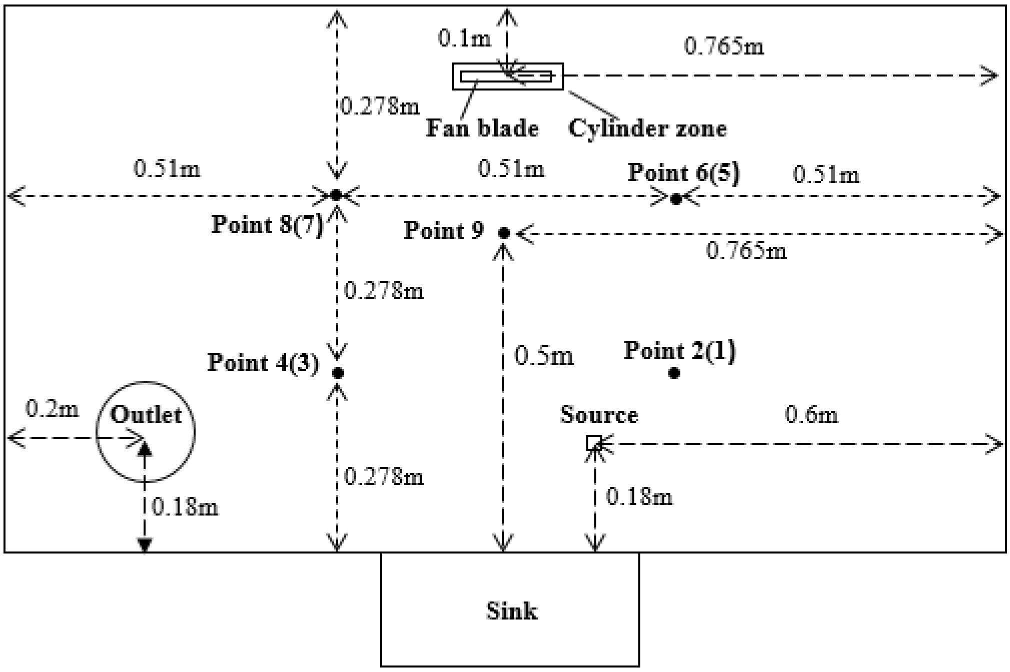
Discharging water appliances, aerosol generation rate, computational fluid dynamics (CFD), legionellosis.

1 Introduction

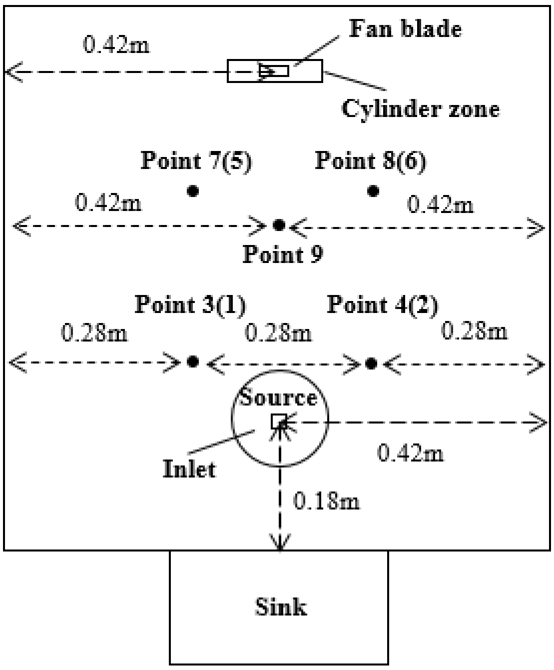
Legionella bacteria are found in natural water resources; they may also be found in water systems for buildings and aerosolized via discharging water appliances, e.g. water taps and showerheads [1,2]. People infected with Legionella bacteria may catch Legionellosis in its most serious and frequently recognized form, Legionnaires' disease (with pneumonia) [3].
To better understand the transport mechanism of Legionella bacteria, aerosol generation rates have been studied for discharging water appliances. It was reported that experimentally in a small well-mixed ventilated chamber (1.53×0.84×0.835 m), where an average aerosol diameter of 4.94 μm was assumed, the aerosol generation rate of a discharging water tap at a flow rate of 10 L min^{-1} was 2.34×10^5 particles s^{-1} [4]. Within an aerosol median diameter range of 6.3 to 7.5 μm, aerosol generation rates recorded for showerheads discharging hot water at a flow rate in between 5.1 L min^{-1} and 9.0 L min^{-1} were in the range 2252 to 2841 μg m^{-3} min^{-1} [5].
This study investigates the concentrations of aerosols generated by a discharging water appliance in a mechanically ventilated test chamber using computational fluid dynamics (CFD). The computational results are compared with aerosol concentration levels reported in the open literature, and the feasibility of applying CFD models to the evaluation of aerosol generation rates of a discharging water appliance is discussed.



(a) Three-dimensional view of the geometric model



(b) Front view of the geometric model



(c) Left view of the geometric model

Figure 1 Mechanically ventilated chamber

2 Simulation study

2.1 Setup

The numerical experiment used in this study was based on an experimental method by Carson [4]. Figure 1 shows the geometric model setup: test chamber size is

1.53×0.84×0.835m; sink size is 0.4×0.33×0.17 m (the sink is located at the bottom of the chamber); circular air inlet and outlet are both 0.15 m in diameter; a flat rectangular blade (0.1×0.02×0.005 m) serves as a mixing fan and rotates to enhance air mixing with aerosols inside the chamber; a cylindrical zone of 0.12 m in diameter and 0.025 m in height is set for fan rotation in the simulations; a cubic zone (0.01×0.01×0.01 m) is set for the source of aerosol generation due to a discharging water appliance in the chamber. Aerosol concentrations at monitoring Points 1 to 9 can be determined computationally; it is noted that Point 9 was the reference aerosol sampling location in the Carson's experiment [4].

2.2 Numerical experiment

The test chamber was automatically 'medium' meshed using the Relevance Center settings of the CFD software ANSYS Fluent 13.0. The suitability of the mesh size was then verified by comparing with simulation results. Finally, 105846 calculation cells and 21361 nodes were set for the chamber.

The Mixture Model of ANSYS Fluent 13.0 was adopted to simulate the aerosol transport in the chamber. The Implicit Body Force treatment was enabled to improve solution convergence by accounting for the partial equilibrium of the pressure gradient and the gravity in the momentum equations. The granular secondary phase (i.e. aerosol) was defined as a salt water droplet of density 1018 kg m^{-3} and diameter 4.94 μm in the Mixture Model. Since the aerosols were fine in size, no slip velocity between air phase and particle phase was assumed in the model in order that the airflow and aerosol velocities were the same.

The Multiple Reference Frame Model (MRF) of ANSYS Fluent 13.0 was adopted to model the flow involving the moving fan in the chamber. Inside the chamber, the momentum and continuity equations for the aerosol-air mixture and the volume fraction equations for the aerosols were solved not only in a moving reference frame in the cylinder zone, but also in a stationary reference frame outside the cylinder zone. Renormalization Group (RNG) k-ε Model was selected to include the effect of swirl on turbulence, while standard wall functions were applied to the near-wall area.

A velocity inlet boundary condition was set at the inlet with initial air and aerosol velocities of 0.67 m s^{-1} and 0 m s^{-1} respectively. As there were no aerosols flowing into the chamber from the inlet, the aerosol volume fraction at the inlet was set to zero. An effective outflow boundary condition was chosen for the outlet and the source was set as the mass flow inlet boundary condition. The mass flow rates of air and aerosols were 0 kg s^{-1} and 1.5×10^{-8} kg s^{-1} respectively.

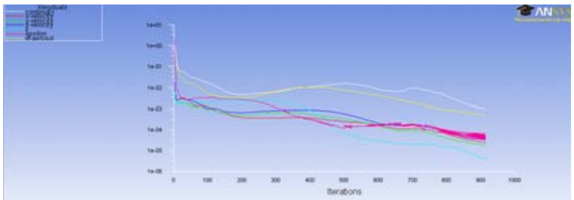
The fan blade was a 'moving' wall with a rotational velocity of 0 rpm relative to the moving reference frame in the cylinder zone, while the chamber and sink walls were the 'stationary' boundary conditions. Assuming there was no translational velocity, four rotational speeds of the moving frame were used in the CFD simulations, i.e. 1000 revolutions per minute (rpm), 2000 rpm, 3000 rpm and 4000 rpm. Table 1 outlines the parameters adopted in the simulations.

3 Results and discussion

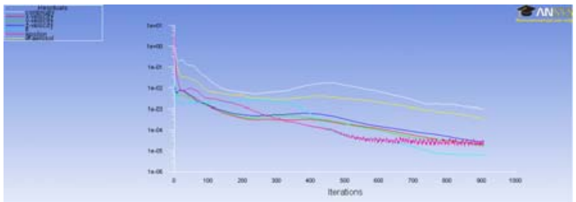
As exhibited in Figure 2, calculations at the four fan speeds namely 1000, 2000, 3000 and 4000 rpm (about 10000 iterations) were converged with the residuals of continuity, velocity, k value, ε value and aerosol volume fraction, decreasing by three orders of magnitude. The results tended to a steady value.

Table 2 shows the simulated aerosol volume fractions ζ and the calculated aerosol concentrations N at Points 1-9. The aerosol concentration N (particles m^{-3}) is determined using the following equation, where V_0 (m^3) is the volume of an aerosol with diameter D (m),

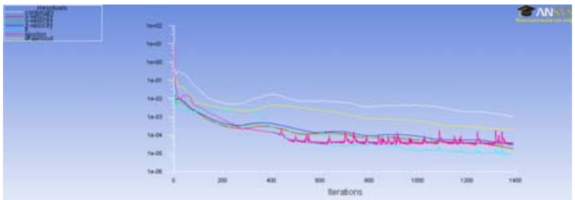
$$N = \frac{\zeta}{V_0} \; ; \; V_0 = \frac{4\pi}{3}\left(\frac{D}{2}\right)^3 \tag{1}$$



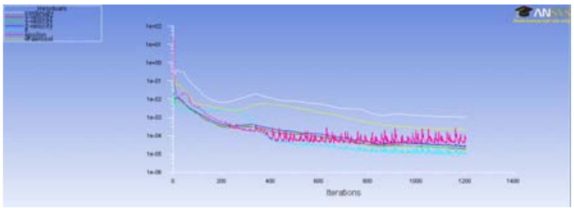
(a) Fan rotational velocity $\omega_{r,1}$ = 1000 rpm



(b) Fan rotational velocity $\omega_{r,2}$ = 2000 rpm



(c) Fan rotational velocity $\omega_{r,3}$ = 3000 rpm



(d) Fan rotational velocity $\omega_{r,4}$ = 4000 rpm

Figure 2 Residuals

Table 1 Parameters involved in the CFD simulations

Zone	Boundary condition	Parameter	Unit	Value	Remark
-	-	Ventilation rate Q	$m^3 s^{-1}$	0.0119	[4]
-	-	Aerosol diameter D	m	4.94×10^{-6}	[4]
-	-	Aerosol density ρ_s	kg m^{-3}	1018	-
-	-	Aerosol generation rate G_s	Particles s^{-1}	2.34×10^5	[4]
-	-	Rotational velocity of moving reference frame ω_r	rpm	1000/2000/3000/4000	-
Inlet	velocity inlet	Air velocity $v_{i,p}$	m s^{-1}	0.67	$v_{i,p}=Q/(\pi Ø_i^2/4)$
		Aerosol velocity $v_{i,s}$	m s^{-1}	0	-
		Aerosol volume fraction ζ_s	-	0	-
Outlet	outflow	-	-	-	-
Source	mass flow inlet	Air mass flow rate m_p	kg s^{-1}	0	-
		Aerosol mass flow rate m_s	kg s^{-1}	1.5×10^{-8}	$m_s=(4/3)\pi(D/2)^3\rho_s G_s$
Fan blade	moving wall	Relative rotational velocity ω_f	rpm	0	-
Chamber, sink wall	stationary wall	-	-	-	-

Table 2 Simulated aerosol volume fractions and calculated aerosol concentrations

Location	Aerosol volume fraction $\zeta\times10^{-9}$				Aerosol concentration N (particles m^{-3})$\times10^7$				
	*$\omega_{r,1}$ =1000 rpm	*$\omega_{r,2}$ =2000 rpm	*$\omega_{r,3}$ =3000 rpm	*$\omega_{r,4}$ =4000 rpm	*$\omega_{r,1}$ =1000 rpm	*$\omega_{r,2}$ =2000 rpm	*$\omega_{r,3}$=3000 rpm	*$\omega_{r,4}$=4000 rpm	[4]
1	0.657	0.972	0.703	0.644	1.07	1.54	1.12	1.02	-
2	1.020	1.39	1.090	0.837	1.62	2.21	1.73	1.33	-
3	0.727	0.844	0.684	0.579	1.15	1.34	1.09	0.92	-
4	0.983	1.17	1.250	1.590	1.56	1.86	1.98	2.52	-
5	0.464	0.809	1.040	0.815	0.74	1.28	1.65	1.29	-
6	0.838	1.200	1.480	1.080	1.33	1.90	2.35	1.71	-
7	0.577	0.867	0.840	0.810	0.92	1.38	1.33	1.29	-

8	0.677	0.880	0.747	0.657	1.07	1.40	1.19	1.04	-
9	0.843	1.190	0.883	0.795	1.34	1.89	1.40	1.26	1.97
Average	0.756	1.040	0.969	0.867	1.20	1.64	1.54	1.38	-

According to Table 2, the calculated aerosol concentrations ranged from 0.74×10^{7} to 2.52×10^{7} particles m^{-3}. As the maximum to minimum ratio was 1.7 to 2.7 in the fan speed range, the assumption of a uniform distribution would not be perfect. All test concentrations were normally distributed ($p\geq0.1$, w/s test), with an average in the range of 1.2×10^{7} to 1.64×10^{7} particles m^{-3}. As illustrated in Figure 3, the simulated average concentrations were not significantly different from the concentrations simulated at Point 9 ($p=0.75$, paired t-test). Hence, the choice of measurement location would be representative for determining the average concentration.

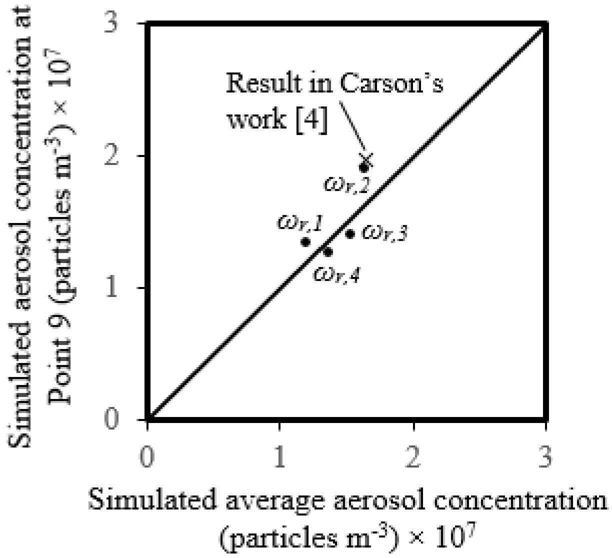


Figure 3 Aerosol concentrations

Simulations were conducted at five aerosol mass flow rates (from the emission source) m_a (kg s^{-1}), namely 1×10^{-8}, 3×10^{-8}, 5×10^{-8}, 7×10^{-8} and 9×10^{-8} kg s^{-1}, for the four fan speeds (i.e. 1000, 2000, 3000 and 4000 rpm); corresponding aerosol volume fractions at the chamber outlet ζ_o were acquired. Average aerosol concentrations at the chamber outlet N_o (particles m^{-3}) under the four test conditions, given by Equation (1), are graphed in Figure 4. The aerosol generation rate G (particles s^{-1}) can be determined by Equation (2), where aerosol density ρ_s = 1018 kg m^{-3}.

$$G = 0.0138 N_o \quad ; \quad G = \frac{m_a}{\rho_s V_0} \tag{2}$$

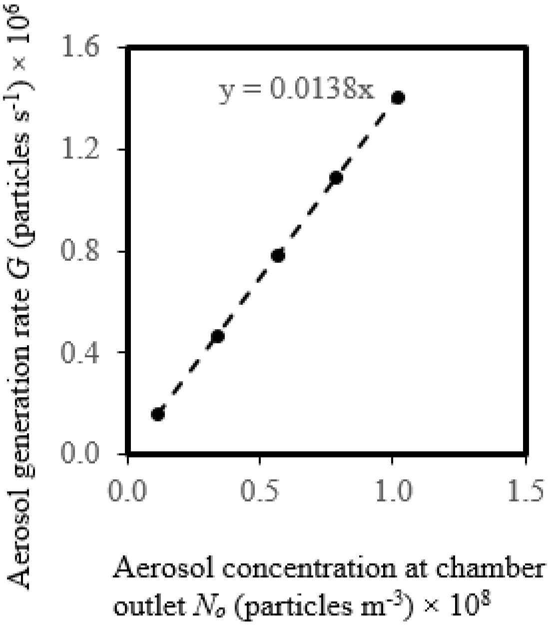


Figure 4 Aerosol generation rates

4 Conclusion

People get Legionellosis by inhaling the Legionella bacteria, usually carried by a fine water mist. Aerosolization of water from discharging water appliances is thus a source for Legionellosis. Using CFD, this study examined the aerosol generation rates of a discharging water appliance in a mechanically ventilated test chamber (chamber 1.53×0.84×0.835 m with a water sink 0.4×0.33×0.17 m) under four situations (i.e. fan rotational speeds namely 1000, 2000, 3000 and 4000 rpm). As the results showed that the simulated aerosol concentration in the immediate proximity of the central point in the chamber did not show significant difference from the experimental measurement values reported in the open literature, the study demonstrated that CFD can be a useful aid in evaluating the aerosol generation rates of discharging water appliances.

5 Acknowledgement

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Session E
Sustainability and climate changes

Reduction in carbon dioxide emission of buildings by water recycling and rainwater harvesting

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Abstract

Expansion of water recycling and rainwater harvesting on the national scale is expected to improve water circulation and conservation of water and energy resources. Day-to-day building operation consumes significant amounts of water and emits large amounts of carbon dioxide. Therefore, reducing water consumption will reduce environmental impact and save energy.

This study examines the water use characteristics of buildings for which water consumption was surveyed based on the management data. Water usage characteristics such as the use of potable water for flushing toilet bowls were surveyed, and the fungible ratio of water to recycling water was determined. In addition, carbon dioxide emissions during the building operational phase due to the energy consumption associated with the domestic water, sewage, and plumbing system utilization of the surveyed buildings were estimated. For evaluating carbon dioxide emission reduction, a water supply form suitable for the research building was determined. Rainwater harvesting case studies were examined. From these, the environmental impact reduction due with water recycling and rainwater harvesting was determined.

Keywords

Rainwater harvesting, recycling water utilization, water use characteristics, resource circulation, environmental impact reduction.

1 Introduction

The use of rainwater harvesting equipment and water-saving equipment is spreading in Japan. These can be expected to contribute to energy saving, and conservation and circulation of water resources. Day-to-day building operation consumes significant amounts of water and emits large amounts of carbon dioxide. Therefore, reducing water consumption will reduce environmental impact and save energy.

In this study, water consumption of educational institutions and commercial facilities located in Tokyo was surveyed. The water use characteristics were determined from management data. The fungible ratio of domestic water to recycling water[1 ※)] was determined for water used for toilet bowl flushing.

Carbon dioxide emissions in the building operational phase from the energy consumption associated with the usage of domestic water, sewage, and plumbing system were estimated. Rainwater harvesting case studies for the research building were examined. From these, the environmental impact reduction effect of water recycling and rainwater harvesting was determined.

2 Overview of the surveyed buildings and management data

Table 1 shows an overview of the surveyed buildings and management data.

The management data (2008/2012) of educational institutions and commercial facilities located in Tokyo was surveyed to evaluate recycling water utilization and rainwater harvesting. The amounts of potable water and recycling water as well as rainfall for both educational institutions and commercial facilities were determined from the management data.

In educational institutions, plumbing system equipment was renovated in fiscal year 2009. The renovation consisted of changing the level type flush toilets with a 15 L flush valve to sensor type flush toilets with a 10 L flush valve and changing the manual valves in hand washing basins to automatic taps.

Table 1 Overview of the surveyed building and management data

Building applications	Educational institutions (University)	Commercial facilities
Outline of the Building	University facilities located in Tokyo.	・Located in the Tokyo metropolitan area ・Food-product sales facility
Plumbing system overview	・Portable water and recycling water are suppled. ・Water-saving equipment has already been renovated.	・Portable water is suppled. ・Water-saving equipment has already been renovated. ・Non-portable water use by the waste water recycling system. ・Rainwater harvesting, condenser water reuse
Management dates ・Item ・Measurement interval	・Portable water supply quantity [m^3/h] ・Recycling water supply quantity [m^3/h] ・Rainfall [mm/h]	・Portable water supply quantity ・Reclaimed water consumption (For employees and customers) ・Amount of rainwater ・Quantity of discharge ・Other non-portable water waste These unit : [m3/day]
Note	Water-saving equipment has already been renovated in fiscal year 2009.	Precipitation used the Japan Meteorological Agency observation data (Fuchu city)

3 Water use ratio of the surveyed buildings

3.1 Water use characteristics of educational institutions

Figure 1 shows water consumption per month and rainfall in educational institutions.
In educational institutions, both potable water and recycling water are used. Potable water is used as drinking water and domestic water, and recycling water is used for flushing toilet bowls.
In fiscal year 2008 (before renovation of the water-saving equipment), water consumption per year was 21,118 m^3, with 42% (9,339 m^3/year) potable water and 58% (12,779 m^3/year) recycling water.
In fiscal year 2012 (after renovation of the water-saving equipment), water consumption per year was 15,708 m^3, with 39%(7,232 m^3/year) potable water and 61% (11,029 m^3/year) recycling water.
In educational institutions, water consumption tends to decrease in vacation months such as August, February, and March. Further, annual rainfall day at educational institutions was 118days in fiscal year 2008 and 108days in fiscal year 2012, and annual rainfall was 848mm in fiscal 2008 and 669mm in fiscal year 2012. The maximum rainfall date is May 3, 2012. Approximately 20mm were confirmed in rainy season(June, July, September and October).

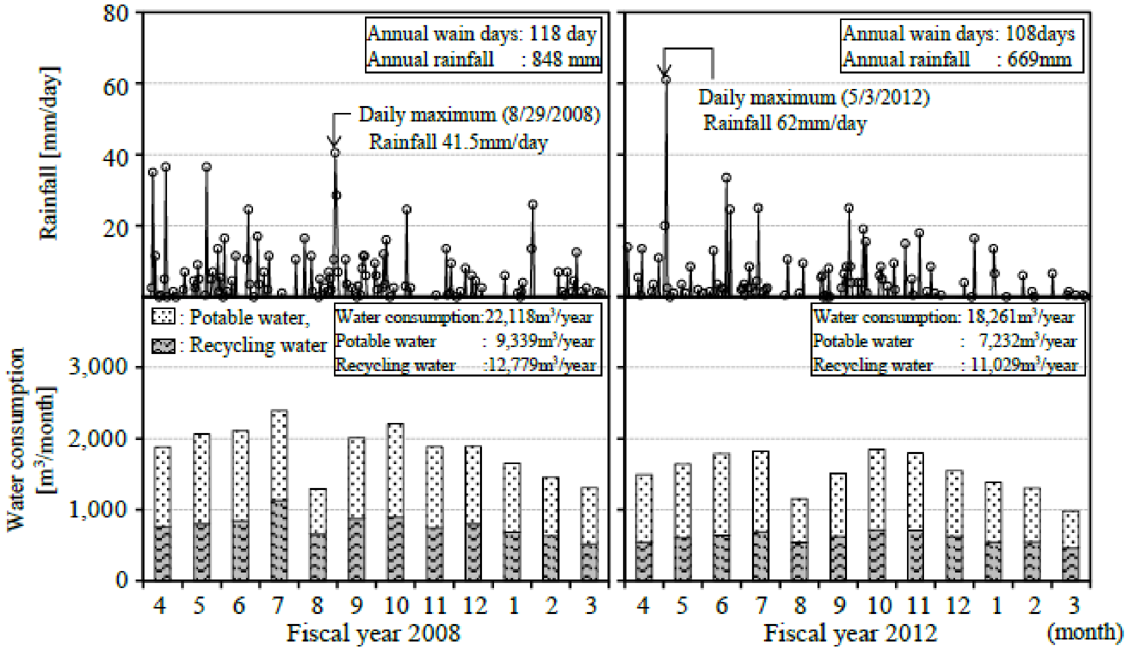

Figure 1 Water consumption per month and rainfall in educational institutions

3.2 Water use characteristics of commercial facilities

The commercial facilities was surveyed for the period from April 1, 2012, to March 31, 2013. Rainfall in this period was in line with the yearly average. Figure 2 shows the water characteristics such as rainfall, water consumption (potable water, recycling water), rainwater consumption, and discharge quantity in a time series.
The rainfall was 1,536 mm/year and the harvested rainwater was 2,553 m3/year. It was used for toilet bowl flushing and in cooling towers. Further, the water used for toilet bowl flushing was rainwater and recycling water from the waste water treatment equipment in the building.
The utilization ratio of rainwater (rainwater usage/collected rain water amount ×100%) was 19.6% for an annual average. The fungible ratio of potable water (rainwater

usage/potable water + recycling water consumption × 100%) was 1.2%. This ratio2※) is small compared with overall water consumption in the building.

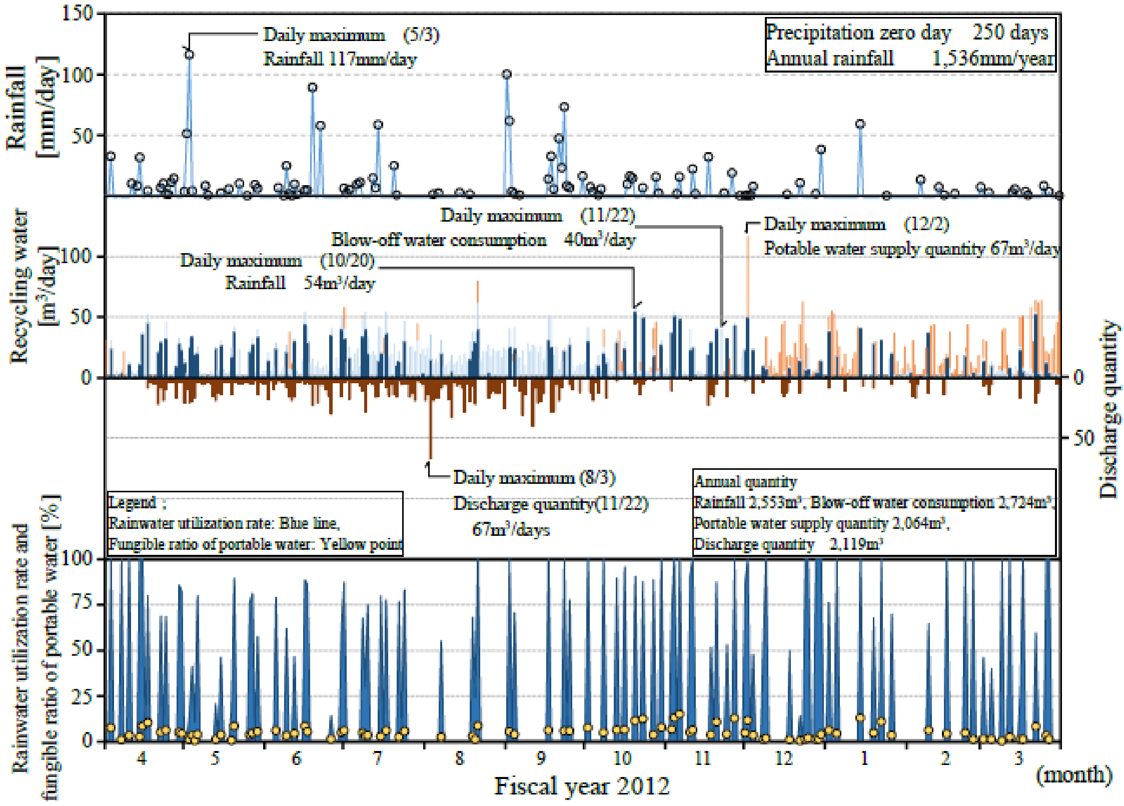

Figure 2 Changes rainfall, water consumption and details of recycling water

Moreover, the commercial facilities include many eateries. Of the total water supply, potable water constitutes approximately 65% (4.2 ℓ/(m2·day)) and recycling water constitutes approximately 35% (2.0 ℓ/(m2·day)).

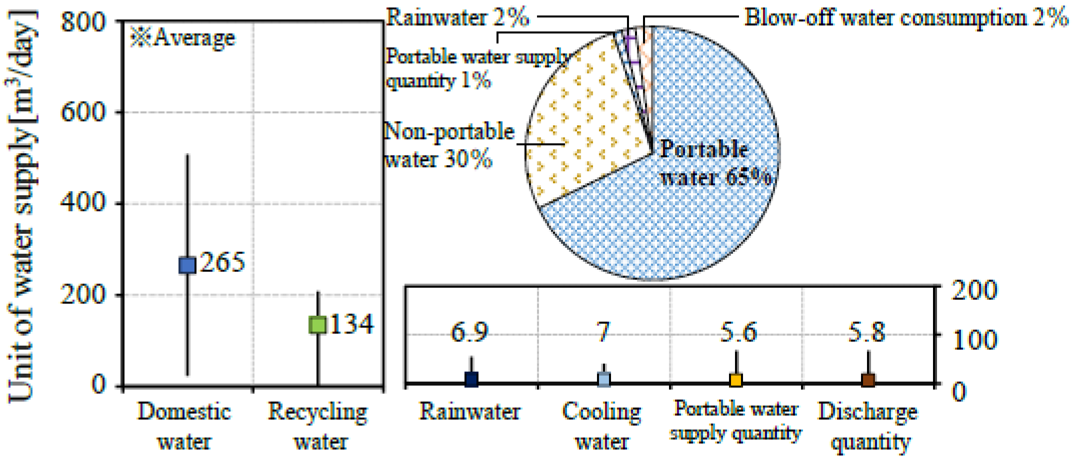

Figure 3 Unit of water supply in commercial facilities

4 Carbon dioxide emission reduction effect of water recycling and rainwater harvesting

4.1 Overview of the evaluation area

Figures 4 and 5 show each survey building and water supply and sewage system flow used in evaluating dioxide emission reduction due to water recycling and rainwater harvesting.

In the educational institutions, recycling water for toilet bowl flushing is supplied by another system. Therefore, the carbon dioxide emission reduction effect is evaluated based on recycling water utilization.

At that time, water consumption of the building is the same. And the evaluation area is expanded to include the water intake from the water source and discharge into public waters. Carbon dioxide emission during the building operation is calculated on the basis of References (3)–(5). Then, public data (the amount of potable water and recycling water, sewage treatment quantity, and the energy usage required for sewage treatment) and interviews were used to determine the results of various facilities such as purification and sewage treatment.

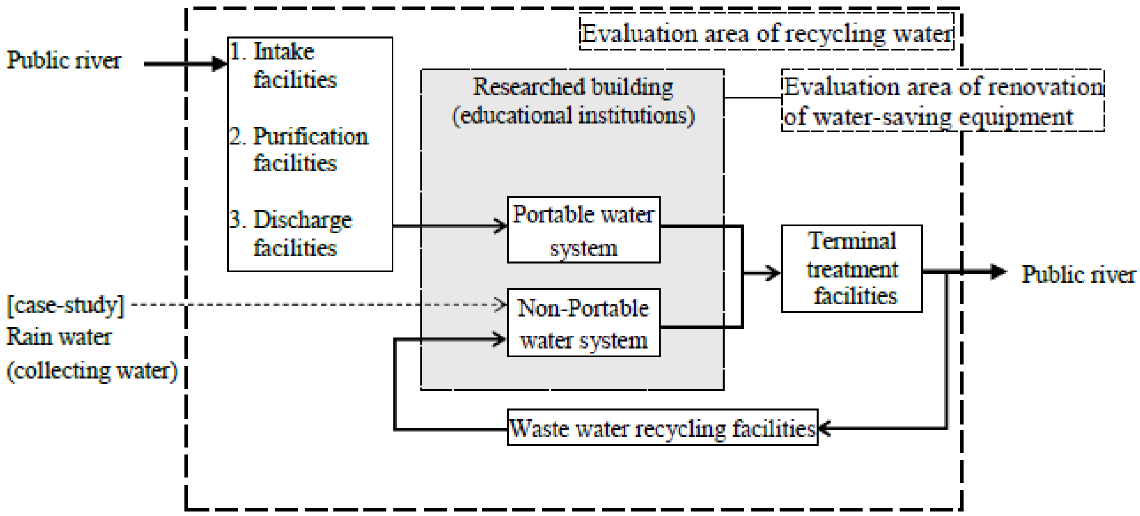

Figure 4 Evaluation area of educational institutions (recycling water and renovation of water-saving equipment)

Figure 5 shows the evaluation area for commercial facilities and carbon dioxide emission by rainwater utilization from management data of commercial facilities where rainwater is used as part of the recycling water supply.

Evaluation of commercial facilities is performed in the same manner as that of educational institutes. To investigate the water supply and sewage activity data related to the building, carbon dioxide emission was determined. Recycling water was generated at the wastewater treatment equipment in the building.

It was compared with the power consumption related to the waste water treatment system and rainwater filtration system for generation of recycling water (toilet bowl flushing water) in the building.

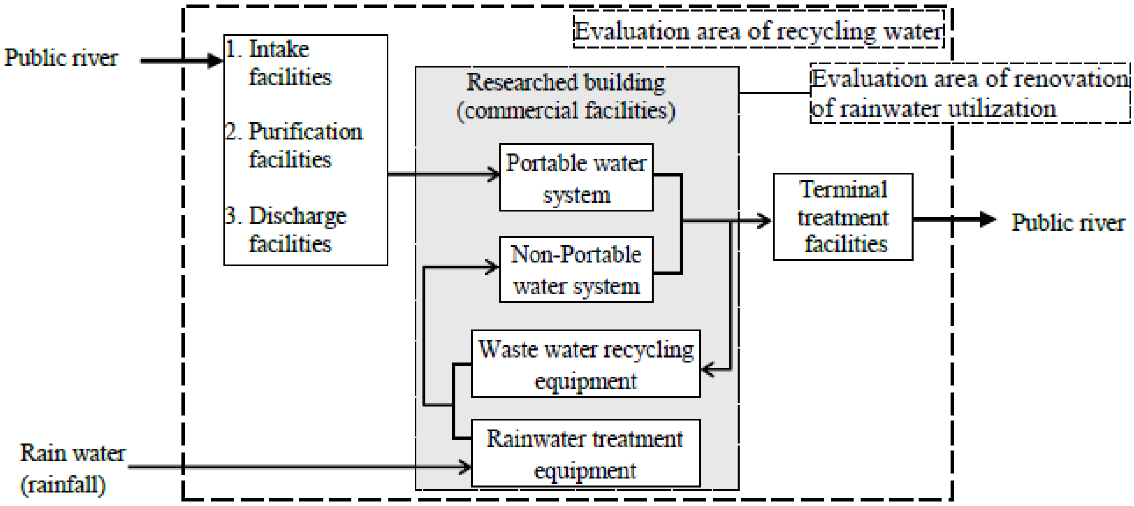

Figure 5 Evaluation area of commercial facilities (recycling water and rainwater utilization)

4.2 Effect of recycling water usage and renovation of water-saving equipment in educational institutions

Figure 6 shows the calculation results of carbon dioxide emission reduction effect due to recycling water usage and renovation of water-saving equipment in educational institutions.

First, the carbon dioxide emission reduction was 0.4 kg-CO2/(m2・year) in fiscal year 2008 and 0.33 kg-CO2/(m2・year) in fiscal year 2012. Therefore, renovation of the water-saving equipment resulted in a reduction of 17% in carbon dioxide emission.

Second, use of recycling water instead of potable water resulted in a 38% reduction in carbon dioxide emission.

In addition, use of rainwater along with recycling water resulted in a 42% reduction in carbon dioxide emission, compared with potable water usage.

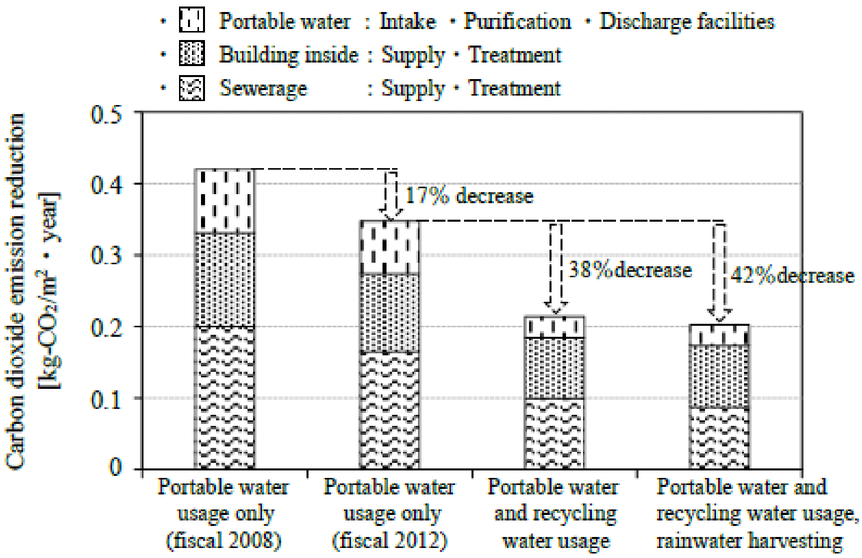

Figure 6 Carbon dioxide emission reduction effect of recycling water usage and renovation of water-saving equipment

4.3 Effect of water recycling and rainwater harvesting in commercial facilities

Figure 7 shows the calculation results of carbon dioxide emission reduction effect by usage of recycling water and rainwater in commercial facilities

Use of recycling water instead of potable water resulted in a 30% reduction in carbon dioxide emission. Moreover, when rainwater was used along with recycling water, the carbon dioxide emission reduction was 34%.

The fungible potable water ratio of rainwater in the evaluated building was 1.2%. An increase in this ratio is expected to contribute to the reduction of carbon dioxide emission.

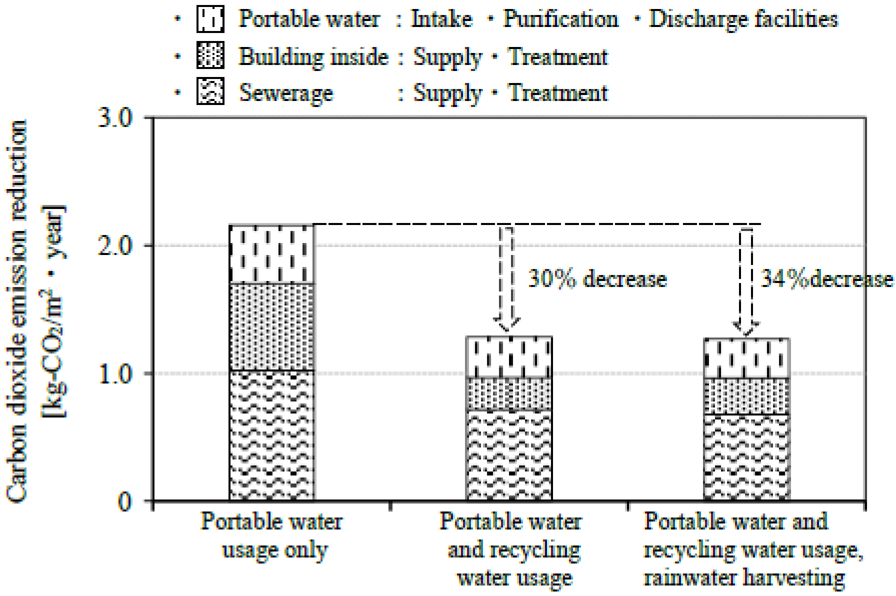

Figure 7 Carbon dioxide emission reduction effect of recycling water usage and rainwater usage

5 Conclusion

In this study, water consumption characteristics of educational institutions and commercial facilities were determined from water usage data.

Carbon dioxide emission reduction due to water recycling and rainwater harvesting was calculated. Power consumption (fossil fuel-derived energy) was calculated based on public data related to water treatment in a wide area.

In educational institutions, renovation of water-saving equipment lead to a 17% reduction in carbon dioxide emission. Moreover, use of recycling water instead of potable water lead to a 38% reduction in carbon dioxide emission.

In commercial facilities, use of recycling water instead of potable water lead to a 30% reduction in carbon dioxide emission. Moreover, use of rainwater as recycling water lead to a 34% reduction in carbon dioxide emission.

6 Note

1※) Recycling water: water treated with the purpose of reusing the treated sewage, water which is used in a non-potable system such as toilet bowl flushing, watering in the building

2※) The recycling water souse which is water treatment in Tokyo; toilet bowl flushing,

kitchen waste water was 2%,rainwater was 2%, Blow-off water consumption was2%, Portable water supply quantity was 1%
3※) Unit of the carbon dioxide emission used in the calculation (list shown below)

	Educational institutions		Commercial facilities	
	Portable water	Recycling water	Portable water	Rain water
City water	0.200 kg-CO_2/m^3 (※1)	–	0.200kg-CO_2/m^3 (※1)	–
Sewerage	0.450kg-CO_2/m^3 (※1)	0.346 kg-CO_2/m^3 (※2)	0.450kg-CO_2/m^3 (※1)	–
Equipment in building	Water supply 0.296 kg-CO_2/m^3 (※3)	Recycling water supply 0.384 kg-CO_2/m^3 (※4)	Water supply 0.296kg-CO_2/m^3 (※5)	Recycling water supply 0.384kg-CO_2/m^3 (※5) Treatment and filtration 0.051kg-CO_2/m^3 (※6) Treatment and aeration 0.013kg-CO_2/m^3 (※6)
Total	0.946 kg-CO2/m^3	0.730 kg-CO2/m^3	0.946kg-CO2/m^3	0.448kg-CO2/m^3

※1 For more information on the water supply and sewerage facilities to the research building was unknown, using the literature value of 5).
※2 Unit of carbon dioxide emission of recycling water supply was calculation by supply water and energy consumption in recycling water supply facilities to the educational institutions.
※3,4 The energy consumption of the transport equipment which is installed in the survey building was calculation from the equipment spec.
※5 For equipment spec for transport equipment in the research building was unknown, using the value of the educational institutions
※6 Energy consumption was calculation by assuming the equipment spec of recycling water consumption of research building

Further, unit of carbon dioxide emission by the power consumption was used 0.384kg-CO2 / kW・h.

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Analysis of building drainage and sewer system performance utilizing a tipping tank with water conserving measures

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Abstract

Efficiently optimised water conservation is an essential tool in achieving sustainable buildings. When designing a building drainage network for servicing a development, recognition must be given to the water throughflow. Reductions to the quantities of the throughflow must be fully understood and should be incorporated into the final design so as to maximise the network's efficiency. The amount of water consumed by occupants is currently increasing. The exploration of water-conserving methods within domestic and commercial buildings continues to grow with the aim of achieving maximum efficiency of the water systems. This paper aims to illustrate that the addition of a tipping tank to a drainage system along with reductions in flush capacities, lowflow showers and behavioural changes of occupants are only a few of many techniques to have been trialled yielding positive results in terms of overall water usage reduction. A major issue associated with the reduction in capacity of any water appliance directly affects the system's ability to perform successfully i.e. remove solids. This paper shows that the reduction of water from a system alone may be counterproductive. Reduced flows may result in an increase in the amounts of operations for the water appliances per unit of drainline carry. The use of a tipping tank, despite the relatively large amount of water required to operate it, can potentially contribute to decreasing water consumption and save more water than it consumes.

Keywords

Water conservation, computer modelling, water supply drainage, water efficiency.

1 Introduction

1.1 Improvements to fitting's water conservation

Since the emphasis of water conservation has been placed on fittings, a number of guidance documents and environmental rating incentives have been developed by the UK. The most predominant of which are BREEAM (created by Building Research Establishment in 1990), the Water Efficient Product Labelling Scheme, the Water Technology List and the Enhanced Capital Allowance Scheme (all endorsed by DEFRA). The Water Technology List was published in 2003 and provides extensive information on almost all W.C.'s in use in the Scotland. As a result of these developments, the maximum flush capacity for a Scotland W.C. is now between 2.9-6 litres and a high percentage contain dual-flush options. Overall in the UK From 1st January 2001 the 1999 Water Regulations (Department of the Environment, Food and Rural Affairs, 1999) specify a maximum flush of 6 litres. Homes with W.Cs installed pre-1999 will have significantly larger cisterns with flush volumes of up to 13 litres.

1.2 Out-of-date building standards still effecting water systems

Before suggestions to improve the water distribution system through improvement in fitting performance can be made, it is important to analyse the entire system to ensure that the proposed changes would actually make a beneficial and meaningful difference. Currently, the internal DWV system of a domestic building is comprised of a series of pipes all with a diameter of 100mm or less, but the main soil pipe has a diameter of 100mm. The reason for this diameter is that the connection flange on a toilet is 3 inches (approximately 75mm) and the connecting pipe cannot be smaller than the flange diameter. In the UK, this is not a regulatory requirement but it is the norm.

The size of the pipe, not the fitting, then dictates the system's performance and so sufficient consideration should be afforded to the pipe's diameter too. Thus water conservation addressed through reduced W.C. flush volumes, reduced white goods water consumption or a move to reduced flow showers and user sensing urinal flushing, must be accompanied by an assessment of drain sizing that will yield comparable performance at the reduced flows likely to be encountered in the future since it is the performance of the whole DWV system that matters.

1.3 Economic rationale for water conservation

Alongside the obvious fact that less water used equates to less water needing to be supplied, there are many other economic benefits that complement the environmental benefits associated with creating water conservative drainage systems. The economic rationale for water conservation is one that has failed to resonate with end users due to the fact that a reduction in usage does not directly translate into monetary reward. If a sustainable plan for water conservation is in place, the water industry will have the opportunity to accurately gauge usage over a sustained period and project the benefits.

Similarly, reductions in water use imply further economies as the existing drainage infrastructure could handle increased occupancy following change of use—a possibility in redeveloped 'brown' site building programmes. It may be argued that the advantages of water conservation will be offset or wholly negated if the outcome for the consumer, either in the domestic or commercial sense, is a rise in maintenance charges brought about by inefficient drain cleansing due to reduce through-flows.

As the predominant percentage of the drainage flow, from a single appliance category, within the building envelope will emanate from W.C. discharge it follows that the interaction between W.C. operation and the drainage network performance should form the basis for drain sizing design criteria.

2 Intermittent discharge devices

One practical method, which has been suggested as an additional tool to reduce water usage in systems is the implementation of an intermittent discharge device or tipping tank. Previous research, exploring tipping tank utilisation in sewer networks, aimed to reduce sewer maintenance costs and intended to offer a technical alternative that could contribute to the extension of sewage services.

The placement of sewer networks in areas without significant gradient has continued to be problematic. To fabricate a slope sufficient enough to assure the self-cleansing of sewage collector pipes results in increasing depths of excavation and pipe laying, which leads to appreciable increases in construction costs.

The application of flush devices also has great importance in areas where water conservation is in practice. Such programs often focus on the reduction of the amount of discharge volume in domestic appliances. This leads to a focus on W.C.'s as they are responsible for most of each house's water consumption.

In the hope of finding a solution which did not compromise on performance but successfully reduced the water consumption of a system, Brunel University developed a tipping tank to explore flushing alternatives. The main objective of the research was to create a tipping tank that could operate at the head of sewer collectors, whilst receiving all of the domestic waste water. This would then, in turn, allow the reduced discharge volumes of appliances (Swaffield, J.A. 1991).

In Scandinavia, syphon tanks continued to be developed (i.e. by SoVent) and used due to the introduction of the 3 litre discharge capacity W.C. The focus of this Swedish syphon tank was to serve isolated or grouped dwellings by being supplied by waste water. Constructed of plastic and with a volume of approximately 20 litres, the implementation of these devices has been successful in Sweden.

3 Testing the tipping tank

A prototype of a modern commercial tipping tank with a volume comparable to contemporary W.C.'s was obtained for testing and the tank's discharge profile was established.

Drain loading calculations have evolved slightly from the original work (Hunter, R. B. 1940) on the fixture unit/discharge unit design method. Values for each W.C. types needed to be assigned and a test to determine the discharge profile for each needed to be developed. Particular focus also needed to be given to the W.C.'s duration and peak flow. Numerous methods have been utilised, falling into two main categories, namely a mass versus time record and a volume discharge versus time record.

An earlier researcher (Pink, B.J. 1973) presented a form of the mass versus time record that illustrates the fundamental problem with this mode of measurement may be a necessity to "take out" the momentum of the discharge flow. This inevitably damps the peak flows recorded.

Uujamhan (1981) utilized the volume versus time methodology, however due to the formation of "waves" on the surface of the collection tank, "noise" was introduced into the readings.

Heriot-Watt University developed a method of calculating the discharge profiles of appliances prior to the turn of the century. Figure 1 illustrates where the volume versus time graph is obtained through a system of depth measurement at a range of locations corresponding the principal nodes and antinodes of the first three degrees of freedom over the surface of the collection tank. A pressure transducer records the average air pressure in vertical tubes distributed across the surface of the tank caused by changes in the rate of water surface height. There are 12 vertical tubes connected to 12 monitoring points and Figure 1 illustrates a comparison of the results obtained by each. The problems associated with the previous test methods are removed using this technique and the output has very good sensitivity and immunity from noise, permitting the detection, for example of the difference between a 6 litre clean flush of a W.C. and the same W.C. with 6 sheets of toilet paper included. This allows progress in improving models of drain loading and W.C. fluid contamination removal (Swaffield, J.A. 1993).

The results of the laboratory test procedure are illustrated in Figure 2. The graph demonstrates the discharge profile of the tipping tank which is then input into DRAINET for the simulations.

With the discharge profile calculated, the specialist drainage simulation software, DRAINET, could be updated.

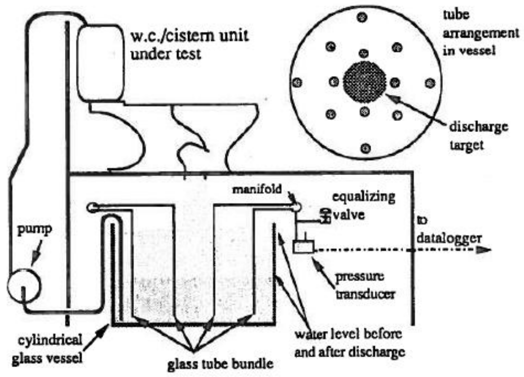

Figure 1 Schematic diagram of the device used to measure the flush characteristics of the tipping tank. It averages the air pressure increase in 12 glass tubes submerged in a tank of known dimensions (Swaffield, J. A. 1993)

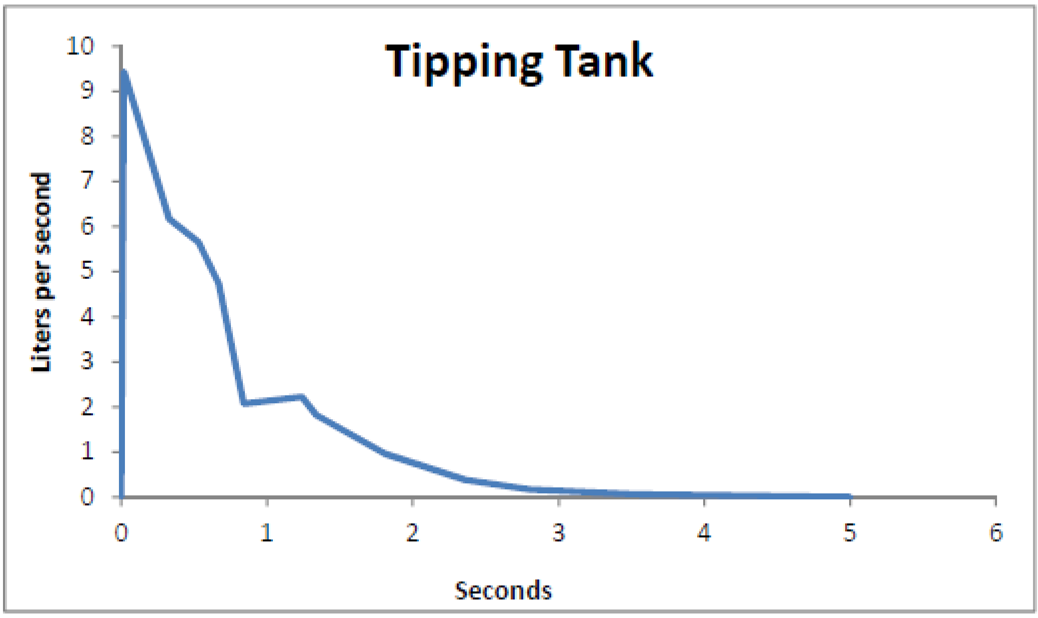

Figure 2 Discharge profile of tipping tank tested in the laboratory

3.1 Computer simulation software – DRAINET

A key tool in the study is a computer simulation package known as DRAINET which can simulate scenarios concerning drainage systems in general in order to determine the performance without having to construct the system or a physical model. When a simulation is run the program provides accurate predictions of flow depth, flow velocity, solid velocity and solid position represented clearly in graphical form.

Using DRAINET, it is possible to simulate drainage system configurations and then to conduct sensitivity analyses which can then be used to influence design procedures. The aim of this approach is to minimize potential maintenance problems while, at the same time, encourage water conservation. DRAINET is based on a finite difference scheme and utilizes the method of characteristics as a solution technique to simulate drainage system operation. This is done via the equations that define unsteady, partially filled pipe flows and the boundary conditions represented by pipes, junctions and other common system components.

A system, hypothetical or representing a real-life system, can be built up through the simple graphical user interface representing pipes, junctions and sanitary appliances etc., assembled schematically to represent the system.

3.2 Layout for drainage simulation runs

A regional water authority (Scottish Water) provided information related to a housing development in west central Scotland (Paisley). The development, Waulkmill Avenue, consisted of a number of houses with a known occupancy value for each. This, coupled with information on the layout of water appliances within the house, was then used to create a model within DRAINET.

The flow profiles for the shower, sink and W.C. were modelled in the Heriot-Watt University services laboratory and their capacities and length of time for operation were aligned to industry standards.

With regards to the dishwasher, washing machine and sink's flow rates and capacities, the

UK averages were found from research and these were incorporated into the simulation. One of the most important aspects of this research was the length of time at which it took the appliances to operate. On average, a dishwasher would take two hours to complete a wash cycle, this was the greatest length of time of any of the appliances. As a result, the entire simulation could not be run for any less than 7200 seconds with the diversity factor chosen. It was decided that it would run for 7300 seconds to ensure all appliances' discharge were accounted for.

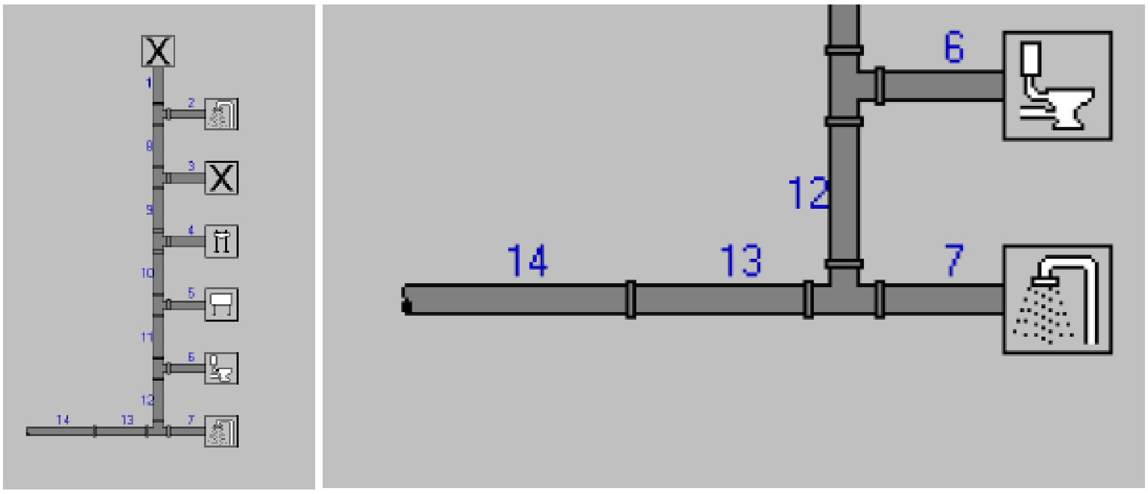

Figure 3 Single house layout with a close up of the solid's route from the W.C. to the outlet pipe and exit. Image is not to scale

Figure 3 depicts the layout of one house used in the simulations. The appliances were all assigned operation times to prevent a mass surge of water being input into the system. During the running of the simulation, only 3 types of appliances would experience a reduction in capacity/water conservation methods: W.C., showers and basin. The reason for selecting these appliances was based on them being the largest, in terms of capacity, within the dwelling with the exception of the basin, which was chosen because of the frequency at which it is used. A reduction in the operating capacity of the basin alongside no reduction in the W.C. does not render any change to the travel distance of the solid. The amount of water discharged by the basin is, therefore, negligible and does not affect the objective of the analysis of these runs. Each of the appliances was then subjected to a reduction in their capacities (80% and 60%) and every possible combination was then simulated.

3.3 Terraced housing

The purpose of the tipping tank is to reduce the overall water usage in housing developments whilst maintaining the required standards of drainage system performance. As a result of this, it would not be prudent to install a tipping tank into each individual property but to strategically place it so that it can benefit numerous properties.
With regards to the site at Waulkmill Avenue, there are terraced houses with 4 adjoining properties sporadically placed around the development. Therefore, the DRAINET model has been modified to include 4 identical, adjoined properties to the example used previously in this section (Figure 3). The exact same water conservation simulations were then performed.

3.3.1 Terraced housing: solid travel distances

The results, in terms of solid travel distance, are as shown in Figure 4.

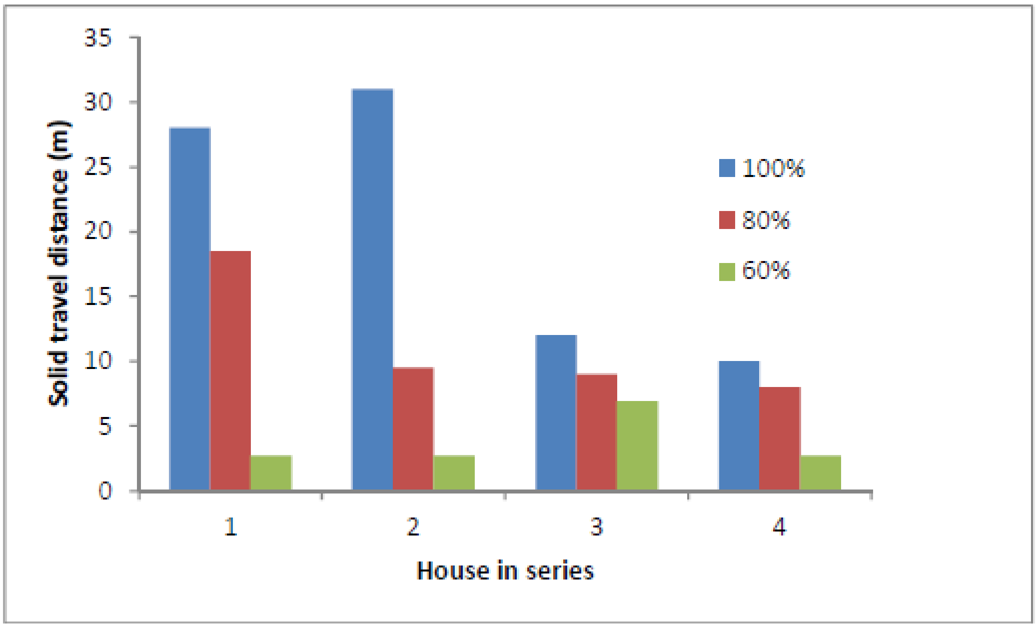

Figure 4 Graph of solid travel distance each house in series

It can be seen in Figure 4 that there was a reduction in the overall travel distance by the solid as the W.C. operating capacity dropped from 100% to 80% and 60%. The change in distance, however, is not linear with a large change observed between houses' 1 and 2 transport distance and with much smaller effect being observed in houses 3 and 4.
A reduction in the operating capacity of the showers alongside the W.C. culminates in a loss of travel distance for the solid. As predicted, the solid travels the least distance when the W.C. and showers are all operating at the minimum capacity, 60%.
It can be seen that the travel distance is only affected by the reduction in operating capacity of the shower alongside the W.C. The basin does not have any bearing on the results.

3.3.2 Terraced housing: solid behaviour

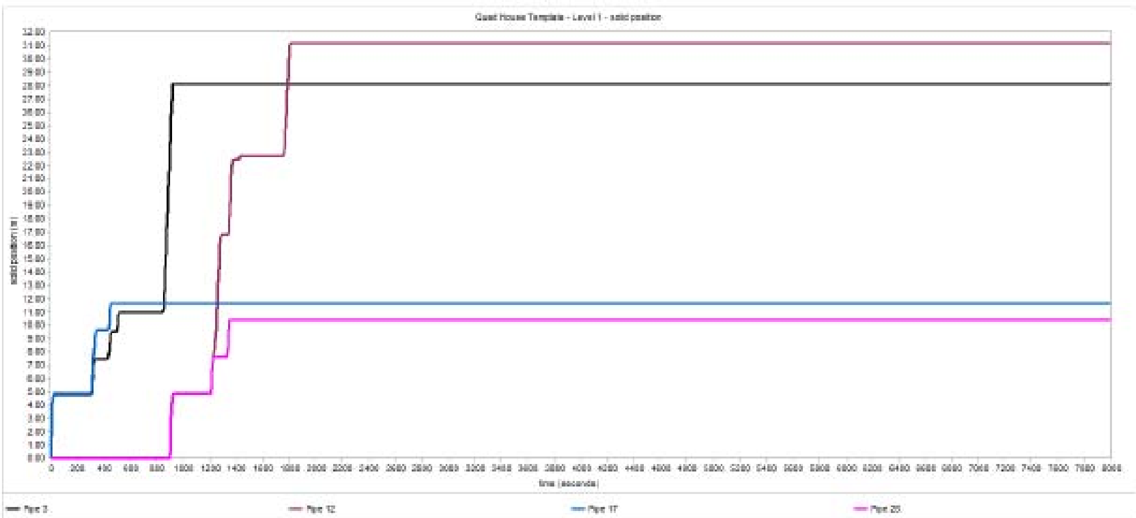

Figure 4 Solid position when appliance operation at 100%

The graph in Figure 5 depicts the movement of the solids that enter the W.C. during the simulation. It can be seen that the solids from house 1 (pipe 3) and house 2 (pipe 12) have a significantly greater carry distance than house 3 (pipe 17) and house 4 (pipe 26). This is the repercussions of the water output of houses farthest from the combined sewer pipe helping to move the solids entering further downstream towards the communal sewer pipe. The surge of movement from the solids from houses 1 and 2 can be attributed to the usage of an appliance (W.C. or Shower) from a house downstream of the pipe system. The graph in figure 5 also gives an insight into the behavior of the solid during times of low flow since its deposition will therefore require water flow with a large enough shear force to dislodge it from where it has deposited. This is testament as to why only appliances with a large flow profile (W.C. and shower) were considered for water conservation measures.

The levelling off of the graph line is a result of the solid remaining stationary in the outlet pipe despite their potentially still being water flow within the system. The solid has failed to completely leave the DRAINET system but it travelled a sufficient distance to suggest it made it out of the original house's pipe network (over 8m) and into the communal sewer pipe.

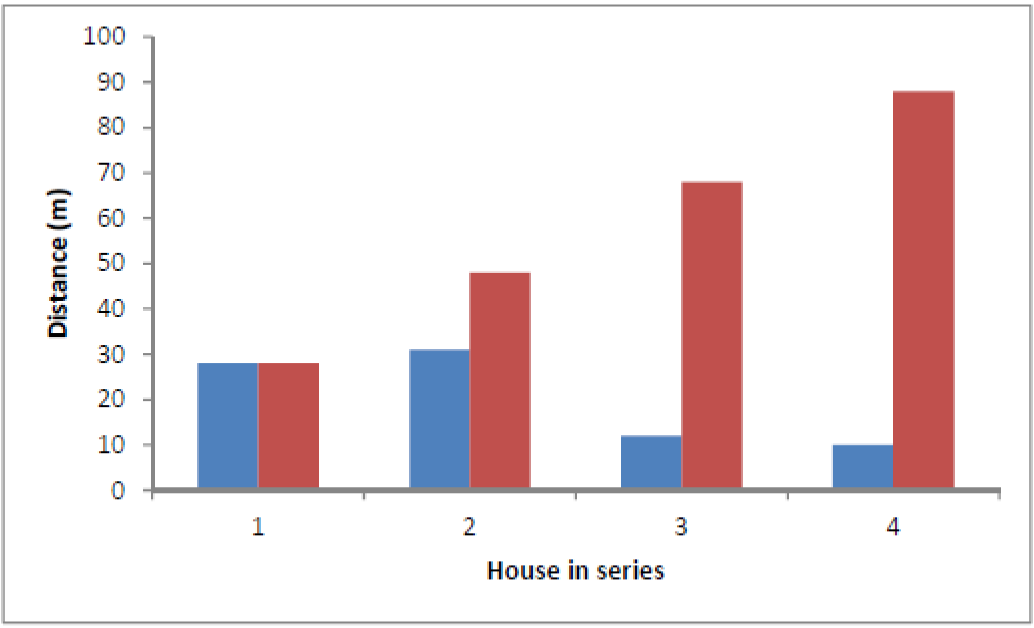

Figure 6 Solid position vs System end for each solid

Figure 6 illustrates the travel distance of the solid that enters the W.C. against the total distance the solid has to travel to exit the communal sewer system. The distances each solid must travel to leave the system increase with the addition of each house as they are further from the exit of the communal sewer pipe, therefore expecting all of the solids to leave the system in one operation is unrealistic. With each appliance operating at maximum capacity it can be seen that the solids from houses 3 and 4 travel relatively short distances, 12m and 10m respectively. When the system is reduced to 60% the distances of solid transport from houses 3 and 4 reduces to 6.9m and 2.7m respectively.
From the data provided by DRAINET, the tipping tank in this series of simulations as it was supplied from the manufacturer was a failure due to the solid travel distance being less of that observed in the simulations with the appliances operating at 100% capacity. Due to this lack of solid movement it can be concluded that the use of a small capacity tipping tank does not provide enough force to be maximally effective.
In the series of simulations with the appliances reduced to 80% of the water consumption this has saved approximately 200 litres of water when compared to zero water conservation measures in effect. This impacts the performance of the system. Using this information, a new, hypothetical (but still realistic) flow profile was created for the tipping tank. The aim was to utilise 10% of the water saved accumulatively from the terraced housing, but this time through an ‘idealised’ tipping tank profile, to demonstrate whether a tipping tank of better design could be beneficial despite the increased water consumption. The tipping tank would then be strategically placed so each of the solids entering the communal sewer pipe are downstream from the tank discharge.

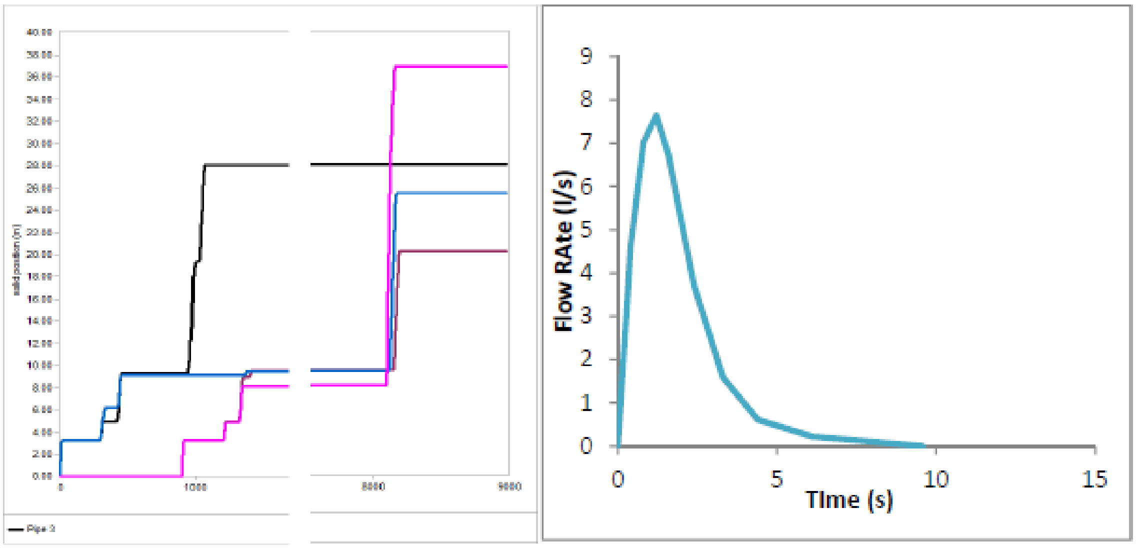

Figure 7 solid travel distances of the system with the tipping tank and the flow profile of the simulated tipping tank

3.3.3 Terraced Housing: Conclusion

In order to test the theory of using 10% of the conserved water, a new discharge profile was created and adjustments were made to create a more ‘ideal’ profile. Figure 8 displays the flow profile of the modified, computer-generated tipping tank. DRAINET data shows that with the modified tipping tank, there is a significant increase in solid transport distance from houses 3 and 4. A single discharge at the end of the initial DRAINET simulation showed increases in distance of 108% and 260% of solids 3 and 4 respectively, while maintaining a net water conserved regime.

4 Planned research continuation

The goal of the research was to establish whether or not introducing a tipping tank to a series of domestic properties could improve the overall efficiency of the DWV system and DRAINET simulations have shown this to be a potentially viable option.

Based on the results obtained from the DRAINET simulations, it is clear that the tipping tank must have the correct discharge profile in order to be effectively utilised. With the correct discharge profile in place, and with suitable dimensions and capacity, a sensitivity analysis can then be performed to determine the most efficient tipping tank usage scheme. With this information, it would then be possible to determine the most water-efficient combination of appliances within the DWV system without having an adverse effect on its overall performance.

The varying nature of housing developments would have to be considered. Housing positions, distances to communal sewer pipes and occupancy all vary around Scotland and the UK. Therefore, numerous sites must be modelled to deduce whether the placement of a tipping tank at Waulkmill Avenue (upstream from House 4) is the most prudent position for each individual development. Perhaps smaller, more frequently place tipping tanks would prove more successful; this should be tested.

Water appliances continue to evolve with the development of new technology and regulations. As a result, tipping tank design will have to follow suit and reflect the changes occurring within DWV systems.

5 Conclusion

DRAINET simulations with a maximally water conserved system indicate that the solid transport distance is less than with a non-water conserved system.
DRAINET simulations with a computer generated tipping tank demonstrate that in areas with water conservation appliances, tipping tanks can increase solid transport in the DWV system and can lead to water consumption reduction despite their additional water consumption.
DRAINET simulations with a computer generated tipping tank results in solids increasing their travel distances. This indicates that the application of a tipping tank has the potential to result in an improvement to drainage systems.

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Non-potable water systems: a sustainable solution or a risk to users?

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Abstract

Water shortage has improved management processes, waste control, and procedures and use of alternative sources of water not only in public systems, but also in building systems. Several initiatives exist to use non-potable water systems in residential and office buildings. Unfortunately, however, these initiatives have little technical support, nor any regulatory norms or legislations to guide managers and professionals on appropriate management and monitoring practices. This situation may put the safety of users and the success of the technology at risk. Considering that to produce a quality building, it is essential to take into account the needs of users, a performance evaluation of non-potable water systems becomes an important tool for the improvement of these systems and for the reduction of health-related risks to users. This paper, thus, aims to evaluate the performance of non-potable water systems of three residential buildings, with regard to design, implementation, operation, and maintenance. For the performance evaluation, case studies were carried out in residential buildings with non-drinking water systems. The results in the cases under study show a lack of systematic water quality control, the occurrence of cross-connection, the absence of identification of the specific type of water conveyor, and of booklets or guides for users. Therefore, these results highlight a lack of technical training of designers, builders, managers, and users and the absence of a specific legislation or of technical standards to regulate such systems. In conclusion, the cases studied are characterized by systems that operate with less-than-adequate performance to meet the needs and ensure the safety of their users.

Keywords
Non-potable water system, water reuse, performance evaluation.

1 Introduction

The use of non-potable water is a reality as an alternative source of water supply for buildings. For this reason, the technology for water treatment systems in buildings has been developed, yet much mustbe done to ensure the safe use of non-drinking water in buildings.
Security during implementation, use, operation, and maintenance of non-potable water systems in buildings depends on the management of consumption, water quality, and of the risks involved in all stages of the process, but not alwaysare these requirements observed simultaneously.
One of the impacts of non-potable water use in buildings that most encourages users is the reduction in the consumption of drinking water. A study conducted in five single houses with treatment system and reuse of greywater in England for a year points out that the use of non-potable water in water closets resulted in a 9-to-36% reduction in the consumption of drinking water in these units[1]. Another study conducted in Malaysia offers even greater values, witha reduction of up to 40% of potable water consumption in residential buildings equipped with this type of system[2].
The results are not always favorable to the reduction of drinking water consumption and, in many cases, no water consumption management takes place. This can be shown in a research study conducted in an office building in Brisbane, Australia, with a non-potable water system using rainwater. The results show that the system was only moderately reliable to meet the demand owing to operational problems. The analysis of the study shows the need to include validation and monitoring to ensure that the system is operating according to the purpose of theproject[3].
Another aspect for the success of this technology is the perception of users. In this regard, a research study conducted in the municipality of SantCugat, Spain, where the implementation of non-drinking water systems is compulsory in new buildings, the results show that the users' perception is very vulnerable to any failure that may occur in the system. Health hazards, operation, costs, and environmental awareness are, to varying degrees, essential for public acceptance[4].
With respect to health risks, a case of a project funded by the Dutch Governmentillustrates the problem. In a housing estate, although a number of precautions were taken during the design phase, some running errors contributed to contaminate drinking water in 1,000 dwellings due to a cross-connection between the potable and the non-potable water supplysystems[5].
This article, therefore, aims to evaluate the performance of three residential buildings, with one or more housing units, with non-potable water systems and to show the different faults that occurred due to lack of training of professionals of the design, implementation, operation, and maintenance of such developments.

2 Potable and non-potable water systems in building

A building water system features two subsystems of water: potable and non-potable water, as illustrated in Figure 1. Thus,different types of non-potable water sources for residential buildings include rainwater, wastewater and underground water, after treatment.

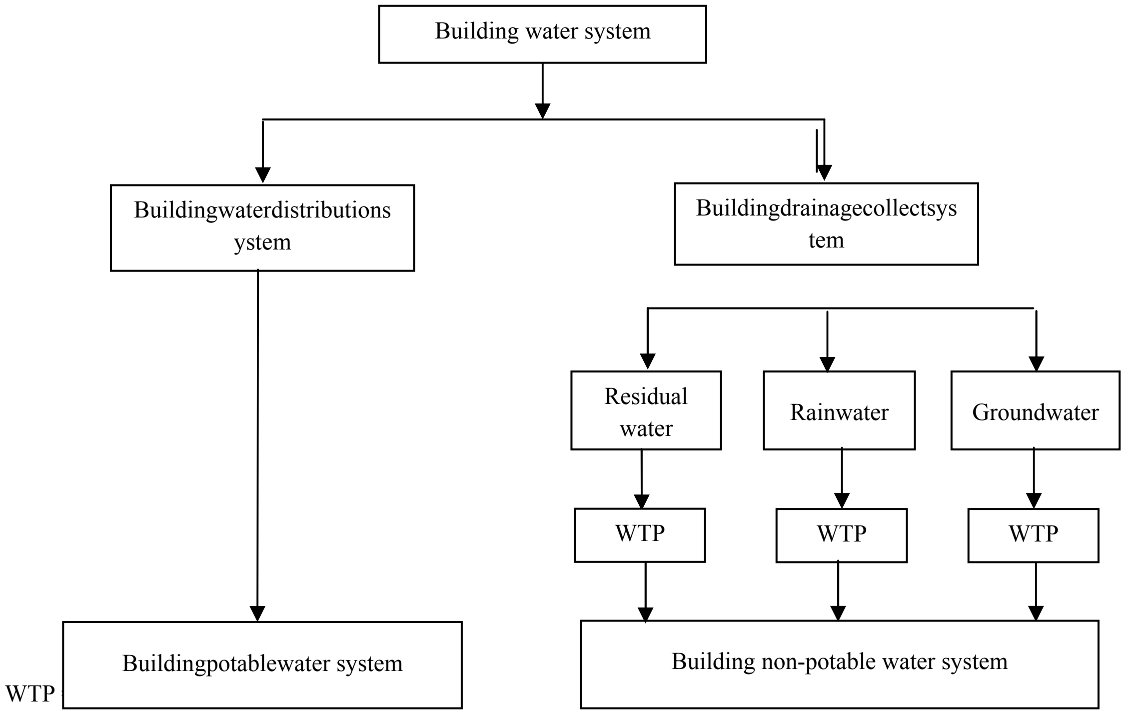

Figure 1 Building potable and non-potable water systems[6]

These features of the non-potable water system make it more vulnerable to risks of contamination than a conventional system of potable water, where only drinking water circulates in reservoirs and at all points of use. Figure 2 shows the types of non-potable water systems according to the generating water source and possible applications in residential buildings.

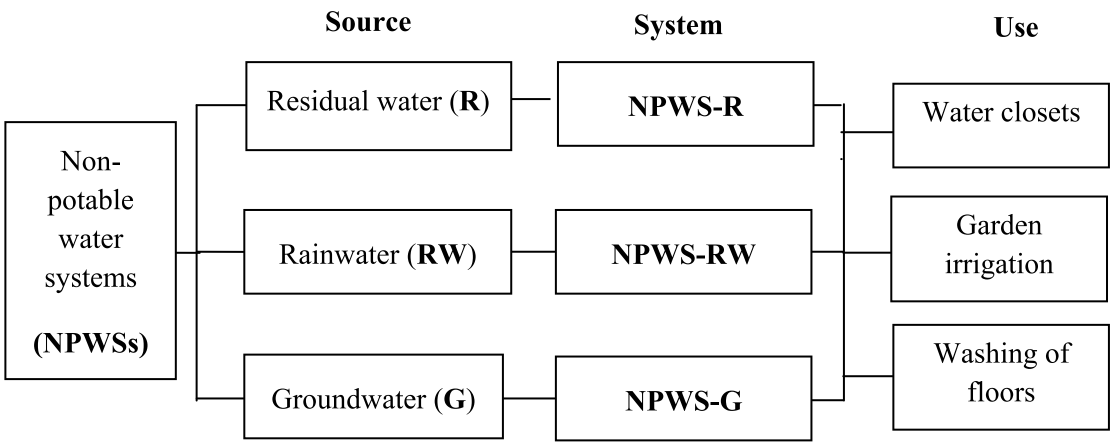

Figure 2 Non-potable water systems with different sources and uses in residential buildings[6]

From the different sources of non-potable water, the presentauthors[6]offer the classification of the following types of non-potable water systems for residential buildings:

- Non-potable water system-recovered (NPWS-R)

Set of pipes, tanks, equipment, and other components intended to collect greywater or blackwater, store, treat, and distribute the treated greywater or blackwater, the goal of which is to reduce both the demand for drinking water and the sewage volume for the collection, transportation, and treatment of toilet sewage.

- Non-potable water system-rainwater (NPWS-RW)

Set of pipes, tanks, equipment, and other components intended to collect rainwater, store, treat and distribute the treated rainwater, the goal of which is to reduce both the demand for drinking water from public or private networksanddampen the flowrates in urban drainage system.

- Non-potable water system-groundwater (NPWS-G)

Set of pipes, tanks, equipment, and other components intended to collect groundwater, store, treat, and distribute the treated groundwater, the goal of which is to reduce the demand for drinking water from public or private networks.

3 Methodology

The method adopted is that of case studies because it aims to understand and describe the way by which the non-potable water systemis usedin residential buildings, where several factors, such as training of professionals in operational and maintenance procedures, influence the performance requirement of "security in the use of water".

The studywas developed in the following stages:

- characterization of the condominium;
- characterization of the non-potable water system;
- semi-structured, face-to-face interviews with users and operators of the system, analysis of documents, in cases when this material was available, and unsystematic direct observations during field visits;
- from the data collected, a general narrative was drawn up foreach visited building by registering each case as a complete study.

4 Results and discussion

The characterization of the three condominiums under study, the description of the non-potable water systems, and the problems encountered are set out and discussed below.

4.1 Case study A

This is a condominium with seven 28-storey buildings, 392 apartments, and 1,500 inhabitants.
The sources of supply of the NPWS are: greywater collected from showers, washbasins, and washing machines; groundwater from drainage wells; and rainwater collected from the roofs and condominium floors.

The rainwater does not receive the same treatment as the greywater and groundwater. Rainwater is filtered and conducted tothe non-potable water reservoir. The greywater and groundwater are treated through the addition of chemical products by automatic feeders. The quantities and periods of addition of chemicals are programmed by system operators.

The identification of containers of chemicals that fuel the system, however, does not correspond to those found in the feeders. Thus, it cannot be confirmed if the chemicals used remain those defined during the project phase. After chemical treatment, the water passes through a filter.
The non-potable water obtained after treatment is conducted to the underground tank of non-potable water, where a blue dye is added. Thenon-potable water is conveyed to the upper reservoirs of each one of the condominium towers.
A foul smellwas observed in the underground non-potable reservoir. There is an entering point of drinking water supply in the underground tank that can be used to supply the NPWS in case of system failure.
Regardingpipe identification, there is not a different color for the NPWS. Green stretches of non-potable water pipes were observed, the same color as that used for drinking water pipes, as illustrated in Figure 3. Pipes of different colors were used, without identification of the type of water theyconvey, with a risk of cross-connection in future maintenance or system changes.

Figure 3 Pressure reducing station of non-potable water with the same color as that of the drinking water pipes

A cross-connection was detectedright afterthe system was put into operation. Some users installed a hygienic shower in bathrooms by adding an extension to the water branch of the water closet without knowing that that stretch of pipe was being fed by non-potable water. During the testing phase of the NPWS, the addition of a dye to non-potable water identified this irregularity in the installation of hygienic showers.
Inadequate quality of water was detected in one of the drainage wells used as a source of groundwater, which went on to havea foul smell. The laboratory analysis of water samples from this well had characteristics that were not in compliancewith the use for which it was intended and, therefore, it is no longer used as a source of NPWS.

The users received information about to the NPWS through letters, communications on elevator bulletin boards, and emails. This information is offered to new residents when they register for access to the condominium. No guides or manuals exist to inform NPWSoperators orusers about the risks inherent to the system, and no newsletter about its operation and maintenance is made available.

The condominium doesnotmanage water and energy consumption levels, which does not afford an analysis of whether or not a reduction impactof these inputs has occurred.

4.2 Case study B

This is a condominium with four 22-storey buildings, 264 flats, and 898 inhabitants.
The original design did not provide a non-potable water system for the building. The users decided to implement a system to make use of rainwater in order to reduce drinking water consumption. In addition to the rainwater collected from roofs and floors,water from washing the filters of the pool is also used as a source of NPWS supply, owing to an understanding that the chlorine present in this water helps disinfect the storedeffluent.
Non-potable water does not receive any kind of treatment, and it is only used to wash the floors of communal areas. There is no pipe conveying non-potable water from the reservoir to the points of use. A pump and a hose were installed in this reservoir. The floors are washed with this hose, using non-potable water pressurized directlyfrom a pump. When the reservoir cover (Figure 4) was open for inspection, plastic packaging waste was found in the water, as can be seen in Figure 5.
Pipes remain brown for rainwater pipes and not purple as an indication of non-potable water. No points of use are fed by non-potable water. The water is used by means of a hose installed in the reservoir. Neither is there any type of signage or identification at the point of non-potable water. The water does not receive the addition of a dye to differentiate it from drinking water,nor does it undergo monitoring or quality control.

Figure 4 Access cover of the non-potable water reservoir

Figure5 Inside the non-potable water reservoir

System management is performed by the janitor, who does not maintain a preventive maintenance routine.
No guides or manuals with technical guidance of the system are available to the NPWS operators or to the users. Those responsible for the operation of the system received only verbal guidelines. The usershave never been informed about the risks inherent to a non-potable water system, nor have they received any information on the operation and maintenance of the system.
The condominium does notmanage water and energy consumption levels, which does not afford an analysis as towhether or not a reduction impact of these inputs has occurred.

4.3 Case study C

This is a horizontal condominium with eight dwellings, designed under the ideal of a sustainable construction, located in a densely-wooded terrain and with a population of 31 people. The eight houses are high off the ground, and they have terraces and private gardens that integrate with collective-use areas.

As sources of supply, the non-potable water system uses wastewater, consisting of greywater, and blackwater, collected from all the sewage from the houses, and groundwater taken from a well. Only the wastewater passes through a treatment system. After treatment, the non-potable water is used for flushing inwater closets, floor cleaning of common areas, and irrigation of gardens and the collective vegetable garden. Rainwater is not used.

The treatment system used is the physicochemical and biological type and the addition of chlorine to non-potable water is made manually by a condominium employee weekly. The water collected from the well doesnot pass through any treatment and is conducted directly to the undergrounded tank of non-potable water. The water in the undergrounded tank and in the well has a cloudy appearance, as can be seen in Figure 6.

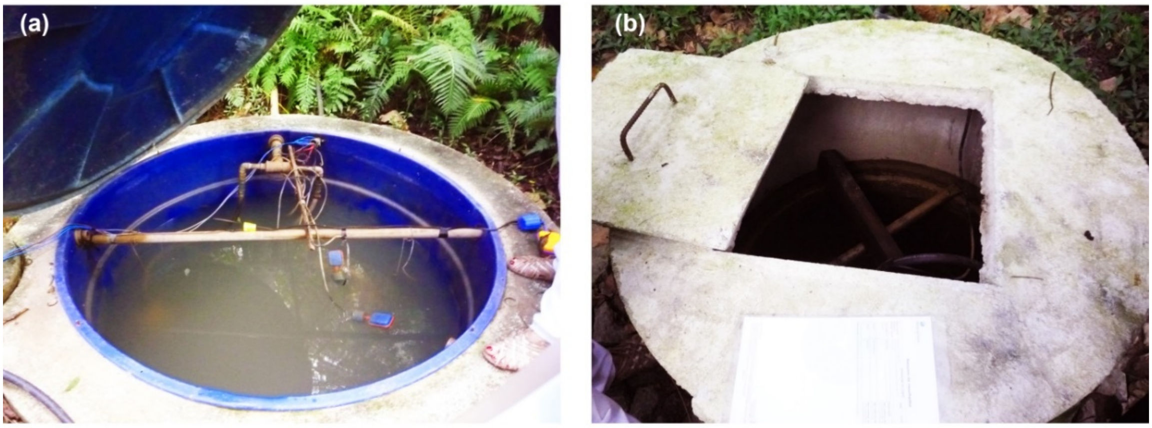

Figure 6 Aspect of the water in theundergrounded tank (a) and in the well(b)

From the undergroundedtank, non-potable water is conveyed to the roof tank. This reservoir can be filled manually by drinking water, in case of failure in the NPWS-R. Non-potable water is distributed by gravity to the points of use.

The NPWS-R piping does not show differentiation by color or identification of any sort. In addition, the same type of pipe was usedfor the distribution of both drinking water and non-potable water. Figure 7 shows the pipes inside the shaft of one of the houses.

Figure 7 Inside a shaft with no identification that differentiates the pipe systems

The NPWS-R management is performed by the condominium janitor.Only corrective but no preventive maintenance is performed in the system. Follow-ups with visual inspection and cleaning without disinfection of reservoirs occur monthly.

In 2014, a cross-connectionwas reported in one of the houses. After an installation of a hygienic shower,next to the water-closet,the users noted that the newly-installed sanitary equipment ran out of water during the period in which the NPWS-R was turned off for maintenance, which indicated that the hygienic shower was being fed by non-potable water.

The condominium does not routinely control non-drinking water quality, but in early 2015, the residents noted that the non-potable water was of an unpleasant color and odor, causing stains on water closets. For this reason, water samples from the non-potable-water roof tank and from the well were collected and sent for laboratory analysis.

The sample from the non-potable-waterroof tank showed non-compliance for the following parameters: total dissolved solids andthermotolerant coliform bacilli. The well water sample showed non-compliance for: color, pH, turbidity, total coliform bacilli, Escherichia coli, and heterotrophic bacteria count.

Despite the non-compliance instances identified in laboratory reports, the NPWS-R was not disabled. For security reasons, the condominium decided no longer to use non-potable water in the irrigation of the collective vegetable garden.

No booklets or manuals exist with technical guidance on the operation and maintenance of the system. Employees were advised verbally on how to operate and maintain the system. The residents received the information during a meeting with the engineer responsible for the project, having been made aware of the risks inherent to the system. There is no periodic recycling of this technical information and users are informed by emails about the maintenance of the system and of all the condominium, as interventions occur.

The condominium doesnot manage water and energy consumption levels, which does not afford an analysis as to whether or not a reduction impact of these inputs has occurred.

4.4 Results and discussion

Categories were established from the information obtained in the case studies, which enabled a general analysis of the evidence obtained. The six categories set out are: water supply, treatment system, installations, points of use, and operation of the system.

- **Watersupply**

This category shows that two condominiums aresupplied with rainwater and groundwater, one with greywater and blackwater, and the other with rainwater and the effluent of a pool.

Among the dwellings that use rainwater, none offers an automatic system for disposal of the first water that runs down the roofs and other collectingsurfaces. Rainwater comes from the roofs and floors, without any separation.

- **Treatment system**

In analyzing this category, it was verified that one of the buildings does not have a collected effluent treatment system. Regarding the two condominiums that have treatment stations, in one of them, based onlaboratory analysis water qualitydata, it was found that the treatment process is not suited to the source used, and produces water of a lower quality than is required for its intended activities. For the other two, insufficient data prevent such an evaluation.

- **Installation**

In this category,it is possible to say that none of the case studies offered differentiation of non-potable water pipes by color.

In one of the case studies, the non-potable water tank does not have any components that allow supplyingit with drinking water, in case of operational failures in the NPWS. Of the two projects that count on a drinking water supply point in the non-potable water reservoir, one does not have a reflux prevention component of non-potable water at the drinking water supply pointand in the other, it was not possible to confirm the presence of the security component.

- **Points of use**

In this category, two of the condominium buildings use non-potable water for water closetflushing, two of them, for cleaning floors, and one of them, for irrigation of gardens.

Only one of the developments has differentiation of NPWSpoints of use by color, only one of the three condominiums had signs at points of use, alerting users as to the distinct quality of water, and none of them keeps restricted access to non-potable water.

- **Operation**

In this category, only one of the condominiums performs a continuousaddition of a dye to non-potable water to differentiate it from drinking water. Only one of them carries out preventive maintenance of the system.The other two onlyconduct corrective maintenance. Most of the time, the system management is carried out by the janitor or another

employee of thecondominium. Only one of the buildings has hired a company specialized in management.
One of the condominiums undergoes water quality control, with periodic laboratory analyses of water samples collected in the system. None of the buildings visited manages non-potable water or electric power consumption of the system. Thus, they cannot assess the performance of the NPWS with regard to water and energy consumption.
Concerning occurrences and irregularities identified in the NPWS during operation, two condominiums reported incidents of cross-connection in the system and verified that low-quality non-potable waterwas produced for its intended use.

5 Final considerations

The NPWShave been implemented in residential buildings in Brazil as an alternative source of water in order to reduce potable water demand. The evaluation carried out in three condominiums shows that the scenario is characterized by NPWSsthat operate with less-than-adequate performance to meet the needs and ensure the safety of users. Among the critical points are the following:

- the supply source changed without changing the treatment process;
- the absence of quality control of non-potable water prevents the assessment of the treatment system, for in monitoring the characteristics of the water produced, the efficiency of the treatment plant is also monitored;
- the systems do not follow the standardization of color, nor do they have water quality information, which increase the risk of cross-connection;
- managers, operators, and users have no manual or booklet available with information on the risks inherent in the system and recommendations for its operation and maintenance;
- two of the three cases studied showed inadequate quality of the water produced and two, cross-connection, situations that expose users to health hazards.

Finally, the results of the case studies show that the success of this type of system depends on the existence of procedures, technical manuals, and regulations that guide practitioners, managers, and users about the implementation, management, and monitoring of these systems to ensure the quality of the water produced and prevent any risks to users and to the environment where they are found.

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7 Presentation of Authors

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Using analogy of heat transfer by conduction and water flow in the soil for determining the overflow time of dry-wells

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Abstract

Seeking to maintain the water balance of built-up areas, the storm water infiltration systems have been used as structural compensatory techniques in order to mitigate the increase in runoff volume caused by the sealing of urbanized areas. These systems act inducing, wholly or partial, infiltration of storm water intercepted by built parts from a lot, on the ground of the own region occupied. Thus, reduce the discharge of large volumes of runoff in urban drainage system, promoting the recharge of groundwater sources and contribute to urban flood control. However, the techniques currently used for the design of storm water infiltration systems are not always so accurate, because it involves many difficult variables determination, and usually carry on an oversizing of the systems. To improve the understanding of the operation and to facilitate the evaluation of hydraulic behaviour and more precise design of storm water infiltration systems, from the construction and monitoring of hydraulic performance experimental dry-wells tested in-loco, considering design flow rates of 2.8 and 10.5 m^3 / h was applied the heat fluxes analogy model on solid media to determine the total filling time and system overflow. The proposed model resulted in a data prediction close to 15% of the relationship between the experimentally measured data and simulated data for the proposed analogy. Thus, it was found that the proposed model can contribute to a consistent prediction of values when compared to what occurs in practice, contributing in this way to more precise definitions of the hydraulic behaviour of the storm water infiltration systems, such as: filling and overflowing time knowledge, saturation time of the aggregate-soil interface, soil retention field capacity, among others.

Keywords

Storm water infiltration; on-lot drainage; dry-well; source drainage, low impact development, heat transfer, hydraulic modelling.

1 Introduction

The urbanization process produces impacts on the water balance of the cities. The increase of impermeable surfaces and built-up areas resulting in decrease of water infiltration and increase of peak flow, volume and speed of runoff, which contribute to the higher incidence of urban flooding.

Seeking greater efficiency of drainage systems in urban areas, the design of a set of drainage systems who act jointly, covering specific solutions to micro, meso and macro levels has been proposed, in order to prevent each urbanized area to expand the natural run-off and to transfer the problem among levels [1] [2].

An important part of a more sustainable urban drainage system are the compensatory drainage solutions applied to building systems (on-lot drainage systems), developed by applying the LID (Low Impact Development) practices [3]. According to [4] and [5], these techniques are applied to small parts of the urban land, which aim to preserve the land natural water balance characteristics by means of engineering actions and, thus, enable more sustainable management of stormwater within built lots. Among the various on-lot drainage systems, those that promote water infiltration into the soil, such as the dry-wells, have been widely used.

The design and performance evaluation of stormwater infiltration systems are not always easy, because of the many variables involved, related to climatic factors, soil characteristics and others [3]. In this way, mathematical modeling techniques can assist in obtaining more accurate data for the design of stormwater infiltration systems.

This research aims to evaluate the hydraulic performance of a dry-well, considering different design flows and, from that, propose a model for determining the total filling time, based on the analogy between the water flow in the soil and heat flow on solid media.

2 Method

An experimental apparatus was constructed in the State University of Campinas (Unicamp), Campinas, SP – Brazil, for the assessment of the hydraulic performance of the dry-well during filling and draining.

The experimental apparatus is the same structure as studied by [6], and it is composed by a cylindrical excavation with 1.50 m depth (net high 1,37 m) and 1.10 m diameter (Figure 1). The side walls of the dry-well are composed by overlapped perforated concrete pipes, externally lined with geotextile fabric and filled at the sides with crushed stones aggregates with diameters between 9.5 and 19 mm at the sides, acting as an interface between the fabric and the soil. The bottom is also composed by a 50 cm layer of the same type of crushed rock aggregates covered by a geotextile fabric. The net volume of the well is approximately 1.1 m^3 (internal storage volume and crushed rock layers of the bottom and side).

Figure 1 Stormwater infiltration dry-well [6]

According to the Unified Soil Classification System (USCS) [7], soil in the experimental area is classified as sandy clay (CL).

The assays were performed with water discharged by centrifugal pumps with adjustable flow and ultrasonic meters for measuring water flow in real time. The assay flow rates were of 2.68 m³/h for 50 minutes and 11.01 m³/h for 14 minutes.

Aiming to simulate the worst functioning condition of the infiltration systems, the experimental units were filled and drained three times in a row, before each test, to increase the moisture and saturation degree of the soil in the region surrounding the infiltration systems. Thus, data were stored just at the fourth filling procedure.

The dry-well overflowed volume was conducted to a buried 500 liters reservoir. The measurement of filling, retained and overflowed volumes was done by level sensors model HOBO U20-001- 01 installed inside the dry-wells and reservoirs.

Finally, these sensors were used to determine the infiltration rate, using the methodology defined by [7]. The infiltration rate was $1,995.10^{-5}$ m³/ m²/s for the test with the lowest flow rate and $3,511.10^{-5}$ m³/m²/s for the test with the highest flow rate.

Hydraulic profile and the downstream hydrograph were determined using the input, overflowed and infiltrated volumes and the emptying time.

2.1 Model for the determination of filling time

Similarly to the variation of internal energy caused by heat flow in a solid, there is a moisture change with the flow of water in the soil. Thus, taking into account the control volumes composed by the dry-well and the lower ground layers (Figure 2), the moisture can be determined in function of the time by:

- water flow in the crushed stone on the bottom of the dry-well with ΔXp thickness, represented by moisture hp^{m+1} (stone "p" in time "m+1") (Equation 1):

$$h_p^{m+1} = h_p^m + \left(\frac{2 * k_{s,1} * A_p * \left(h_1^m - h_p^m\right) + Q_p}{\Delta X}\right) * \frac{\Delta t}{\left(A_p * \eta_p * \Delta X_p\right)} \quad (1)$$

- water flow in the first layer of soil under the crashed stone, with ΔX thickness, represented by moisture h_1^{m+1} (layer "1" in time "m + 1") determined by Equation 2:

$$h_1^{m+1} = h_1^m + \left(\frac{2 * h_p^m - 3 * h_1^m + h_2^m}{\Delta X}\right) * \frac{k_{s,1} * \Delta t}{(\Delta X * \eta_{s,1})} \tag{2}$$

- water flow in the layer "i" (generic) of soil with ΔX thickness, represented by moisture h_i^{m+1} (layer "i" in time "m+1") Equation 3:

$$h_i^{m+1} = h_i^m + \left(\frac{h_{i+1}^m - 2 * h_i^m + h_{i-1}^m}{\Delta X}\right) * \frac{k_{s,i} * \Delta t}{(\Delta X * \eta_{s,i})} \tag{3}$$

- water flow in the layer "n" of soil with ΔX thickness, represented by moisture h_n^{m+1} (layer "n" in time "m+1") Equation 4:

$$h_n^{m+1} = h_{n-1}^m + \left(\frac{h_{n-1}^m - h_n^m}{\Delta X}\right) * \frac{k_s^n * \Delta t}{(\Delta X * \eta_{s,n})} \tag{4}$$

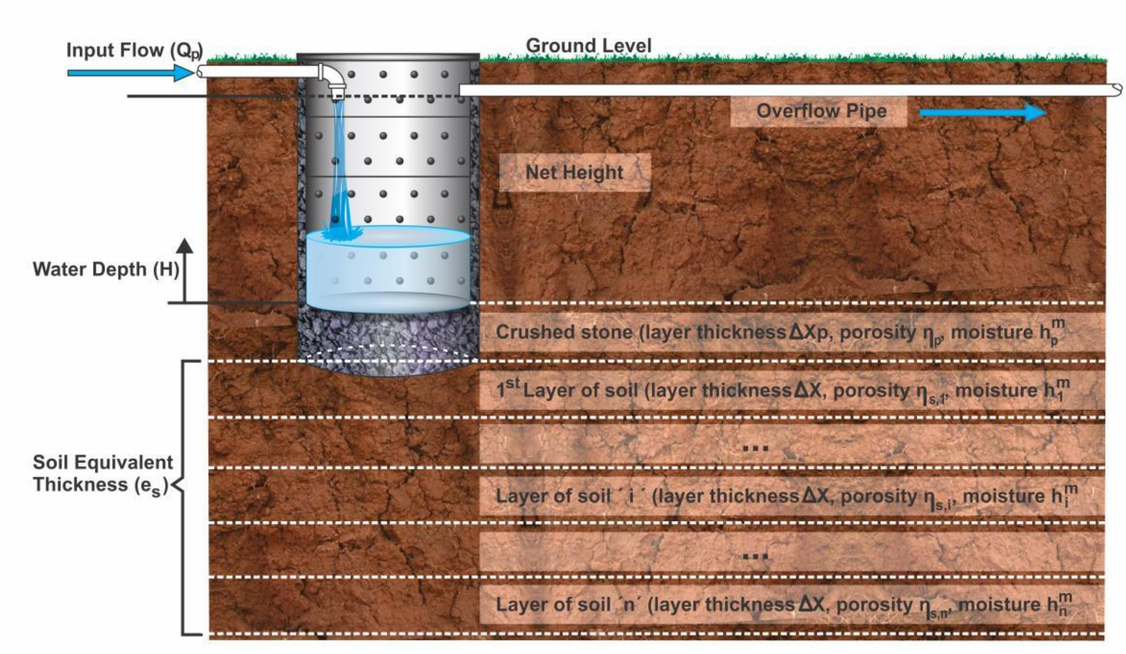


Figure 2 Model parameters - Drawn from [11]

For the determination of moisture in each layer, it is necessary to know the porosity of soil and crushed stone.

The porosity of the crushed stone can be experimentally determined as in [8]. For soil, it was used the drainable porosity, that is, the set of soil pores that can not hold water against the force of gravity, which can be determined by equations showed in Table 1.

Table 1 Soil drainable porosity from hydraulic conductivity [9]

Author	Equation	Unit of hydralic condutivity -Ks
Van Beers (1965)	$\eta = Ks^{1/2}$	cm/ day^{-1}
Chossat e Sagnac 1 (1986)	$\eta = 0{,}025 + 0{,}006\ Ks^{1/2}$	m. day $^{-1}$
Chossat e Sagnac 2 (1986)	$\eta = 0{,}0153 + 0{,}017\ Ks^{1/2}$	m. day $^{-1}$
Chossat e Sagnac 3 (1986)	$\eta = 0{,}033\ Ks^{0{,}289}$	m. day $^{-1}$
Otto 1 (1988)	$\eta = 6{,}37238 + 0{,}457879\ Ks^{1/2}$	cm. day $^{-1}$
Otto 2 (1988)	$\eta = 2{,}53619\ Ks^{0{,}309505}$	cm. day $^{-1}$
Poulsen (1999)	η = 10 [(logks-4,3)/2,8]	cm. day $^{-1}$

Legend: η = drainable porosity Ks = hydraulic conductivity

For this study, soil hydraulic conductivity was determined by [6], based on [10], using drawdown test in a dug well auger (0.15 m diameter and 2.50 m depth)
Equations 1 to 4 refer to the process of filling the dry-well; so the moisture in time "m + 1" must be greater than the moisture in time "m"; for this to happen, the multiplicative part, which contains the parameters: hydraulic conductivity (Ks), iteration time (Δt), layer thickness (ΔX) and porosity (η) must be greater than zero, for ensuring the convergence of iterations.
For the convergence, it is determined the minimum value of the thickness of the analyzed layer, by isolating the value of the layer thickness (ΔX) of the other parameters (Ks, Δt, ΔX) and taking up ΔX equal to the minimum value of the thickness. Because of this convergence depends on the Ks and porosity η, it is adopted the value that corresponds to the lower ratio between these two parameters.
The infiltration system has infinite soil layers under the crushed stone layer, being it is necessary to determine the depth of soil to be analyzed; in this study, it was used equivalent thickness concept, that is, in heat flow, the thickness of an element driving the same heat flow, at the same time, of another element with different thickness. In the case of hydraulic flow, the equivalent thickness can be determined by Equation 5:

$$e_s \quad \frac{\eta_p}{\eta_s} e_p \tag{5}$$

Where:
es = soil equivalent thickness [m];
ηp = porosity of crushed stone, determined by [8] [%]
ηs = soil porosity, Table 1, by convergence process [%]
ep = crushed stone thickness [m]

Values of moisture “h” were obtained by Equations 1 to 4, for each time period t = 10s, (which is the same time period used for the experimental data).

From values of layer moisture "h" as a function of time, it was determined the water depth “H” in the time “ m+1”, by Equation 6:

If $hp^{m+1} \leq \eta$, H = 0 cm

(6)

If hp^{m+1} □ η, $H = (hp^{m+1} - \eta)^{*}$ Xp

Water depth is determined from the filling of the crushed stone with porosity η.
At the time corresponding to the calculated value of the water depth "H" equal to the overflow net height of the experimental dry-well, the iteration process ended, obtaining the filling time for the model.

3 Results and discussion

Figure 3 shows hydraulic profiles of filling and overflow of the experimental dry-well and the overflow discharge hydrographs for the input flows.
The period of time until the beginning of overflow, that is the filling time, defines the net volume required for the dry-well; the overflow time, on the other hand, allow us to determine the rainwater volume damped relative to the total discharge volume.

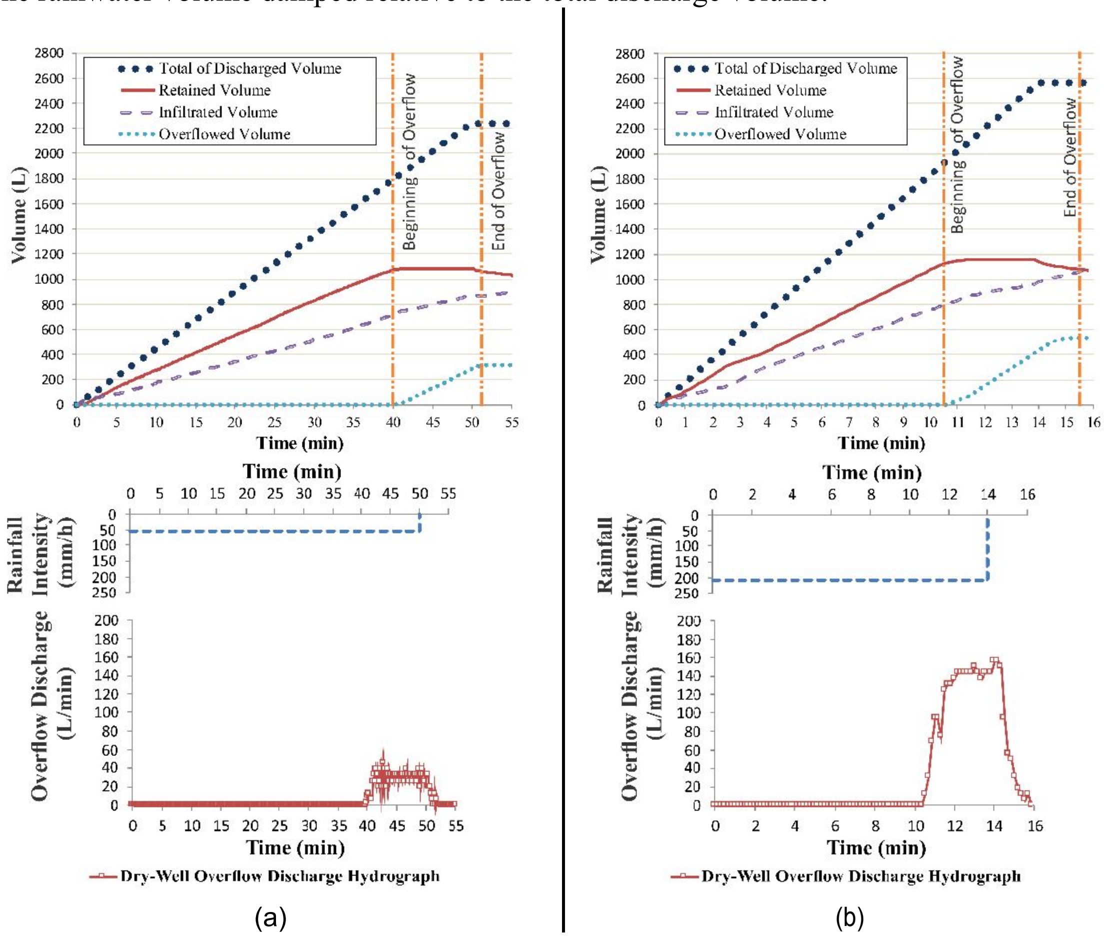
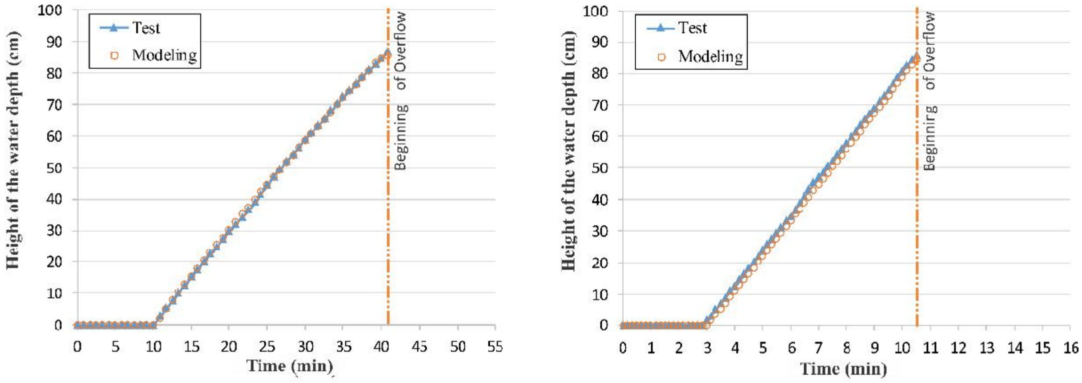


Figure 3 – Hydraulic profiles of filling and overflow of the experimental dry-well and overflow discharge hydrographs: (a) input flow of 2,68 m³/h over 50 minutes and (b) input flow of 11,01 m³/h over 14 minutes.

For the input flow of 2.68 m³/h, the filling time of the dry-well, until the beginning of the

overflow, was 40 minutes. Considering the total assay time, 86% of the total input volume was retained and infiltrated. For the input flow of 11.01 m³/h, the filling time until the beginning of the overflow was 10 minutes and 30 seconds. In this case, 79% of the input volume was retained and infiltrated.
Using the proposed model, the minimum value of the thickness of the soil layer was 0.09 m and the equivalent thickness was 0.36 m, totalizing four layers 0.09 thickness.
Figure 4 shows the values of the water depth within the dry-well obtained experimentally and by the proposed model for both input flows. Correlation coefficients (R^2) of 0,999978 e 0,999915 indicate proposed model fits properly.



(a) (b)

Figure 4 Water depth within the dry-well: (a) input flow of 2,68 m³/h for 50 minutes and (b) input flow of 11,01 m³/h for 14 minutes.

Dry-well filling times, obtained in the experimental set and by the proposed model, for both input flows, are showed in Table 2.

Table 2 Dry-well filling times

Input flows (m³/h)	filling times		Diference between measured and modeled values (%)
	measured	modeled	
2.68	40 min	40 min 50 sec.	2.04
11.01	10 min 30 sec	10 min. 30 sec.	0.00

4 Conclusion

The hydraulic profile of an experimental dry-well considering two input flows were evaluated in this paper. From experimental data, a model based on analogy of heat flow and water flow was proposed for determining the filling time of the dry-well.
The biggest difference between measured and modeled values of the filling times was 2.04%, which shows the goodness of fit the proposed model. Besides the proximity of results, correlation coefficients near to 1 (one) were found when comparing the modeled and observed results, indicating a strong correlation between them.
Thus, it can be concluded that, for the water infiltration modeling proposed in this work, the analogy of water flow in the soil to heat flow in solid media is a viable mean to determine the ability damping rain water dry-wells, representing an advance of the knowledge in this area.

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Rainwater harvesting in buildings with green roofs: Runoff coefficients

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Abstract

In the face of climate change, it is imperative to assess their effects in buildings, as well as study mitigation and adaptation measures to be implemented in new constructions or in building rehabilitation. The use of green roofs on buildings, for example, 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. On the other hand, rainwater harvesting is also important in urban areas, not only as a contribution for the global sustainability of buildings, through the increase of their water efficiency, but also to reduce flood peaks on public storm water drainage systems. Green roofs technology combined with rainwater harvesting is particularly promising, although further studies on the water quality runoff, depending on the plants and substrates used, as well as the study of the runoff coefficients are still needed.
This paper describes studies within the combination of conventional green roofs with rainwater harvesting systems in a Mediterranean climate, in terms of determining runoff coefficients using pilot green roofs. Additionally it will be discussed the use of agglomerate cork as an alternative drainage layer to the traditional cup-style product. Is presented a new expression to estimate of the monthly runoff coefficients under Mediterranean climate in extensive green roofs and are described ongoing studies with new solutions for green roofs, as well the drainage capacity evaluation of the agglomerate cork boards with different densities. Are presented several results that enable the adoption of new solutions for green roofs and the sizing of rainwater utilization systems combined with such roofs.

Keywords

Green roofs, rainwater harvesting, runoff coefficients, agglomerate cork.

1 Introduction

Impacts of climate change on urban environments are starting to feel. By the end of this century global average temperature will rise 2.6 to 4.8 ºC higher than at present (Chalmers 2014) and the increased intensity and frequency of heavy rainfall and other extreme weather events, such as heat waves is expected to intensify in the next decades (Ekström et al. 2005).

In the face of climate change, it is imperative to assess their effects in buildings, as well as study mitigation and adaptation measures to be implemented in new constructions or in building rehabilitation. The use of green roofs on buildings, for example, 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 (Silva-Afonso & Pimentel-Rodrigues 2014).

On the other hand, rainwater harvesting is also important in urban areas, not only as a contribution for the global sustainability of buildings, through the increase of their water efficiency, but also to reduce flood peaks on public storm water drainage systems, improving stormwater management(Kasminet al. 2010; Stovin 2010). Green roofs technology combined with rainwater harvesting is particularly promising, although further studies on the water quality runoff, depending on the plants and substrates used, as well as the study of the runoff coefficients are still needed (Monteiro et al. 2016).

In this paper presents the results of a study to determine the run-off coefficients in a conventional extensive green roof, located in a Mediterranean climate region and planted with native species, and is also referred an ongoing study, which aims to develop innovative solutions for green roofs, with use of agglomerate cork substrates.

2 Determination of run-off coefficients in green roofs: The results of a pilot system in Mediterranean climate

2.1. Run-off coefficients in conventional extensive green roofs

The implementation of green roofs can have many environmental and economic benefits, such as mitigation of the urban heat island effect, improve air quality in urban areas, add aesthetic value to urban architecture, enhance biodiversity and increase the life span of the building materials (Berndtsson 2010; MacIvor et al. 2013). On the other hand, the construction of green roofs combined with rainwater harvesting systems appears as a fundamental measure to reduce peak flows in the drainage of stormwater, improving the water management in urban areas (Silva-Afonso & Pimentel-Rodrigues 2014).

This is achieved by collecting the rainwater into the growing substrate and drainage layer and storing the runoff in a rainwater harvesting tank, thereby reducing peak runoff into the public drainage system, helping to prevent overflow in stormwater systems and creating an alternative source of water for use in buildings (Lee et al. 2013). Systems for rainwater harvesting in buildings are particularly suited to answer the many impacts of climate change because besides reducing the flood peaks in urban areas, it promotes additional water storage in buildings.

The combination of green roof technology with rainwater harvesting systems is a particularly promising tool in the Mediterranean basin, where climate change could cause a significant increase in annual average temperatures and exceptional rainfall events(Silva-Afonso and Pimentel-Rodrigues 2011).

When designing an rainwater harvesting system combined with a green roof structure, it should take into account several factors such as rainfall intensity and substrate hydraulic properties as well as the roof runoff coefficient (ETA 701-2012), that should be assessed for each particular climate.
The runoff coefficient is a dimensionless parameter that depends on the characteristics of the roof surface. It is calculated based on the total runoff volume and the total amount of precipitation in a certain time period (ETA 701-2012). Even if the roof water runoff coefficient can be considered valid within similar climatic zones, it is dependent on the type of coverage used in the systems, on the type of plants used and on the characteristics of the substrate, and there is still a large potential for research in this area.

2.2. Material and methods

The pilot green roof system was located on the top of a building at Escola Superior de Biotecnologia – Universidade Católica Portuguesa, Porto. This Portuguesescity has a Mediterranean climate, although with Atlantic influences.. The extensive pilot system of 0.5 m^2 followed the extensive green roof structure – with geotextile membranes, a water holding capacity layer using expanded clay, and the growing substrate with 10 cm height, composed of a mixture of expanded clay and organic matter (Monteiro et al. 2016).
The green roof pilot system was established with three different aromatic plant species: *Saturejamontana*, *Thymus caespititius* and *Thymus pseudolanuginosus*. The study was in operation for a period of 12 months (March 2013-February 2014), through different rainfall conditions (Monteiro et al. 2016).
For the calculation of runoff coefficients, the water that drained from the system was manually collected for a jerrycan every 24 hours and the volume was measured using a graduated flask. Rainfall-runoff volume was measured for several natural rainfall events during an year, in order to develop a model to evaluate monthly runoff coefficients of the system (Monteiro et al. 2016).
Although atmospheric temperature might influence evapotranspiration and the amount of rainwater retained by the green roof system, the goal was only to quantify the amount of rainwater that runoffs the system and relate it directly with rainfall and temperatures in prior periods and not establish relationships with evapotranspiration and retention on the roof. Atmospheric data were provided from a meteorological station from FEUP (Faculdade de Engenharia da Universidade do Porto), located one kilometer distance from the pilot green roof (Monteiro et al. 2016).

2.3. Results

Constant runoff coefficient values through the year for green roofs systems (or even values for each season), which are proposed in some publications, are revealed manifestly inadequate in Mediterranean climates where there may be extended drought periods in the hot season in opposition to cold and rainy winters (Uhl and Schiedt 2008).In the Mediterranean climate (like Portugal) it is highly recommended that the design of rainwater harvesting systems, in particular the design of the storage tank, should be made based on monthly average runoff coefficients (Silva-Afonso and Pimentel-Rodrigues 2014). Therefore the study focuses on obtaining a practical mathematical expression that allows, with acceptable approximation, to determine average values of the monthly runoff coefficient for a particular green roof.
Measurements made in the experimental green roof system allowed for the development

of the following expression for monthly runoff coefficient prediction(Monteiro et al. 2016):

$$C_M = [0.016\ (P_M + R_M)]/(2\ T_M - T_{M\text{-}1})^{1.2} \quad (1)$$

where:
C_M = Runoff coefficient of the month M;
P_M = Precipitation of the month M (mm)
R_M = Watering of the month M (mm)
T_M = Mean air temperature of the month M (ºC)
$T_{M\text{-}1}$ = Mean air temperature of themonth M-1 (ºC)

The obtained expression, which depends essentially from temperature in previous periods and precipitation, has similarities with the well-known Turc formula (Chow 1964), widely widespread in hydrological studies to determine flow deficit, that can be considered an indicator of its consistency. Figure 1 shows experimental values obtained vs. the model prediction.

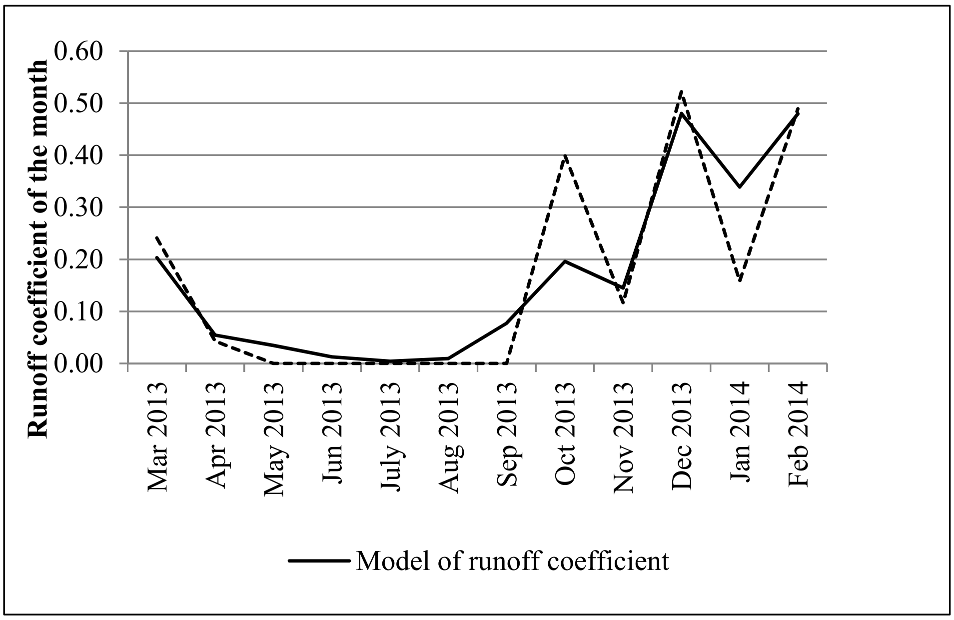

Figure 1 Monthly runoff coefficient of the pilot green roof system (Monteiro et al. 2016)

The developed expression (valid for the extensive green roof studied) revealed a correlation coefficient of 0.81 when compared to experimental values, which can be considered an excellent approximation, since this type of determination is affected by several other parameters that could not be controlled (e.g. wind). The obtained value for runoff coefficient is quite reliable as we can consider that the error of this value is lower than the parameters variability (Monteiro et al. 2016).

3 Innovative green roofs with use of agglomerate cork on drainage layer.

3.1 Framework

Contemporary buildings search for better ~~energy~~ efficiency and desirable environmental integration is pushing building designers to adopt distinct building techniques and materials(Sadineni *et al.,* 2011) (De La Rosa *et al.,* 2014) (Civic and Vucijak, 2014) Agglomerate cork offers a good compromise between thermal insulation, environmental impact and natural integration. More often applied as a layer between other building materials, agglomerate cork is starting to appear simultaneously as the insulation layer and the external finishing layer of a building.
Agglomerate cork is an 100% natural material(Gil, 2013) made just from waste generated by the capture process of cork. Its production is achieved by compressing in an autoclave the granules of cork with superheated steam. The cork granule agglomeration occurs by the induced overpressure and temperature but also by the release of suberin triggered by this production process. The result is a block then usually cut to form boards with the desired heights.
Despite the established insulation properties of cork(Sen *et al.,* 2014), some properties like the permeability of the material when exposed to rain is not well known. This experiment assesses the agglomerate cork water permeability with the end goal of use it simultaneously as insulation a building and the drainage layer of green roofs as an alternative drainage layer to the traditional cup-style product.

3.2 Materials and methods

On this practice were sampled four varieties of agglomerate cork. They were two thicknesses, 50mm and 200mm at standard and high density with 97-117kg/m^3 and 161-176kg/m^3 respectively. In order to perform the test it was built an apparatus constituted by three elements: Box container for the agglomerate cork and loaded water, metallic workbench holder of the box test specimen and a recipient collector of the water flow.
To achieve a test piece able to contain the agglomerate cork and the water, boxes were built with marine plywood for shuttering, screwed and sealed at the edges. Measures at the interior are 0,25m width per 0,25m depth and 0,60m height. Both ends of the boxes are open and the agglomerate cork was placed at one bottom end.

3.3 Test procedure

The tests were carried at a laboratory temperature of 22º C and 52% HR and the procedure followed was: 1. Hydrothermal stabilization for 15 days of the test piece in climatic chamber at 23ºC and 50% RH; 2. Weighing of the test piece; 3. Assembly on the workbench holder; 4. Calibration of the measure equipment (balance); 5. Record of the balance reading for two references weights (500g and 10000g); 6. Water collector box tare; 7. Start the measurement of continuous weighing; 8. 11,25 litres load of water, equivalent to a 180mm water blade on the tested area; 9. Continuous weighing until no more water drops; 11. Weighing of the saturated test specimen to determine water retention; 12. Verification of balance calibration by weight of previous references; 13. Hourly weighing of test piece for the first 5 hours; 14. Daily weighing at the same hour of the test piece for 5 days. Water flow was monitored and recorded continuously until no more water drops occurred. The equipment used was a laboratory balance branded "Sartorius Cubis" with precision to the centesimal of gram (0,01g). For this test the device was outputting the weighted values at a rate of 5 records per second. The results were directly feed to a computer.

3.4 Experimental results

On this experiment was observed the water permeability of agglomerate cork boards. The procedure used four different agglomerate cork samples and observed the flow of 11,25 litres of water thru it. The water permeability of the materials is diverse. The water flow capacity of the standard material is much higher than the high density material. It was necessary 210 minutes on the 200mm high density agglomerate cork against 35 minutes on the 50mm standard agglomerate cork until the measure equipment registered no more water drops. On the samples tested the standard agglomerate cork had the capacity to flow from 200g up to 400g of water per second depending on height of the water blade (Figure 2). This is equivalent to an average water flowing capacity of 4,8 litres/second per m^2. At the standard agglomerate cork the water flow occurred immediately, discharging the water as promptly as loaded with it. The testing with the high density agglomerate cork observed a very different behaviour. Its water permeability was just 3g up to 6g per second averaging 0,07 litres/second per m^2 (Figure 3). Behaving quite differently from the standard sample, several seconds elapsed before the first water drops could be observed on the high density agglomerate cork.
About water retention it was observed that the high density material has the ability to retain more water, about 10% to 15% more than the equivalent height agglomerate cork on standard form. After no more drops, the standard material registered 112g and 294g of water retention on the samples tested with 50mm and 200mm respectively. This is equivalent to about 1792g and 4704g per m^2.

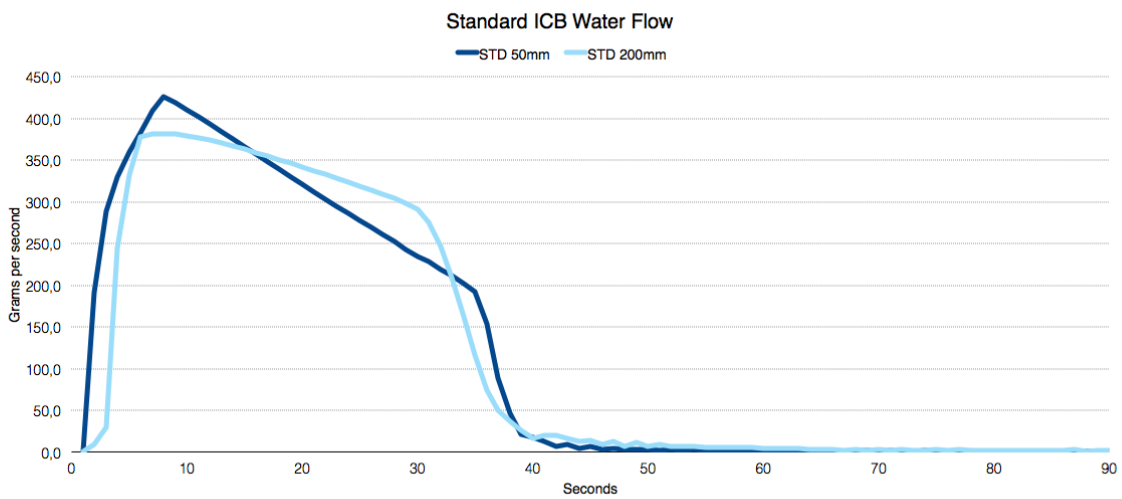

Figure 2 Water flow for STD 50mm and STD 200mm ICB (90 seconds frame time)

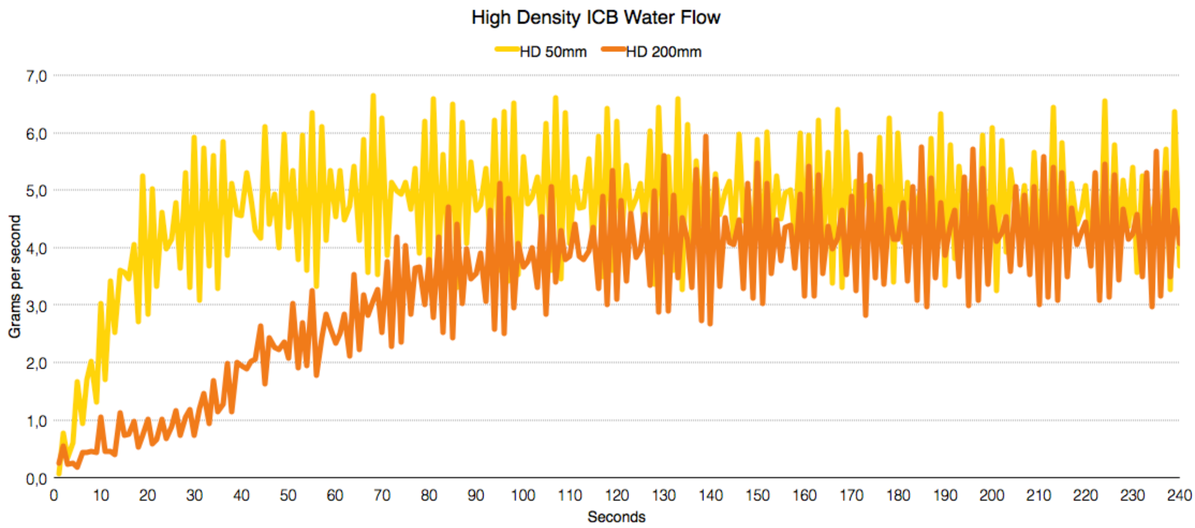

Figure 3 Water flow for HD50mm and HD200mm ICB (4 minutes frame time)

4 Conclusions

Mediterranean countries are among those with high risk of water stress. It is crucial to develop water efficiency measures, like the rainwater harvesting in buildings (Silva-Afonso and Pimentel-Rodrigues 2011) which requires the proper knowledge of criteria for the design of systems in this climate. The combination of green roofs with rainwater utilization systems seems a promising solution that 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. However, the design of these combined solutions has a great dependence on particularities of local or regional climate and research in this field is needed at present.In this context, the results of a study for evaluation of the average monthly runoff coefficients in an extensive green roof in Mediterranean climate are presented.
In this context, also the development of innovate solutions need the study of run-off coefficients.In the ongoing experience (experimental campaign) described in this paper, was measured the water permeability of a natural material made from the waste of the capture process of cork, the agglomerate cork. It was determined the quantity of water going thru the material, the time consumed to flow a certain amount of water and the retained water. Were tested four different samples of agglomerate cork corresponding at two thicknesses and two densities with the aim of evaluate their adaptability to be used as the drainage layer of a green roof.
It is significant that the density of the material changes notably its water permeability and that the use of high-density material delays considerably the beginning of water flow. Between same densities the height of the material does not affect significantly its ability to drain water and the higher density material retains more water.

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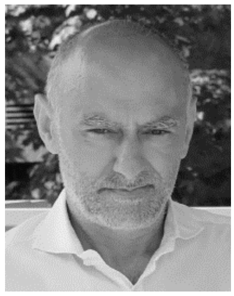

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Green wall applying to the grey water recycling in residential building

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Abstract

Using green wall as a design strategy of building façade has been taken for years inside our country. Its main aim is for aesthetic and energy saving in building. Some broader thoughts of ecology and urban climate has also been considered as well. But in the dimension of water resource, green wall is a resource-consumption facility. Constructed wetlands imitates the natural one to achieve the function of purification and ecosystem conservation. Its application of using natural mechanism to purify wastewater has been taken in many countries all over the world. The first step of this research is adopting the results of existing research and relative system-operation theory, and combining the green wall system with the wastewater treatment mechanism of constructed wetlands system. Thus, a purification green-wall system (PGWS) would be established for which can apply independently to housing. Second, using experiments to testify the wastewater treatment ability of PGWS and discussing the effect of different control variables to the pollutants removal performance. As the results, from the viewpoint of grey water's recycle-treatment-reuse in house, the feasibility and rationality of PGWS is validated when it apply to buildings as an effective program of domestic water use which can both expand resource and reduce consumption.

Keywords

Green wall, grey water, reuse, constructed wetlands, domestic water consumption, on-site circulation.

1 Introduction

Green building is seen as a crucial strategy for climate change and sustainability. Using green wall as a design strategy of building façade has been taken for years inside our country. Its main aim is for aesthetic and energy saving in building. Some broader thoughts of ecology and urban climate has also been considered as well. But in the dimension of water resource, green wall is a resource-consumption facility. Constructed wetlands imitates the natural one to achieve the function of purification and ecosystem conservation. Its application of using natural mechanism to purify wastewater has been taken in many countries all over the world. Through combination and discussion of green wall and constructed wetlands, an innovative, reasonable and feasible PGWS was established, as well as being testified its greywater treatment efficiency. The experimental results showed that less polluted water from shower and basin of housing treated by PGWS and simple disinfection techniques could meet the water quality adopted by the current regulations of water reuse in Taiwan. The PGWS is a new ecological device used for both vertical greening and water saving, and also can be expanded from housing to all architectural pattern in the future. Meanwhile, the system can result many aspects of benefit for high-density urban area such as air quality improvement, heat island reduction, landscape aesthetic enhancement, reduction of water resource consumption and cost-down of sewage treatment, which has actively positive function to the sustainability of the whole environment.

2 Theories and Methods

2.1 Design theories of the PGWS

To enable the function of wastewater treatment, this study combined the purification theory of constructed wetlands with the green-wall system, which is the basic conception of the PGWS. The operational methods were:

1) Dividing the horizontal subsurface flow constructed wetlands into small units in the direction of parallel water flow to maintain the mechanism of wastewater treatment (Figure 1).

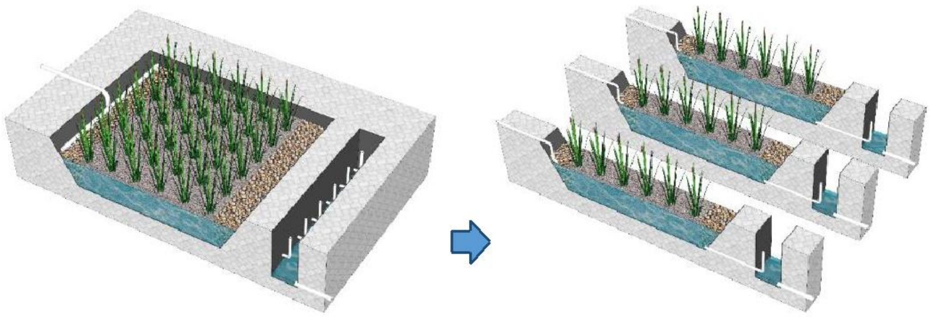

Figure 1 Dividing units of horizontal subsurface flow constructed wetlandsv(HSF CWs)

2) Adjusting the type of single planting pot in green wall, so that it could accommodate the wastewater treatment mechanism of constructed wetlands (Figure 2).

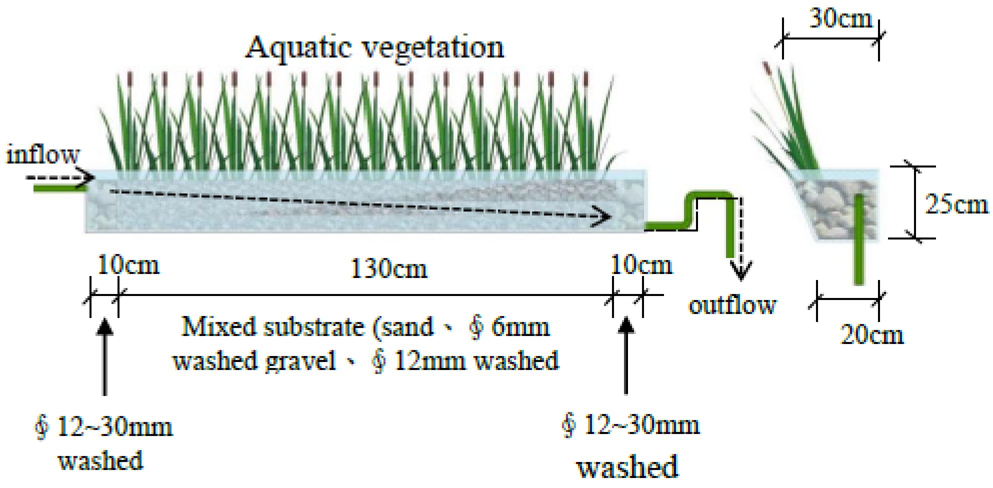

Figure 2 Adjusting single planting pot – HSF CWs

In addition to both water quality and operability, the PGWS applying to housing need to fulfill the aim of greening and aesthetics. Among many types of constructed wetlands, HSF system was chosen as experimental subject for its smaller pot façade area, operational feasibility of the inflow system, and controllable hydraulic retention time (HRT). Besides, the substrate of green wall needs to meet the basic principal of lightweight. Thus, the washed gravel was replaced with materials such as vermiculite, perlite, expanded clay etc. which are commonly used in the green wall.

2.2 Laboratory equipment of the PGWS

The experimental site was located in a forecourt of a household in Yilan, Taiwan. There are no high buildings which can affect sunlight surrounding by and it has a transparent roof made of glass which can prevent the planting pot from rainwater to avoid affecting the quality of treated water. Laboratory equipment include HSF planting pot, substrate, aquatic vegetation, inflow and outflow pipelines, pumps, storage tanks, etc. (Figure 3).
After setting up all the equipment required, a start-up period was taken which continued 3 months operating from Jan to Mar 2016. This procedure ensured the development of bio-film in the PGWS and stabilization of the system performance in terms of removal efficiency and flow. The system maintained its operation and the water source would be added depending on its consumption during this period without sampling. The water-cycle mode of the experiment process is as shown in Figure 4.

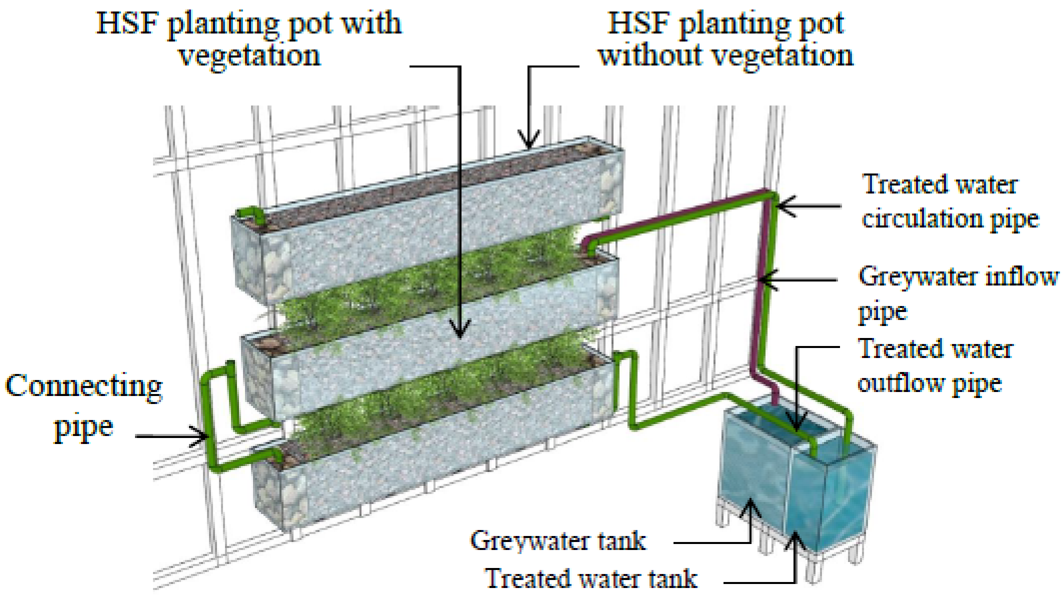

Figure 3 The equipment of laboratory

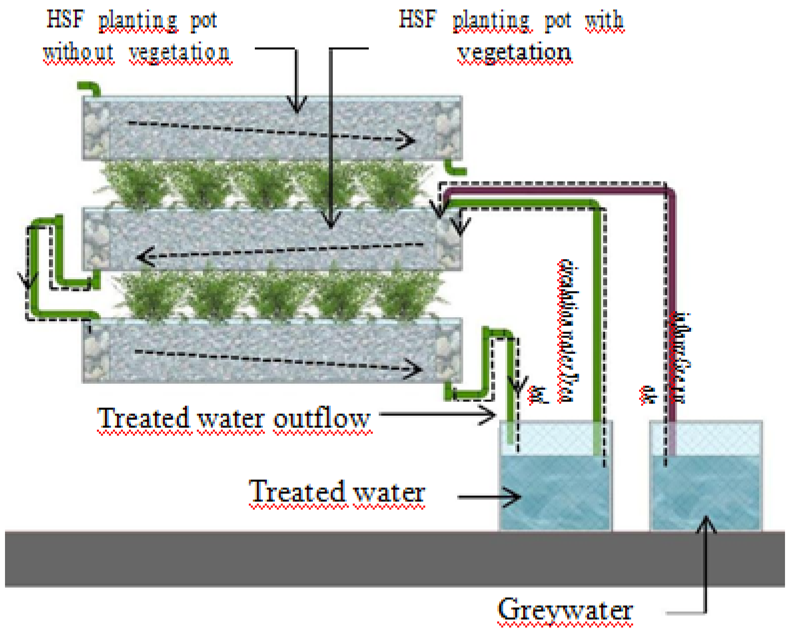

Figure 4 Process of the equipment operation

3 Experiment and results

3.1 Laboratory variables control and water sampling

The purpose of this experiment is to testify the treatment capacity of the PGWS for domestic greywater and if it can meet the standard of reuse for flushing. Considering the time for the study, research costs, experimental site and the data required, we set the presence of vegetation, number of circulation, and its frequency as three variables of this experiment to explore.

Group(A) : two single planting pots, one with vegetation and the other without. There was no circulation with 16 hours of HRT.

Group(B) : two planting pots connected with vegetation, each circulation had 8 hours of HRT and two times of circulation.

Group(C) : two planting pots connected with vegetation, each circulation had 4 hours of HRT and four times of circulation.

After sampling the water, its smell and appearances were observed and its value of pH was detected on site immediately. The analysis items in lab were BOD_5, TC, turbidity, residual chlorine. Items mentioned above came from current regulations of water reuse in Taiwan.

Table1 Experimental sets

Experimental set		Sampling condition	Total HRT
A-0	HRT 16 hours	Before treatment	0 h
AN-1	HRT 16 h (no vegetation)	treated 4 h	4 h
AN-2	HRT 16 h (no vegetation)	treated 8 h	8 h
AN-3	HRT 16 h (no vegetation)	treated 12 h	12 h
AN-4	HRT 16 h (no vegetation)	treated 16 h	16 h
A-1	HRT 16 h (with vegetation)	treated 4 h	4 h
A-2	HRT 16 h (with vegetation)	treated 8 h	8 h
A-3	HRT 16 h (with vegetation)	treated 12 h	12 h
A-4	HRT 16 h (with vegetation)	treated 16 h	16 h
B-0	HRT 8 h	Before treatment	0 h
B-1	HRT 8 h	treated 4 h in 1st circulation	4 h
B-2	HRT 8 h	treated 8 h in 1st circulation	8 h
B-3	HRT 8 h	treated 4 h in 2nd circulation	12 h
B-4	HRT 8 h	treated 8 h in 2nd circulation	16 h
C-0	HRT 4 h	Before treatment	0 h
C-1	HRT 4 h	After 1st circulation	4 h
C-2	HRT 4 h	After 2nd circulation	8 h
C-3	HRT 4 h	After 3rd circulation	12 h
C-4	HRT 4 h	After 4th circulation	16 h

3.2 PGWS performance

The results of water quality analysis show that PGWS can remove the pollutants which recycled from shower and basin of housing. The variation of each item on water quality is shown as Table 2, Fig.5 and Fig.6. The characteristic features include:

1) In the beginning, TC could be removed effectively, but its concentration was still higher than the standard of 200 CFU/100mL. Therefore, simple disinfection techniques such as chlorination would be added in the treated water tank.
2) Removal efficiency of BOD_5 was satisfied. The higher rate of cycle, the better of removal efficiency would be. After processing 4 hours, each set could meet the

standard of 10 mg/L.

3) Removal efficiency of turbidity under the condition of having vegetation was obviously better than not. The same result also exited in condition of flow and circulation. The higher rate of the circulation, the better of removal efficiency would be. Greywater treated 8 hours at an inflow frequency of 4.5 liters per hour, or treated 4 hours at an inflow frequency of 9 liters per hour could let the turbidity meet the standard of 2 NTU.
4) The variation of pH value was between 7.3 and 8.7. With vegetation, all the results could meet the standard of 6.0~8.5.
5) The emission degree of odor was proportional to the turbidity and its removal efficiency was lower without vegetation.

Table 2 Results of lab analysis

Set	Total Coliform (TC)		BOD_5,20℃		Turbidity		pH
	CFU/100mL	Removal%	mg/L	Removal%	NTU	Removal%	--
A-0	600	0%	39.216	0%	30.70	0%	7.53
AN-1	50	91.67%	6.299	83.94%	5.05	83.55%	7.72
AN-2	80	86.67%	3.547	90.96%	4.40	85.67%	8.40
AN-3	130	78.33%	4.517	88.48%	4.42	85.60%	8.65
AN-4	110	81.67%	4.330	88.96%	3.64	88.14%	8.45
A-1	210	65.00%	9.067	76.88%	3.48	88.66%	7.47
A-2	420	30.00%	5.105	86.98%	2.54	91.73%	7.69
A-3	2400	-300.00%	3.772	90.38%	1.70	94.46%	7.68
A-4	6600	-1000.00%	4.332	88.95%	1.11	96.38%	7.64
B-0	470	0%	38.424	0%	26.70	0%	7.60
B-1	65	86.17%	10.011	73.95%	3.23	87.90%	7.56
B-2	430	8.51%	3.541	90.78%	0.66	97.53%	8.29
B-3	35000	-7346.81%	6.686	82.60%	0.60	97.75%	7.50
B-4	13000	-2665.96%	7.483	80.53%	0.49	98.16%	7.91
C-0	260	0%	43.530	0%	29.20	0%	7.94
C-1	850	-226.92%	5.316	87.79%	1.03	96.47%	8.02
C-2	4400	-1592.31%	4.530	89.59%	0.81	97.23%	8.03
C-3	5400	-1976.92%	4.725	89.15%	0.53	98.18%	7.89
C-4	1800	-592.31%	4.720	89.16%	0.30	98.97%	7.81

Greywater treated 4 hours at an inflow frequency of 9 liters per hour could meet the current regulations of water reuse in Taiwan in items of odor, appearance, pH value, BOD_5, and turbidity. As for TC and residual chlorine, adding simple disinfection techniques such as chlorination in the treated water tank is required. Overall, applying PGWS to domestic greywater recycling is feasible for water quality.

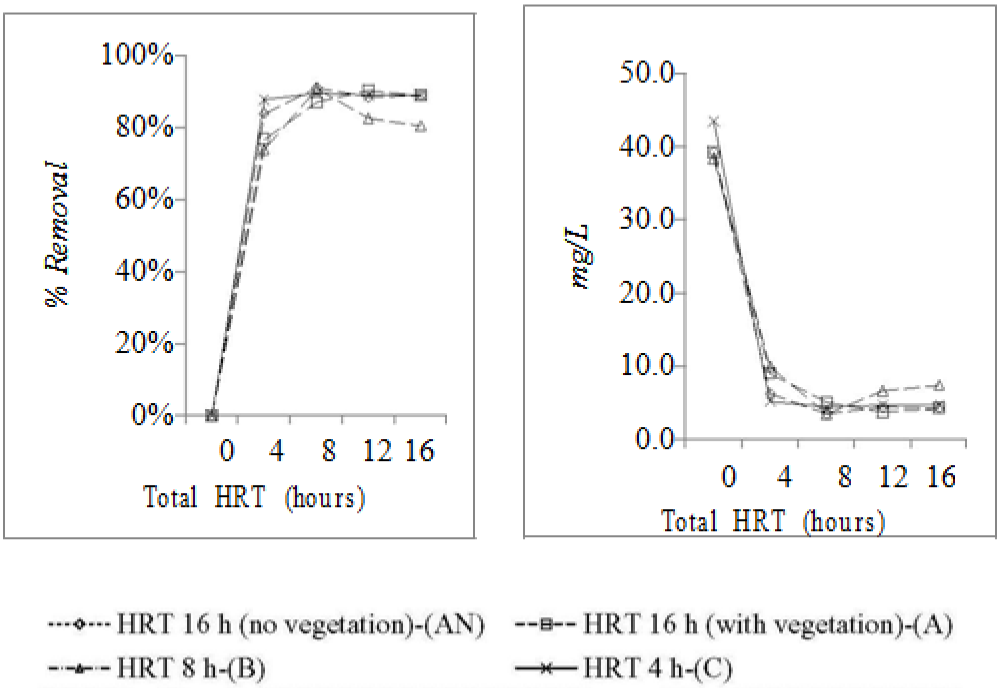

Figure 5 Variation of BOD5,20℃

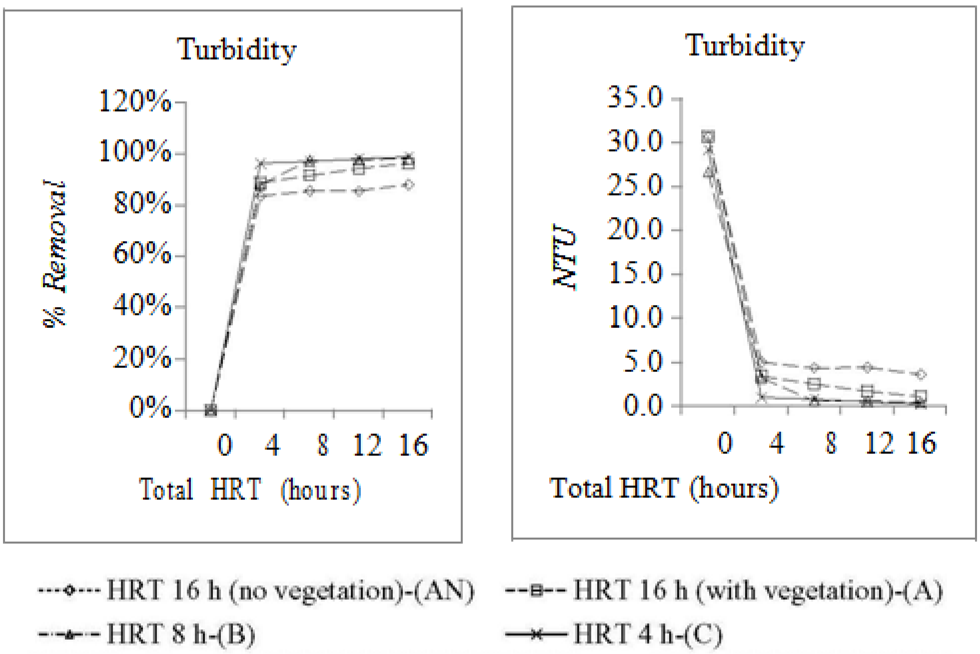

Figure 6 Variation of turbidity

4 Discussion and application

According to the reports from Water Resource Agency, Minister of Economic Affairs of Taiwan, the average tap-water consumption of housing is 157.8 liters per person per day, 19.12% of which is laundry, 20.47% of which is shower, 11.41% of which is basin, 21.95% of which is flushing, 14.14% of which is kitchen, and the remaining 12.93% is for other use. After the treatment process of PGWS, less polluted greywater from shower and basin of housing can be reused for flushing and landscape, which means a saving of 50.3 liters per person per day on tap-water consumption and a burden reduction of 34.7 liters on sewage treatment.
According the results of laboratory , two planting pots connected full of 18 liters each, under a model of 9 liters per hour inflow frequency, 4 hours HRT, could be a feasible PGWS. This system can treat 216 liters of less polluted greywater continuously each day. The water recycled from daily shower and basin in a 4 people family(201.2 liters) can be treated by a set of PGWS. But when considering the routine maintenance and stability of biological treatment mechanism, two sets of PGWSs for alternative as an operation mode are needed. The water supply and drainage system is shown as Fig. 7.

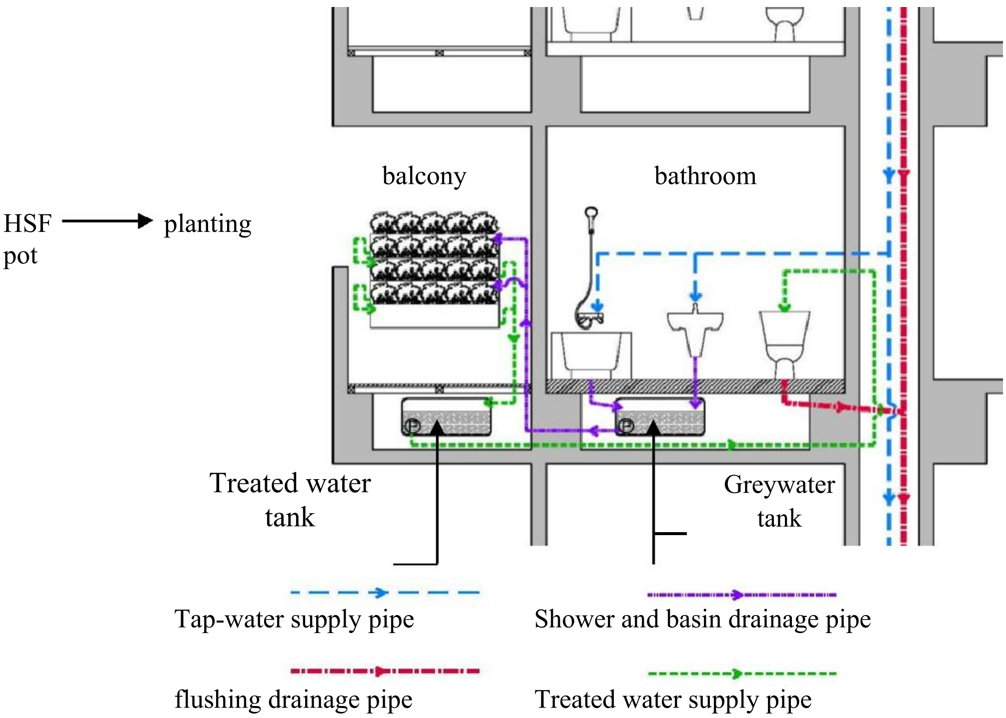

Figure 7 The water supply and drainage system of PGWS in apartment

Considering the mode of PGWS installation in apartment buildings, a set consisting of 4 planting pots(each pot is 150cms in width, 20cms in depth, and 25cms in height) stocked up to a total height of 100cms, can fit the balcony space of an ordinary housing unit. A vegetation height of 85 to 160cms above from the floor is ergonomic for ornamentation, trimming and maintenance. Considering the double layer floors of bathroom and balcony, the positions of greywater tank and treated water tank can be arranged under the floor. The moveable maintenance gate can be planned in the housing unit for independent cleaning.

The vicinity of bathroom and balcony is needed for the length of water pipes and the slope of drainage.

5 Conclusion

The experimental results showed that less polluted water from shower and basin of housing treated by PGWS and simple disinfection techniques could meet the water quality adopted by the current regulations of water reuse in Taiwan. The system brings a saving of 50.3 liters per person per day on tap-water consumption and a burden reduction of 34.7 liters on sewage treatment. The PGWS is a new ecological device used for both vertical greening and water saving, and also can be expanded from housing to all architectural pattern in the future. Meanwhile, the system can result many aspects of benefit for high-density urban area such as air quality improvement, heat island reduction, landscape aesthetic enhancement, reduction of water resource consumption and cost-down of sewage treatment, which has actively positive function to the sustainability of the whole environment.

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Green walls and their crucial role in current ecological situation

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Abstract

Green walls are not only spectacularly beautiful, but also helpful and these days very needed. This article talks about the green veneers as one of the vertical greening frameworks. Green divider is not a new idea; go back to hanging greenery enclosures of Babylonia in 600 BC, yet thrived in current decades. In the time of manageable advancement organizers and modelers search for answers for green the structures conceals and restore ecological conditions. An assortment of various wording demonstrates the significance of the issue: Hanging or vertical greenhouses, overhang gardens, vertical homesteads, compartments or grower boxes greening, green rooftops or housetop patio nurseries, green or eco structures, green dividers, divider grower, green wraps and green exteriors. Green walls come in two primary formats: panels and cables, defined by the systems upon which the plants are placed on a wall's surface. Living green walls, panels of plants, grown vertically using hydroponics on structures that can be either free standing or attached to the walls. Popular in Europe and Asia, through the plants, they help make cities cooler and quieter through shading and absorption. They can improve indoor quality, air quality lastly improve social and physical prosperity of city tenants. In current research we have focused onto potential air and water purification functions of green walls. Air purification through plant curtains and water, especially grey water purification through green walls acting like constructed wetlands using gravity.

Keywords

Green wall forms, features of green.

1 Introduction

The ground lost green space, from the dimensional surface of the building to retrieve the trend of urban landscape and mitigate the heat island effect build and good space for humans and nature. Green walls have many multiple uses and functions. We have to understand why green wall is so important, and it is very important, it is not just supporting agriculture, plants, ecology and this part human´s lives, but we can treat it by adding different values. Then green wall can be understood in terms of saving energy, sound insulation in the buildings, protection for the buildings, real estate. It also can be known as a man-built environment useful in buildings, wellness and something natural to save green places and architecture [1].

Figure 1 Example about intelligent spaces at homes couvtesy of diamond Schmitt architects and living wall 2015/2016

Figure 2 Green walls make buildings prettier by Alexander Dixon 2008

2 Saving energy

2.1 Losing heat

The vertical garden is designed to help promote urban garden heating. A lot of people working in the field of green walls thought that the green walls can reduce the temperature in the building and therefore it can reduce the bill of the energy whom it necessary to heat the building that have plants on their wall, but the studies shows that the green walls, they contains a thermal conductivity close to the concrete walls and these green walls are not working as insulation quality as known that the green wall can transfer from heating the atmosphere between outside and inside. Plus there are many factors to calculate the thermal resistance of green walls and it is can be changing a lot and these can be depended on (types of plants, types of walls, sun orientation, humidity, earth density and thickness) so these can prove that the green walls cannot keep the heating inside the building in winter [2].

2.2 Cooling effect of green walls

The green garden offer better circulation of the air. Almost every modern building is built of concrete, steel and glass. These three materials have a high heat temperature, especially in summer and winter. In summer it is very hot and in the winter, it is very cold so when we have a green wall on the buildings it can protect the building from raising its surface temperature [3].
The green wall can reduce the temperature from the heating of the wall from 5-10°C in the summer. So the green walls benefits for cooling effect and that means cooling down the buildings we need to agriculture the wall of buildings by plants and to stop an extension of this function, the green walls are able to reduce the heat island effect and these heat island effect it specially happened in the cities, also because of heavy traffic, the sun, engine and the general population from concrete and asphalt surfaces and these can creates a temperature from 1-4°C higher in the cities than the rural areas surrounding and these effects can cause an overconsumption of energy in a lot of cities, so green walls do not concentrate heating like bricks, concrete and asphalt. In the end, we notice that the plants can give the shadows on the walls, sidewalk and roads and reduce the temperature in the cities.

Figure 3 How green plants catch the rain / world wide fund of nature company /2015

3 Sound insulation of the building

The top of the wall will generally have more disturbance from wind. The problem in big cities is that it is so noisy. The green buildings can reduce a lot of these noisy things in a big city and the number of reducing of sounds by the green wall its reach to 50 dB, but this number is able to change because it depends on the kind and differences of plants on the wall of the buildings there are some products make kind of green walls that can be insulator sounds from the outside (CANEVAFLOR) it is one of French companies that they produce this kind of insulator sounds from green walls and the thickness of these green walls it can reach to 35 cm and maximum effect from the sounds it reach from 25 dB to 35 dB from the air and also 15 m just from leaves can stop the sound effect from outside it is rich to 1 dB so the green walls can reduce a lot of sounds effect by the plants make a lot of noise we can hear them by the winds and also when it is raining or from the birds yes it reduce the sounds but it also create their own atmosphere [4].

Figure 4 Green deals with nature, Van den Linden / 2007

3.1 Protection for buildings

The garden is designed as a functional space. Green walls have two different kinds of function that we can protect the buildings, so the age of buildings we can increase it and give it more life [5].

3.1.1 Protection of the building against the rain

When rainfall is high and there are fewer permeable surface. Our buildings are vulnerable to external factors and one of these external factors is rain water and it can effect on the life spam of the buildings in many cases one of these cases acid rains [6].

This acid rains can move so slowly on the façade of the buildings also a lot of natural raining cause a lot of damage on the buildings, especially on the basis of the buildings and it can make the water escape in the envelope building so the green wall it is so benefiting against these problems. Especially the leaves of the plants, even so the plants or green walls it looks like kind of materials that protect the buildings from rain water and acid rain, water also the rooted plants into the ground around the buildings to reduce the amount of water on the ground to drink it and it can keep the ground and the soils more dry.

3.1.2 Protection of the building against the changing the temperature

There is no way to move them out of the suns path. We all know that there are a lot of differences in temperature in the whole world, even between two cities in a same country and these differences in temperature can make a lot of damage in the buildings, especially the highest degrees can make the materials in buildings moving because of increasing in degrees and it leads to a crack in the buildings construction also the cold temperature when it reach to frozen can damages the buildings and these damages can cost a lot of money to fix it or replace it. So here green walls can help to reduce the changing in temperature degrees and make it equal and benefit from the buildings and makes the buildings more good and lives more [7].

Figure 5 Save natural Christine Goodwin / 2011

4 Intelligent spaces

Because of the high prices in the big cities, so it is so hard to find a space to make a small park so the green walls solved this problem you do not need to use a land beside your home, you can do it by the vertical way agriculture the plants on the wall and it is giving you a big surface of many kinds of plans (Fig. 1). 1460 square foot living wall located in drexelin Philadelphia act as indoor air purifier on mechanical heating and cooling [8].

Figure 6 Beech tree

5 Green walls make buildings prettier

Green + building work together. Green walls makes the buildings more value cause when we put plants on the walls it makes the buildings more attractive and more beautiful and more value cause the value of the building can reach from 15 to 25 % and it gave a pictures about this buildings or cities how much it modern and the prices for renting shops and buildings and homes it become more higher and we can use it shows how much these companies whose build this green walls are civilized and caring about the environmental and global warming (Fig. 2) [9].

6 Environmental uses in the building

6.1 Sewage system and rain water

No need for a water supply pipe. There is a lot of spaces in cities that have roads and buildings so when it is raining in these cities and the rains are moving on these roads and houses and buildings etc., so it catch a lot of poison sand oil and big materials and metals and trash and grease and rubber etc. and these can makes pollution of water in rain water and it makes more pollution in the ocean and in small and big rivers and beaches and these populations reaches by canals under the ground.
Bottom of sewage system costs a lot of money to separate the sewage system for cleaning water from pollution and dirt and these bad materials and small stones.
But the big problem all these waters are treated in one station and it also cost a lot of money. So when we put green walls it can reduce rain water and it makes with the sewage water system that does not cost a lot of money (Fig. 3) [10].

Figure 7 Green wall 50 m^2, Graeme Hopkins / 2007

6.2 Green dealing with nature

It is extremely important to try and create new nature. A lot of animals such as bird and butterfly and bees etc., will feel that they are with their mother nature so a lot of these animals feel they are at their homes and they can build their own homes and houses and it give a food and flowers and a lot of things for the wildlife (Fig. 4) [11].

Figure 8 Diseases from atmosphere of buildings

7 Environment and sustainability

The community is becoming more sophisticated in understanding of climate change and the urgent need for individuals as well as government and large corporations to operate in a more sustainable way. Big cities make a lot of pollution because of concrete and asphalt and roads and cars and cutting trees and break the mountains and drilling in the ground. Arts and all these produce waste and carbon dioxide, so it takes a lot from natural such a tree we cut and this is not good for nature.
So when we cut any trees we have to agriculture another trees and if we keep on this way we can save the balance of the earth and saving the natural and keep the sustainability (Fig. 5) [12].
There is a lot of global warming because of carbon dioxide, so the studies show on beech tree and her age from 100 to 120 years with diameter 20 m and her area 180 m^2 it can gave and produce 2 kg of oxygen when we have 2,5 kg dioxide carbon and 100 kg water and 25 kg heat energy and this can give oxygen equals ten people of human per hour. So these kinds of trees it takes a lot of dioxide carbon and give us a lot of oxygen (Fig. 6).
Studies show each person of humanity can take oxygen when we have $50m^2$ from green walls that it covers one person for one years of oxygen.
Green walls it is not good to produce oxygen or to take dioxide, carbon case it is not so much just one person for one year (Fig. 7).

Figure 9 Green wall in offices, Nigel Dunnett / 2008

8 Health

Green walls reduce pollution and runoff, help insulate and reduce the maintenance needs. 40% from the new and renew buildings in the whole world, it will be an ill buildings and a lot of people who is living in these buildings and it cause some disease like sensory irritation of the eyes, throat, nose or general health problem and skin irritation and all these diseases happened because of air and closed places this is what world health says (Fig. 8). The scientist says that if we have planted in our rooms or homes it is so benefit from our health and the studies say if we have planted in our offices it reduce the illness and cough and tired from 25 – 40 % cause the plants can make the atmosphere more pure and also it reduce the dryness and cough threat and facial skin to 25% so the plants is so healthy and benefit for our bodies and for our oxygen [13].
Imagine if we have a green wall in the rooms or in the offices and it is so good, especially for the health and psychology of the old people and it gave feeling more active in the work (Fig.9).

9 Architecture

Make a beautiful, practical, environmentally conscious garden, even in a small space - grow UP with a living wall! A living wall is a vertical structure, usually outside the home, that is built with live plants growing in containers hung in a decorative arrangement. A lot of the kind of green walls we can put the green walls inside or outside and there are many sizes of green walls and also we have a lot of kinds of plants and this gave us a lot decoration in plants that gave us a beautiful view and a very good looking in our eyes because there is many colors in just one piece and a lot of architecture they use this way in their buildings (Fig. 10) [14].

Figure 10 Decoration in green walls by Noel kingsbury /2004

10 Nutrition

We can have as many kinds of vegetables from green walls if we put some kind of plants such as carrots, peas, beans, potatoes, peppers and tomatoes etc. These kind of plants can grow up on the green wall. At least 15 cm between each small plant sand 30 cm between big plants and the people can eat it is kind of a small farm in your home and you can save a lot of money because instead of buying it from the shops you will have your own shop but in your home (Fig. 11) [15].

Figure 11 Kind of vegetables on green wall /clean your air by Dan Hayes / 2010

11 Conclusion

Green walls are another innovation by nature, images to have another kind of backing for plant. As it is used, advantages were found, considered and misused. Green walls are sharp structure; they are versatile. They can be raised outside (green exterior, living divider) or inside a building envelope in different nation and under different atmosphere. There is no compelling reason to know botanic to look after them. The aim of this article was to define few advantages green walls have and explain them in terms of crucial ecological values.

12 Acknowledgments

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Design of submerged MBR technology for grey water treatment

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Abstract

Decentralized water infrastructure is an alternative of traditional centralized systems. Grey water as one of the option in decentralized water systems could serve as a sustainable way of treatment with water in urban areas. However grey water is not considered as a high polluted waste water, it is necessary to treat this water before further utilization. There are different options in treatment of this water, however as an optimal and usually most efficient are considered biological treatment systems. Therefore in laboratories of Civil Engineering Faculty, we are going to test one of the biological treatment technologies – submerged membrane bioreactor. This paper represent a description of the system design in laboratory conditions and will introduce the first stage of the research.

Keywords

Membrane bioreactor, grey water, water treatment.

1 Introduction

Grey water could be considered as an option of waste water recycling with relatively great potential (1). The reliability of grey water stems from the fact that it is a constant water source, contains plant nutrients and has a comparatively low concentration of pathogens compared with mixed wastewater and black water, therefore it could be considered as a tool of sustainable water management. According to the (2) grey water may contain high levels of disease causing organisms (such as bacteria, viruses, protozoa, helminths), suspended matter, organic matter, fats and oils, including but not limited to dirt, lint, food, hair, body cells and fats, and traces of faeces, urine, and blood, chemicals derived from soaps, shampoos, dyes, mouthwash, toothpaste, detergents, bleaches, disinfectants, caustic dishwashing powders and other products (such as boron, phosphorus, sodium, ammonia and other nitrogen based compounds). Therefore is important to ensure proper treatment of this water before reuse, and avoid the dangerous consequences on water quality, environment and human health (3). There are numbers of different grey water treatment approaches, range from simple, low-cost devices or advanced treatment processes incorporating sedimentation tanks, bioreactors, filters, pumps and disinfections units (4). The treatment technologies, usually used for grey water system applications are based on physical, chemical and biological systems, or the combinations of them (5), however as the most efficient systems are considered biological systems in combination with physical treatment technologies (4). According to proved efficiency of biological treatment processes, in this paper we focused on the one type of this technology- membrane bioreactor MBR, which will be applied and tested in laboratories of Civil Engineering Faculty in Kosice.

2 Quality of grey water

Quality of water could be considered as an essential part of grey water system. Important are both types of water in system - discharged grey water and quality of water after treatment process-white water. According to grey water characteristic and white water requirements, an appropriate treatment process is chosen as a tool of sustainable and safe reuse applications. As mentioned above, the water quality is affected by several aspects, in principle is the quality and concentration of different pollutants changing according to grey water source and in form of its utilization by user (5;6). Concentration of some of pollutants according to their origin are shown in Table 1. In regards to establish the suitable and safe grey water system function, have these pollutants to be eliminated by appropriate treatment process selection.

Table 1 Pollutants contained in grey water according to different sources

Parameters	Light grey water			Dark grey water		
	Sink	Shower	Bathtub	KS	DW	WM
BOD_5 (mg/l)	33–252	40.2–424	129–424	5–2,762	390–4,450	44.3–472
COD (mg/l)	95–587	77–645	100–633	15–1,340	1,296	58–1,815
TSS (mg/l)	40–259	89–353	54–303	134–720	15-525	65–315

P_{total} (mg/l)	-	1.12	0.2- 2	0.69-74	68	0.06-57
N_{total} (mg/l)	10.4	8.7–10.92	5-17	6.44-74	40	1-40
Total coliforms (MPN/ml)	9.42E3	2E2–6.8E3	6,350–5.1E6	2E2–5.29E2	4.3E6	2E2–4.2E6
E. coli (MPN/ml)	10	2E2–1.49E3	82.7	2E2	-	-

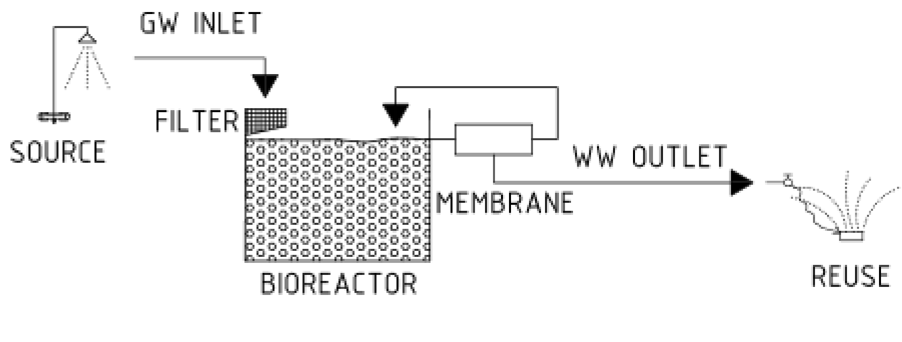
3 Biological treatment systems

Biological treatment technologies applied individually or in combination with additional treatment systems are usually considered as the most efficient technologies (4) ensuring the required water quality after treatment. There is a wide range of biological treatment processes, including rotating biological contactor (RBC) (7;8), membrane bioreactor (MBR) (9;10) sequencing batch reactor (SBR), anaerobic filters (UASB), fluidized bed reactor FBR (5), or constructed wetlands (11;12).

3.1 Membrane bioreactor (MBR) system

MBR as a technology combining conventional biological sludge process, physical separation of colloidal substances, including pathogenic bacteria, with aerobic biological treatment of dissolved organic matter, microfiltration or ultrafiltration membrane system, could be considered as an attractive method also suitable for grey water treatment (13).

The basics of MBR technology stems in the biodegradation of waste compounds in biological unit and a membrane module which is responsible for the physical separation of treated water (14). MBR systems can be divided into side-stream MBR, where the membrane module is placed outside the bioreactor and submerged MBR, where the membrane module is directly submerged in the reactor (14) (Figure 1).



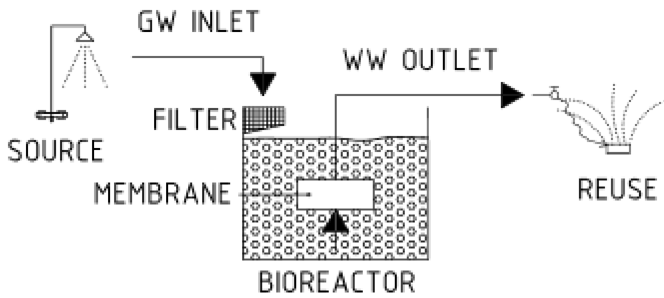


Figure 1 Basic flow diagrams of side-stream and submerged MBR systems for grey water system

According to the features that both systems dispose, could be submerged MBR considered as a suitable technology, especially since submerged MBR has simpler configuration and proved energy savings, using coarse bubble aeration instead of the high-rate recirculation pump in side-stream MBRs (14). Therefore the further research applied in laboratories of Civil Engineering Faculty, will be focused on testing the efficiency of submerged MBR technology treating real grey water. The results will be compared with the efficiency of natural treatment technology – vegetated wall, in regards to the quality of treated water, economical aspects and sustainability of the whole system. According to the fact, that the testing is in the primary stage – building the system, the aim of this paper is to introduce the design of the system and further plans of the tests and research, which is planned in laboratories of Civil Engineering Faculty.

4 Laboratories of Civil Engineering Faculty

The laboratories placed in the basement of the Faculty of Civil Engineering, serve as a centrum for different fields of research. This laboratories dispose with different appliances and systems as hydraulic wall, indoor stand capable to test the stationary or dynamic changes of air temperature, humidity and the surface temperature of building structures, thermographic camera, blower-door tests etc. However these laboratories are still expanding. In regards to test the MBR technology there is developing an area of sanitary appliances (Figure 2), which will besides the further test of grey water treatment technology, serve as a tool to educate future students at the Faculty.

Figure 2 Current form of the sanitary appliances area in laboratories

5 Grey water system applied in laboratories

Grey water systems are usually designed as a gravity discharge systems (Figure 3), however, according to the fact that the sanitary devices and a treatment plant are at the same floor, this system was not applicable in laboratory conditions. The new approaches have been suggested and the inlet into a treatment plant will be ensured by the pump, located on the grey water discharge pipeline (Figure 4). It is expected that the power of the pump will ensure an appropriate flow and fluent inlet of water into the treatment plant.

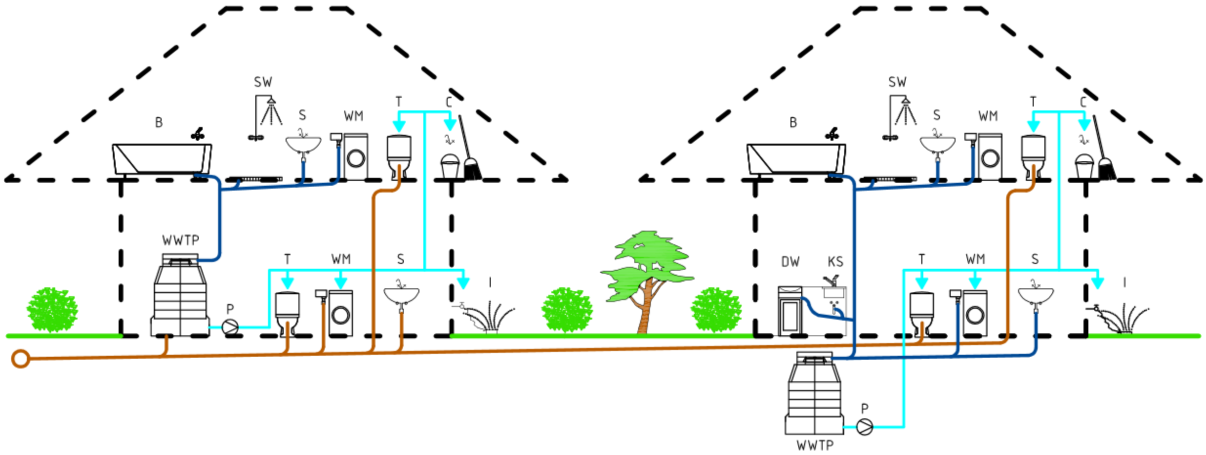


Figure 3 Grey water systems based on gravity discharge systems
B- bath, SW- shower, S- sink, WM- washing machine, T- toilet, C- cleaning, WWTP- waste water treatment plant, P- pump, I- irrigation, DW- dishwasher, KS- kitchen sink

Figure 4 Pump ensuring the treatment plant inlet

5.1 Grey water system design

Grey water, supplying the system could be divided into two basic sources: devices in laboratories and real grey water, discharged from the sinks in classrooms.
According to the laboratories devices composition (Figure 5), will be grey water discharged from one shower and one sink. As mentioned above the inlet into the treatment plant will be ensured with the pump (Figure 4). The real grey water from two

sinks of two classrooms will be discharged from an upper floor, therefore in this case the gravity discharge could be applied. On the inlet to the treatment plant, these two sources will be connected in common pipeline leading to the treatment plant. After treatment process, will be treated grey water- usually called white water, used for the flushing of toilet and urinal placed on the sanitary devices area in laboratories. There is also option to add to the system one washing machine, when this device will serve as a source of grey water and also as point of white water utilization.

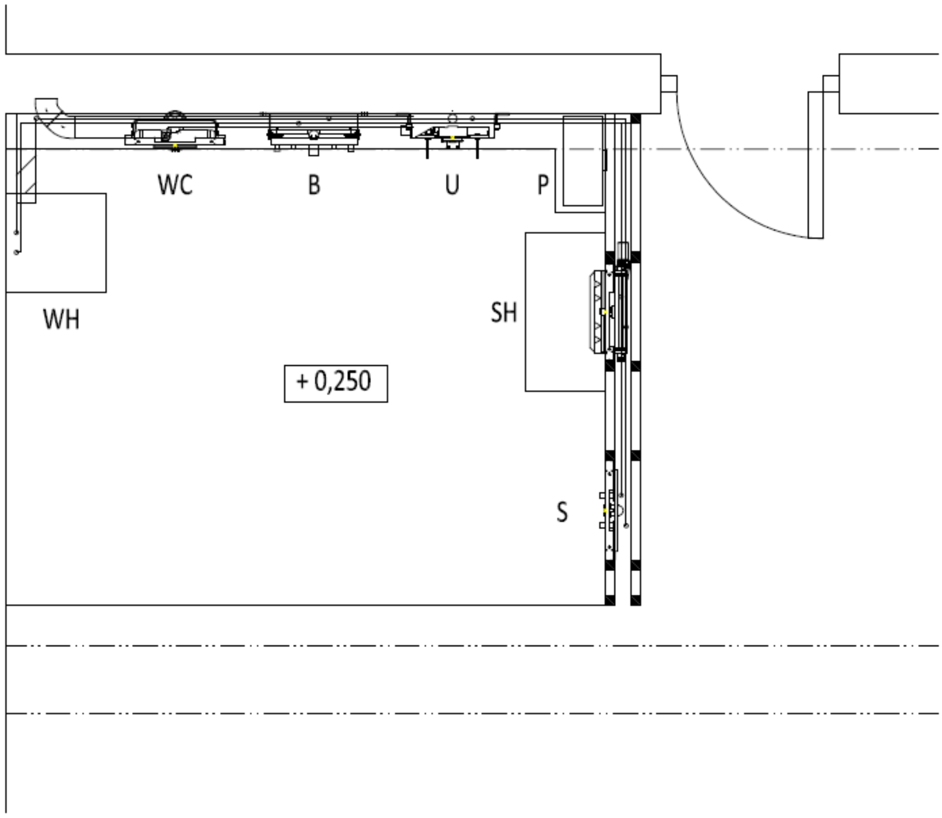


Figure 5 Composition of sanitary devices area in laboratories
WH- water heater, WC- toilet, B- bidet, U- urinal, P- pump, SH- shower, S- sink

5.2 Treatment plant - submerged membrane bioreactor

As mentioned above grey water from both sources will go through treatment process based on combination of biological processes and membrane filtration. The first stage of the treatment process is to capture the mechanical particles, therefore on the inlet to bioreactor, water flows through the filter. A bioreactor, where is submerged membrane module is containing an aeration system on its bottom, ensuring the flow of water through module. Above the membrane module is placed a pump utilizing negative pressure, sucks water through the membranes and leads it to the accumulation tank of a treated water - white water. The reaction tank is equipped with a safety overflow, serves in cases of high production of grey water and ensuring the natural discharge of grey water to the sewerage system. On the contrary, insufficient production of grey water may occur, therefore the amount of water will be insufficient for water demand. To avoid this situation, the reaction tank is equipped with potable water supply. White water in reaction tank is retained until the utilization of the toilet, urinal or washing machine, when the water is pumped back to the system (Figure 6).

Figure 6 Submerged MBR, bioreactor with the filter for mechanical particles and pump supplying system with white water

6 Conclusion

This paper serves as an introduction for the future research planned in laboratories of Civil Engineering Faculty. This research will test the global efficiency of grey water system in laboratories conditions and will be compared with natural treatment technology – green walls. In consideration of the fact that Slovakia doesn't have the application or applied research dealing with the topic of grey water, it is expected that the research applied in Slovakia conditions will help to popularize this option in sustainable treatment with water. According to the ongoing work in laboratories, it is expected to start with research in foreseeable future.

7 Acknowledgments

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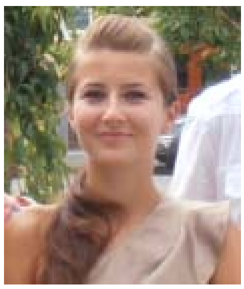

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