CIB W062 2004

Invitation

The International Council for Innovation and Research in Building and Construction (CIB) was created in 1953 in Paris. Fifty years later, the Working Commission W062 decides to held its 30^{th} annual symposium in Paris and asks CSTB (French Building Research Centre) to organize it. Therefore, on behalf of CSTB, the Organizing Committee is pleased to invite you to participate in this CIB W062 2004 30^{th} International Symposium on Water Supply and Drainage for Buildings, to be held on September 16-17, 2004, in Paris, France.

The symposium is open to all those experts, researchers, practitioners, regulators and industry from all over the world, with an interest in the developments in the field of water supply and drainage for buildings.

Symposium objectives

The aim of this symposium is to provide a forum where participants will be informed and exchange :

- experiences on recent developments in water supply and drainage for building,
- information on the characteristics and performances of systems and data for their design,
- on the implementation of codes and standards,
- on future research coordination.

Topics

Within the general area of concern, the topics in which papers are encouraged should preferably include the following :

- management and maintenance of water systems, commissioning, non destructive techniques, water conditioning, health aspects,
- sustainable construction, water conservation, rainwater and grey water reuse,
- hydraulics of water systems in buildings,
- influence of natural disaster, flooding, earthquakes, terrorism,
- durability, materials, historic buildings
- standardisation, certification, drinking water regulations.

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CIB W062 2004

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WATER SUPPLY AND DRAINAGE FOR BUILDINGS
30th International Symposium September 15-16-17, 2004
Scientific Program

September 15

4 p m – 5 p m Registration at CSTB Premises
7 p m – CIB W062 members meeting (on invitation)

September 16

8 30 a m – Welcome of participants, opening *: J. Rilling (CSTB), K De Cuyper (CIB W062)*

8 45 First Session - Supply systems
Coordinators : *O. M. Goncalves and B. de Gouvello*

- *M. C. Lee, C. L. Cheng, Y. H. Lin* – Hot Water Plumbing System and Temperature Drop Mechanism in Residential Buildings in Taiwan
- *H. Takata, S. Murakawa, D. Nishima, Y. Yamane* – Development of the Calculating method for the Loads of Cold and Hot Water Consumption in Office Building
- *L. Barta* – Modelling of Domestic Hot Water Tank Size for Apartment Buildings
- *H. Kose* – Measurement of Water, Electronic Power and Gas Consumption and Questionnaire about Act of Water Usage in the Apartment House
- *M. Mae, N. Noriyoshi, M. Kamata, T. Sawachi* – Survey on Residential Hot Water Consumption in Japan
- Discussion

10 30 Coffee break

11 00 First Session (following) - Supply systems
Coordinators : *J. A. Swaffield and L. T. Wong*

- *P. Ivanova, D. Alitchkov* – Investigation of Water Demand in Commercial Buildings
- *S. Murakawa, H. Takata, D. Nishina* – Development of the Calculating Method for the Loads of Water Consumption in Restaurant
- *N. Ichikawa, F. Kiya, Y. Misono, J. Doh* – Examination of Direct Booster Water Supply System in Japan
- *I. Toma, O. Alexandrescu, Th. Mateescu, C. Galatanu, M. Profire* – Pumping for Iasi Water Supply
- *O. Correc, F. Derrien, Y. Diab* – Degradation Risk Assessment in Drinking Water Distribution Systems
- *A. Temizsoy, S. Esen, K. Sahlan, N. Tunc, S. Telatar* – Original Water Supply and Heating Systems in a 14th Century Bath : Cukur Hamam in Manisa, Turkey
- Discussion

1 00 p m Lunch

2 00 Second Session - Standardisation, Certification, Regulations
Coordinators : *K. De Cuyper and L. Barta*

- *L. Galowin* – Water Closet Tests Survey, Limit Impacts and Variations
- *J. Dirksen, J. Bryant, G. White* – Real World Testing of Drain Line Carry
- *O. Nuijten, J. Buis, T. Scheers* – Soundspotsim : Instrument to Predict the Level of Noise Resulting from Sewage Pipes in Buildings
- *F. Derrien, F. Bellenger, O. Correc* – The need for Certification in the Field of Water Distribution Systems
- *H. S. Abdel-Halim, W. Abdel-Halim, M. Nazih* – Selection and Evaluation of Appropriate Sanitation Systems in Rural Egypt. Case Study in Sohag Governorate, Upper Egypt
- Discussion

3 30 Coffee break

4 00 Third Session – Sustainability
Coordinators : *F. Kiya and D. C. Santos*

- *B. de Gouvello, Y. Khouil, F. Derrien* – The French Rainwater Reuse Experience in Buildings for Collective Use
- *H. Tamaki, G. Silva, O. M. Goncalves* – Submetering as an Instrument of Water Demand Management in Building Systems – University of Sao Paulo Case Study
- *D. C. Santos, H. Masini, B. M. Lobato, L. S. Masini* – Establishing Priority of Water Conservation Actions on a Building to obtain the Sustainability of Water Resources
- *M. A. Campos, S. V. de Amorim* – Rainwater Harvesting in a Residential Tall Building in the City of Sao Carlos, Brazil
- Discussion

September 17

8 30 Third Session (following) – Sustainability
Coordinators : *C. L. Cheng and S. Murakawa*

- *K. De Cuyper, K. Dinne, L. van de Vel* – Rainwater Discharge from Green Roofs
- *M. C. Liao, C. L. Cheng, C. H. Liaw, L. M. Chan* – Study on Rooftop Rainwater Harvesting System in Existing Building of Taiwan
- *M. Ilha* – Indicators for Water Consumption Estimation
- *S. Fiori, V. C. Fernandes, H. Pizzo* – Qualitative and Quantitative Evaluation of the Greywater reuse in Constructions
- *O. Oliveira Junior, J. Silva Neto* – Application of a Vacuum Water Closet in a Brazilian Airport
- *W. van der Schee* – Experiences with a Collective Domestic Water System in Leidsche Rijn
- Discussion

10 20 Coffee break

10 50 Fourth Session - Drainage Systems
Coordinators : *L. Galowin and K. Sakaue*

- *K. De Cuyper, J. A. Swaffield* – Report on the SARS Conference held in Los Angeles by WHO
- *L. B Jack, J. A. Swaffield, S. Filsell* – Identification of Potential Contamination Routes and Associated Prediction of Cross Flow in Building Drainage and Ventilation Systems
- *J. A. Swaffield, L. B. Jack, D. P. Campbell* – The active Control and Suppression of Air Pressure Transient within Building Drainage and Vent System
- *C. L. Cheng, W. H. Lu, K. C. Ho* – Current Design of High-Rise Building Drainage System in Taiwan
- *V. M. C. Fernandes, O. M. Goncalves* – Study of the Limit Conditions for Single Stack and Fully Vented Systems in Brazilian Residential Building Drainage Systems
- *W. H. Lu, C. L. Cheng, M. D. Shen* – An Empirical Approach to Peak Air Pressure on 2-Pipes Vertical Drainage Stack
- *L. T. Wong and K. M. Mui* – A survey of Sanitation Load for Domestic High-Rise Building Estates in Hong Kong
- Discussion

1 00 p m Lunch

2 00 Fourth Session (following) - Drainage Systems
Coordinators : *L. B. Jack and C. Galatanu*

- *B. Ipekoglu, K. Reyhan* – Investigation of Water Installation System in a Group of Ottoman Baths
- *K. Sakaue, S. Okada, K. Ikeda* – The Function of Traps and Assessment of Drainage Gas
- *Y. Minami, M. Otsuka* – Study of the Flow Pattern of the Ground Food Waste in the Drainage Stack
- *Th. Mateescu, V. Cotorobai, M. Slavu, M. Profire* – Theoretical and Experimental Researches about the Flow in Interior Sewerage Installations
- Discussion

3 30 Coffee break

4 00 Fourth Session (following) - Drainage Systems
Coordinators : *Th. Mateescu and F. Derrien*

- *M. Otsuka, M. Nanyo* – Proposal of the Flow Capacity Prediction Method for Drainage Systems Considering the Influence of Combined Drainage Load Inside House Drains
- *Y. Asano, M. Asano* – A Study of the Proper Number of the Fixtures in Toilets of Schools
- *M. Gormley, D.P. Campbell, J. A. Mc Dougall* – The Interaction of Solids in Above Ground near Horizontal Drainage Pipes
- *G. B. Wright, L. B. Jack, J. A. Swaffield* – Investigation and Numerical Modelling of Roof Drainage Systems Under extreme Events
- Discussion

Symposium Conclusions

International Council for
Research and Innovation in
Building and Construction

Centre Scientifique et
Technique du Bâtiment

Wallace Fountain

As illustration for our symposium's documents, I have chosen the Wallace Fountain, a Parisian institution.

These fountains were installed thanks to Sir Richard Wallace (1818 – 1890) who was an English philanthropist and collector, wishing to contribute to the well-being of Parisian people.

The first Wallace Fountain was unveiled in August 1872, enthusiastically : everybody wanted to drink the good potable water and the wait was long before reaching the tin beaker chained up to the basin's rim. Every district in Paris received first two of them. Their number increased up to hundred.

About eighty are still remaining today. Their initial function has been reduced due to the installation of potable water distribution systems in buildings and in 1952 the tin beaker was removed in the interest of hygiene.

François Derrien

Modelling of Domestic Hot Water Tank Size for Apartment Buildings

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Abstract

The properly designed hot water tank should provide water supply at prescribed parameters during operation time within the apartment building at the lowest investment and operation costs. Its size is based on the graph sketch of two timely dependent functions. The first one describes the energy supply into the tank; the second describes the energy (hot water) output from the tank. Especially the second function depends on factors with random character. The paper deals with the analysis of both functions and evaluates their influence on the tank size. Starting basis for solving these problems are real data series picked up from measurements of hot water consumption within apartment buildings. The paper is focused on central domestic hot water supply systems with small outputs of heat resources which supply the number of flats between 32 to 60. There is created the probability model of hot water demand and following application of this model leads towards the determination of the possible usable tank size. Therefore it can be stated that: (a) in the case of continuous heat supply during the whole period (24 hours) the decisive factor for the tank design is the Sunday curve of hot water demand, heat losses do not influence the tank sizing but they have to be compensated by higher output of heat source, (b) in the case of continual heat supply except night hours (17 hours) during which the heat supply is interrupted there is decisive the characteristic curve for working days, currently there is a distinct increase of tank size which rises with heat losses too and which is most remarkable during working days.

Keywords

Apartment buildings; hot water consumption; analysis; probability model; usable tank capacity.

1 Introduction

One of the partial tasks of this currently proceeding research within existing central domestic hot water supply systems which prevail in the apartment buildings in the Czech Republic is the optimalization of the capacity of hot water storage tanks. The object of interest is the system which supplies one apartment building, respectively one residential section with the number of flats between 32 to 60. The energy is usually supplied from the district boiler room which is common for more buildings and which is located in a separated building. During night hours the supply is usually interrupted. The boiler room output stipulated only for water heating is divided into particular tanks, so it is limited for a concrete building.

The prepared reconstruction of these systems will have to be focused not only to guarantee a reliable and safety-working function but also to achieve the lowest investment and operation costs. It can be said that the research aim is the system keeping the comfort of hot water supply on the present level or aptly on higher level but currently with lower consumption of water and energy. For the hot water tank design there is the decisive factor the time course of energy supply into the tank and the time course of energy consumption (hot water) during the day. The water supply depends on a number of difficultly characterised factors and it has a probability character.

In this contribution there is presented the simulation method for the determination of optimal water tank sizing. The probability behaviour of hot water consumption within apartment buildings results from experimental monitoring.

2 The principle of hot water tank sizing

For the determination of the hot water tank capacity there can be used a high number of methods starting with empirical procedures which are suitable especially for preliminary projects to exact calculation methods. But the reliability of results depends always on the accuracy of the input data which is valid especially for exact methods. The method which is currently used in the Czech Republic belongs among exact methods. It concerns mostly the numerically-graphical method whose result is the minimal storage of heat (hot water) which is necessary to take into the water tank. This storage of heat is given by the curve of heat supply into the tank and by the curve of heat consumption (hot water) from the tank (Figure 1). The curve of heat supply is the dependency of the heat supply into the tank which depends on the time τ during the period. It is given by the output of heat source and heat supply duration. The curve of heat consumption is the dependency on heat consumption (hot water) from the tank on the time τ during the period. This curve can be determinated by measurements of water consumption, time analyses of water consumption or it is possible to use the standard curve stated in technical standards.

This presented method supposing the knowledge of course of heat consumption from the tank and the course of heat supply into the tank this is the basic element for the calculating algorithm.

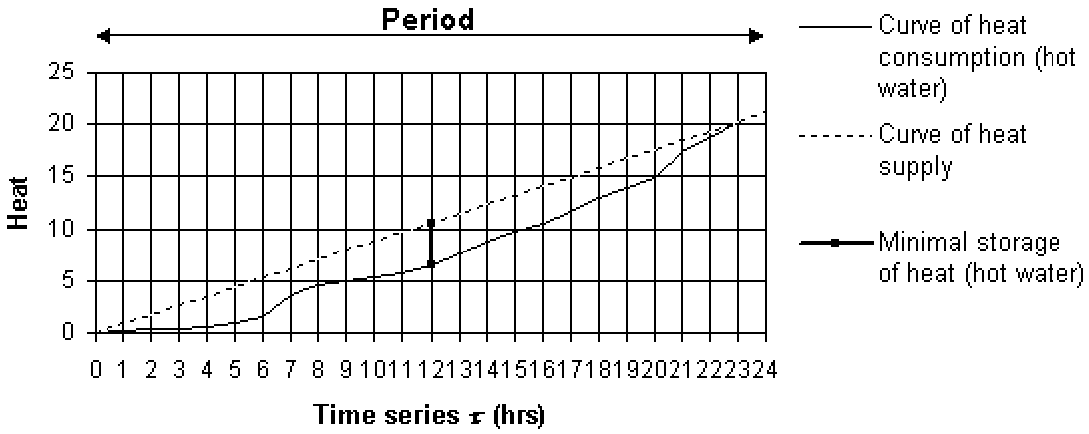

Figure 1 – Principle of hot water tank design

3 Heat supply into the tank

For the daily heat demand needed for the production of hot water H_1 and daily heat demand taken away from the tank H_2 there must be applied

$$H_1 = H_2 \tag{1}$$

The amount of taken away heat demand we can determinate according the equation

$$H_2 = H_{2t} + H_{2l} \tag{2}$$

where H_{2t} is the heat amount contained in the consumed hot water and E_{2l} are the heat losses of storage tanks and the distribution system.

For the heat H_{2t} contained in the hot water there is applied the following equation

$$H_{2t} = m \cdot c \cdot (t_2 - t_1) \tag{3}$$

where m is the demand of hot water during one period (day), c is the specific thermal capacity of water; t_2 is the temperature of hot water and t_1 is the temperature of cold water. In the following solution there is considered with the thermal difference 45 C^o.

The heat loss H_{2l} is given by the geometry of the system, thermally-technical properties of distribution and reculciraculation pipes and thermal insulations, thermal parameters of hot water and the environment and the operation time of this system [2]. The heat loss H_{2l} does not depend on the consumption of hot water. We usually assume that particular quantities which influence the heat losses do not change with the time, therefore the heat loss can be considered as the quantity periodically not dependent. Within present systems which have not suitable insulation completation, these losses can achieve up to 100 % from the value H_{2t}, after the reparation of the insulation the losses can be up to 30 %.

The output of the heat source can be determinated according the equation

$$Q_1 = \frac{H_1}{\tau} \tag{4}$$

where τ is the total duration of the heat supply within the whole period.

Within the 1st research phase there where included these two simplified cases:

- continual heat supply into the tank during the whole period,
- continual heat supply into the tank with interruption due to limited operation time for heat source.

The cycled tank heating which occurs within these two observed cases will be the focus of the following research phase and therefore it is not presented in this contribution.

4 Analysis of hot water demand

4.1. Results of experimental monitoring

The water consumption in apartment buildings depends on many factors among which ranks e.g. the building category, number of users, their professional orientation and age structures of inhabitants, the way of spending their leisure time, seasonal period or technical realization of the system. Due to influence of these factors the consumption of hot water supply can fluctuate within particular buildings, during the course of a week or day. When we compare the consumption of hot water within several apartment buildings we can identify during its periodical distribution the following trends (Figures 2 through 4):

- during working days there appear the peak consumptions during evening hours, particular peaks can be observed during morning or midday hours,
- for Saturdays there is typical a peak consumption before the noon and a particular peak in the evening,
- Sundays are approximately the opposite of Saturdays.

These findings result from experimental observations of hot water consumption within several apartment buildings [1]. By these measurements there was moreover found out further:

- specific consumptions of hot water supply are lower then it is stated in technical standards,
- coefficients of water consumption variations among particular buildings do not substantially differ,
- the highest consumption of hot water supply is during the evening period (17:00 – 23:00) with the exception of non-working days.

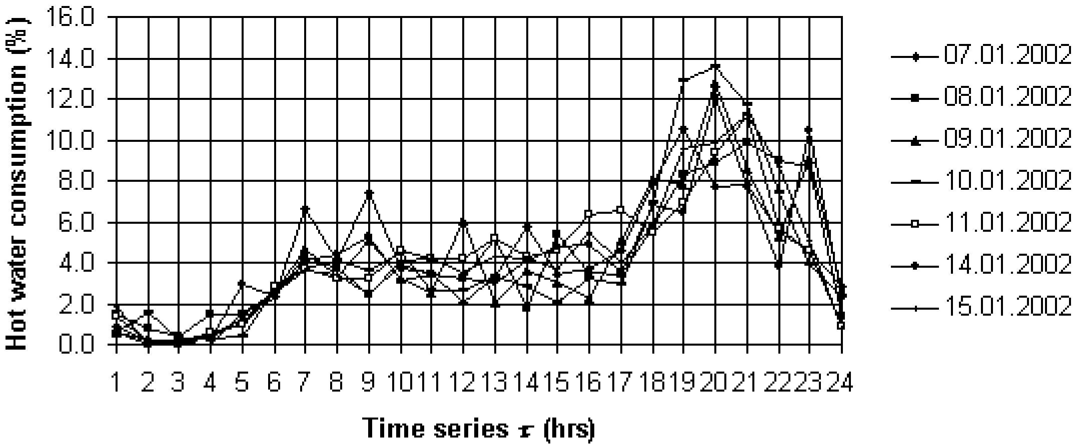

Figure 2 - Hourly consumptions within working days – examples of measurement

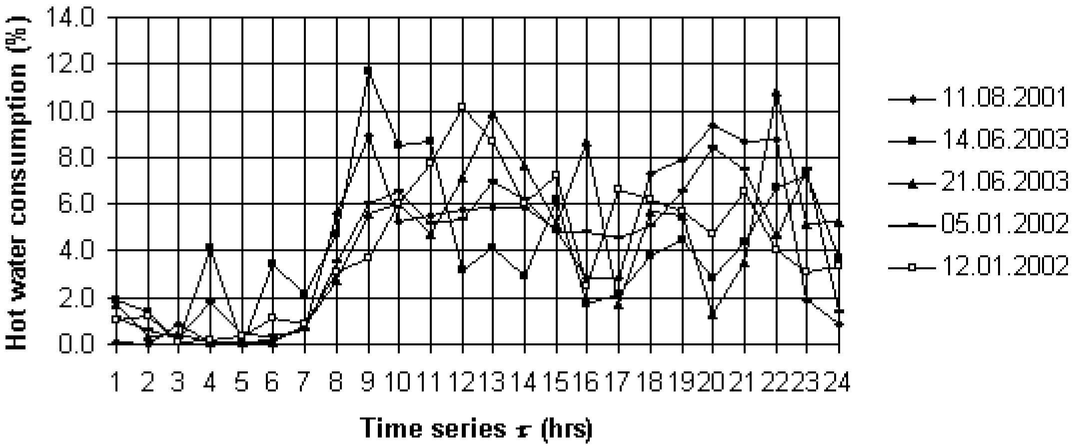

Figure 3 - Hourly consumptions within Saturdays – examples of measurement

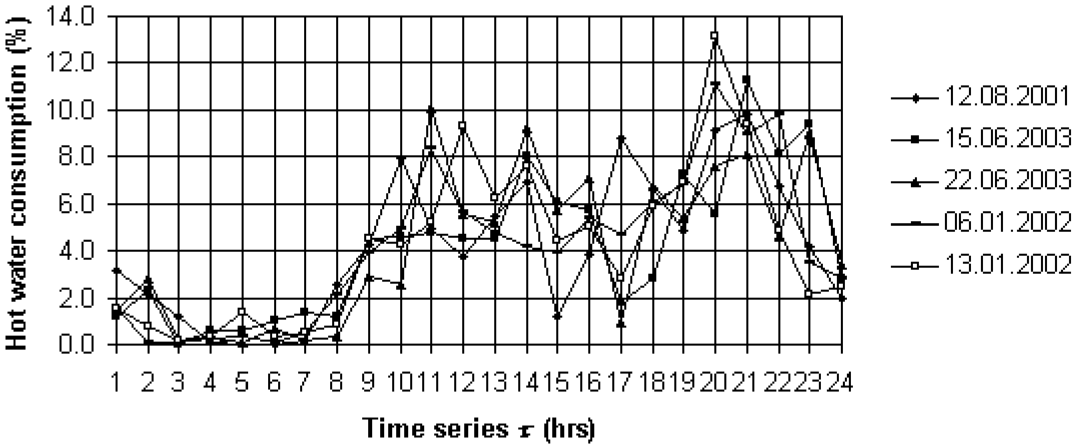

Figure 4 - Hourly consumptions within Sundays – examples of measurement

The analysis of hot water supply within apartment buildings requires higher amount of measured data on different types of apartment buildings. The current data basis is the result of continual measurements during one-week and three-week intervals within three different apartment buildings.

4.2 Probability model

On the basis of experimentally observed trends in hot water consumption and on the basis of application of probability theory there is created the probability model of hot water demand. By using the computing simulation we can obtain unlimited number of various daily distributions of water demands.

The probability behaviour course of curve of the hot water demand in apartment buildings can be defined as follows:

- hot water demand is divided into *n* intervals within one period,
- demand in the interval *i* is continuous random variable X_i at $i=1$ up to *n*,
- each random variable X_i has uniform Probability Density Function f_i with parameters a_i, b_i, where $P(X_i = x_i) = 1/(b_i - a_i)$ for $x_i \in \langle a_i, b_i \rangle$, note there can be also used another precondition about shape of PDF e.g. Laplace - Gauss,
- parameters of particular PDF are determinated on the basis *m* of experimental measurements (records of water consumption in *m* periods),
- if the random variable attains X_i value from intervals $\langle x_{i,\min}, x_{i,\max} \rangle$ and by sufficient number of experimental measurement realizations, i.e. $m>20$ then it is possible to get relatively reliable parameter estimations considering PDF f_i, then $a_i = x_{i,\,min}$ a $b_i = x_{i,\,max}$,
- above described probability behaviour of the demand curve is then consequently used for its computing simulation i.e. for the realization *k* trials (Figures 5 through 7),
- following applications of the above described mathematical model lead towards the determination of the continuous random variable *Y* and its PDF *g*, i.e. the possible tank size,
- further we can define the continuous random variable *Z* i.e. water demand in the period where $Z = X_1 + \ldots + X_n$.

5 Hot water tank modelling

5.1 Variants of solutions

The formed mathematical and probability model of hot water demand can be used for modelling the usable tank capacity by using the computing simulation. On the basis of fundamental factors analysis in Sec. 3, 4 which influence the tank volume there is

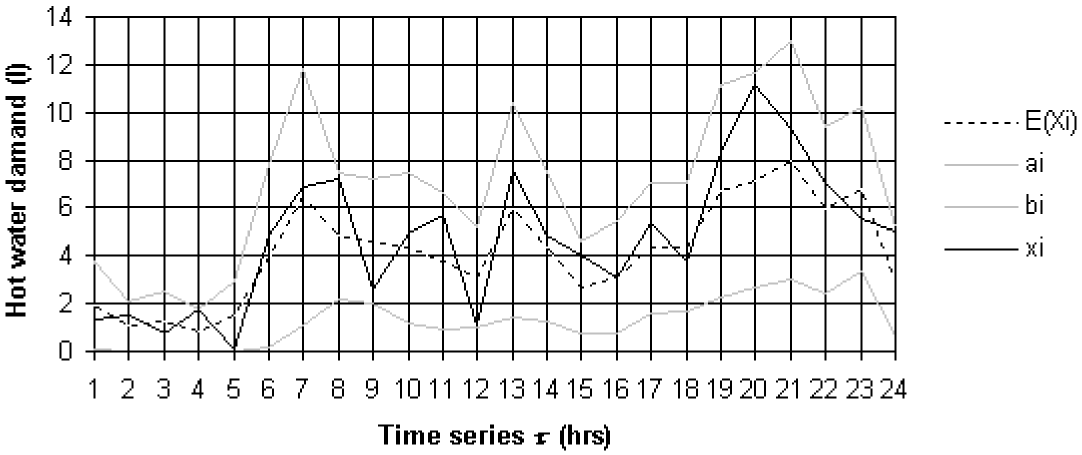

Figure 5 – Time distribution of standardized hot water demand – working days

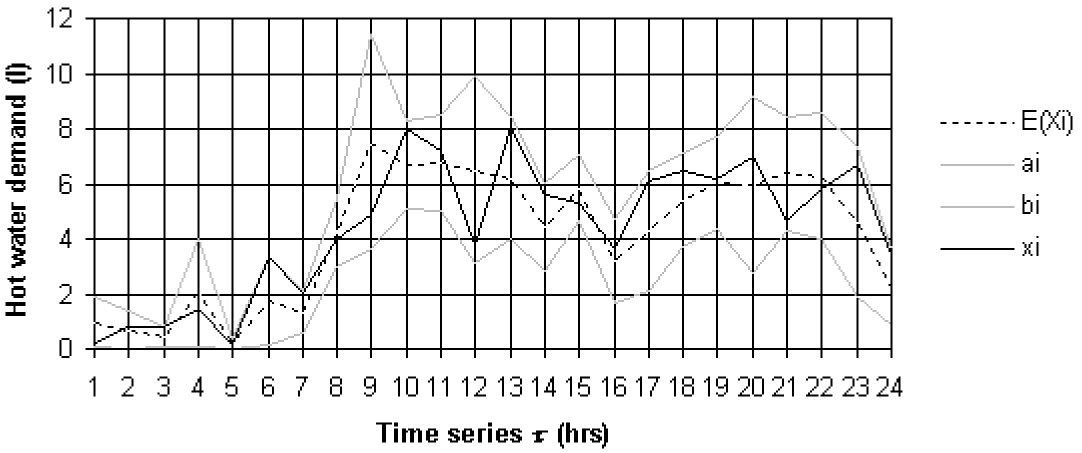

Figure 6 **– Time distribution of standardized hot water demand – Saturdays**

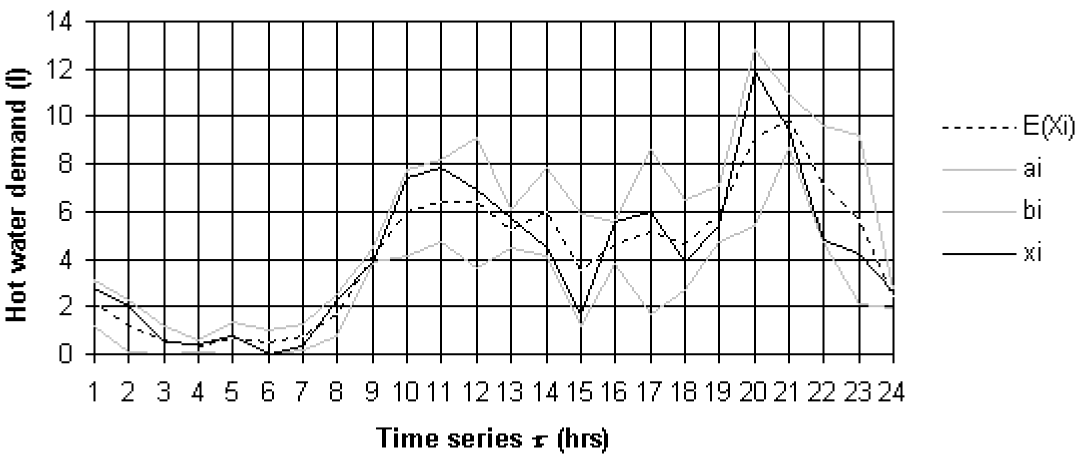

Figure 7 – Time distribution of standardized hot water demand – Sundays

defined 6 variations of solutions. The aim is to found out the influence of particular factors on the tank size.

Within all variations there is chosen the same period length corresponding to 24 hours and they are divided into hourly intervals. Within particular intervals there is differentiated the length of continuous heat supply, characteristic curve of daily demands for various days and heat losses within the system (Table 1)

Table 1 - Solved variations

Variation	Day	Heat supply	Resulting solution
A1	Working day	Continuous (24 hours)	Figure 8
A2		Continuous (17 hours)	Figure 8
B1	Saturday	Continuous (24 hours)	Figure 9
B2		Continuous (17 hours)	Figure 9
C1	Saturday	Continuous (24 hours)	Figure 10, 11
C2		Continuous (17 hours)	Figure 10

For each variation there were computed 2999 simulations.

5.2 Results and discussion

Results of usable tank volume modelling are presented within the graphical outputs (Figures 8 through 11).
Histograms in Figures 8 through 10 show the number appearance of random variables *Y* i.e. possible standardized the tank size within particular calculated variations. Therefore it can be stated that:

- in the case of continuous heat supply during the whole period (24 hours) the decisive factor for the tank design is the Sunday curve of hot water demand, heat losses do not influence the tank sizing but they have to be compensated by higher output of heat source,
- in the case of continual heat supply except night hours (17 hours) during which the heat supply is interrupted there is decisive the characteristic curve for working days, currently there is a distinct increase of tank size which rises with heat losses too and which is most remarkable during working days.

Figure 11 is example of outputs for the C1 which show the realization number of two-dimensional random variable (*Y, Z*) where the random variable *Y* is the possibly standardized tank size and the random variable *Z* is the possibly standardized water demand during the period. It is obvious that to one value of the daily demand is possible to rank to various tank sizes and visa versa. The stated dependency results from the probability behaviour of the input curve of the water demand.

The probability behaviour of the random variable *Y* or the random vector (*Y, Z*) can be used for the definition of hot water supply comfort as follows:

- it is possible to require that this system will never fail or

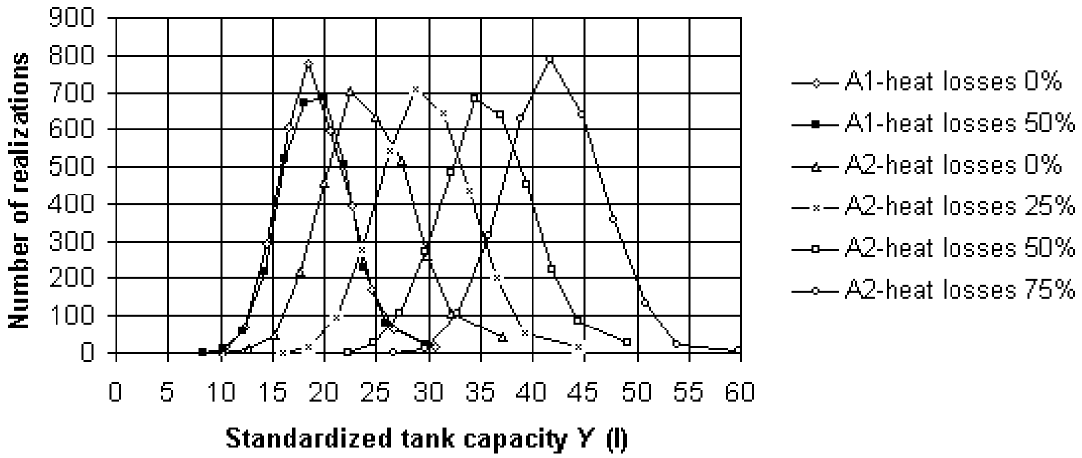

Figure 8 – Possible tank capacities for working days

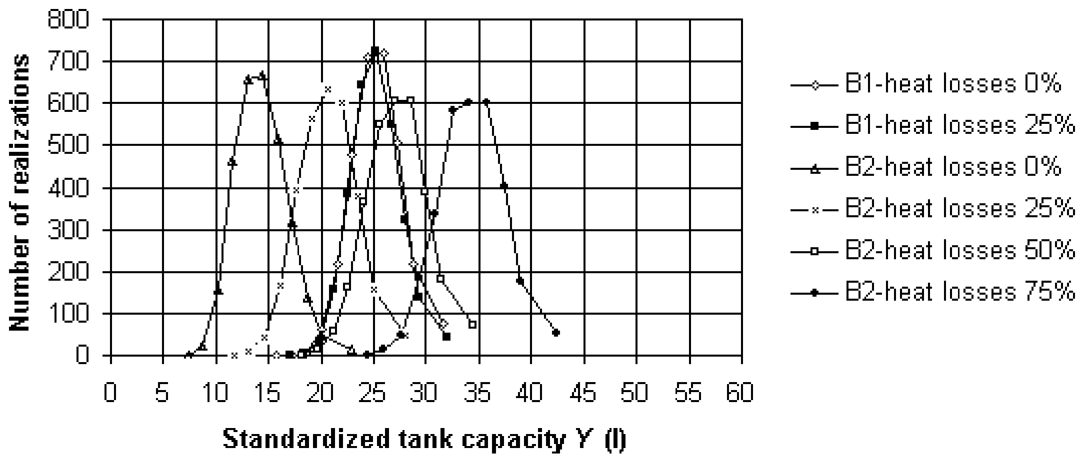

Figure 9 – Possible tank capacities for Saturdays

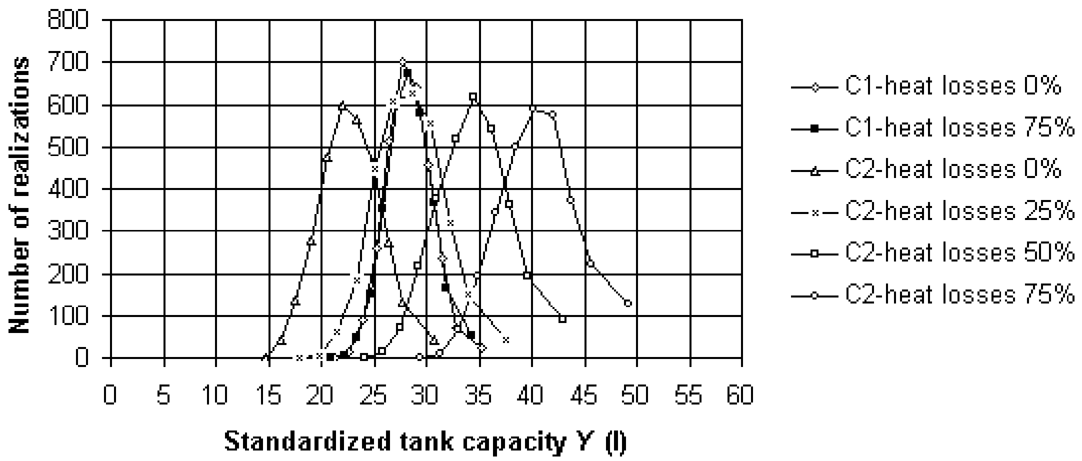

Figure 10 – Possible tank capacities for Sundays

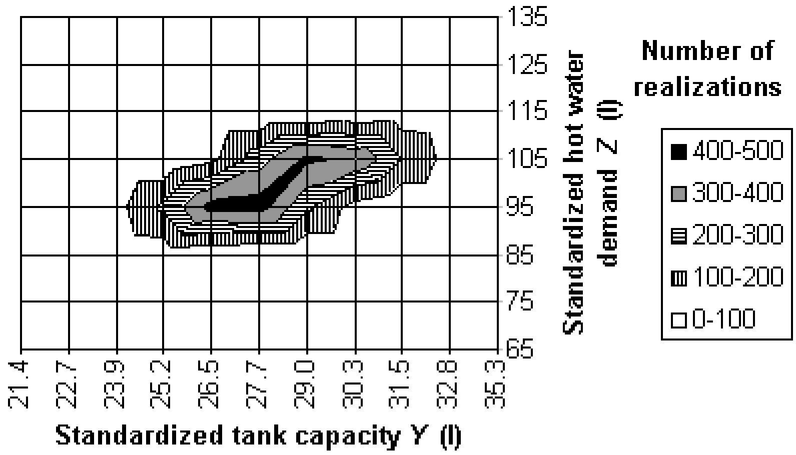

Figure 11 – Possible tank capacities for Sundays – variant C1

- it can be taken into account a certain percentage of cases at which there will not be achieved the requested parameters of hot water supply (short-time decrease of water temperature).

From the probability point of view the above stated comfort of hot water supply can be defined as $100.\gamma$ procentual quantile $y(\gamma)$ (5) of the random variable Y, where $1-\gamma$ is the already mentioned probability of the system failure.

$$P(Y \leq y(\gamma)) = \gamma \qquad (5)$$

6 Conclusions

At this present research stage the presented probability model is applied for solution of 6 chosen variations which include the cases which are based on probability distribution of hot water demand and the minimal possible output of the heat source.

The results prove that the usable tank size depends on the daily hot water demand, daily distribution of hot water demand, duration of heat supply into the tank, output of the heat source and on heat losses of the complete system. Details are described in Sec. 5.2.

The next research task will focus on the enlargement of the data basis enabling the higher accuracy of the model and especially on the system modelling for cases of higher output of the heat resources.

Acknowledgements

Acknowledgements are made to the Ministry of Education of the Czech Republic for the assignment of research project MSM 261100006 Development of methods of modelling and management water and transport systems whose support allowed for the mentioned research to be realized.

7 References

1 Bárta (Ladislav), *Experimental Monitoring of Hot Water Supply Systems*, 29th International Symposium Water Supply and Drainage for Buildings CIB W62, (pp 199 - 212), Ankara (Turkey), September 2003.

2 Bárta (Ladislav), *Energy Conservation of Domestic Hot Water Distribution Systems*, 27th International Symposium Water Supply and Drainage for Buildings CIB W62, (pp B6/1-B6/10), Portoroz (Slovenia), September 2001.

8 Presentation of Author

Ladislav Bárta is the assistant professor at the Brno University of Technology, Faculty of Civil Engineering, Institute of Building Services. His specializations are Plumbing Systems and Pumps Systems. Recently he has been concentrated on the field of internal water supply systems especially with the point of view of possible savings within investments and operation costs.

Degradation Risk Assessment in Drinking Water Distribution Systems

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Abstract

This article deals with a methodology building for degradation risk assessment in drinking water distribution systems. Nowadays, degradations of piping systems inside buildings are not finished. The degradations understanding is not vulgar. She requires implementation of specific methods such as Failure Mode and Effect Analysis or Fault Tree Method. This original approach allows to avoid emergency situations.

Keywords

Sanitary water; building; prediction of failure.

1 Introduction

The preservation of sanitary water quality inside buildings is a major concern at the beginning of this 21st century [1]. The European Council Directive of 1998 on the quality of water intended to human consumption was transposed in French regulations in 2001 [2]. Consequently, the conformity of water quality is appreciated at the consumer's tap and no more at the building entry. This fact leads to new responsibilities for the quality of distributed water, not only for the water company but also and especially for the owners and building managers.

Moreover, piping system inside buildings suffer from chemical and mechanical degradations, expressed by corrosion and scaling phenomena [3]. The effects of these pathologies are not only risks for the user's health (dissolution of metallic components in water, development of bacteria) but also for the installation (pipe destructions, equipment damaging and leakage).

The origin of theses damages are listed as design errors (pipe size), bad implementation (realization of soldering) or maintenance, but also as water and material composition [4].

Therefore to take into account all these factors, the creation of a scientific tool is wished, because, at the present time, there is no general method to investigate a water installation. The diagnosis remains expert skill. The aim of this study is to evaluate the degradation risk of a water distribution system, as well as the design of an alarm system. The role of this latter being to define a dysfunction potential.

The methodology used is based on the methods coming from the functioning safety in the industrial world, like the Failure Mode and Effect Analysis (FMEA) and the Fault Tree Method (FTM) [5]. They allow to identify and index all the possible failure mode. The quantitative approach, allows the access to the deterioration state of a domestic water supply system, through the linguistic assessment of the dysfunction risk.

The first part deals with the corrosion and scaling phenomena of pipes inside building and their origins. Then, we develop methodology that allows to predict the degradation risk.

2 Pathologies: corrosion and scaling phenomena, origins

Corrosion and scaling phenomena are the two main degradations on the domestic water supply [6]. Galvanized steel and copper are the studied materials because they are both used very often. The first is usually used for the belt and ascending pipe and the second, for the antennae in the private part. Experience has shown that both materials have good corrosion resistance to drinking water when properly selected and properly installed. But either can be subject to corrosion failures when abuses occur in designing the system or by installation production.

2.1 Pipes corrosion

Metals, alloys and metallic coating using, in the sanitary water installation, involve corrosion effects and under especially conditions may cause damages like leakage or red water.

The corrosion is an electrochemical phenomenon trade off electrons between two electrodes in an aqueous medium. For instance, the iron:

Oxydation reaction : $Fe \longrightarrow Fe^{2+} + 2e^{-}$

Reduction reaction: $2\,H_2O + 4\,e^{-} + O_2 \longrightarrow 4\,OH^{-}$

The electrochemical corrosion start when several conditions are combined: conductive medium, the flow of electric current and the presence of a system asymmetry, on the metal or in the solution. This asymmetry can be result of an oxygen concentration difference or a surface heterogeneity.

Galvanized steel is made up of iron and carbon (steel), its surface combines some zinc layers with a percentage of iron. The later layer, in contact with water, is a pur zinc coating. Attack on the galvanized steel may be general or localised [7]. Three main corrosion types may be observed.

First, *galvanic or bi-metallic corrosion* [8]. Because of the difference of electrical potential between copper and iron, for instance, a driving force is created between the two metals when in contact with a common electrolyte, such as water, and when they are electrically connected. Therefore, in presence of copper upstream from galvanized steel, the latter corrodes.

Figure 1: Galvanic corrosion

The second type of corrosion is the *differential aeration corrosion*. An oxygen different concentration involves a corrosion cell, because of sediment presence or no tight threading.
Finally, *selective corrosion* of the zinc layer, leads to the presence of sandy, zinc corrosion product in house installations, often combined with heavy red water problems. These troubles were caused by the bad quality of the zinc layer and especially silicon and phosphorus concentration of steel, but also by the air-blown pipes.

Figure 2: Differential aeration corrosion

Figure 3: Selective corrosion

At the beginning of its life, **Copper** builds a protective layer: malachite $Cu_2CO_3(OH)_2$, green colour. Copper extern corrosion is due to humidity of the atmosphere or domestic product aggressiveness .Four sorts of corrosion may be remarked for internal corrosion.
Generalized corrosion is due to water acidity and low bicarbonate concentration. High pH tends to initiate blue water problems.
Pitting is a form of extremely localized attack that results in pinholes in the metal. Pitting is one of the most destructive and insidious forms of corrosion. The presence of thin carbonaceous films on the internal surface and composition certain of cold water lead to *Type I pitting* of copper tubes [9] et [10]. Carbonaceous films derive from lubricants used in manufacture for the drawing and which are carbonized during annealing. The water has to have a critical composition that is determined by a combination of six inorganic parameters (dissolved oxygen, sulphate, chloride, nitrate,

sodium and pH). The corrosion pits are small size and are usually covered with a greenish scale of copper corrosion products. Foreign matter can also introduce in water line and builds the film for start the pitting. So two or more factors need to be present for Type 1 pitting damage to occur.

Type II Pitting is developed in soft hot water (i.e. greater 50°C) with low pH. Some studies suggest that the ratio of bicarbonate to sulphate HCO_3^-/SO_4^{2-} is the critical factor. In the most case, there are not corrosion products for this one.

Corrosion erosion is the acceleration of metal rate deterioration because of relative movement between water and the metal surface. Generally, on the copper, corrosion erosion occurs when water rate exceeds 1,5 m/s. It is characterized by waves and horseshoes. The orientation of the pits indicates the flow of the water.

Cavitation damage is a special form of erosion corrosion which is caused by the formation and collapse of vapour bubbles in a liquid near a metal. Cavitation damage occurs in pump impellers or other surfaces where high-velocity liquid flow and pressure changes are encountered, like fittings without branch piece tee.

There are an others type of corrosion. The solder paste releases from surface metal some oxide to join both tubes. But if it is not wash after the welding, the corrosion may be carry on because flux contains chemicals agents that are aggressive for copper. Using Cu-P soldering may result in galvanic corrosion because, in contact with water, the soldering join become a cathodic area and the copper an anodic area.

2.2 Scale in household tubes

The increasing temperature in hot water tends to move the "calcocarbonic equilibrium" to the direction (1).

$$Ca^{2+} + 2HCO_3^- \underset{(2)}{\overset{(1)}{\rightleftarrows}} CaCO_3 + CO_2 + H_2O$$

The water composition and the temperature may lead to precipitate the calcium carbonate. The equilibrium is rarely reached by water intended to human consumption, so it has to know if water tends to precipitate calcium carbonate (aggressive water) or to dissolve calcium carbonate (scaling water). With the aid of Legrand Poirier's software, water tendency is determined. If the deposition is excessive it can result in appreciable reduction in pipe diameter and in an extreme case can completely stop the flow of water. But Sometime the scale deposit can restrain the corrosion action.
Water composition is the main cause of pipes and equipments scaling, nevertheless there are some worsening factors as missing flush under the hot water balloon, a wrong monitoring of water softening…

2.3 Pathologies origins

The different corrosions above show that the degradation causes are multiple. Five origins may be listed: design, realization, maintenance, water and materials quality.

The design is the first operation led on a water installation so it's very important for its future life. Design may act on several points and in particular on the circulation flow, the water stagnation with creation of dead arms or unsuitable feed pumps. Air relief cock oversight at the balloon and ascending pipes top, increase thus water aggressiveness (free CO_2 is not eliminated).

Bad realization could also cause important damages when the soldering are overheated (higher than 875 °C) and zinc galvanized steel is vaporized. Or curving too strong so the protective layer may be damaged, when cutting are not carried out in state of art. Some cavitations troubles can appear on copper when connection piece are not branch piece T. Fittings require a permanent monitoring as temperature control or water treatment appliance control: softening, "filmogène" treatment, chlorine injection. Products effectiveness is assessed with quantitative analysis or discharge tube indicator observation. Network balancing must be control by temperature probe laid at either rising mains feet. This balancing is possible with control valves.

Material quality is important for his composition, his surface state, thickness, grammes per square meter zinc and galvanized layer composition. For instance, steel with a specific composition of silicon and phosphorus may lead to selective corrosion (sandy effect). And of course, water quality studied in the first part.

3 Methodology: Risk prediction tool

Clearly, the fittings understanding are not easy. So the paper aims to build a suitable tool which is able to assess degradation risks. Both degradation risks are corrosion and scaling, described in the part 2. The knowledge of each corrosion type is essential to predict damage risk. That‘s the reason why the Failure Mode and Effect Analysis (FMEA) and the Fault Tree Method (FTM) are used. They allow to identify and index all possible failure modes. But before that a technical and functional analysis is wished to characterize the system and his environment, but it doesn't develop here. Finally the quantitative reasoning, multicriteria evaluation method, permits to estimate the degradation risk level, i.e. to know if the installation tends to have high, average or low level risk.

These three stages are included in the prediction analysis of the functioning safety which is composed of four main parts

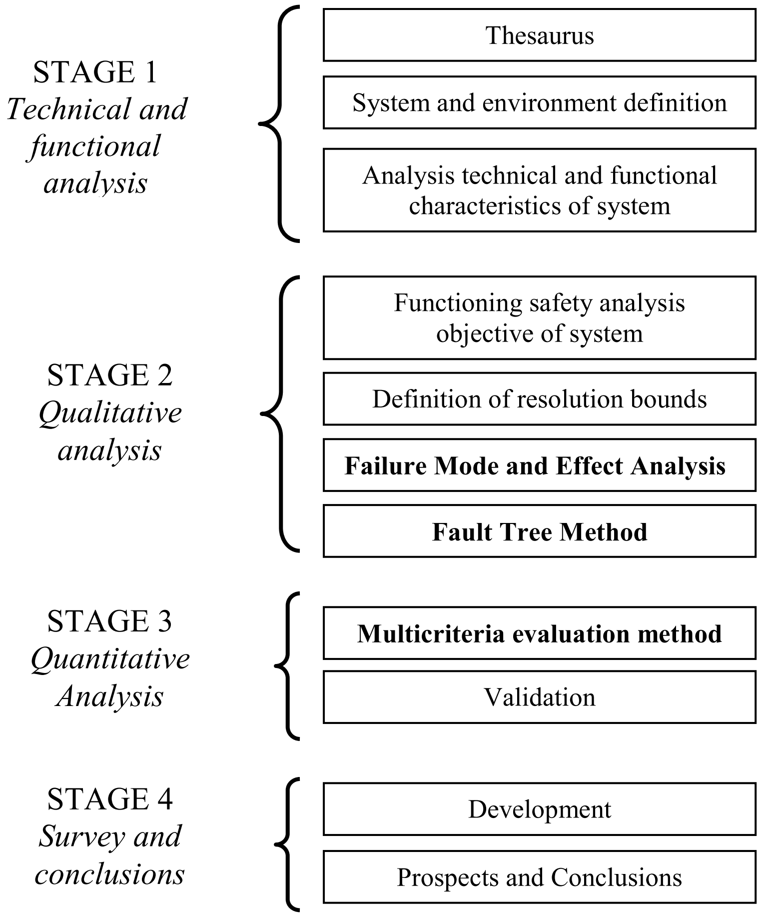

Figure 4: General methodology

3.1 Qualitative analysis: Failure Mode and Effect Analysis (FMEA) and the Fault Tree Method (FTM)

The qualitative analysis is devoted to understand the installation functioning, to reveal all possible failures and explanations but also the ways to detect them. Parameters, they could measure on the site, emerge from this qualitative analysis and are used for the quantitative analysis, in order to assess the degradation risk.

3.1.1 Failure Mode and Effect Analysis

FMEA has been using for the first time in the sixties to analyse the plane safety. FMEA is a system analysis method; it studies the failure causes and effects. It is intended to analyse and reduce the risk, anticipating all the dysfunction possibilities and origins of equipment, product or process. So each component is examined and their several corrosion and scaling type are described. FMEA is divided in two parts, process FMEA and product FMEA.

Process FMEA

This one includes the failures during the design and the realization. The example chose is galvanized steel which is used very often in the domestic water installation inside building. For which many damages are encountered.

Components	Operations Modes	Modes	Causes
Distribution SCW		Design	
	Choice Material/Water	Uniform corrosion …	pH…
	no galvanized malleable cast iron fitting	Uniform corrosion	no steel protection
	Material different G S	Galvanic corrosion	Copper presence
		Realization	
	soldering	Uniform corrosion	Work temperature > 810°C
	Screwing	Differential aeration corrosion	screwing too long
Distribution SHW		Conception	
	Choice Material/Water	Selective corrosion	Si and P of steel too high
	Dimensioning	Differential aeration corrosion	Pipe with too big diameter

Tableau 1: Extract of process FMEA

Product FMEA

FMEA is linked installation exploitation and all possible failure during drinking water fittings life. This analysis enhances the links of cause to effect. Product FMEA provides for each component, their failure modes and causes.

Components	Functions	Failure modes	Possible causes	Possible Effects	Possible Symptoms
Filter	Filter matter in suspension	Wipe	No maintenance	Deposit, Differential aeration corrosion.	Pimples, red water
Water softener	Soften water	Salting out chloride	Regeneration damaged	Pitting corrosion	Pimples, red water
		No softening	By pass damaged	Scaling	Scaling
			Hardening	Scaling	Scaling
		No regeneration	No maintenance	Scaling	Scaling
		Too much softened	Hardening	Corrosion	Pimples, red water

Tableau 2: Extract of product FMEA

3.1.2 Fault Tree Method

(FTM) provides events sequence which can lead to unique degradation. Each event is itself stemmed from one or several undesirable events. Thereby all degradation causes are detected. Nevertheless these combinations are represented by means of tree structure. FTM has appeared in 1961 in Bell office for missile reliability. FTM is a deductive method; the structure starts from undesirable top event (corrosion or scaling) to intermediate and base events. Each event is linked in cascade by means of symbols matching to logic connective (or, and, if…). FTM undergoes some troubles on failures mode exhaustiveness, so Villemeur recommends using FMEA simultaneously in order to don't forget any failures in the tree construction. The structure is finished when base events are achieved. Failure likelihood for each base event should be known to lead to top event failure likelihood.

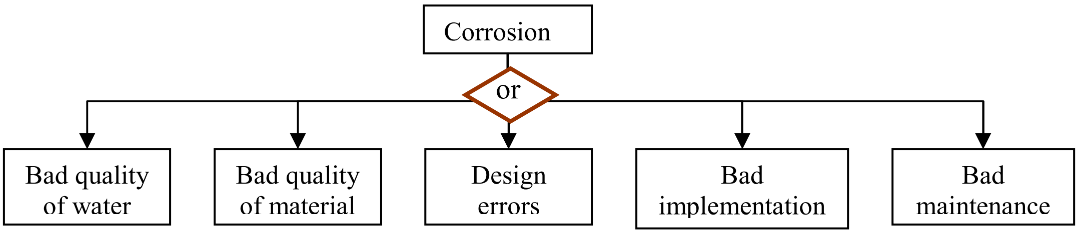

Figure 5: Extract of main tree

Our FTM doesn't contain event successions rather than different possibility of failure and their explanation. In this study, failure likelihoods are not known because of information lack. There is not enough damage survey. So another method has to design to model sanitary water system and assess the degradation risk level. That‘s the reason why multicriteria evaluation method has been choosing.

3.2 Quantitative analysis: Multicriteria evaluation method

This stage consists in assessing the degradation level of water installation by means of risk ciphering and linguistic quantization. The multicriteria evaluation method aims to combine base parameters, which were found with Failure Mode and Effect Analysis and the Fault Tree Method, into risk assessment. Aggregation method refers to the process of combining values (numerical or non numerical) into a single one. The three paragraphs following deal with, representation of input parameters, risk functions and output data.

3.2.1 Parameters representation

Factors calculated on site may be marred by mistakes. Actually some of them are difficult to see and when it's possible, sometimes it's hard to measure or quantify them. In order to take into account these mistakes, the fuzzy sets are used. They come from fussy sets theory [11] and possibility theory [12].

In fact, fuzzy sets allow to represent linguistics variables, "class", which can not represent with the usual mathematical like "the class of tall men". But also some classes that are not sharps boundaries. Fuzzy logic provides a wide range tool for dealing with uncertainty and imprecision in knowledge representation.

A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function which assigns to each object a grade to membership ranging between zero and one. And no more with the classical values, zero and one. For example the figure 3 shows the representation by means of fuzzy set the imprecision measure. This is an entry value of model.

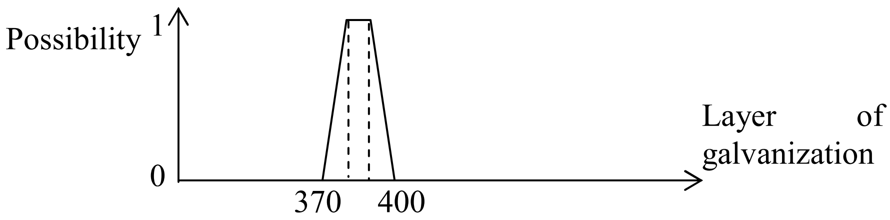

Figure 6: Representation of imprecision

By relying on the use of linguistic variables and fuzzy algorithm, the approach provides an approximate and yet effective means of describing the behaviour of systems which are too complex or too ill-defined to admit of precise mathematical analysis.
Each entry parameter is represented like the figure above to take into account entry value imprecision. Now in order to know degradation risk following each parameter, risk function is built and compared with value calculated on site.

3.2.2 Risk function
Risk function has to build with fussy sets. This construction assigns parameter impact on degradation risk of installation, like figure 2. The risk value is assessed between 0 and 1, 1 represents the maximum risk and 0 is the risk null.

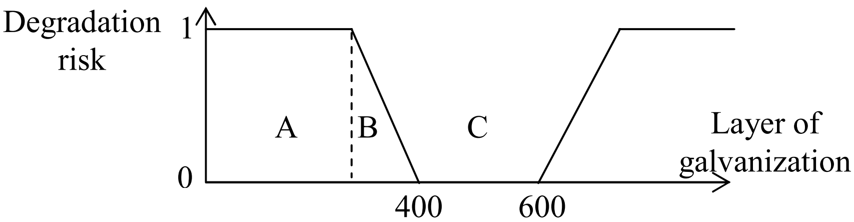

Figure 7: Representation of risk function

The graphic is cut into three parts:
- Zone A where parameter value involves a maximum risk for the system
- Zone B where the dysfunction risk is partial.
- Zone C where the risk is null.

These risk functions are established by means of bibliography on water chemistry, material science but also on terrain experiment, European and French Standard, DTU…
Now both fussy sets are going to compare with the intention of study their compatibility, so to perform a fuzzy screening. Let C be requirement elementary proposition and F fact elementary proposition, they refer to same variable X on field U and are represented by possibility distribution μ_C and μ_F respectively. Our wish is going to know the compatibility degree between F and C. Possibility theory give two scalar measures to estimate this compatibility [13].

$$\Pi(C,F) = \sup_{u \in U} \min(\pi_C(u), \pi_F(v))$$

$$N(C,F) = 1 - \Pi(\overline{C},F) = \inf_{u \in U} \max(\pi_C(u), 1 - \pi_F(u))$$

$\Pi(C,F) \in [0,1]$: is called possibility measure, matching to level of possibility so that the value x in F was compatible with C.
$N(C,F) \in [0,1]$: is called necessity measure, matching to level of necessity so that the value x in F was among compatible value with C.

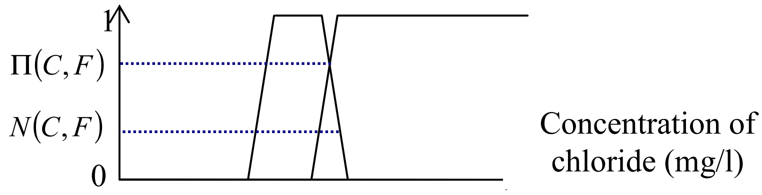

Figure 8: Possible and sure compatibility of two fuzzy sets

Therefore, $\Pi(C,F)$ here, is the plausibility to be in a wrong situation (degradation) for one parameter. Multicriteria evaluation methods allow to aggregate all parameters to have a whole vision on degradation risk.

3.2.3 Output data
Model outcome results in three levels, high risk, average risk and low risk. This ladder is intended to represent all dysfunction possible cases. Each output has a certain level of possibility and must be describe to know their meaning.

-**Low risk**: there is no problem of corrosion or scaling phenomenon. The fittings haven't to undergo modifications.

-**Average risk**: the fittings show signs of tiredness, some modifications should be made and a monitoring of key parameters has to be done.

-**High risk**: fittings functioning must be reviewed. Damages are obvious and are leading inevitably to the ruin of water installations.

Thus numerical variable must be transformed in linguistic variable. This operation is a key of tool built, indeed boundaries between the three kinds of risks have to validate by experiments on site.

4. Conclusion

Fuzzy aggregation of risk function should be the next stage. Aggregation operators have to choose among averaging operators, weighted averaging operators and or fuzzy integrals. Averaging operators have the property to be compensative but it couldn't be use with dependent parameters.
This original approach may be use in prevention to avoid emergency situations. The accuracy of results depends on amount of information available. This tool allows to class water installation according to level of degradation risk and to schedule interventions.

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Examination of Direct Booster Water Supply System in Japan

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Abstract

This paper reports on Direct Booster Water Supply (DBWS) system adopted in Japan. The DBWS system is a method to connect a booster pump to the water service pipe that diverged from a distributing water pipe. In some countries this system has already been adopted quite a long time ago in order to supply water to buildings. This system was introduced for middle scale buildings in Japan about 10 years ago. The main reason this system was not adopted earlier in Japan is that of a legal issue. On the other hand, there have been no legal regulations on maintenance of small capacity receiving tanks (less than capacity of 10 m^3). As a result, degradation of water quality in receiving tanks has been continuously pointed out. To solve this problem, various examinations have been performed for an extensive period of time. This resulted in the introduction of the DBWS system to Japan ten years ago.

This paper illustrates the introduction process of the system to Japan, current trends, related criterion and the decision method of booster pumps.

Keywords
Direct Booster Water Supply (DBWS) system, Waterworks, Booster Pump Unit, Estimated Terminal Pressure Peak Flow Rate,

1 Introduction

Since the adoption of European and US technology, Japanese plumbing system has advanced to the state of today. On-site and buildings' water supply system can be classified into two types of system, the direct supply system and the receiving tank system, as shown in Figure 1. Until recently, the former method that utilizes the

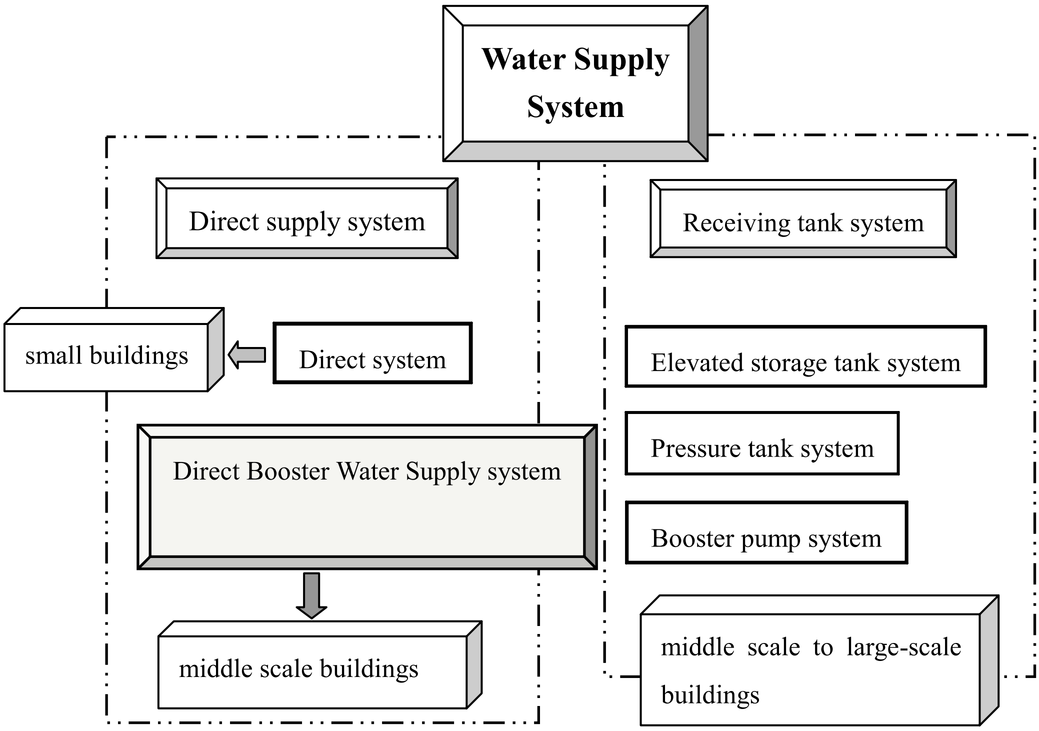


Figure 1 Type of water supply system in buildings

pressure from the distributing water pipe has been used for houses and small scale-low rise buildings. The latter method which first stores water in a tank and after distributes on demand has been adopted in middle to large-scale buildings. However, the collaborative works among the public, private and academic sectors with various perspectives resulted in the implementation of the DBWS system for middle scale buildings in Japan. Since the beginning of the implementation, Ichikawa and Kiya have led and planned projects to implement the DBWS system.

2 Implementation Process

2.1 The Japanese policy on implementing the DBWS system

An announcement of 'Long-term goal of water supply improvement towards the 21st century' by Ministry of Health, Labour and Welfare (MHLW) in 1991 gave opportunity to implement the DBWS system. MHLW is one of the Japanese government administration offices that deal with the public health & sanitation, labor and aging population issues, and also devise the standards for quality of potable water.

(A) MHLW directive basic policies

a) Waterworks accessible by all people
b) High safety level waterworks
c) Safe waterworks

(B) Detailed objectives for waterworks improvement

Seven items have been selected as the detailed objectives for the waterworks improvements. The following is one of the items expansion of subject for the direct water supply system.

a) With the long run perspective, promote the implementation of direct water supply on 3 stories to 5 story buildings and execute the required facility improvement. Moreover, enhance the service level of water supply and solve the sanitary issues of small size receiving tanks.

(C) Background of detailed objectives

a) To resolve the sanitary issue of under $10m^3$ receiving tanks that are exempted from the regulation.
b) To further expand the range of direct water supply system.
c) Other

2.2 Details and progress of DBWS system implementation

The method of raising the pressure level of a water supply can generally be classified into two types; one where a supplier raises the pressure of the entire water supply area, and the other where users of individual buildings can increase the pressure by directly connecting a booster pump onto a water service pipe that has branched off from the distributing water pipe. The former has been used by water suppliers until now. The latter is the DBWS system that has recently become popular in Japan.

The DBWS system has been adopted in Europe and US since the 1960s. The reason for Japan's late implementation of the system is that a pump that could affect a distributing pipe should not be connected to a water service pipe according to the Water Works Law of Japan. In other words, without even evaluating whether the pump would affect the main pipe, a notion of "a pump should not have a direct connection" delayed an adaptation of the system.

Figure 2 shows the flow of DBWS system from introduction phase to present day. In Japan as mentioned above, the MHLW's guideline of 1991 that directs 'improvement on facilities to expand the direct water supply' has been the start of DBWS system implementation. Today, 79 local governments have approved the implementation.

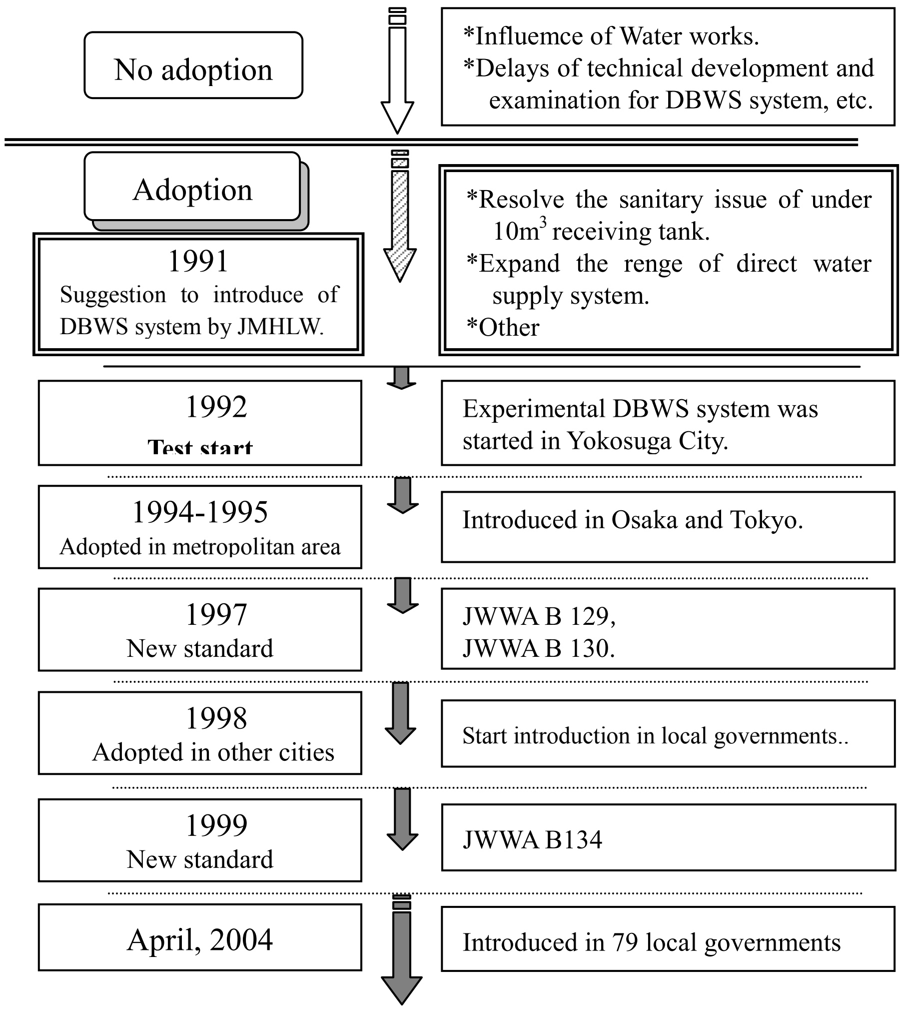


Figure 2 Flow of adopt DBWS system in Japan

Figure 4 illustrates detailed implementation results of Tokyo Metropolitan Government. Meanwhile, new technological standards have been set to date. Examples of such new standards are JWWA(Japan Water Works Association) -B-130 "Pressure booster for direct water supply"(1997), and JWWA-B-134 "Reduced pressure principle backflow preventers for water supply (BFP)"(1999).

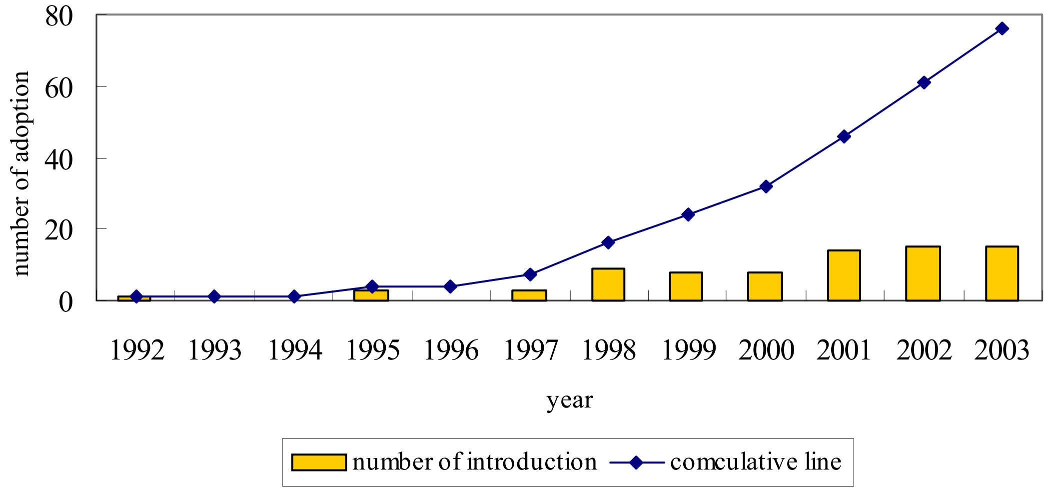


Figure 3 Transition of introduce DBWS system in local governments

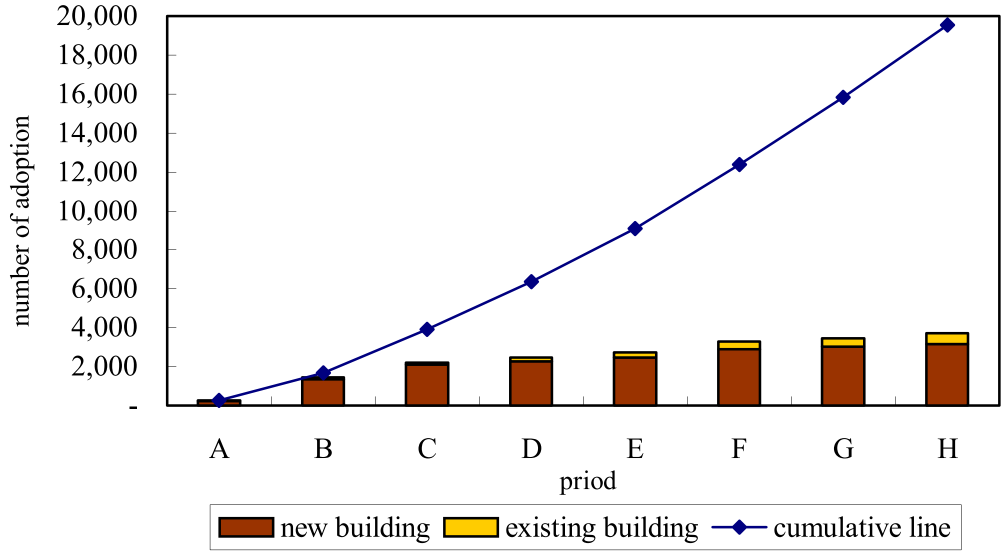


Figure 4 Transition of adopt DBWS system in Tokyo

3 DBWS system outline

3.1 DBWS system configuration

Figure 5 shows an outline of the DBWS system. Figure 5 (a) is a general system, and figure 5 (b) explains the method to apply the system to an existing building equipped with an elevated storage tank. Figure 5 (b), however, should only be considered as a temporary scheme. Installation of the BFP on the suction side of the booster pump is mandatory. The parts that were used as a reduced pressure principle backflow preventer in Japan for a short

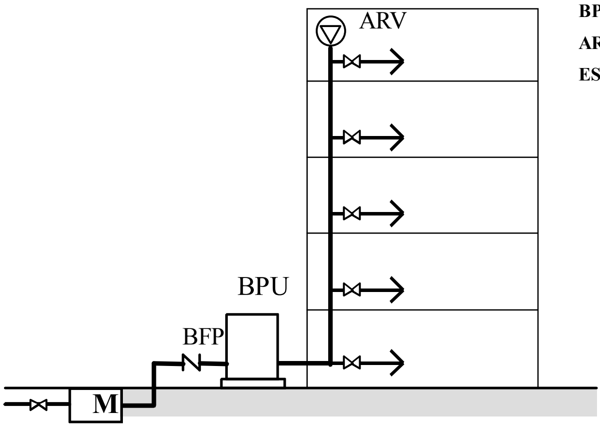


Figure 5 (a) DBWS System

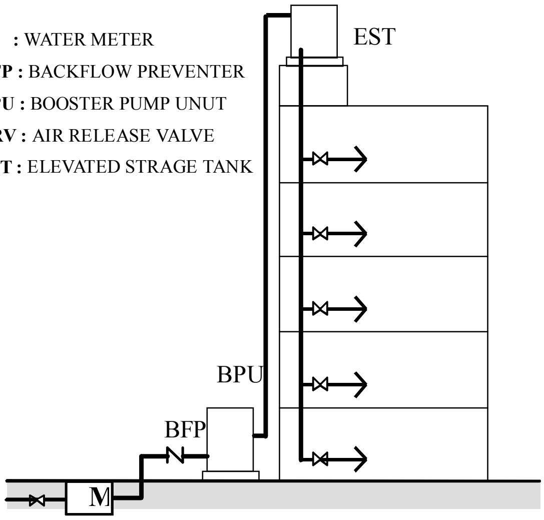


Figure 5 (b) Application to existing elevated tank

period of time from 1992 had been all imported goods. However, since an establishment of a new set of standards in 1999, domestic products (Picture 1) have been in use. Also in Tokyo Metropolitan Government, installation of a Meter Bypass Unit such as Picture 2 is obligatory in respect of periodical replacement of water meters.

Picture 1 Backflow preventer
(JWWA B 134) / by QSO[*1)]

Picture 2 Meter bypass unit
/ by QSO[*1)]

3.2 Booster Pump Unit

Main contents of JWWA B 130 "Pressure booster for direct water supply" is as follows

a) Applied of usage: Under 50A in nominal sieve size of unit. Under 0.75MPa discharge pressure.
b) Number of pumps: Install over 2 pumps per unit.
c) Discharge pressure:
  * Discharge pressure change tolerance level at the change of flow rate and suction pressure fluctuation is within 5% differential of target pressure.
  * Pressure change tolerance level when start and stop of pump is within 30%

differential of target pressure.

* Pressure change tolerance level when replacing pump is within 30% differential of target pressure and under 0.07MPa.

d) Suction pressure:

* When the pump starts, drop of a suction pressure is within 25% of the previous pressure and under 0.05MPa.

* When the pump stops, increase of suction pressure is under 0.1MPa of the pressure from the stopping point.

e) Others

3.3 Control of booster pump unit

Figure 6 shows the composition of a direct booster pump unit, and Figure 7 illustrates the concept of control flow of pump operation. These two pumps take turns operating, and are typically managed by a control method of *estimated terminal pressure at a constant* (a).

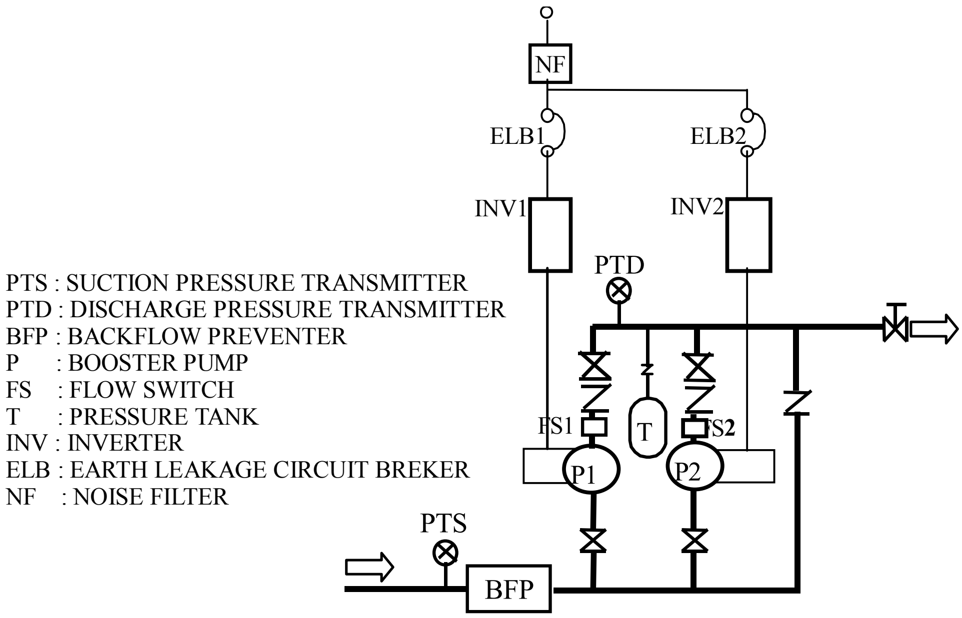


Figure 6 Composition of booster pump unit

This control method enables a steady pressure at the terminal by estimating the resistance of distributing water pipe relative to the amount of water used with readings from pressure transmitter of discharge side(PTD), pressure transmitter of suction side(PTS), pump rotation signals and etc(a). Flow switch(FS1 or FS2) detects the decrease in amount of water used(b). The pressure accumulation of the pressure tank(T), resulting from the increase in the discharge pressure of the pump, stops the pump(c). While the pump has stopped, pressure of discharging side is monitored by pressure transmitter(PTD)(d). If the use of water is confirmed, pressure tank(T) will supply water. At this point, if the discharge pressure drops lower than the set pressure (start pressure of pump) then water is supplied by activating a pump (P1 or P2). Perform control of estimated terminal pressure at a constant via pump operation (a).

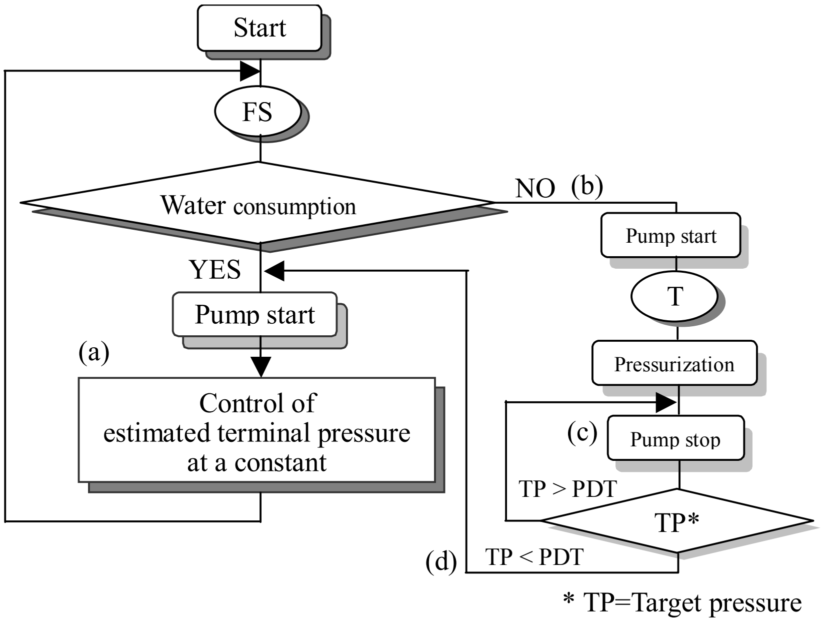


Figure 7 Flow of control for booster pump unit

4 Selection of applicable building and pump

4.1 Applicable Building

Table 1 shows the use of buildings currently using DBWS system. Generally, it is adopt the system for multiple dwelling house and office buildings. In respect to safety concerns on backflow, it is impossible to implement this system at factories and facilities that operate chemicals, medicines substances (toxic, poison, etc). Also, hospitals, schools and hotels are considered inappropriate due to the reservoir capability and other reasons.

Table 1 Applicable Buildings

	Buildings
Impossible	Factories and facilities that operate chemicals, medicines (toxic, poison, etc).
Unsuitable	Hospital, School, Hotel
Applicable	Multiple dwelling House, Office Buildings
Height	30m + less than 4 stories

If the DBWS system is to be used, the height of a building is automatically limited from the fact that discharge water pressure be under 0.75MPa, as stated in JWWA B 130. Normally, it is known that the limit for the height of a building is 30m + 4 stories considering the various resistance and minimum required pressure. In reality, many local governments set the limit to 10 story buildings.

4.2 Peak flow rate of water supply and the diameter of booster pump unit

4.2.1 Identifying peak flow rate of water supply

In order to select a booster pump unit, a peak flow rate of water supply needs to be clearly identified. The calculation method for this rate is described in SHASE (The Society Heating, Air-Conditioning and Sanitary Engineers of Japan). It is defined this calculation method especially for multiple dwelling houses by Better Living, Urban Development Corporation and local government. The following is an example of Tokyo metropolitan government.

* Formula to estimate a peak flow rate of water supply Q [L/min] by the number in residents P [persons]

$P = 1 - 30 : Q = 26.0 P^{0.36}$

$P = 31 - 200 : Q = 13.0 P^{0.56}$

$P = 201 - 2000 : Q = 6.9 P^{0.67}$

4.2.2 Setup of the diameter of booster pump unit and discharge water pressure

Figure 8 shows the relationship between the peak flow rate of water supply that is calculated through the formula above and the number of dwelling units (a family of 4 and 3). This shows the result according to the diameter of the booster pump unit when a flow speed of discharging side is 2.0m/s. As in Figure 8, a 50A diameter booster pump unit will be able supply water to 46 units with a family of 4 or 61 units with a family of 3. Figure 9 shows the concept to set the discharge water pressure of the booster pump unit. This is generally the same as calculating the needed pressure.

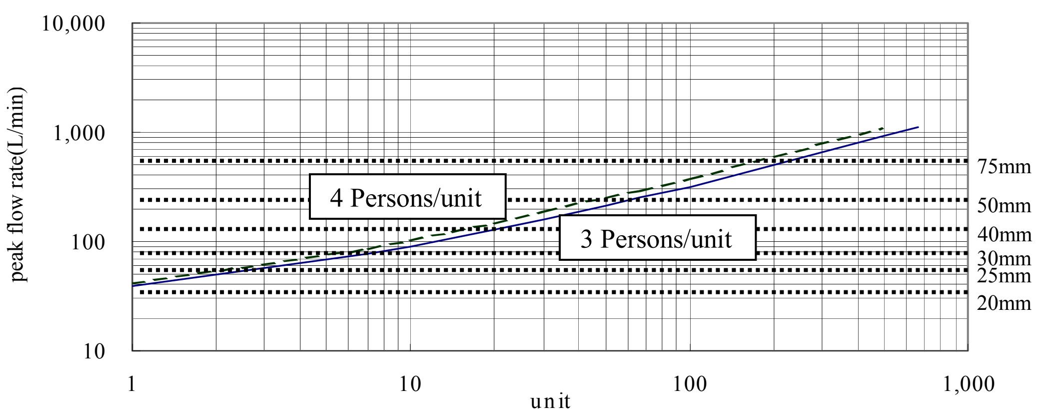
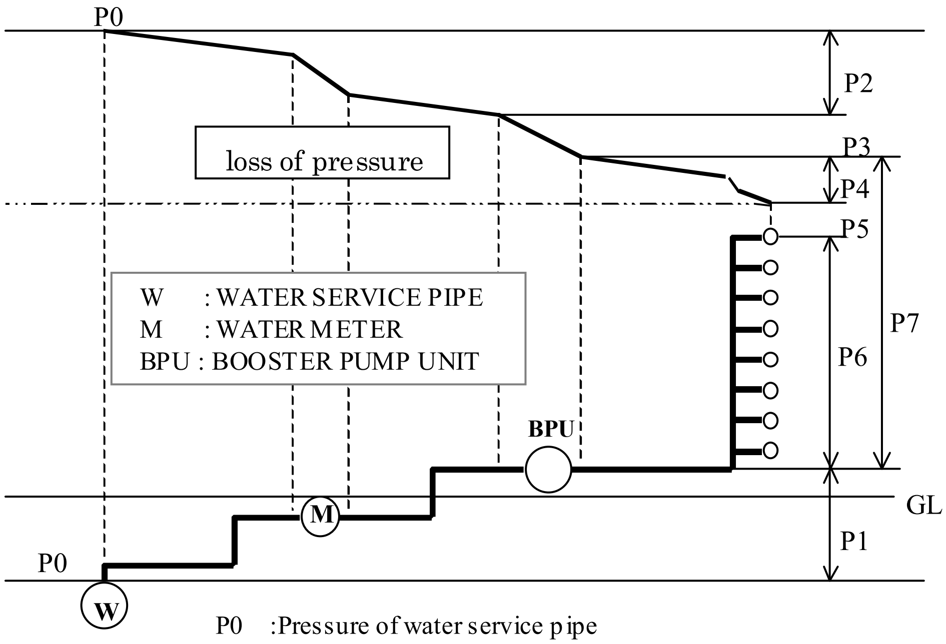


Figure 8 Relation of peak flow rate and number of unit



P0 :Pressure of water service pipe
P5 :Demand pressure of terminal fixture
P7 :Need pressure for BPU's discharge pressure

* P7 = P4+P5+P6

Figure 9 Scheme to need pressure for BPU's discharge pressure

5 Energy consumption

The DBWS system can efficiently use the retained energy of distributing water pipe. Table 2 shows an example of a pump's power consumption amount of the booster pump in the receiving tank system, which has been widely used, and of the DBWS system. At a few existing buildings, the authors are conducting field studies on the amount of power consumed in cases where a receiving tank system has been modified to a direct booster system. The authors believe that the power consumption per unit water consumption can be reduced by approximately more than 40%.

Table 2 Energy Consumption

	Pressure [MPa]		**Consumption**		
	start	stop	electricity [kWH]	water [m^3]	unit of electricity [kWH/ m^3]
Receiving tank *1)	0.24	0.43	120	163	0.74
DBWS system *2)	0.26	0.31	59	155	0.38

*1) booster pump system, *2) Control of estimated terminal pressure at a constant

6 Movement toward to the expansion of range of water supply for the future

Bureau of Waterworks in Tokyo Metropolitan Government (BWTMG) has a significant amount of influence in the waterworks of Japan. In Tokyo Metropolitan Government, DBWS system (under 50A in meter diameter) has been implemented since October of 1995. Due to the many advantages of the system, investigations for implementing the system on large-scale buildings are being performed. For example, Ichikawa has led the researches such as "Technological examination of DBWS system expansion[4),5)]" for 2 years since 1999. In this project, research on the peak flow rate, field study on existing high-rise buildings, various tests on a high-rise (100m), evaluation of management conditions etc.

On the basis of these results, BWTMG approved the diameter of booster pump unit up to 75A (80A) in June 2004. As results, the range of a number of units (160, 220 units (a family of 4, a family of 3)) with accessible water supply in the house complex has broadened in using DBWS system with 75A diameter(Figure 8). In future, BWTMG's this policy to expand the range of water supply may largely influence other local self-governing bodies in Japan.

7 Conclusion

About 10 years has past since the initial implementation of DBWS system in Japan, and the new expansion of water supply range is in progress. Hereafter, The authors predict a nationwide increase in installation of 75A diameter DBWS systems in Japan. The authors plan to further continue our research focusing on the following items.

* Continue understanding of current situation after implementing the DBWS system.
* Research and investigation on leak water.
* Development and investigation of related equipment and system control.
* Effect on distributing water pipe with an implementation of multiple DBWS systems.
* Examination of system implementation in super-high-rise buildings.
* Economic comparison with receiving tank system.
* Investigation of energy conservation considering environmental load.
* Investigation of performance evaluation and maintenance of backflow prevention devices.
* Others

8 Acknowledgments

The authors would like to thank Mr. Hiroo Kawada of the Waterworks Association of Japan, Mr. Hiroshi Ito of BWTMG, Mr. Toshihiro Matsuzaki of Maezawa Kyuso Industries co. Ltd.(QSO[*1]), Mr. Kaoru Nakajima of Ebara corporation, Mr. Yoshinori Hayakawa of Kawamoto Pump Mfg. co. Ltd., Student Naoko Tokunaga at Tokyo Metropolitan College, and all others who have helped us compose this paper.

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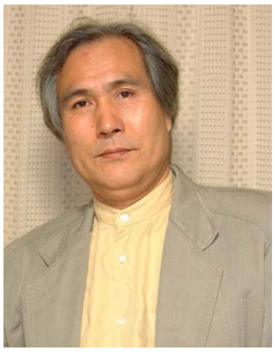
10 Presentation of author



Dr. Noriyoshi Ichikawa is professor at the Tokyo Metropolitan College. The Tokyo metropolitan government plans to combine four existing colleges into the New Tokyo Metropolitan University in April of 2005. As a result he will become a professor of the New TMU starting next April. He is conducting various researches on his major field of study of water supply and drainage system in buildings. He is also actively involved in governmental and academic institutions and committees related to his field of study as chief coordinator and board member.

Investigation of Water Demand in Commercial Buildings

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Abstract

The paper presents the results from the case study of the water consumption in public buildings in Bulgaria.
The main purpose of the investigation is updating of the National water supply norms for commercial buildings and reflecting the influence of the current technical, economical, social-demographic and habitat factors. The selection criteria for the choice of representative consumers are defined and special sheet for data collection is developed.
One of the representative office buildings selected for the case is the Municipality of Sofia. Data loggers for recording of the consumed water and the pressure in the building water supply network are installed.
The collected data is processed applying statistical methods. The results are based on the systematic statistical approach for analysis of the water consumption and water losses.
The parameters of the water losses are determined and mathematical model is created;
The harmonic and the stochastic components of the consumption are separated and analysed.

Keywords

water demand, water consumption, water supply norms, modelling, monitoring, daily demand patterns.

1 Introduction

In Bulgaria more investigations of water consumption in the residential buildings than in the public buildings are carried out. Water consumption per consumer varies for the different type of buildings and even for buildings of the same type.

The current water supply norms in Bulgaria per consumer in the public buildings are taken mainly from foreign sources [3,4], without detailed analysis of the real consumption and reflecting the national peculiarities. That is why the investigation of the water consumption for the purposes of control and updating the National water supply norms requires the application of systematic approach that allows consideration of the influence the basic technical, economical, social-demographic and habitat factors with minimum data surveying is a problem of the present day in Bulgaria.
Consumption in the public building sector depends on many factors [1]:

- type of the public building;
- sanitary equipment;
- type and degree of maintenance of the plumbing systems;
- consumers' water use culture;
- price of water, etc.

Developing of the supporting input data base is of a great importance for the realistic analysis and future forecasting of water demands of various consumers (residential, commercial, administrative, public and industrial buildings). For the purposed of the analysis of water consumption in buildings, due to the influence of so many factors, which are difficult to be identified, assessed and predicted, the statistical approach is more appropriate to be applied [2].
During the last years the improvement of the technical means for construction of the water supply and drainage systems for buildings, implementation of water conservation measures lead to dynamic change of the water consumption of different users.

This paper reports results from the case study of the consumption in commercial office building of Municipality of Sofia. It is a part of complex investigation of the current water consumption in the different types of public buildings.

2 Commercial buildings water consumption

There is a big variety of classifications of the commercial buildings and also the specification of the different consumers depending on the way water is consumed. After the performed analysis, reflecting the local conditions [1] of water use a classification of the commercial buildings with the corresponding units for the water supply norms is proposed.

The results are shown in table 1.

Table 1 – Classification of the commercial buildings

COMERCIAL BUILDINGS	UNITS
1. Administrative buildings (offices)	l/employee
2. Shops	
2.1 Food	l/employee
2.2 Industrial goods	l/employee
3. Hotels and Motels	
3.1. Room without bath	l/bed
3.2. Room with bath	l/bed
4. Restaurants and Clubs	l/place
5. Other activities	
5.1. Hair dresser, cosmetic centre	l/work place
5.2. Laundry	l/kg clothes
5.3. Garage	l/employee
5.4. Car washer	l/car

The proposed classification could be different for the different countries.

3 Choice of representative consumers

For investigation of water consumption, representative buildings located in Sofia are chosen. Data loggers for recording of the consumed water and the pressure in the building water supply network are installed.
For the data collection a special form (data sheets - matrixes) developed especially for the case are used. The data sheet is shown in table 2.

Table 2 – Data sheet

№					
BUILDING					
LOCATION	Identification	City			
		Address			
		Type of building			
		Type of work			
		Size of building			
		Pressure (atmospheres)			
	Water supply service connection	Type of the service connection in building			
		Booster pump set implementation			
		Number of floors after water-meter			
		Number of consumer after water-meter			
	Criteria	Connection with central heating (Yes:1/No:0)			
		Recirculation of hot water			
		System to conserve water			
MAIN WATER-METER	Identify № of water meter				
	Start date dd/mm/yyyy h:m				
	Start volume (m^3)				
	Finish date dd/mm/yyyy h:m				
	Finish volume (m^3)				
	Identify № of data logger				
	Interval (s)				
MAINTENANCE OF BUILDING	Year of built				
	Sanitary equipment	Bathroom sink			
		Kitchen sink			
		Flushing cistern			
		Public lavatory			
		Bath-tub			
		Shower			
		Washing machine			
		Dish-washer			

The criteria in this sheet are chosen so to provide complete information for the consumer.
The buildings which are subject of investigation are selected so as to respond to the following requirements:

- to be built or reconstruct during the last years;
- to have installed contemporary sanitary fixtures which are harmonized with the current Standards;
- to have installed main water-meters for cold and hot water;
- to represent different types;
- to permit investigation of large range of parameters.

In addition to these 5 years historical data for the billed water of the consumers in the buildings is collected.

4 Experimental data and results

4.1 Primary data

The building of Municipality in Sofia is one of the representative commercial office building consumers. Data loggers for recording of the consumed water and the pressure in the building water supply network are installed there for seven days.
The primary information for the number of the consumers and the sanitary equipment are shown in Table 3.

Table 3 – Sofia Municipality data

Number of floors		7
Number of employees		69
Sanitary equipment	Bathroom sink	31
	Kitchen sink	4
	Flushing cistern	32
	Public lavatory	0
	Bath-tub	0
	Shower	2
	Washing machine	0
	Dish-washer	0

The recorded data for the water consumption and the average pressure in the building is shown on figure 1.

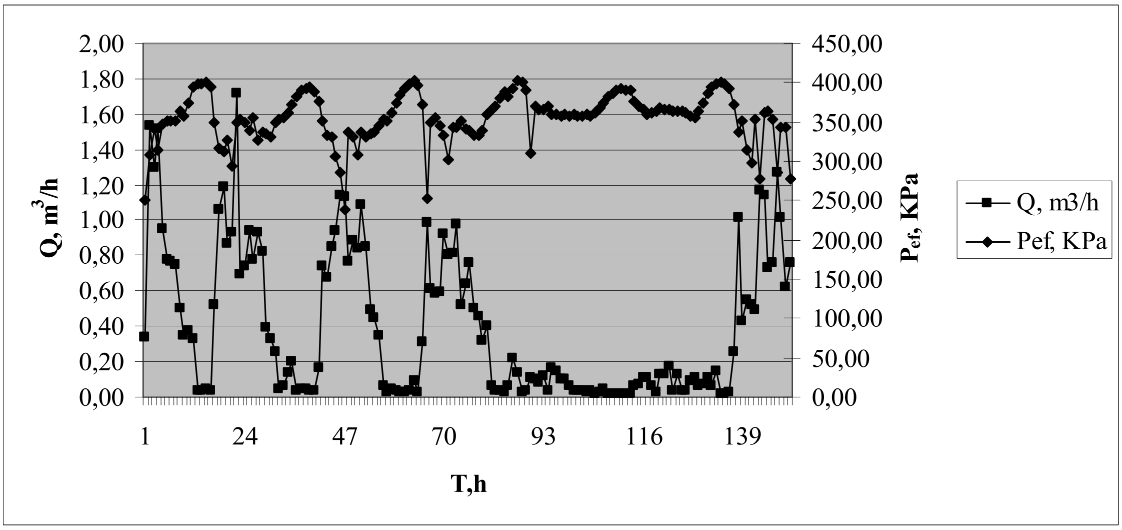

Figure 1 - Pressure (P_{ef}) and Water consumption (Q) variation

4.2 Losses of water

Water losses are important factor that has to be considered, when developing norms, because the level of maintenance in the different types of building varies considerably. For the public buildings it appears to be dynamic parameter, which varies on daily basis. That is why suitable mathematical expression is the one shown bellow [1, 2]:

$$q_{i(t)}^{h} = b_i \int_0^h P_{ef(t)} dt \text{ , dm}^3\text{/h,} \quad (1)$$

where b_i is a parameter, which is determined for every *i* day during the time without consumption.

The pressure (P_{ef}) is determined by the following equation:

$$P_{ef} = \frac{\rho.g.(H-h)}{1000}, KPa \quad (2)$$

where:

H – manometer head at the data logger, m_{H2O};

h=f(n, h_{fl});

n – number of floors;

h_{fl} – height of one floor, m.

The results for the estimated water loosed during the experiment are shown on Figure 2.

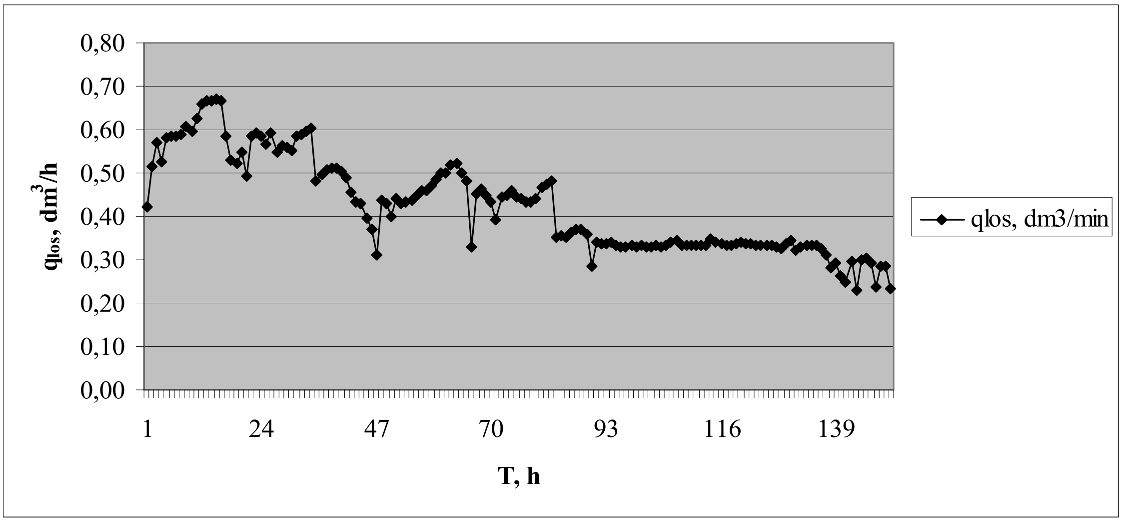

Figure 2 – Water losses

4.3 Water consumption without losses

In order to analysis the real consumption we separate the share of the losses the whole process of consumption. The results for the real water consumption without losses for observed building are shown on Figure 3.

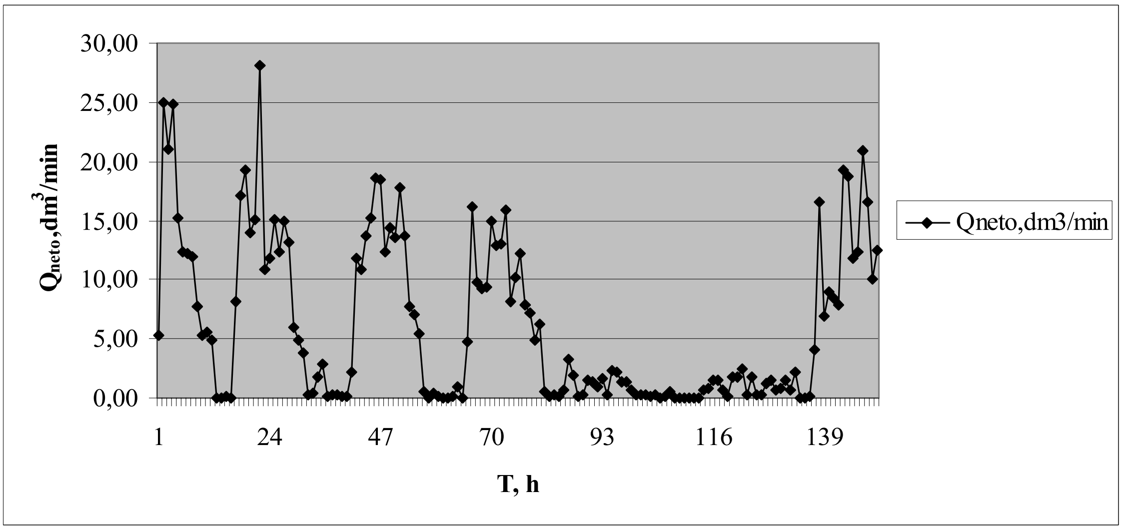

Figure 3 – Real water consumption without losses

4.4 Average Daily Pattern

Daily average daily pattern is a basis for creating standardized daily profiles of the different types of buildings. It represents the harmonic component of the water consumption [1, 2].
The results from the statistical analysis for the average daily pattern are shown on figure 4.

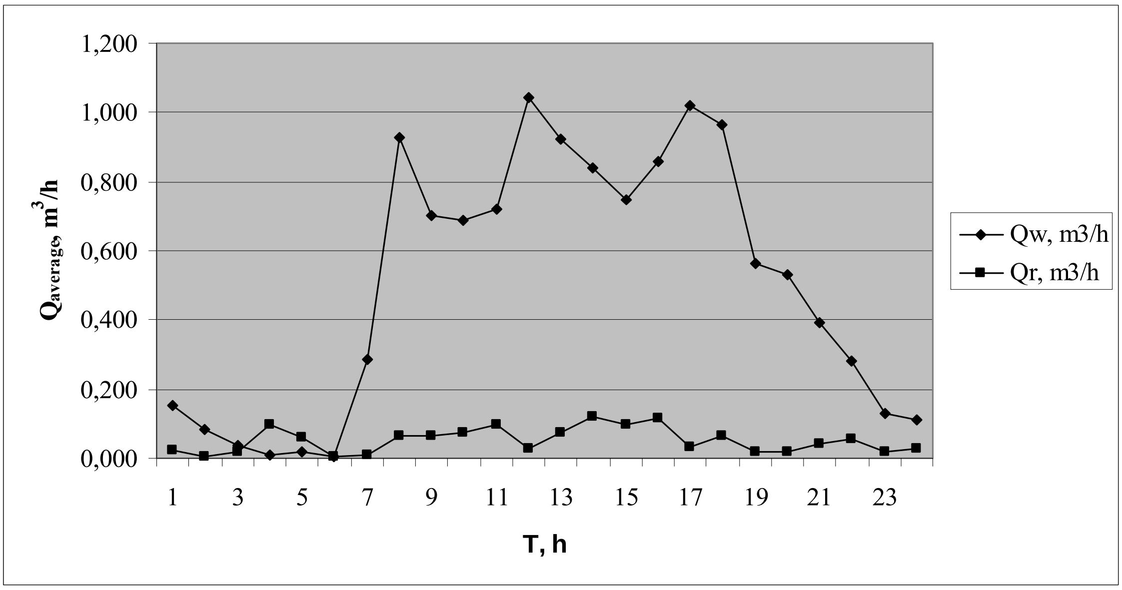

Figure 4 - Average hourly water demand

Where: Q_w - working days; Q_r - resting days

We can easily identify three periods of maximum consumption, where the biggest is during the lunch time.

4.5 Stochastic Component of the Consumption

The Stochastic component appears to be the difference between the whole process of consumption and the harmonic process [1, 2]. The results for this component for the investigated building of Municipality of Sofia are shown on figure 5.

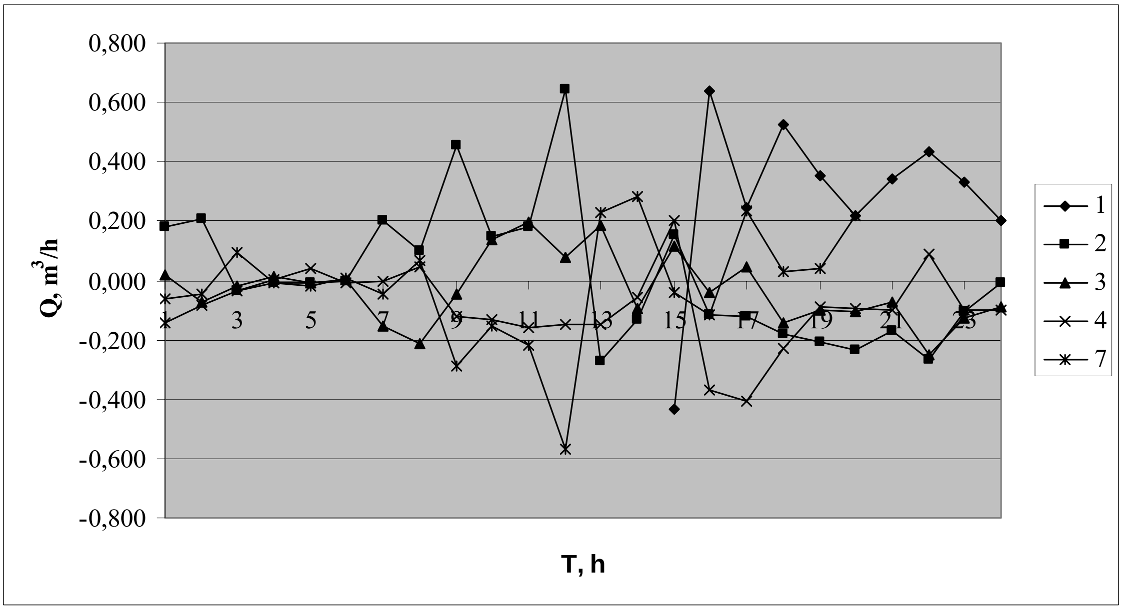

Figure 5 – Stochastic component of water consumption for the working days

The results show the stochastic character of the process of water consumption.

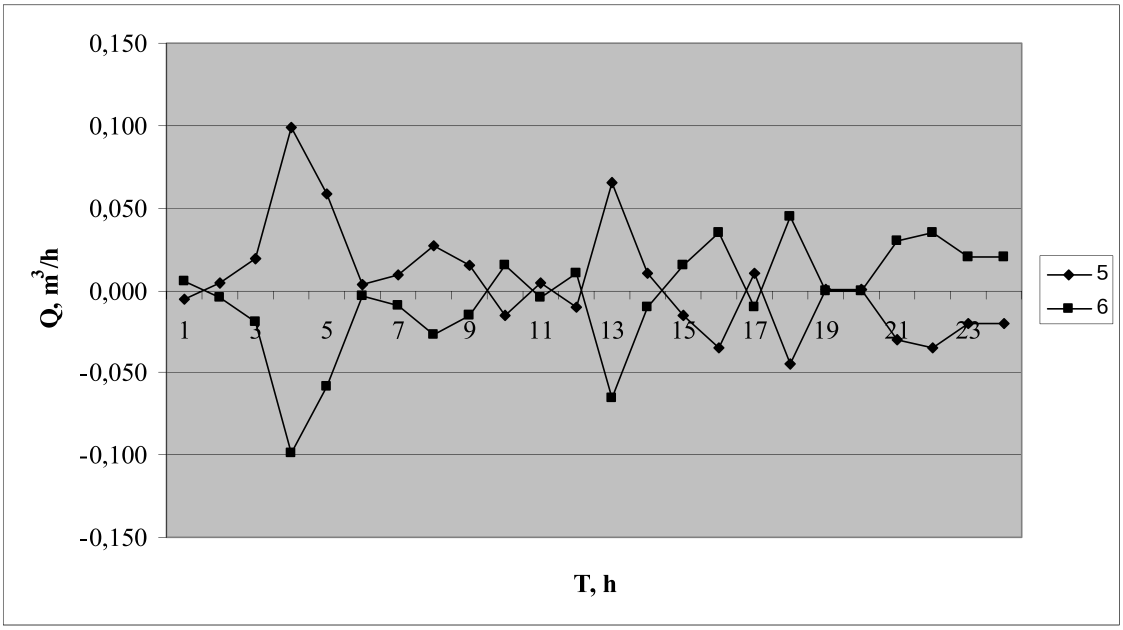

Figure 5 – Stochastic component of water consumption for the week end

5 Estimation parameter M of the water demand model

The parameter M describes the relationship between the variance of harmonic component - $Var(Q_h^c)$ and the stochastic component - $Var(Q_h^r)$ of the daily water consumption [1].
The determined results after the statistical analysis are shown on Table 3.

Table 4 – Parameter M for the Municipality of Sofia

Parameter	Working days	Week end days
$Var(Q_h^c)$	0.139	0,001263
$Var(Q_h^r)$	0.044	0,002
M	3,166	0,631

6 Conclusions

1. A detailed study and statistical analysis of the water consumption of an office building is Sofia is performed.
2. The selection criteria for the choice of representative consumer building are defined and special sheet for data collection is developed;
3. The parameters of the water losses for a representative building - building of Municipality of Sofia are determined and mathematical model is created;
4. The harmonic and the stochastic components of the consumption are separated and defined;
5. The value of the parameter *M* for this particular office building is determined. It is expected that applying the same procedure for the other buildings, subject of the

complex study will give enough practical summery results to define water demand norms and standardized daily patterns of the public buildings in Bulgaria.

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8 Presentation of Author(s)

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Measurement of Water, Electronic Power and Gas Consumption and Questionnaire about Act of Water Usage in the Apartment House

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Abstract

Water use is changing with change of a life style or housing equipment with the time. It is indispensable to the plan and design of plumbing system to catch the water use act and the water consumption. Then, for every month, this study read meter and recorded the water consumption, electricity consumption, and gas consumption in each household of an apartment. Moreover, the questionnaire was performed to the residents of the same apartment about environmental consciousness, water conservation consciousness, water use act, and use equipments. And those relations were analyzed. The unit data about the water consumption was obtained from this result. Moreover, change of the monthly water consumption has been grasped. Furthermore, cross tabulation and regression analysis showed quantitatively the relations between water consumption and electricity consumption / gas consumption / a water use act / use equipments.

Keywords

life style, measurement, questionnaire, cross tabulation, regression analysis

1. Introduction

By change of a life style or housing equipment, a water use act is also in the tendency to change with a time. While consideration of the environment in global environment problems or a life is cried for, it is in the tendency for environmental consciousness and water conservation consciousness to increase. It is expected that such a tendency appear also in change of water consumption. Moreover, it is indispensable to the plan and design of plumbing system to catch the water use act and the water consumption of the man used. Although water consumption has large variation, it becomes possible by catching the relation between the water use acts of each household, and water consumption to examine the change factor. Then, in this paper, while measuring the water consumption of each household, both relations were analyzed by catching domestic environmental consciousness / water conservation consciousness and water use act by the questionnaire. In addition, this paper is created based on the reference (1) and (2).

2. Characteristic water use in the home in Japan

The feature of the water use in the home in Japan is seen in a bath, a meal, a toilet, etc. The main features are shown below.

Since Japan is heat and high humidity in summer and is very cold climate in many areas in winter, it has many people who take a bath every day. Although only a shower is used in many cases in a summer, it is common to fill hot water in a bathtub and to warm the body. Moreover, the body and their head are shampooed in the washing place besides a bathtub (**Figure 1**). Since the bath water pump is attached to the washing machine, the remaining water of a bathtub is used in many cases at the time of wash, without throwing away.

Although the staple food is as various as rice, noodles, and bread, it is rice which becomes main. Although a precooked thing can also be purchased in a supermarket etc., rice is washed with water at home and, usually it cooks with a rice cooker. The pre-cleansed rice of washing needlessness called “Musenmai” is sold in recent years, and spread is progressing (**Figure 2**).

Although the squatting type toilet was used, generally the western toilet is used at home now. A toilet seat unit with warm-water bidet functions and a heated seat has spread widely, and has spread through the home about 50 percent.

3. Measurement of water consumption and the method of questionnaire

In the apartment for investigation (**Figure 3**, **Figure 4** and **Table 1**), water consumption of all dwelling units was measured over 27 May 2001 to 3 May 2002 (for 341 days) by reading water meter at intervals of about one month. In addition, Chapter 6 and Section 7.1 use the measurement data for 279 days by March of the same year. Moreover, over 3 February 2002 to 3 May (for 89 days), Watt-hour meter and gas meter were measured. The questionnaire was distributed to 160 households considered to reside in October 2001, and obtained the reply from 100 households (62.5% of recovery rates). The basic data obtained by measurement and the questionnaire in **Table 2** in the outline of a questionnaire item is shown in **Table 3**.

Figure 1 - Typical bathing scenery in Japan [4)]

Figure 2 - Typical meal scenery in Japan [4)]

Figure 3 - The target apartment

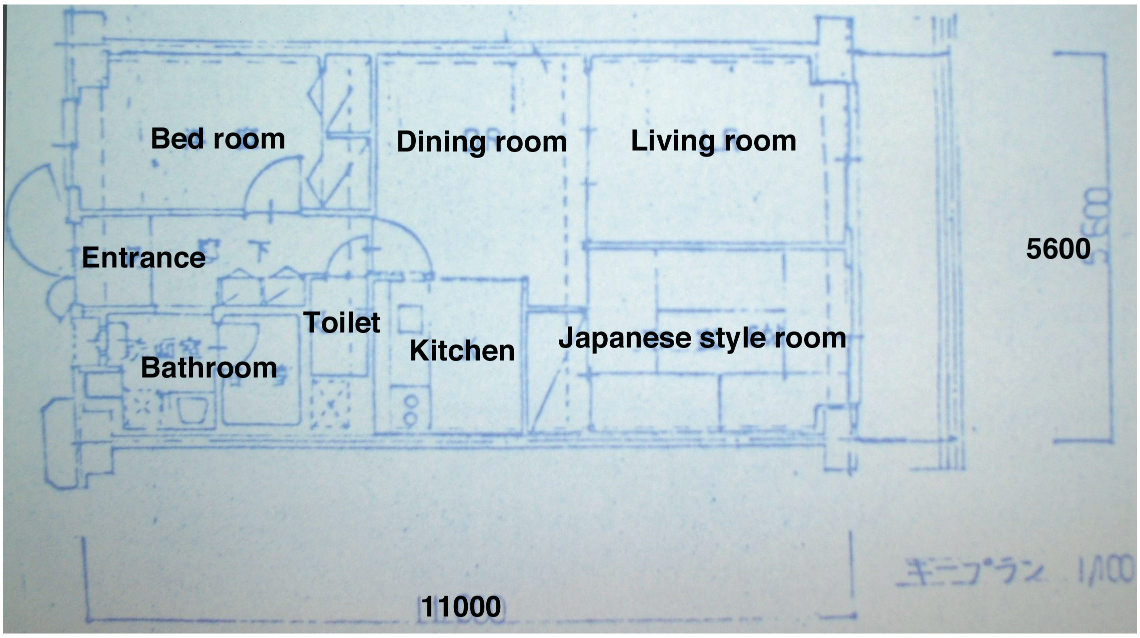


Figure 4 - The typical floor plan of the apartment

Table 1 - The outline of the target apartment

Location	Warabi City, Saitama Prefecture, Japan (From Tokyo to about 20km)
Zoning	Quasi-industrial zone, 200% of floor area
Completion year	July 1979
Site area	6,297m^2
Building area	1,807m^2(28.7% of building coverage)
Total floor area	11,722m^2(10,729m^2 of indoor area, 1,930m^2 of veranda area, 186.2% of floor area ratios)
Number of houses	164 houses (A janitor room is 1 house inside)
Structure, Number of stories	SRC, 10 stories
Monopoly area of each house	61.9-79.11m^2(2LDK-4LDK)
Storage tank	made from FRP, 69t

Table 2 - The outline of the target apartment

Category	Main contents
1 Family profiles	Moving-in year Household numbers Sex, age and hometime of each household member
2 Environmental consciousness	Concern about an environmental problem (6 items) Consciousness of the life which considered environment (7
3 Water conservation consciousness	Water conservation consciousness (7 stages)
4 Water use act	Bathing, Wash, Cooking, etc. (The number of times or selection)
5 Equipments	Reformation, Washing machines, Water saving equipments, Hot water supply temperature

Table 3 - Basic data obtained from measurement and the questionnaire

Data obtained from the data measurement household

Water consumption of a household per day (The average for 341 days, 158 households)	Average:771L/day, Standard deviation:355L/day, Maximum:1,886L/day(4 persons), Minimum:41L/day(2 persons)
Electronic consumption of a household per day (The average for 89 days, 160 households)	average:10.3kWh/day, Standard deviation:3.9kWh/day, Maximum:20.9kWh/day(5 persons), Minimum:1.82kWh/day(2 persons)
Gas consumption of a household per day (The average for 89 days, 158 households)	Average:1.7m^3/day, Standard deviation:0.8m^3/day, Maximum:4.0m^3/day(4 persons), Minimum:0.1m^3/day(Unknown the number of household persons)

Data obtained from the reply of a questionnaire (100 households)

Moving-in year	1979-2001(average:1985,Average habitation years:16 years)
Household members	Average:3.03, Maxumum:7, Minimum:1
Household number	1 person:10 households, 2 persons:25 households, 3 persons:27 households, 4 persons:30 households, 5 persons:7 households, 7 persons:1 household
Sex	Man:143 persons, Women:157 persons, Unknown:3 persons
Age	Average:40.2 years old, Maximum:94 years old, Minimum:1 year old ; unknown:9 persons
Age distribution	20 or less years old:59 persons, 21-39 years old:73 persons, 40-59 years old:113 persons, 60-79 years old:44 persons, 80 or more years old:5 persons, Unknown:9 persons

Data obtained from the household which has filled in the room number by the questionnaire

Water consumption per person per day (Theaverage of 341 days, 96 households)	Average:292L/day, Standard deviation:95L/day, Maximum:523L/day(4 persons), Minimum:21L/day(2 persons)

4. The tendency of water consumption

4.1 Frequency distribution of water consumption

The histogram of water consumption per day was computed using the measurement data for 341 days. By the frequency distribution of water consumption per household for all dwelling units (**Figure 5**), the frequency of 750-1000 [L/household/day], which is average value, is high, and it turns out especially with a 4-person household that the distribution has spread greatly. If water consumption per person per day in the household which answered the questionnaire (**Figure 6**) is seen, with a 2-person household, a large distribution will be seen from 50 L until it exceeds 500 L per person per day. Since the monopoly area of each household and equipment are similar, this difference is considered to be what has the large place depended on the difference in a life style.

4.2 Water consumption according to household members (Figure 7)

Like past data, when household members increase, it is in the tendency for the water consumption per person per day to decrease. Especially in a 2-person household, it turns out that the variation in water consumption is quite large.

4.3 Monthly water consumption

Monthly water consumption per household (**Figure 8**) has few seasonal variations. However, as compared with other months, there is much water consumption in July as 50-60 L, and water consumption in August has decreased as 30-40 L. It is thought that it will have the influence of intense heat July, and will have the influence of a summer vacation and a temperature fall August. The monthly water consumption per person per day (**Figure 9**) is before and after 300 [L/person/day] through one year, and a seasonal tendency is not seen. However, with a 1-person household, a monthly change is large. When the correlation coefficient of water consumption of each household in every month is computed, it is set to 0.79 at the minimum, and is set to 0.97 at the maximum, and it turns out that the tendency of water consumption in each household is the same. **Figure 10** is what plotted and measured water consumption, and it turns out that water consumption of each household is plotted near the regression line.

5. Relation between water consumption and electricity consumption / gas consumption

If some factors of water consumption should be based on the difference in a life style, since it was thought that water consumption and electricity consumption / gas consumption had correlation, the regression analysis was performed.

5.1 Relation between water consumption and electricity consumption

The correlation coefficient of water consumption and electricity consumption in February to April is set to 0.47 - 0.51, and correlation of a degree is seen in the middle.

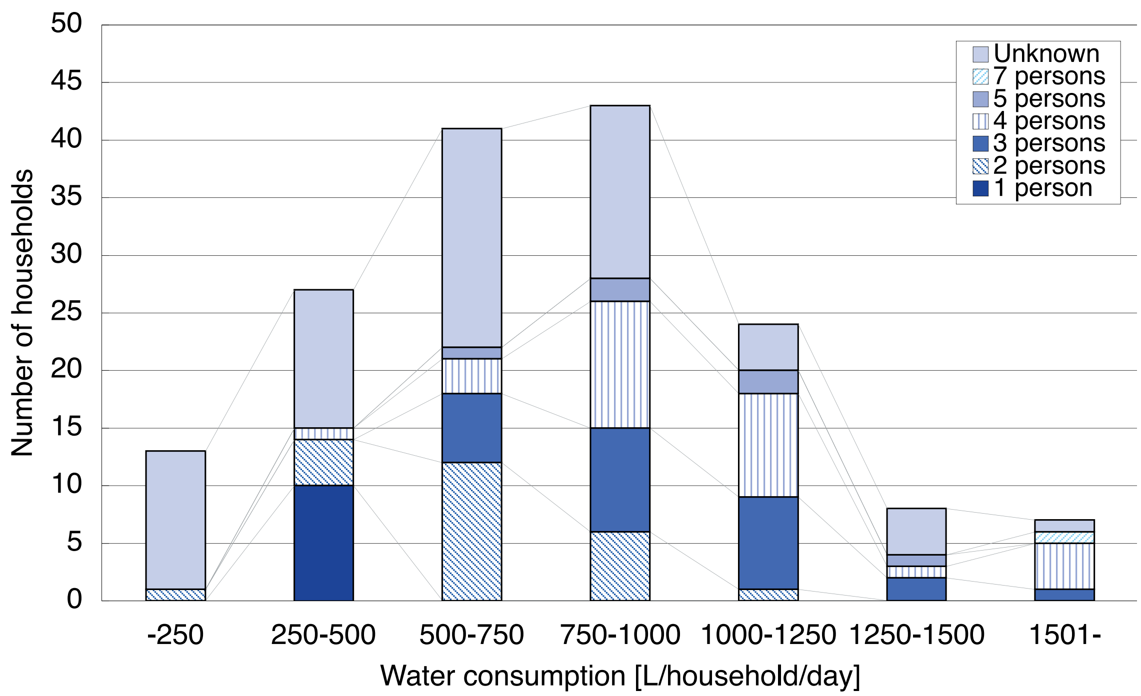


Figure 5 - Frequency distribution of water consumption per household for all dwelling units

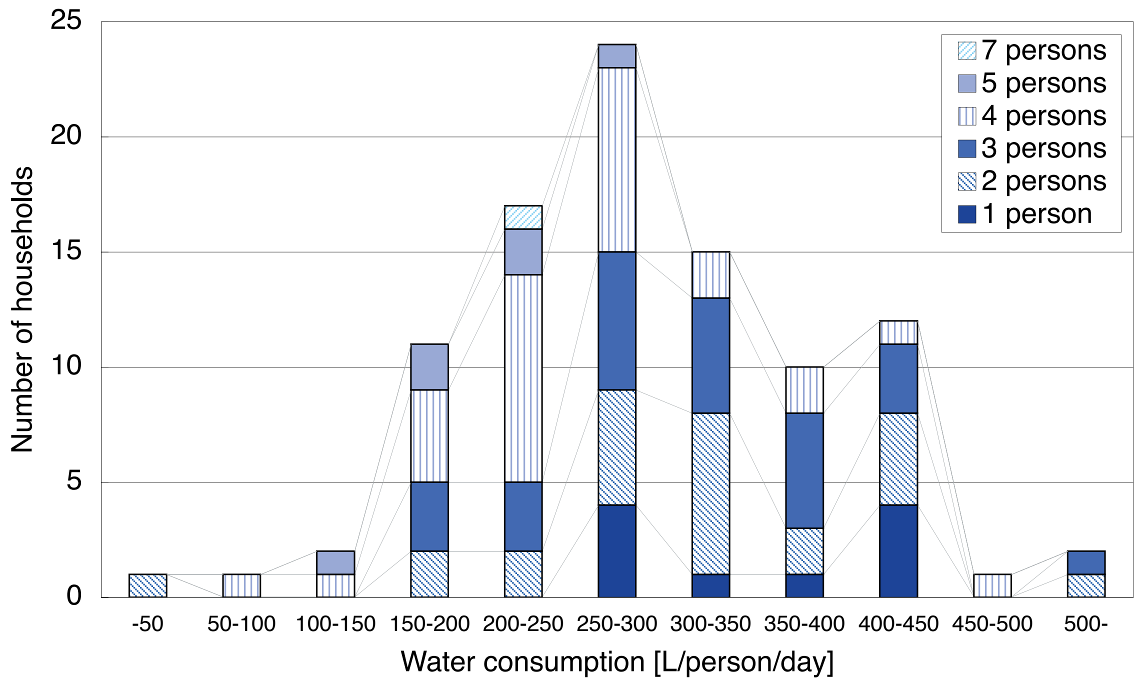


Figure 6 - Water consumption per person per day in the household which answered the questionnaire

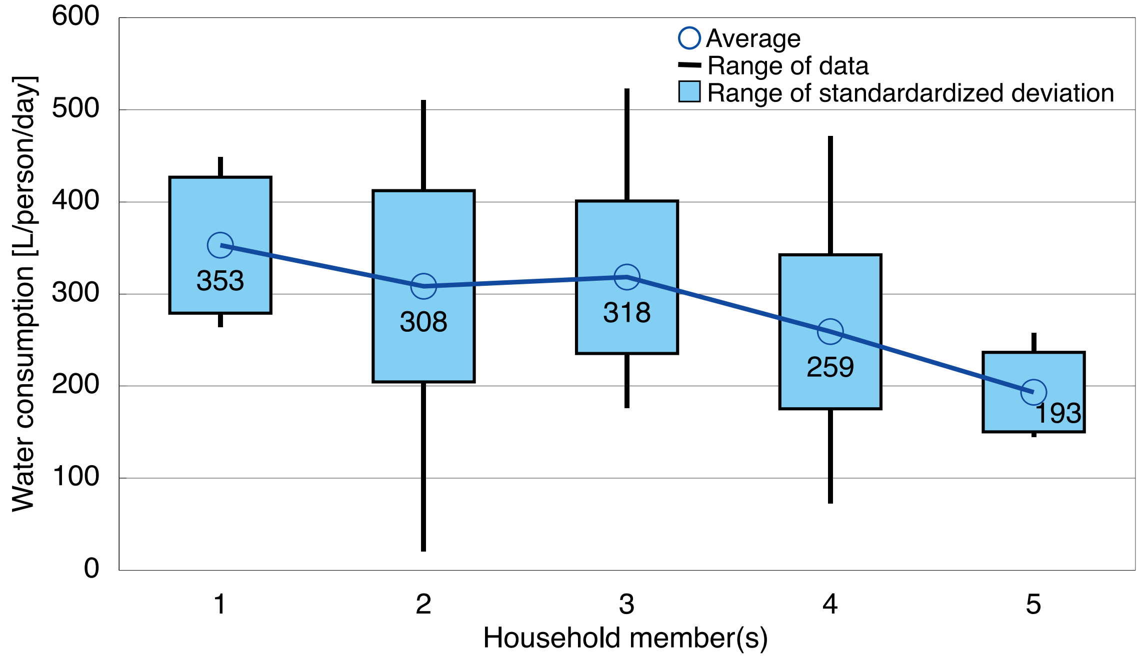


Figure 7 - Average water consumption according to household members

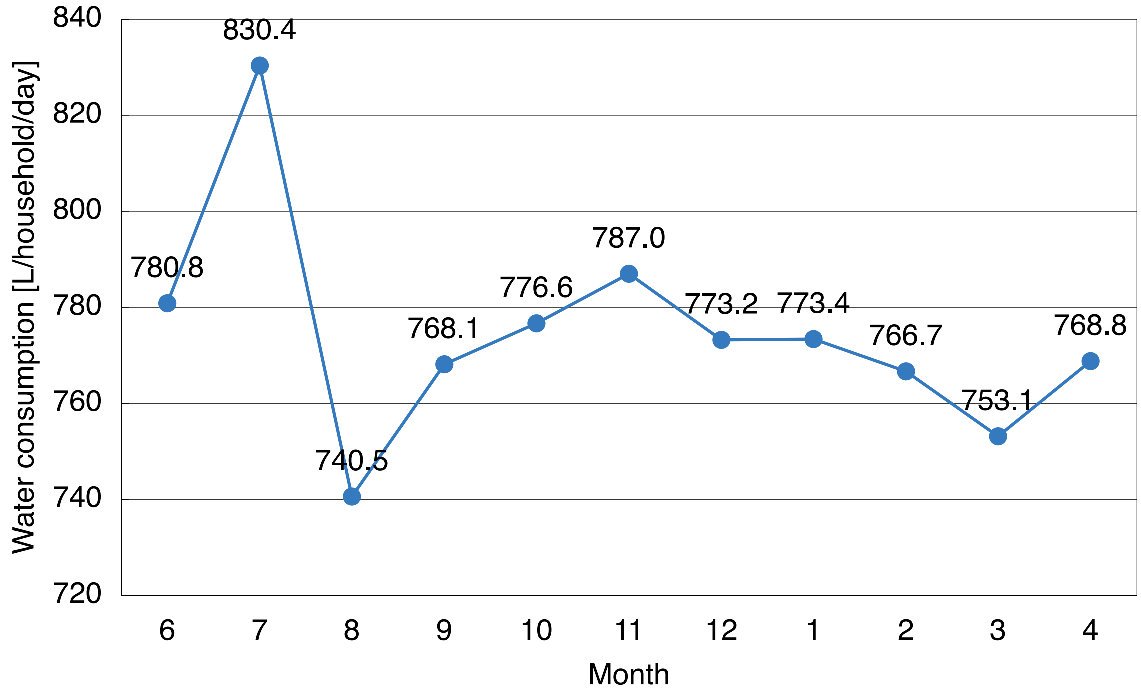
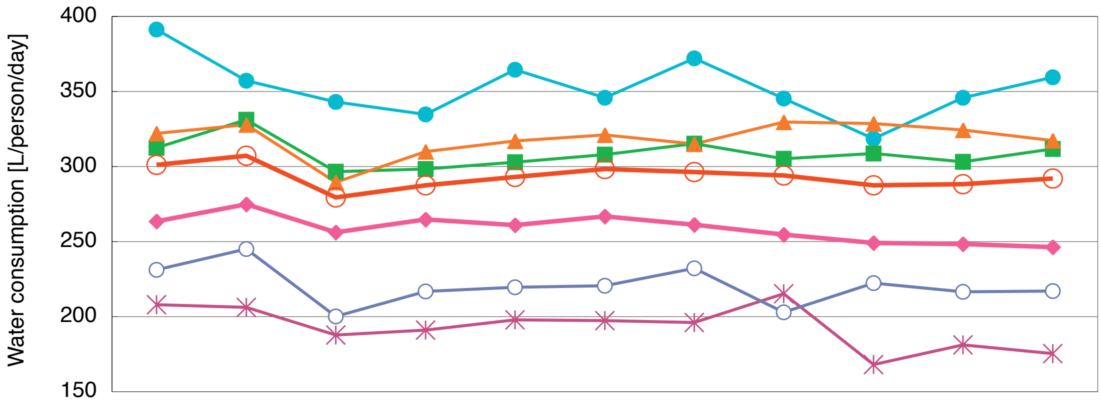


Figure 8 - Monthly water consumption per household



	2001/06	2001/07	2001/08	2001/09	2001/10	2001/11	2001/12	2002/01	2002/02	2002/03	2002/04
1 person	391	357	343	334	364	346	372	345	319	346	359
2 persons	313	331	296	298	303	308	315	305	309	303	312
3 persons	322	328	289	310	317	321	315	330	329	324	317
4 persons	263	275	256	265	261	267	261	254	249	248	246
5 persons	208	206	188	191	198	197	196	215	168	181	175
7 persons	231	245	200	217	219	220	232	203	222	216	217
All	301	307	279	287	293	298	296	294	287	288	292

Month

Figure 9 - Monthly water consumption per person per day

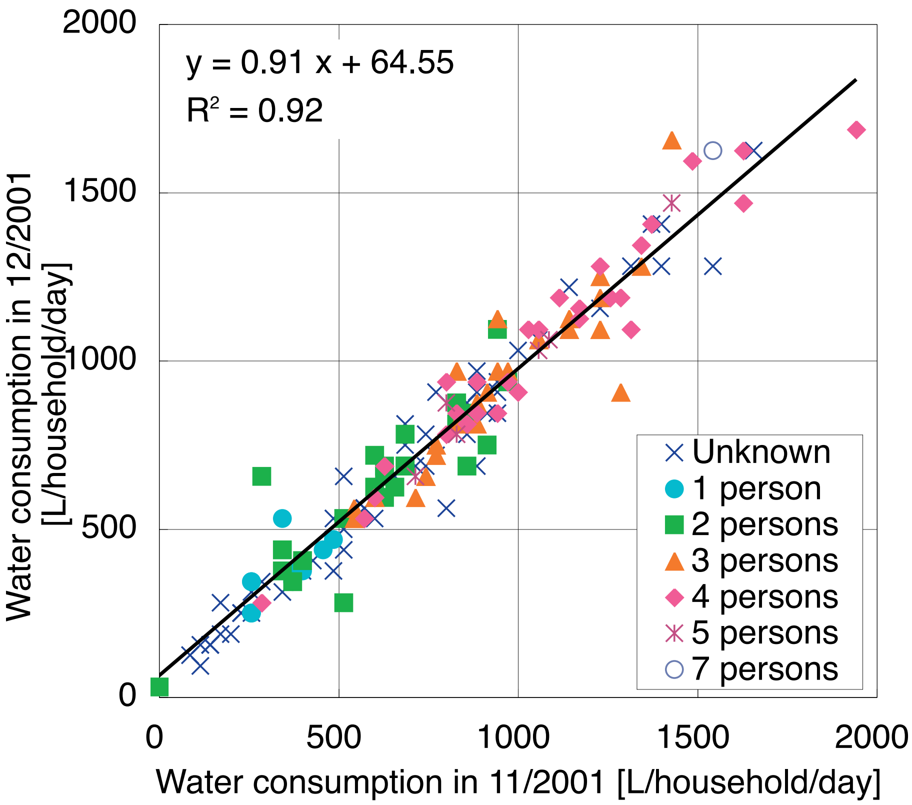


Figure 10 - Water consumption of November 2001 and December 2001

When it sees in graph (**Figure 11**), although variation is large, it turns out that there is a fixed correlation tendency.

5.2 Relation between water consumption and gas consumption

If a correlation coefficient is computed like the foregoing paragraph, it will be set to 0.79-0.87 and high correlation will be seen. When expressed to graph (**Figure 12**), the tendency carried out clearly is known. This is considered to be because for gas to be used mainly for hot water supply or cooking. Therefore, it turns out that gas consumption can be predicted to some extent from water consumption.

6. Relation between environmental consciousness / water conservation consciousness and water use

6.1 Relation between environmental consciousness and water conservation consciousness

What carried out the crossing total of environmental consciousness and water conservation consciousness of each respondent is shown in **Figure 13**. A reply called evaluation 5 (it is conscious of a few) occupies about 2/3 replies for environmental consciousness and water conservation consciousness. In addition, in Section 6.3 or less paragraph, it is analyzing by dividing seven steps of replies into two categories, “Yes” and “No”. However, since there were very few four or less evaluation replies about water conservation consciousness, the five or less-evaluation reply was made “with no water conservation consciousness”. Moreover, about environmental consciousness, four or less reply was made “with no environmental consciousness.”

6.2 Relation between environmental consciousness / water conservation consciousness and water consumption

Average water consumption in each evaluation of environmental consciousness and water conservation consciousness is shown in **Figure 14**. It is in the tendency for water consumption to decrease, so that water conservation consciousness is high except for the evaluation 3 whose number of specimens is only one in water conservation consciousness. Moreover, it is in the tendency, which water consumption increases, so that environmental consciousness is high except for the evaluation 7, which is the highest evaluation in environmental consciousness.

6.3 Relation between environmental consciousness / water conservation consciousness and water use act

In order to check the relation between the existence of environmental consciousness / water conservation consciousness, and a water use act (**Table 4**), the reply rate of each water use act was computed for every category (**Figure 15** and **Figure 16**). From the difference of the existence of consciousness “16. The tableware stained with oil is washed after wiping off in paper etc.” “39. A tooth is rinsed with the water filled in the glass.” and “38. A face is washed using the washbasin which collected water.” etc.,

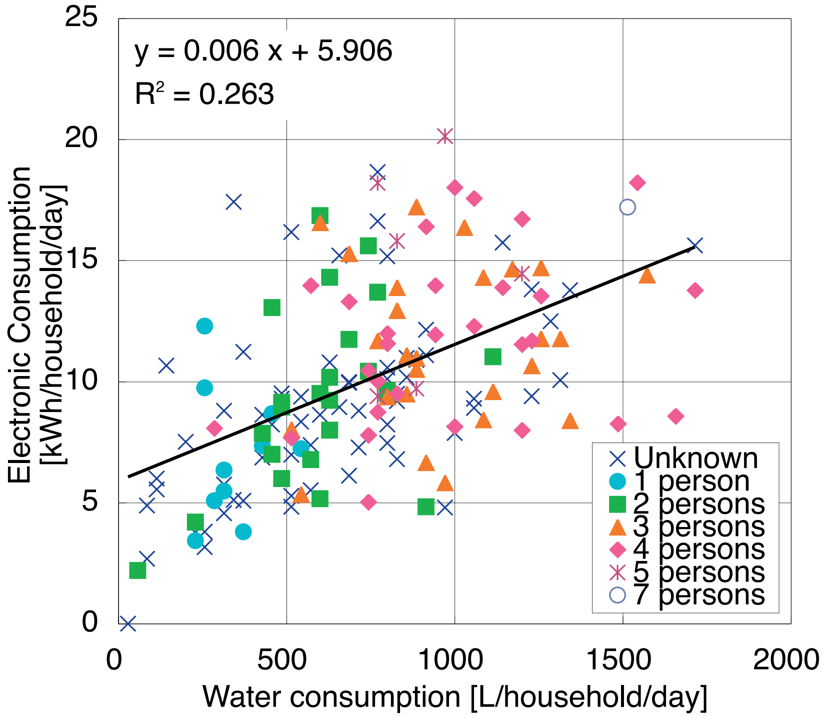


Figure 11 - Relation between water consumption and electricity consumption (March 2002)

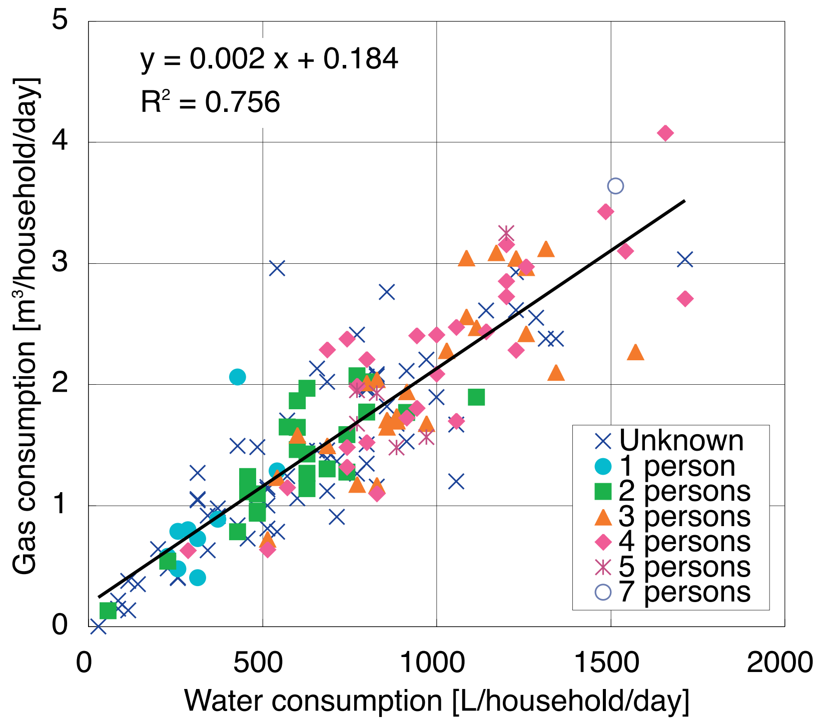


Figure 12 - Relation between water consumption and gas consumption (March 2002)

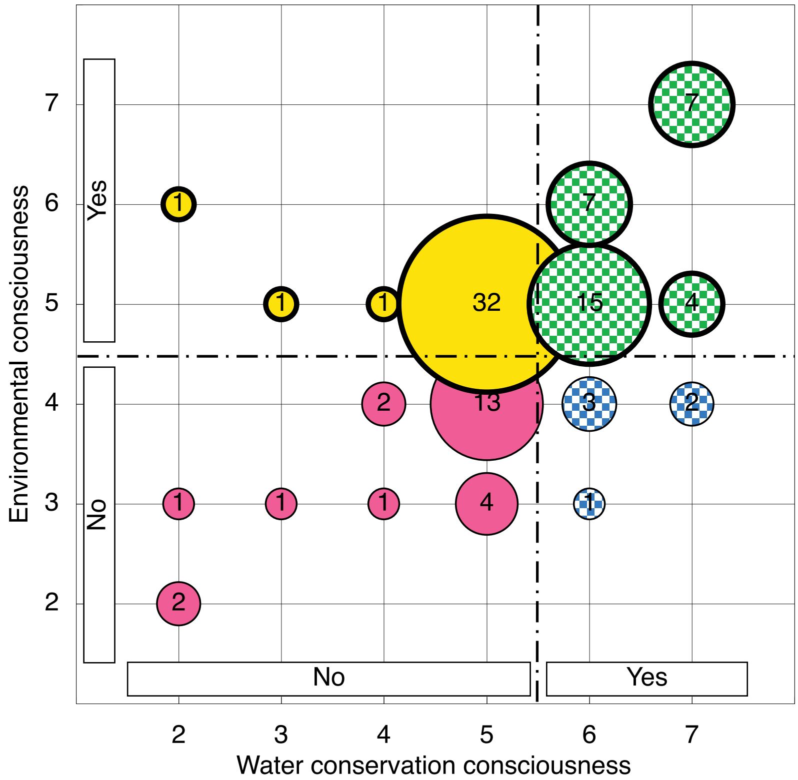


Figure 13 - crossing total of environmental consciousness and water conservation consciousness of each respondent

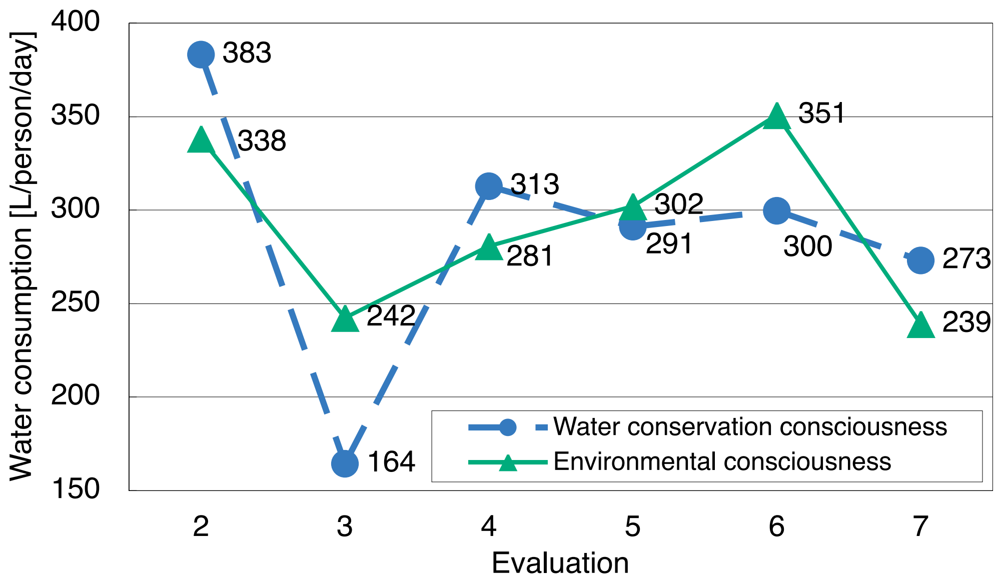


Figure 14 - Average water consumption in each evaluation of environmental consciousness and water conservation consciousness

Talbe 4 - Question number (Water use act)

Question Number	
1	Hair and the body are washed with the water of a bathtub.
2	Water to the extent that it overflows is not put into a bathtub.
3	When washing hair and the body, hot water is stopped briskly.
4	The shampoo containing a rinse is used.
5	Bathing time is not vacated with a family.
6	Bath cleaning is carried out with the remaining hot water of a bathtu
7	It washes at a house, without taking out to cleaning.
8	Rinse with stored water without pour water.
9	The remaining hot water of a bathtub is used for wash.
10	It washes, after dividing by the quality of the washing.
11	Use of fabric softener.
12	It is washing collectively as much as possible.
13	Not synthetic detergent but soap powder is used.
14	It is washing using a hand.
15	Soak washing is carried out.
16	The tableware stained with oil is washed after wiping off in paper etc
17	Hot water is used when washing tableware.
18	The tableware stained with oil is washed after rinsing lightly.
19	Water is briskly stopped at the time of tableware washing.
20	Water is filled in a tub etc. and tableware is rinsed.
21	Detergent is not used as much as possible.
22	A PET bottle etc. is rinsed and thrown away.
23	Tableware is washed as much as possible collectively.
24	Processed foods, such as frozen food and canned food, are used.
25	Tableware is divided and washed according to the grade of dirt.
26	wash-free rice is used.
27	The bottle is put into the low down flush tank.
28	If possible, it is made not to carry out a flash twice.
29	Mineral water is purchased and drunk.
30	What boiled tap water is cooled and drunk.
31	The water purified with the water purifier is drunk.
32	Tea and coffee are made and drunk.
33	Soft drinks, milk, etc. are purchased and drunk.
34	A fish and amphibians are kept.
35	The mammals, such as a dog and a cat, are kept.
36	The plant is cultivated.
37	The yard is watered.
38	A face is washed using the washbasin which collected water.
39	A tooth is rinsed with the water filled in the glass.

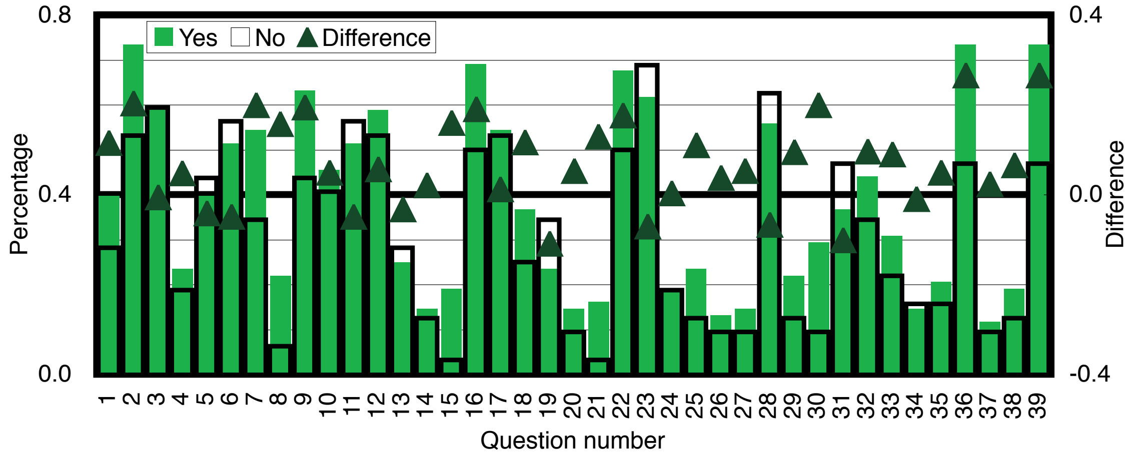


Figure 15 - The reply rate of each water use act for each category of environmental consciousness

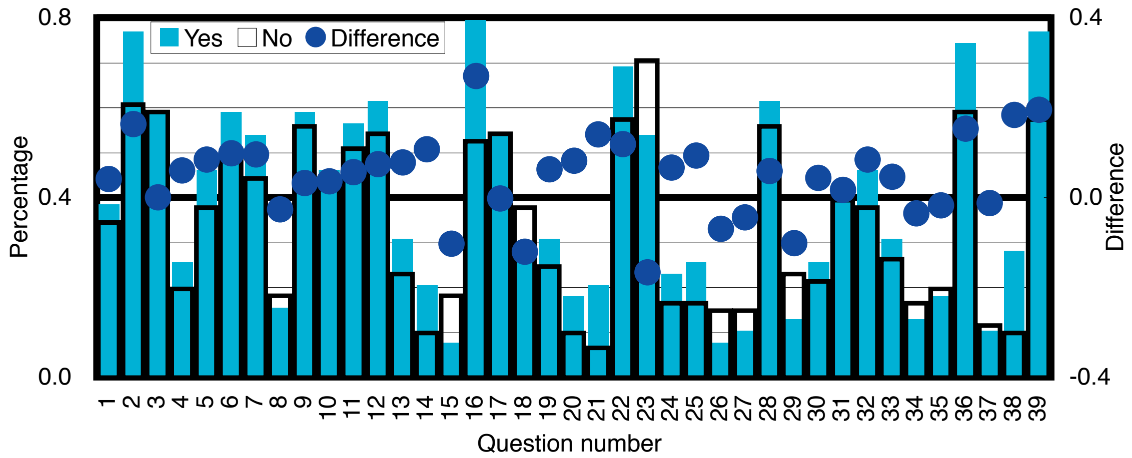


Figure 16 - The reply rate of each water use act for each category of water conservation consciousness

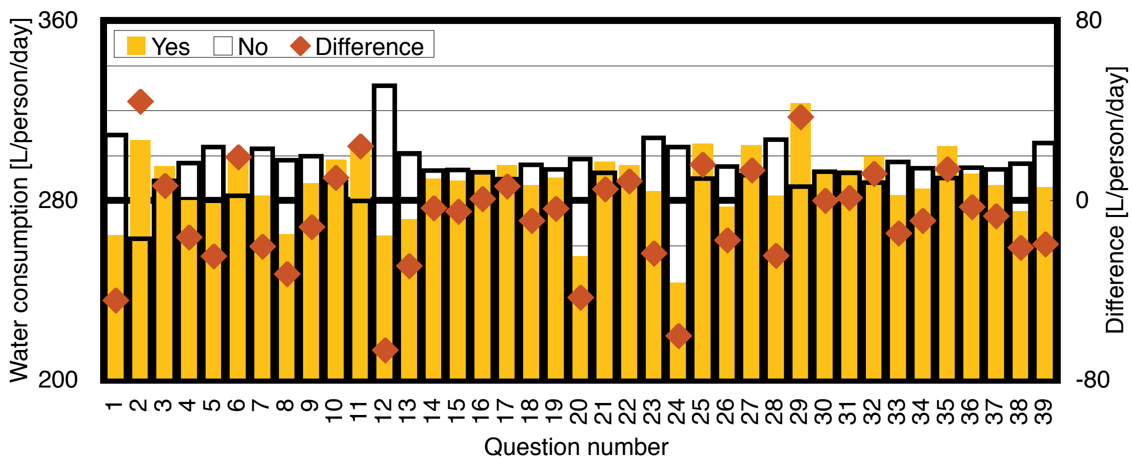


Figure 17 - Water consumption for the category of each water use act

water saving consciousness is connected with the act which does not collect water or is not used water. On the other hand, it is thought that environmental consciousness is connected with acts other than the above-mentioned item, such as “36. The plant is cultivated.” “22.A PET bottle etc.is rinsed and thrown away.” “30. What boiled tap water is cooled and drunk.” and “7. It washes at a house, without taking out to cleaning.” These are the acts to which water consumption may be made to increase.

7. Relation between water use act and water consumption

7.1 Relation between the existence of a water use act, and water consumption

In order to clarify the water use act of influencing water consumption, average water consumption per person per day was computed for the category of each water use act (**Figure 17**). That water consumption is decreasing greatly “12. It is washing collectively as much as possible.” “24. Processed foods and such as frozen food and canned food are used.” “1. Hair and the body are washed with the water of a bathtub.” and “20. Water is filled in a tub etc. and tableware is rinsed.” etc. By the category, which answered that it was “Yes”, average water consumption of 40-70 L decreased. On the contrary that water consumption is increasing greatly “2. Water to the extent that it overflows is not put into a bathtub.” “29. Mineral water is purchased and drunk.” and “11. Use of fabric softener”. The average value of water consumption in the category, which answered that it was “Yes”, average water consumption of 20-50 L increased. Although these acts are considered to be also the acts in which water consumption decreases, they are considered that there is indirect causal relationship with other factors from having brought a result which water consumption is increasing statistically.

7.2 Relation between the time and the number of times of a water use act, and water consumption

After totaling two or more thin items about the item answered by time or the number of times, correlation with water consumption was analyzed. That in which the tendency appeared is shown below.

7.2.1 Relation between home time and water consumption

The relation between the sum total of the home time all the members' households and water consumption is shown in **Figure 18**. A correlation coefficient is set to 0.55 and correlation of a degree is seen in the middle. Regression shows that water consumption has increased about 11 L, when home time increases for 1 hour.

7.2.2 Relation between the number of times of shampoo and water consumption

The relation of the number of times of a shampoo and the water consumption in summer is shown in **Figure 19**. A correlation coefficient is set to 0.55 and correlation of a degree is seen in the middle. Regression shows that water consumption has increased about 22 L, when the number of times of a shampoo increases once.

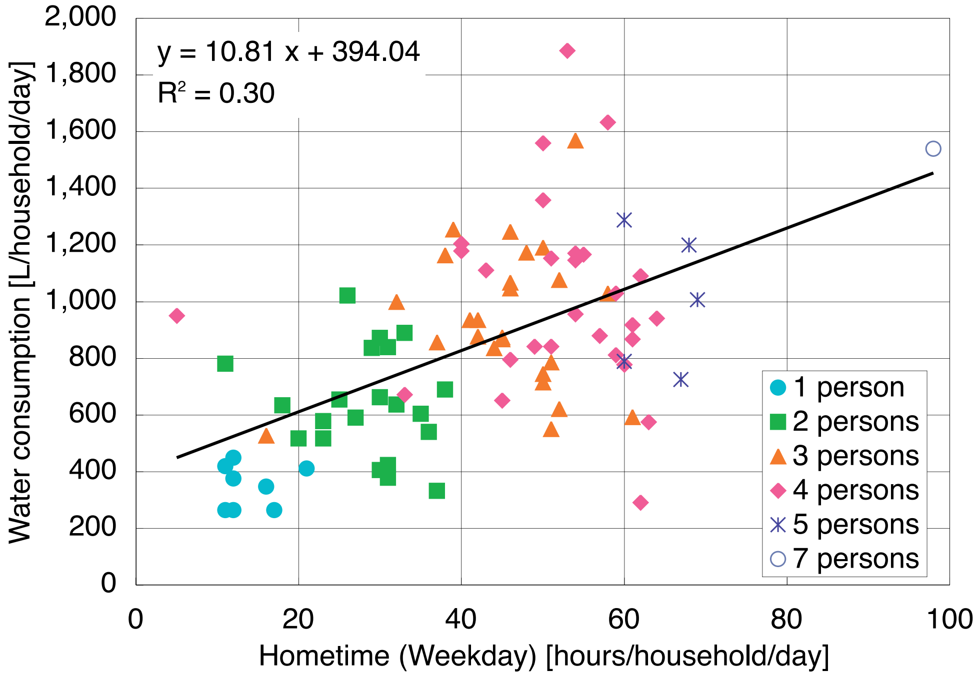


Figure 18 - The sum total of the home time all the members' households and water consumption

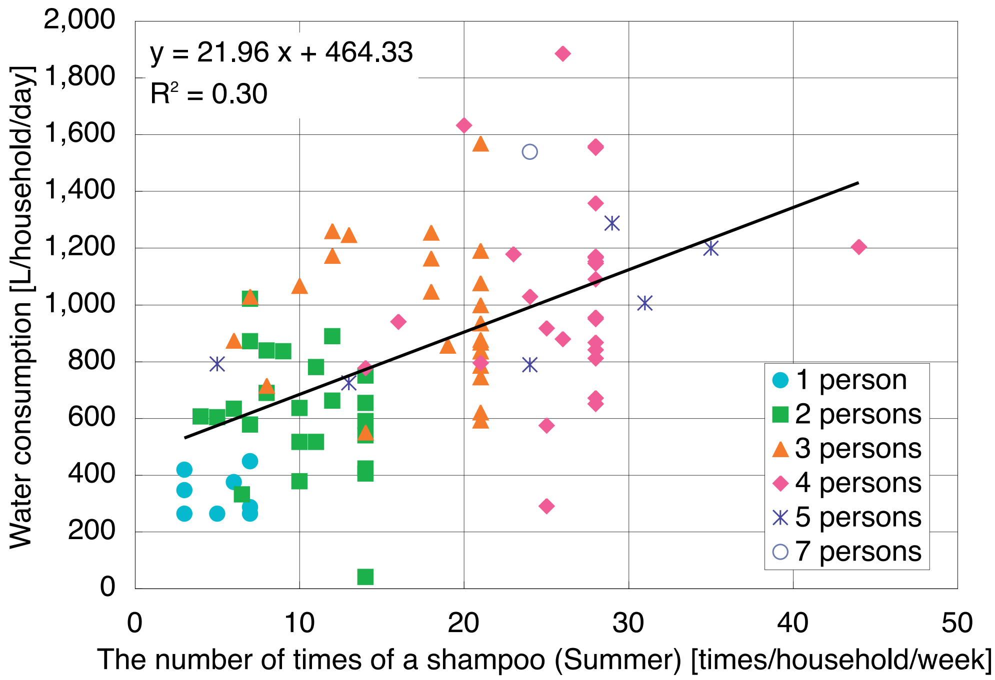


Figure 19 - the number of times of a shampoo and water consumption in summer

7.2.3 Relation between the meal prepared by the number and water consumption

The relation between the meal prepared by the number and water consumption is shown in **Figure 20**. A correlation coefficient is higher than other items at 0.61. Regression shows that water consumption has increased about 35 L, when the meals prepared by the number increase one person.

8. Relation between reformation / use equipments and water consumption

After catching the tendency of the existence of reformation and use equipments (**Table 5**), the relation between those and water consumption was analyzed. The rate of the existence of reformation and use equipments is shown in **Figure 21**. And the average water consumption according to every category of each reformation and equipment is shown in **Figure 22**. Since 22 years have passed after a building is made, the rate which reform a water heater is about 80% and the rate which reform a water equipment is about 60%. With the household, which reformed a water heater, average water consumption has decreased about 40 L. Moreover, with the household, which reformed a bathroom, average water consumption has decreased about 30 L. On the contrary, with the household, which is using a spray faucet in a kitchen, average water consumption has increased about 50 L. Those are considered to have the influence by change of the feeling of use by equipments chance.

9. Conclusion

This study clarified the relation quantitatively between a water use act / use equipments and water consumption while obtaining the basic data about water consumption by performing survey investigation and a questionnaire in an apartment. While water conservation consciousness had influenced reduction of water consumption, it turns out that environmental consciousness is not necessarily connected with reduction of water consumption. It thinks because the act considered to use many water, such as an act, which rinses a PET bottle, a tray, etc., and an act, which cultivates a plant, is performed of the high person of environmental consciousness. While catching synthetically the factor which influences water consumption from now on, it is necessary to consider the application to a design.

10. Acknowledgement

Investigation of this study is considered by Vision (1) WG of Vision examination committee (1999/4-2002/3) in Japan Society of Plumbing Engineers (JSPE). Moreover, in measurement, investigation, and data analysis, we received great cooperation of Mr. Yoshiro Sugiyama and Mr. Takahiro Okubo. Gratitude is expressed here.

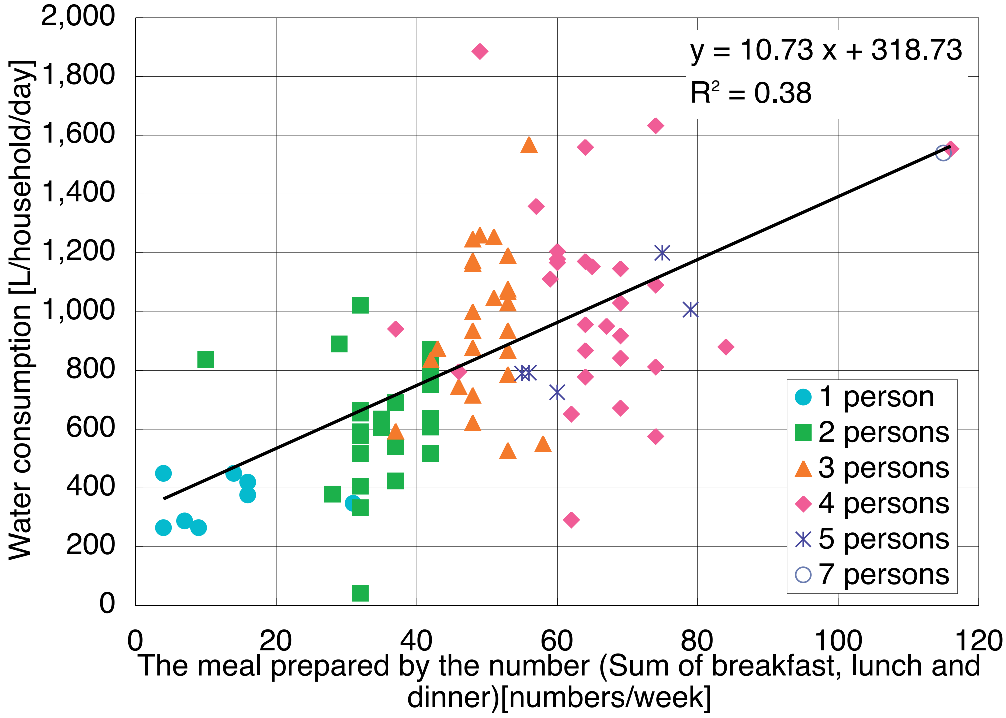


Figure 20 - The meal prepared by the number and water consumption

Talbe 4 - Question number (Reformation and use equipments)

Question number (Equipment)
1 Reformation of a water heater
2 Reformation of a water equipment
3 Reformation of a bathroom
4 Reformation of a kitchen
5 Reformation of a toilet
6 Use of a full automatic washing machine
7 Use of the bath water pump of a washing machine
8 Use of a fixed quantity stopping faucet in a bathroom
9 Use of a single lever faucet
10 Use of a thermostat faucet at a bath
11 Use of a spray faucet in a kitchen
12 Use of a shower faucet in a kitchen
13 Use of the water purifier attached to a faucet
14 Use of a non-portable water purifier
15 Use of a water saving loose disk
16 Use of a shower head can stop water at hand
17 Use of a shampoo dresser
18 Use of a toilet seat unit with warm-water bidet functions and a heated seat
19 Use of the bathtub with a water circulation and purification system

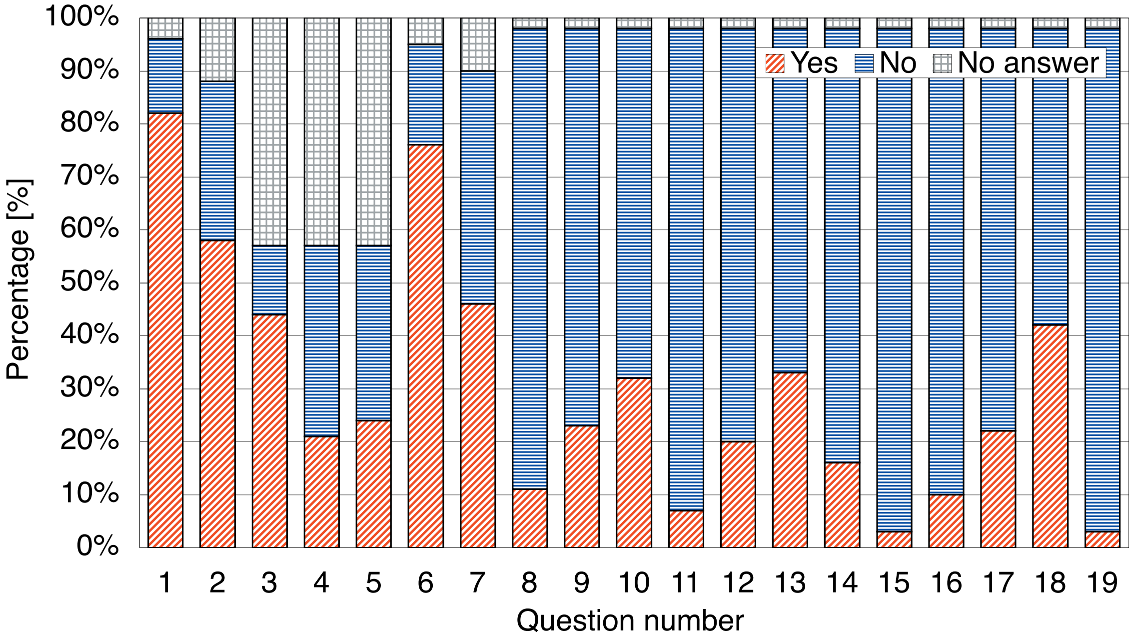


Figure 21 - The relation between Reformation / use equipments and water consumption

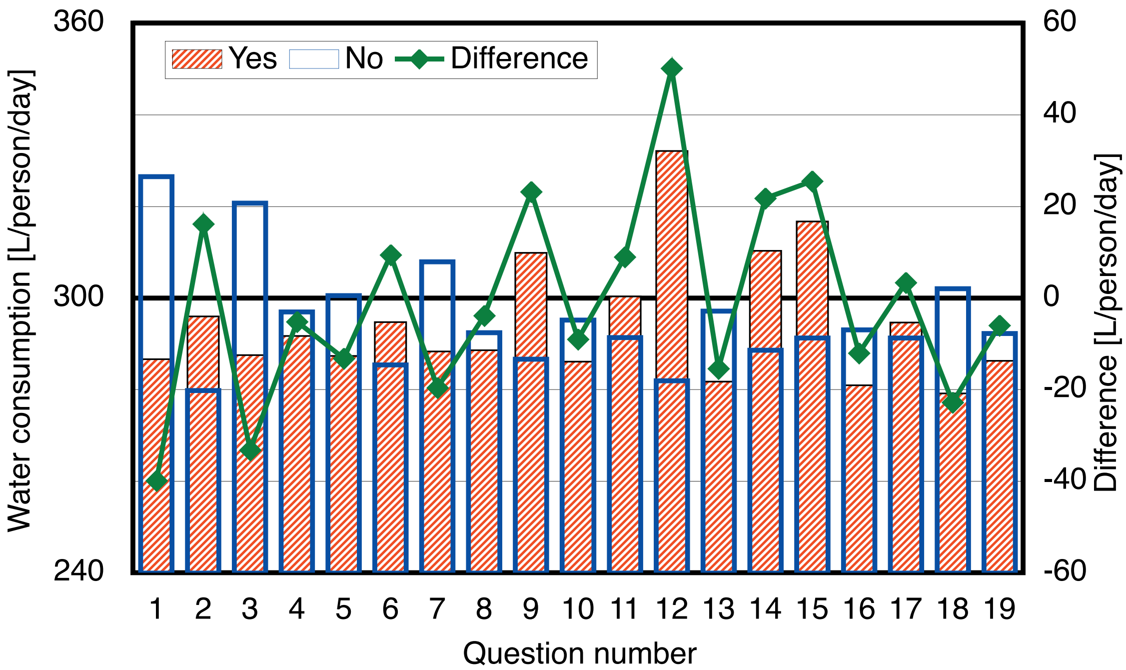


Figure 22 - Average water consumption according to every category of each reformation and use equipments

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12. Main author presentation

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Hot Water Plumbing System and Temperature Drop Mechanism in Residential Buildings in Taiwan

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Abstract

This paper focuses on the plumbing material of hot water supply system and present results of primary investigation in residential buildings in Taiwan as an example in subtropical countries. Experimental device has been set up to verify the temperature drop mechanism in residential buildings in Taiwan, which can also link to the energy consumption issues of the hot water supply system. Firstly, we conclude the results of investigation and figure out the current problems of hot water plumbing system. Through the statistic method with experimental design, the inference factors were clarified, which include material feature, thickness, caliber, length, etc. We also conduct a quantitative equation to calculate temperature loss in hot water transmission, hence figure out correlative equation between water temperature and air temperature. Finally, we will use infrared (IR) thermo-view, which is a non-destructive and visible measurement, to survey the variation of temperature decreased on surface and inner pipes.

Keywords
hot water supply system, residential building, investigation, experimental design, temperature drop

1. Introduction

Hot water supply is not only an important equipment in the plumbing system but also consumes lot of energy in residential buildings. According to former research [1], most people use hot water just in bathing time in subtropical area such as Taiwan; each person consumes the approximately 0.8KWH energy each time. And main factors that affect energy consumes are temperature of hot water using, utilization volume of hot water, and heat loss by transmission in linking pipes.

Hot water using space and heater disposition involves length of linking pipes which cause heat loss and energy waste, and this is often a problem for architecture planners and designers. A lot of studies also propose various kinds of research such as Building Energy Conservation Regular in Japan [2] which focused on heat loss by transmission in linking pipes, and SAKAUE [3], KAMADA [4], who proposed water temperature of hot water supply system based on energy conservation in Japan.

About 80% instantaneous gas heaters were setup in residential building in Taiwan. For safety consideration, most gas heater are located outdoors in the balcony, which leads that hot water linking pipes run across many interior spaces to bathroom. For this reason, while using hot water, much ill warm water stayed in linking pipes must be bled so as to waste energy.

Till now, there is not this kind of studies in subtropical area, so this study we will focus on isolated hot water supply system and discuss temperature drop with different condition of distribution pipes.

2. Research Method

Taiwan is located in the subtropical area. A few researches have raised the influence of hot water transmission energy consumption, but no research in heat loss estimation and quantitative evaluation is available. Only in air conditioning industry where transmitted water temperature influenced by ambient temperature is concerned, so there are some studies and quantitative evaluation of linking pipes. But those are different from hot water transmission exothermic function in hot water supply system. Therefore, this study will focus on hot water transmission exothermic evaluation investigates present status then set up an experiment to evaluate heat loss by linking pipes.

Firstly, we studied the literature review[5] and referenced a quantitative equation of heat loss by distribution pipes as eq.1. From this equation it is known that heat loss related with caliber of pipes, shall thickness of pipes, heat conduction and heat transfer with material conditions of pipes. According to these factors and investigated results of present status to design an experiment, this experiment includes three issues: the first issue is to measure temperature drop caused by different various factors of linking pipes, the second issue is to induct correlative equation between water temperature and air temperature, and the third issue is to propose a non-destructive observation measurement with the infrared thermo-view surveying the variation of temperature decreased on surface and inner pipe.

$$q_o = \frac{\theta_i - \theta_o}{\frac{1}{2\pi}\left(\frac{2}{D_i h_i} + \frac{1}{k_p}\ln\frac{D_o}{D_i} + \frac{2}{D_o h_o}\right)} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(1)$$

3. Investigation

This study uses random sampling questionnaire, takes the household as a sample unit, then focuses on three metropolitan areas—Taipei, Taichung, and Kaohsiung. About 200 questionnaires were collected in each area, but only 451 are effective questionnaires, including 167 row houses, 26 one family houses, and 258 apartments.

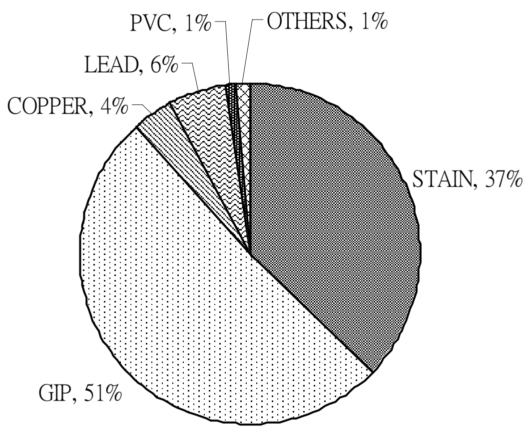

Fig. 1. Frequency of material in hot water distribution pipe before 1990

Based on these questionnaire results, the material of linking pipes differs in age and market direction. Before 1990, there was no policy to stipulate material of hot water supply pipes in Taiwan; therefore, material of pipes was determined based on economical consideration. According to this investigation results, most pipes before 1990 are used in galvanized iron pipes (GIP), which represent 51% and the stainless pipes (SP) represent 37% as shown as Fig.1. In February 1992, Taipei Water Department deployed a regulation that "material of hot water supply pipes should be stainless or copper …" [6], so the material of hot water supply pipes have been regulated since then. As shown in Fig.2, the SP has been in place of the lead pipes and GIP pipes in recent 15 years.

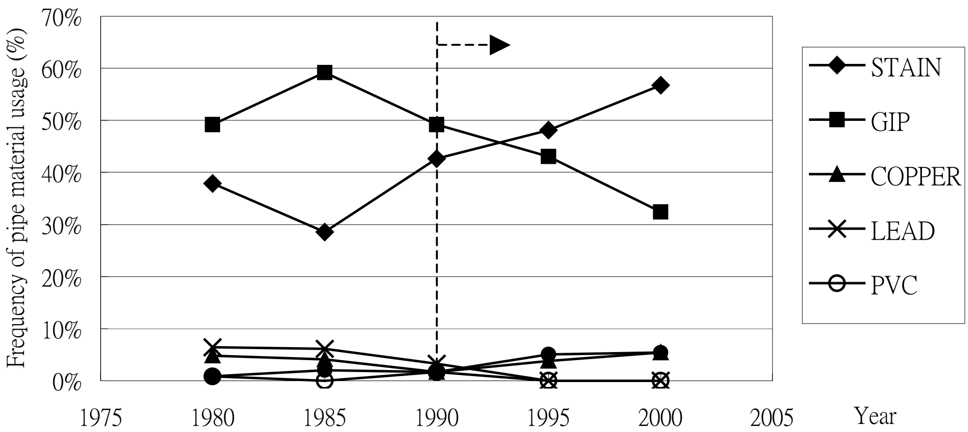

Fig.2 Frequency of pipe material usage form 1980

Moreover in the investigation results it is also discovered that the used proportion on covered pipe for heat preservation is gradually increasing. Another feature of hot water supply pipe distributed disposing method is that about 67.6% are underground pipes which are difficult to maintain and repair, so more and more one family houses gradually switch to non-underground pipes, as shown as Fig.3.

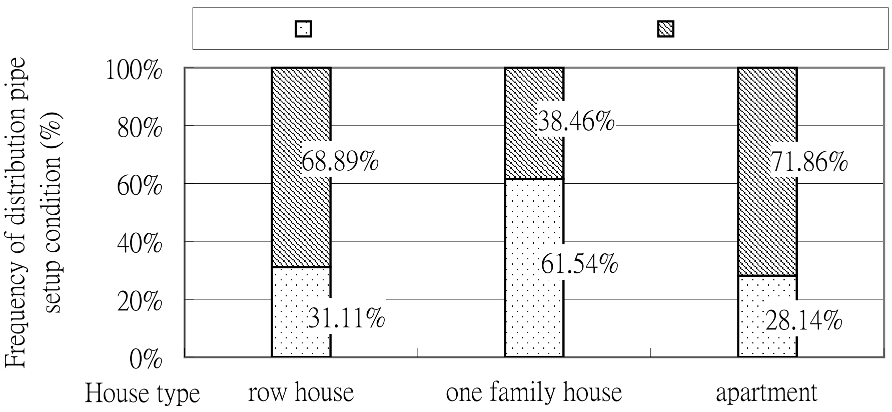

Fig. 3 Distribution pipe setup condition in different type of residential building

According to #30, Chapter equipment of National Building Code in Taiwan[7], the majority of caliber of linking pipes used in supply system is 13mm in diameter. Therefore, about 80% pipes used in residential hot water supply system are 13mm in diameter, and a few pipes diameter are 19mm or 25mm. Their corresponding water supply quantity is summarized in Fig. 4. Since most of the hot water supply pipes are still setup without coved, ambient temperature cause heat loss in linking pipes system.

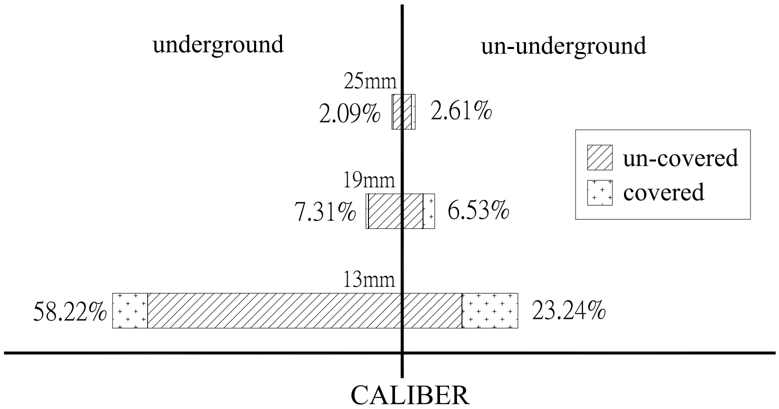

Fig. 4 Frequency of distribution pipe setup condition and covered pipe

Linking pipes lengths are different due to the distance between hot water used space and heater position. In our investigation results the shortest length is just 0.5m, the longest one 22.0m, and the average one 6.56m as shown as table 1.

Table 1. Summary of hot water supply pipe length in different building type.

Building type	Under 5m	5-10m	10-15m	Over 15m	Average length (m)
Row house	52	35	11	12	6.63
Apartment	50	108	22	8	6.68
One family house	16	2	1	2	5.02
Summary	118	145	34	22	6.56

For different pipe materials the heat conductivity is not the same, and the heat loss is also different. Through in the same pipe material, the heat loss of bigger caliber, thicker, and longer pipe is less than that of smaller caliber, thinner, and shorter one because of larger calorific capacity. Based on the investigation results, we took the factors that may influence heat loss in the water distribution as the basis factors in our experiments, and then we design the experiments accordingly.

4. Experimental design method

The investigation results demonstrate all features of hot water supply distribution pipes in residential buildings. The materials of pipe include SP, GIP, and CP (copper pipe); the connection method is separated into compression connect and screw connect; and disposal method contains underground pipes and un-underground pipes. Each kind of disposal method usually uses different caliber: caliber of underground pipe is usually in 13mm and 19mm, and un-underground pipe can be not only in 13mm and 19mm but also in 25mm. When pipe length is considered, current average length tends to be in 2m, 4m, and 8m.

To conclude all above features as factors in the experiment arrangement, we would need to run 80 groups of experiments and to spend a lot of time. Consequently, our experimental design method took Latin Frame decrees experiment factors and standards for decreasing experiment groups as shown table 2.

Table 2. Latin Frame decrees experiment factors and standards

Factors	1st standard	2nd standard	3rd standard
A: **connection**	Screw	Compression	
B: **material**	Stain Pipe (SP)	Galvanized Iron Pipe (GIP)	Copper Pipe (CP)
C: **caliber**	13mm	19mm	25mm
D: **disposition**	Un-underground	Underground	With covered
E: **length**	2m	4m	8m

Because factors are included in two standards and three standards, we used compound straight frame as L18 (2^1x3^7) dispose factors. Two standards of factor A were allocated in the first column while the other three standards were allocated from the second to the eighth columns. Table 3 summarizes the allocation results, so only 18 groups are required in our experimental design.

5. Experiment design

The temperature drop gradient of different pipe material will be discussed through experiment, and heat loss will be calculated in the end of this study. The experimental schematic is drawn as Fig.5: an electric heater and a temperature sensor as a core are set to ensure the temperature stability of hot water bled out. All pipes are installed with different materials, calibers, and lengths beside the core. Lengths of pipes in temperature lost experiment are 2m, 4m, and 8m, and each end of pipe joints are also installed temperature sensors to measure the temperature drop by ambient temperature and time. This experiment uses common hot water supply pipes condition according to the investigation results and measures water temperature drop in different pipes as shown in Fig.6. According to the measured results we calculated heat loss in every pipe condition by Multi-variables analysis.

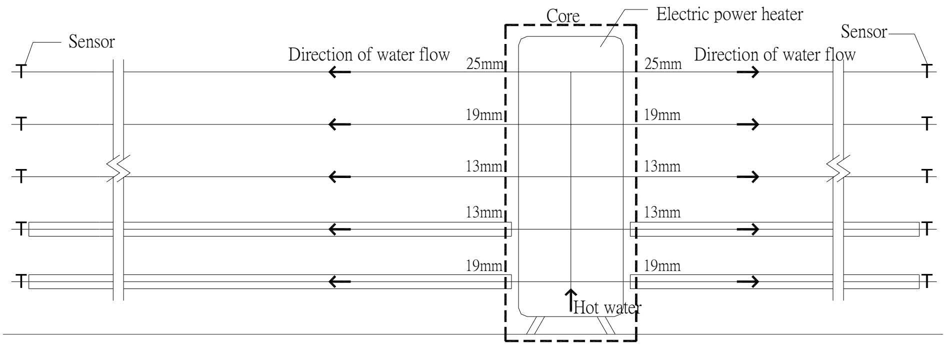

Fig. 5 Experimental schematic drawing

Table 3. $L_{18}(2^1 \times 3^7)$ compound straight frame

	A	B	A*B	C	B*C	D	E	error
1	compression	CP	1	25mm	2	covered	2M	2
2	screw	GIP	2	19mm	3	covered	2M	1
3	screw	SP	1	13mm	1	un-underground	2M	1
4	compression	SP	3	19mm	2	un-underground	2M	3
5	screw	CP	3	13mm	3	underground	2M	2
6	compression	GIP	2	25mm	1	underground	2M	3
7	screw	CP	1	19mm	1	covered	4M	3
8	compression	GIP	3	13mm	2	covered	4M	1
9	compression	CP	2	13mm	3	un-underground	4M	3
10	screw	GIP	3	25mm	1	un-underground	4M	2
11	screw	SP	2	19mm	2	underground	4M	2
12	compression	SP	1	25mm	3	underground	4M	1
13	screw	SP	3	25mm	3	covered	8M	3
14	compression	SP	2	13mm	1	covered	8M	2
15	screw	CP	2	25mm	2	un-underground	8M	1
16	compression	GIP	1	19mm	3	un-underground	8M	2
17	compression	CP	3	19mm	1	underground	8M	1
18	screw	GIP	1	13mm	2	underground	8M	3

Fig. 6 Experimental instruments and pipes storage

Another experimental method to measure hot water temperature inside pipes is to measure the temperature of pipe surface in different pipe material then to infer water temperature inside the pipes. In the past thermo-couple was pasted on pipe surface to measure the temperature, but it is not easy to measure untouchable pipes and underground pipes. By the technical improvement, infrared (IR) thermo-view makes it easy to observe pipe surface temperature changed by ambient temperature under any condition. In this research, one infrared (IR) thermo-view was setup for visible pipe surface temperature as shown in Fig.7, and the variation of temperature dropt on surface and inside the pipes is measured.

Fig. 7 Infrared (IR) thermo-view for visible pipe surface temperature

6. Study analysis

We ran experiment measurement to obtain water temperature drop by ambient temperature under different setup condition. Fig 9 shows one sample experimental result of copper pipe: when hot water flows through copper pipe for 30 minutes, the temperature is dropt fast as a linear function at first then tends to be close to the air temperature. The interpretation analysis as follows:

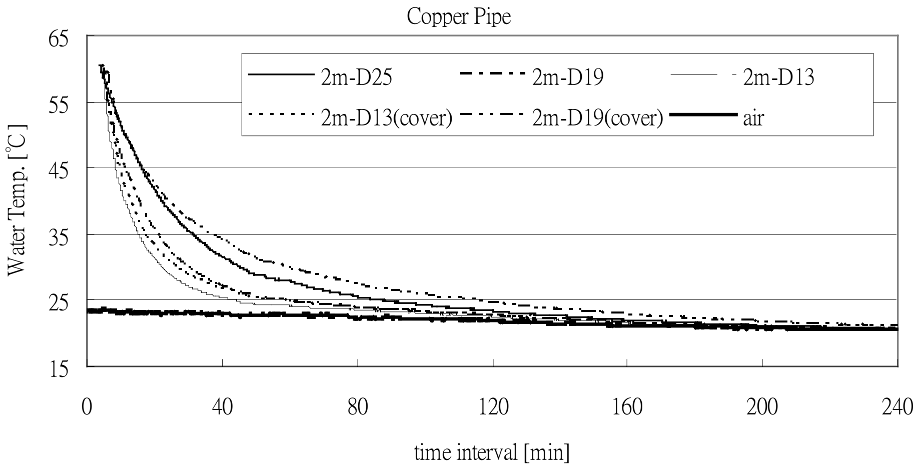

Fig. 8 Temperature drop of different caliber in copper pipe

(1) Correlation between air temperature and water temperature

In order to extrapolate correlation between air temperature and water temperature, we waited for more than 4 hours in each experiment until water temperature approximates air temperature in a stable status. Then we measured temperature in stable status for 10 minutes to analyze the correlation between air temperature and water temperature. Because the temperature sensor was installed before hot water entered into the 13mm stainless pipe, the measurement results would not be changed under different experiment condition.

We obtained experiment results based on 20 times of experiment and conducted regression analysis as in Fig.9 to get a correlation equation as eq.2. The R-square of this equation is 0.98, and the standard deviation is 0.51, so it is an effective equation. This equation may estimate water temperature by meteorological data and is easier to use than eq.1 in calculating energy consumption. (Because this experiment is running on subtropical area, the equation is just representative for the weather changes in this area.)

$$T_W = 0.93 \times T_A + 1.78 \qquad \text{……………………(2)}$$

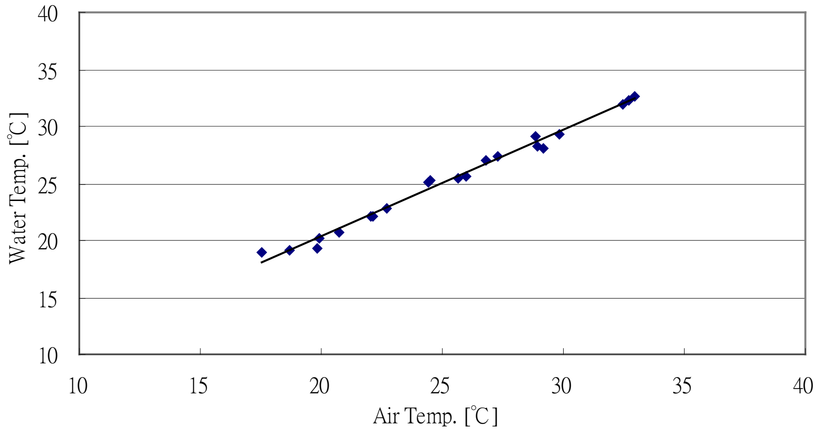

Fig. 9 Correlation between water temperature and air temperature

(2) Hot water temperature drop gradient

Referencing eq.1, we know that in the same pipe material, the heat loss of bigger caliber, thicker, and longer pipes is less than smaller caliber, thinner, and shorter ones due to larger calorific capacity as shown in Fig.8 and Fig.10. According to measurement results, we analyze water temperature drop inside of the pipes under different experiment conditions.

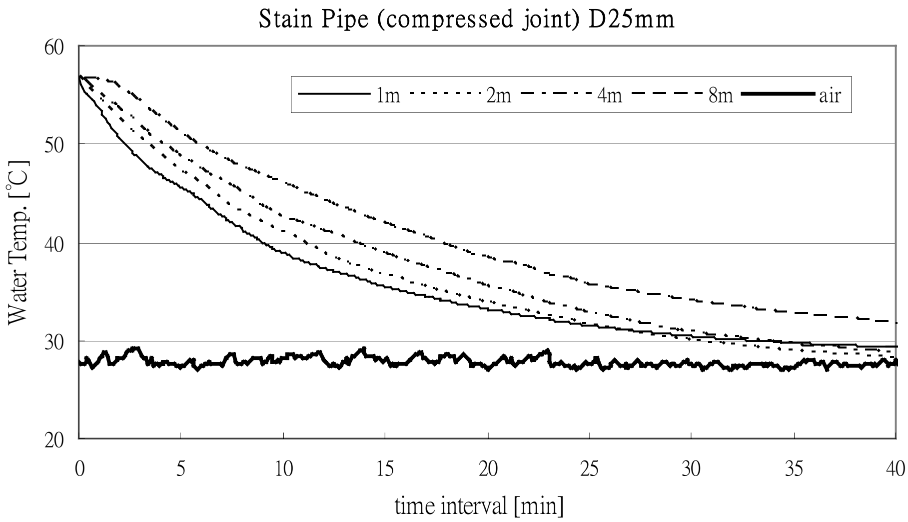

Fig. 10 Temperature drop of different length in stainless pipe

Because the average body temperature is 36.5℃, human would feel water cool when the water temperature is lower than 36.5℃. On the other hand, water with temperature over 55.0℃ and contact human body over 10 seconds would cause burns. Therefore we need to set hot water temperature within the range between

35.0℃ to 55.0℃ when conducting temperature drop coefficient analysis. Then we did a linear regression analysis based on experimental results of every pipe condition to calculate the linear slop in temperature drop gradient and recorded all values while ambient temperature basis on 20℃ as table 4.

Table 4. Temperature drop gradient in different pipe condition

Material	Type	Caliber (mm)	Thickness (mm)	Temperature drop gradient (℃ / min)		
				2M	4M	8M
Stain Pipe (Compression connect)	uncovered	13	0.8	-2.384	-1.928	-1.684
		19	1	-1.557	-1.487	-1.376
		25	1	-1.111	-1.004	-0.920
	covered	13	0.8	-1.474	-1.741	-1.497
		19	1	-0.669	-0.618	-0.602
Stain Pipe (Screw connect)	uncovered	13	2.5	-1.907	-1.993	-3.761
		19	2.5	-1.306	-1.096	-2.026
		25	3	-0.939	-0.688	-1.388
	covered	13	2.5	-1.283	-1.448	-1.920
		19	2.5	-0.627	-0.557	-0.512
Galvanized Iron Pipe	uncovered	13	2.8	-0.656	-0.452	-1.479
		19	2.9	-0.424	-0.364	-1.325
		25	3.4	-0.281	-0.279	-0.651
	covered	13	2.8	-0.349	-0.306	-1.039
		19	2.9	-0.189	-0.228	-0.421
Copper Pipe	uncovered	13	1.5	-2.316	-2.305	-1.301
		19	2.2	-1.615	-1.534	-1.288
		25	2.8	-1.011	-1.160	-1.053
	covered	13	1.5	-1.912	-1.607	-1.028
		19	2.2	-0.743	-0.684	-0.578

By table 4 it is obvious that different pipe conditions--length, material, caliber, and coverage--lead to different temperature drops. This table may provide reference of temperature drop in every kind of hot water distribution pipe setup and saves energy that would otherwise be wasted at hot water used space and during peak bathing time.

(3) Infrared thermo-view visible measurement

IR Thermo-view makes it easy to distinguish the change of initial water temperature. However, when the temperature inside of the pipes is too close to ambient temperature, it is difficult to measure the change of water temperature since there is not any obvious change. Nevertheless, we can still record the change of initial flowing hot water temperature as in Fig. 11.

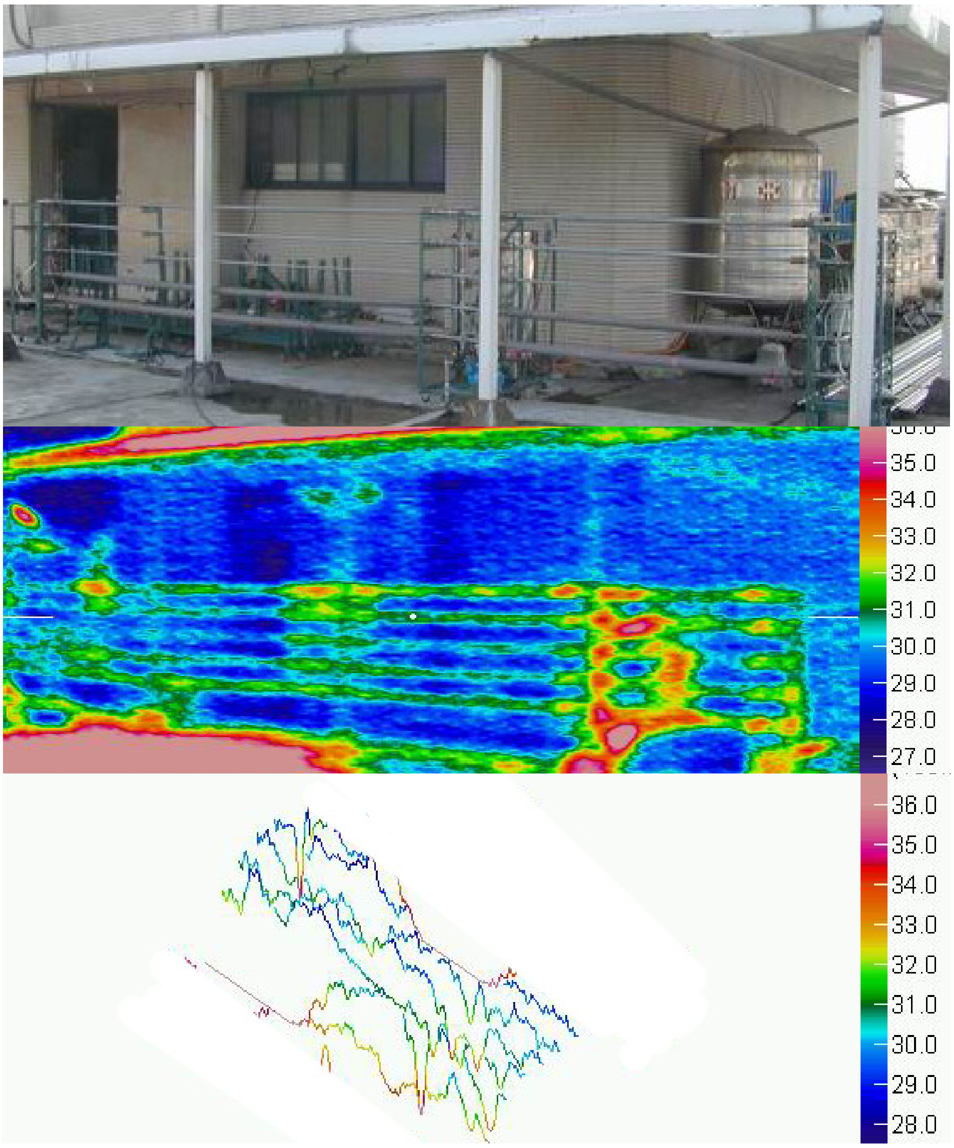

Fig. 11 IR thermo-view for visible pipe surface temperature distribution

7. Conclusion

This paper has illustrated current hot water supply system in Taiwan. The results of investigation clarified the current problems of hot water plumbing system. Through the statistic method with experimental design, the inference factors were clarified, which include material feature, thickness, caliber, length, etc. We also conduct a quantitative equation to calculate temperature loss in hot water transmission and figure out correlative equation between water temperature and air temperature. The following conclusions may be drawn with respect to the current issues of hot water supply system in Taiwan.

1. Hot water supply pipes are most in 13mm SP and GIP with average length is 6.56m, and mostly installed underground in Taiwan.
2. We propose an equation to estimate water temperature by meteorological data and calculate the linear slop of temperature drop in every pipe condition and recorded all values as table 4.
3. Using IR thermo-view visible measurement to estimate water temperature drop inner pipe has some limitation when the water temperature is close to ambient temperature, which suggests that the IR thermo-view can observe the pipe leakage examination.

8. Nomenclature

D ：Diameter（m）	Subscript：
h ：Heat transfer coefficient (kcal/m^2・h・℃)	***A*** ：air
k ：Heat conductivity（kcal/m^2・h・℃）	i ：inner
q_o ：Heat loss（kcal/m・h）	***o*** ：outer
θ ：Pipe temperature（℃）	p ：pipe
T ：Temperature（℃）	W ：water
t ：Time（min）	

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10. Presentation of Author

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Survey on Residential Hot Water Consumption in Japan

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Abstract
For the energy conservation in houses, hot water segment is very important because it occupies one third of total consumption. But contrary to it's importance, hot water consumption in houses is not fully investigated yet. In this paper, we choose the best data format for hot water consumption, and analyze the average and fluctuation in short and long period. Finally we made the test mode for experiment of hot water heater, composed with 6 days, which has typical average and daily fluctuation.

Keywords
Hot water, House, Energy conservation, Test mode,

1 Introduction
As awareness of global warming terrible impact is growing, there is little doubt about the importance of energy conservation these days. Japan is under obligation to reduce CO2 emission by 6 % in 2008-2012 from 1990 level in COP3 "Kyoto Protocol", and government is prompting many research and technology for that purpose. Energy consumption in houses occupies 14 % of total consumption all over Japan. The ratio might not seem so large, but remedy must be developed immediately considering the

current quick up-trend and room for living standard improvement.
Japanese is known for strong affection of bath taking, and energy consumption for hot water takes up one third of total amount. So energy reduction in that segment is getting more attention, and many technologies are developed such as “Gas condensing water heater”, “CO2 heat pump water heater”, “Fuel cell ”, “Gas engine co-generation” or so.
These new system is presented as the highly efficient, but actual performance in real houses is not known so well. Considering the variety of hot water consumption in each house, the measurement of hot water usage in existing houses and classification of typical usage is strongly required as the first step. For that purpose, format of data is also important to compare each measured data beyond system and regional difference.
In this paper, we define the data format considered most suitable first, and sum up many existing data in that format. And as the prototype of test mode, we introduce the “Modified M1 mode”, composed of sequent 6 days and now being used in full scale experiment in BRI (Building Research Institute).

2. Definition of format for hot water consumption

2.1 Hot water supply system

Ordinary hot water system and measurement point is shown in Figure 1. Central water heating system for each house is introduced in almost all houses in Japan, so we won’t deal with local hot water supply system in this thesis.

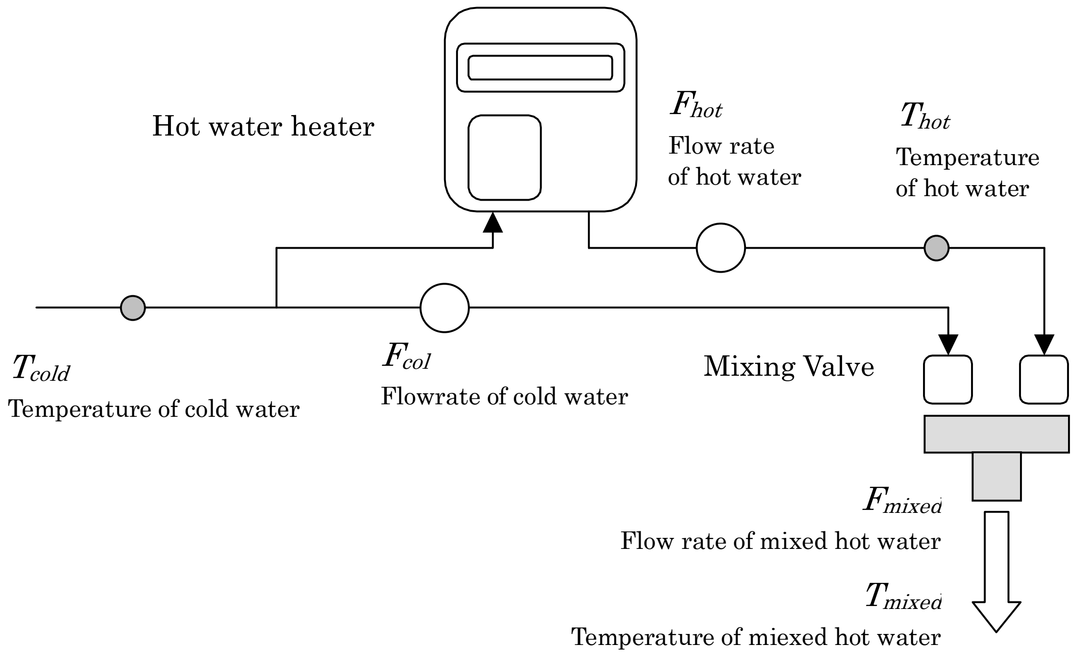

Figure 1 Definition of Mixed hot water

We use the term “Cold water” for water excluding the water for heater, “Hot water” for water boiled up to usually 38 to 60 degree, “Mixed hot water” for water mixture of hot and cold water in mixing valve. In this thesis, we put the emphasis on “Mixed hot water”, because we usually use the hot water by that form.

“Mixed hot water” has two aspects of “volume” and “heat”, so some kind of data format can be devised to express its consumption. In this paper, we would compare three kind of format shown below.

- Format 1: Hot water’s volume and heat load
- Format 2: Mixed hot water’s volume and heat
- Format 3: Mixed hot water’s volume with fixed temperature

2.2 Format 1: Hot water’s volume (and heat load)

In this data format, you only have to measure points around hot water heater, F_{hot}, T_{hot} and additionally T_{cold} if possible. There is no need to measure cold water flow rate F_{cold}, so preparation is simplified, cost is low. Especially in the case of apartment house with central water heating system, hot water volume (F_{hot}) is measured for monthly payment, and hot water temperature (T_{hot}) is monitored in operation, so data can be obtained very easy. Total hot water volume V_{hot} is expressed as equation (1).

$$V_{hot} = \sum F_{hot} \quad (1)$$

To express “heat” aspect of hot water, total heat of hot water is considered less useful. So you usually adapt the form of “Heat load”(H_{load}), a needed heat in heater to produce hot water, expressed in equation (2).

$$H_{load} = \sum c\rho(T_{hot} - T_{cold})F_{hot} \quad (2)$$

c means heat capacity, and ρ means specific gravity of water

Sometimes, T_{cold} might not be available. In that case, you can use forecast equation with outdoor air temperature or so.

The benefit of this format is the simplicity of measurement and flexible adaptation to many measured data. You can omit measurement of cold water flow, which is difficult in many cases. Time interval is not so critical, so this format can be adapted for data with almost all time intervals, from 1 sec to 1 month. And usually it is sufficient to refer only to heat load (H_{load}) for comparison and evaluation, and that makes comprehension fairly easy. The drawback is the V_{hot} and H_{load} is affected by fluctuation of cold water temperature (T_{cold}). T_{cold} varies in seasons and regions. So even in the case that you use same volume of same degree mixed hot water, V_{hot} and H_{load} would vary. That makes the comparison beyond seasons and regions almost impossible.

2.3 Format 2: Mixed hot water's volume and heat

To avoid the format 1's problem, it is most desirable to measure cold water flow rate (F_{cold}) additionally and shorten measurement time interval. Using both cold and hot water's flow rate and temperature, we can estimate the detail of actual usage at the valve such as mixed hot water volume, temperature, flow rate or so on (Simultaneous usage on more than one valve is not considered in this thesis). The property of mixed hot water can be expressed, in both aspect of volume(V_{mixed}) and heat(H_{mixed}). Equations are shown below, (3) and (4).

$$V_{mixed} = \sum F_{hot} + F_{cold} \tag{3}$$

$$H_{mixed} = \sum c\rho (T_{hot} F_{hot} + T_{cold} F_{cold}) \tag{4}$$

In this expression, you can compare each data beyond cold water temperature difference and concentrate on the usage itself. This format2 is most desirable format to investigate hot water usage in detail. If you need the heat load or hot water volume, you can easily obtain by hot water and cold water temperature.

But usually, measuring the cold water flow rate is very difficult and costly. And for the accuracy, necessary time interval is limited to several seconds in this format. Those conditions restrict data to which this format can be adapted so severely. And making the matter worse, you have to cope with the 2 data "V_{mixed}" "H_{mixed}" at the same time for comparison, and it is burden to comprehend.

2.4 Format 3: Mixed hot water's volume with fixed temperature

Format1 and format2 both have each advantages and disadvantages. To put each advantage together and reduce the deficits, we can point out the format of "mixed hot water's volume" with assuming the mixed hot water temperature at valve to some reasonable fixed value (T_{fixed}). The mixed hot water volume with fixed temperature $V_{mixed}(T_{fixed})$ can be expressed in equation (5) with T_{hot} and T_{cold} and F_{hot}.

$$V_{mixed}(T_{fixed}) = \sum F_{hot} \frac{(T_{hot} - T_{cold})}{(T_{fixed} - T_{cold})} \tag{5}$$

The first benefit of this format is the simplicity of expression. The two aspects of volume and heat is converted in one variable, and you only have to refer to that single value. The second is that, by omitting the measurement of cold water flow rate, almost every existing hot water data can be arranged by this format. The third is, which is very important, influence of cold water fluctuation is deleted as well as format2. The deficit is, actual temperature of mixed hot water (T_{mixed}) cannot be grasped. But T_{mixed} can be measured in laboratory experiment or so, so can be considered not so serious.

2.5 Comparison

The advantages and disadvantages of each format are shown in. Table 1. As the examination already mentioned, format 3 is most suitable for our goal. So we use this format exclusively for comparison. In this thesis, T_{fixed} is set to 40 deg., considered normal for every usage on faucets.

Table 1 Pros and Cons of each format

		Format 1	Format 2	Format 3
Required Data	Hot water temperature	Necessary	Necessary	Necessary
	Hot water flow rate	Necessary	Necessary	Necessary
	Cold water temperature	Desired	Necessary	Necessary
	Cold water flow rate	Not Necessary	Necessary	Not Necessary
Cost of measurement		Flexible	Expensive	Flexible
Number of sample		Many	Restricted	Many
Remove fluctuation the Cold Water Temperature		Impossible	Possible	Possible
Necessary time interval		Flexible	Very short	Flexible
Degree of actual usage evaluation		Good	Best	Better
Easy to understand		Better	Difficult	Best

3 Analysis on actual hot water consumption

3.1 detail of measured data

In this thesis, we treat data measured in houses acquired through several measurements. Total house number amounts to 71, considered a fairly large compared with existing research. Detail of each data is shown in

Table 2. Each data's measured period is different from two months to three years, and that difference may have the effect on reliability of calculated average and standard deviation. On this paper, we simply avoid using the data with short period for analysis of seasonal fluctuation, but this matter needs examination on another occasion.

Each data has some "0" value of daily consumption, caused by measurement trouble, inhabitant's absence or so. Sometimes, it is difficult to decide the subject of "0" value. So, on this paper, we treat the "0" value as "N/A" (Not Available) and simply ignore, assuming that usually family members consume hot water every day if they stay in house.

Table 2 Detail of Acquired data

Data Name	Measured Period	Region	House Num	Measured Points				Time Interval
				F_{cold}	T_{cold}	F_{hot}	T_{hot}	
OK Apt.	1993Jan, Jul	Tokyo	22	○	○	○	○	1sec
TK Apt.	1998Nov-2000Mar	Osaka	10	○	○	○	○	1sec
NX Apt.	2000Jan-2002Oct	Osaka	14	○	○	○	○	10min
FO Apt	2003May-2004Jan	Kyushu	19	×	○	○	○	1min
BL	2001Nov-2003Nov	Tokyo	6	○	○	○	○	2sec

- BL is "Better Living", a institute to guarantee the quality of domestic equipments
- Data of "TK Apartment" and "NX Apartment" is presented by Osaka Gas corp.
- Data of "FO Apartment" is presented by AIST (National Institute of Advanced Industrial Society and Technology) and Saibu Gas corp [1]

Example of daily consumption in one house is shown in Figure 2. Daily consumption is suggesting the vague average, but also indicating the many kind of fluctuation, such as seasonal, weekly, or almost random one.

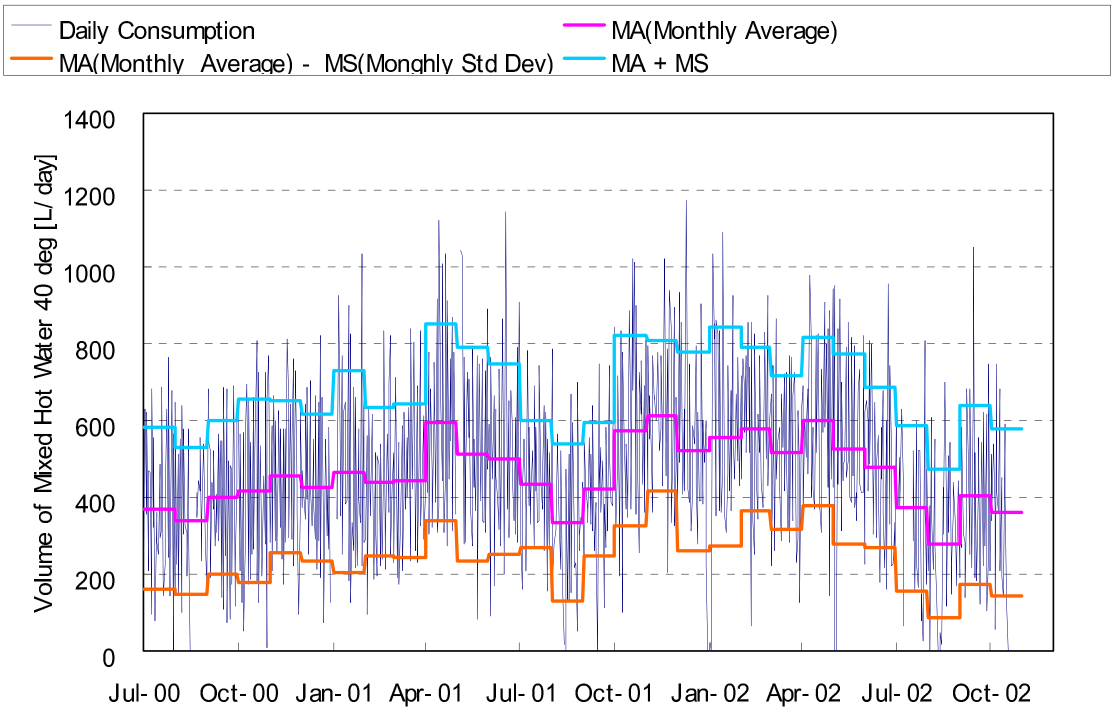

Figure 2 Fluctuation of daily mixed hot water (40 deg) consumption

In this paper, we would like to make a point of fluctuation of consumption, not only average. To separate the short and long fluctuation, we calculate the average and standard deviation on each month and call them as "MA (Monthly Average)" and "MS

(Monthly Standard Deviation)”. MA means rather long trend and changes seasonally, and MS means short fluctuation of daily consumption. Figure 2, also shows the “MA” and “MA+MS”, “MA-MS”. If the distribution of daily consumption can be assumed as “Normal distribution”, almost two third of all days would fall between “MA+MS” and “MA+MS”.

3.2 Average Consumption

It is well known that persons’ number affects hot water consumption definitely. So we sum up the total average of MA in all measured term first. “Average”, “Largest” and “Smallest” in each family number are shown in Figure 3. Volume varies widely, but average values show the clear increase in accordance with the family number. House with 4 persons, considered typical family in Japan, consumes 444.9[L/day]. (Houses with unusual small volume are omitted for accuracy).

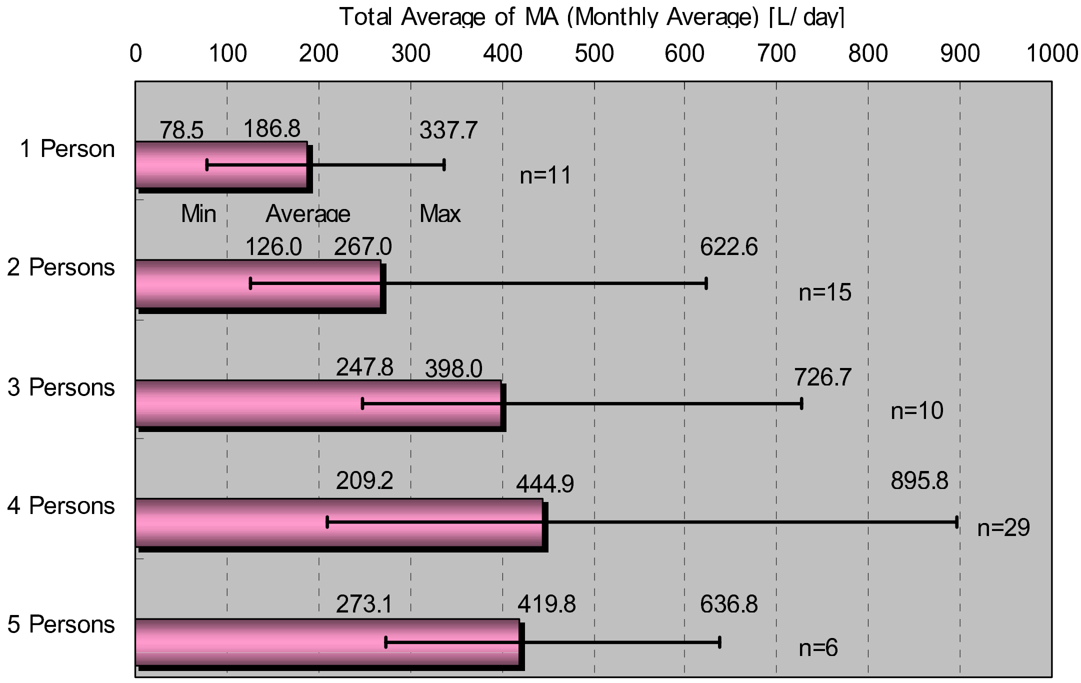

Figure 3 Average of MA (Monthly average) on number of persons in house

3.3 Daily Fluctuation (Short trend)

Next, we analyze the behavior of “MS” (Monthly Standard Deviation) to grasp the daily fluctuation, which is critical for heater with storage. Total average in all measured term of “MA” and “MS” in each house is shown in Figure 4. MA varies widely from about 50 to 900[L/day]. MS indicate the obscure increasing in accordance with MA, but values in most houses fall in the range between 100 and 200[L/day]. That means MS doesn't increase as much as MA.

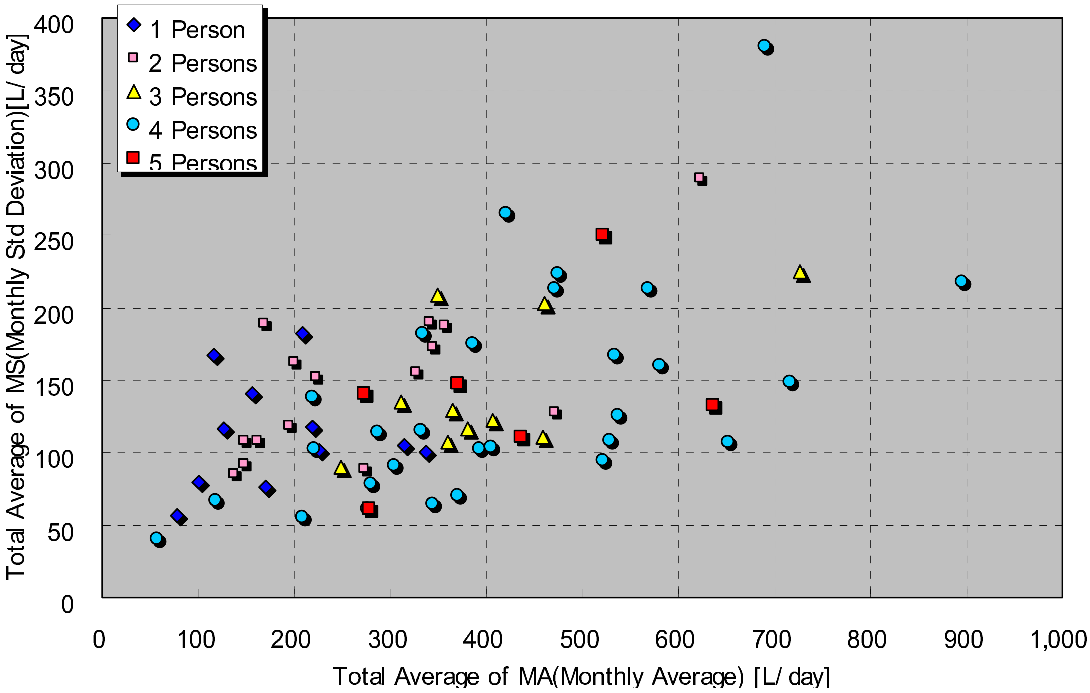

Figure 4 Total average of MA and MS

To see this tendency more clearly, the relation of MA and "Coefficient of Variance" is shown in Figure 5. "Coefficient of Variance" is the standard deviation divided by average, and indicates the degree of fluctuation. As shown, Coefficient decreases when MA increased, and this indicates that Consumption increase leads to the stabilization. The consequence may be explained this way. In houses with one or two persons consumption volume is rather small, but inhabitants is at home or absent day by day, so fluctuation is inclined to be large. On the contrary, in houses with more persons, consumption is large but fluctuation is stabilized by the centralization effect caused by increased number of family members.

Maximum volume is also important to decide the storage tank size, avoiding the hot water shortage. The maximum consumption happened in measured period is shown in Figure 6. This also shows that extra ordinal large consumption can happens even in the house with small average such as maximum 1200[L/day] in average 200[L/day], and ratio of maximum volume to average decreases as average volume increases. But maximum value is considered to be affected by the length of measured period, so we have to say that this consequence needs more study.

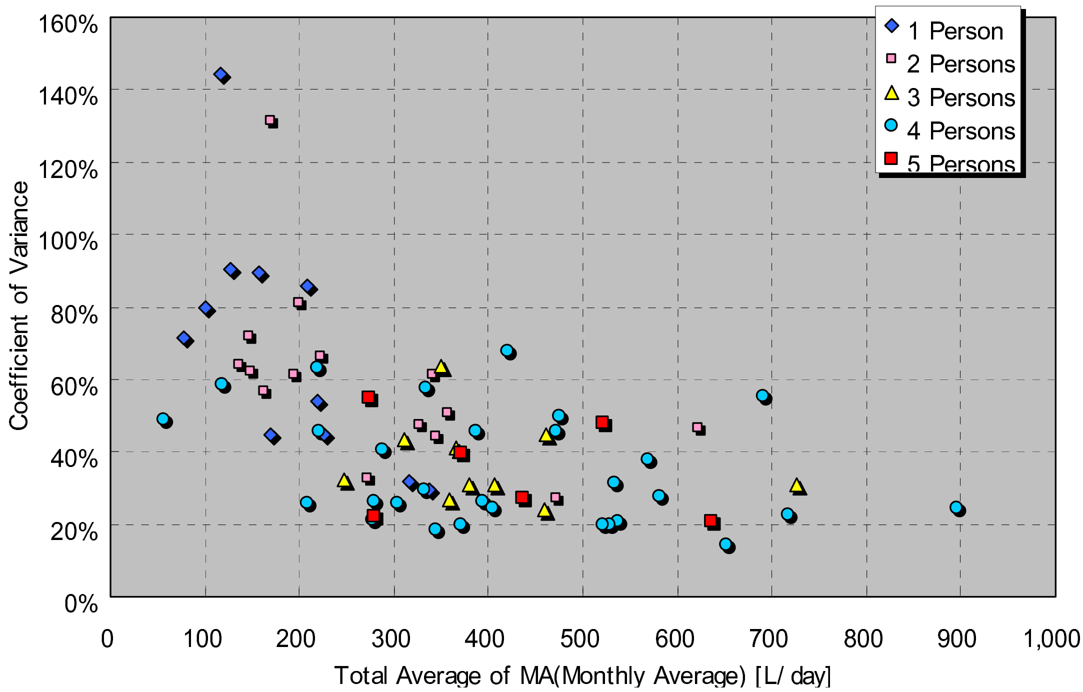

Figure 5 Total average of MA and Coefficient of Variance

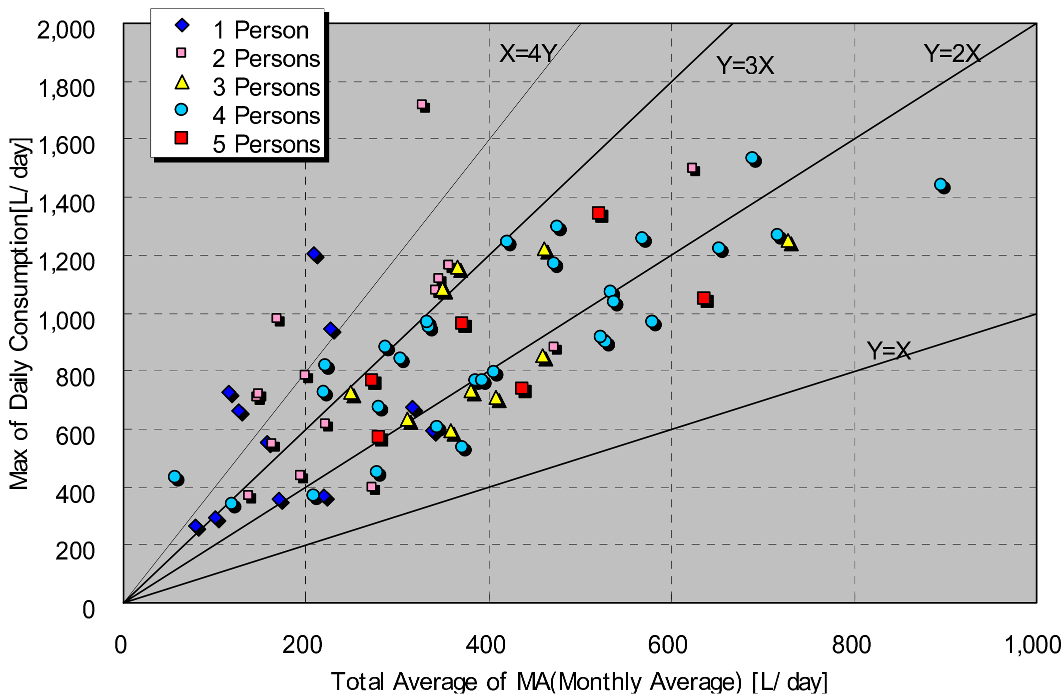

Figure 6 MA and Max of daily consumption

3.4 Seasonal fluctuation (Long trend)

The seasonal variance of MA could be considered the "Seasonal fluctuation" or "Long Trend". Average, Standard deviation, Maximum and Minimum in the houses with measured period more than 8 months, are shown in Figure 7. It is very important that by using chosen format with mixed hot water (40 deg), the effect of cold water temperature's seasonal and regional fluctuation is deprived, and the hot water usage could be analyzed exclusively. As the coefficients of approximation equation show, the maximum values is about 130% of average value, minimum value is about 70 %. This means the ratio of maximum month (usually in winter) is about twice as large as minimum value (usually in summer). But as we see the each data, minimum month usually indicate the irregular decrease, which can be caused by long time absence such as summer vacation. So standard deviation can be considered to be fairly good alternative to grasp range of seasonal fluctuation for many cases.

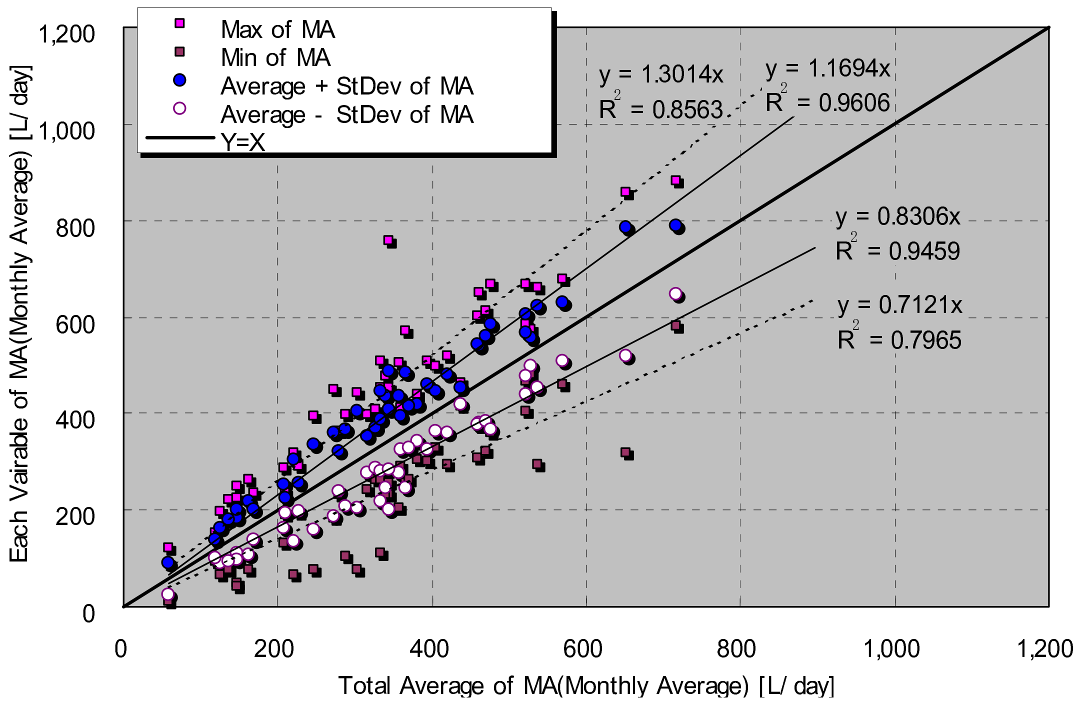

Figure 7 Seasonal Fluctuation

4 Test mode for water heaters' energy-efficiency evaluation

4.1 Overview of experiment

Energy conservation is becoming prior subject for Japanese government and companies, and many technologies are developed. Those technologies are advertised as high efficiency and saving energy dramatically, but performance in real usage must be evaluated carefully for the valuable remedy. For that purpose, “Ministry of Land Infrastructure and Transport” carries out the “Self Sufficient House” project, experimental house is built in Building Research Institute(BRI).

Outside of experimental apartment house is shown in Figure 8. The apartment is three story and two houses are dedicated for this experiment. To compare the equipments’ performance, Ordinal equipments are installed in “Standard House” and Energy conscious ones are installed in “Energy Saving House”.

This experiment covers all kinds of devices such as air-conditioning, lighting and electrical appliances. About hot water, such devices below are now under experiment.

- Normal gas hot water heater (Thermal efficiency 80%)
- Condensing gas Hot water heater (Thermal efficiency 95%)
- CO2 heat pump hot water heater (with 370L storage tank)
- Solar Heat collector hot water heater (with “Forced” and “Natural” Circulation)

In this experiment, valves installed in “Kitchen”, ”Bath”, ”Shower”, ”Lavatory” are manipulated by automation systems with PC (Figure 9). Valves are opened and closed on pre-set time schedule of daily consumption and water, gas and electric power are monitored in every second. By this experiment, we can examine the real performance of hot water heaters installed in the real house.

Figure 8 Experiment apartment house

Figure 9 Computer manipulated Valve

4.2 Test mode for experiment

To make this experiment more concrete, time schedule of hot water consumption (test mode) is very important. And test mode must be accurate in the daily fluctuation, as well as average, for the correct evaluation of heat with storage tank. Through the analysis already mentioned, we made the test mode called “Modified M1 Mode” composed of 6 days as shown in Table 3. This mode is adjusted to be 456[L/day] in average, 99[L/day] in standard deviation when expanded on one month.

Table 3 Daily consumptions in Test mode (Modified M1 mode)

	Days in Month	Kitchen	Bath	Shower	Lavatory	Total
Weekday(S)	11days	100	150	80	50	380
Weekday(L)	11days	120	150	140	60	470
Weekend-Indoor(S)	2days	160	150	140	100	550
Weekend-Indoor(L)	4days	200	150	140	100	650
Weekend-Outdoor(S)	1day	10	0	200	30	240
Weekend-Outdoor(L)	1day	10	150	200	20	380
Monthly Average	30days	119	145	130	62	456
Monthly Std. Dev.	30days	44	27	45	21	99

5 Conclusions

On this paper, we mention three main topics below.

- As the first step, we compare several formats for hot water consumption, and select the “Mixed hot water volume (40deg.)” as the best for its simplicity and flexibility.
- Using the chosen format, we analyze the behavior of hot water consumption through data acquired in up to 71 houses. The average and fluctuation in short and seasonal term are evaluated.
- Based on the obtained knowledge, test mode is made for the correct and realistic evaluation of domestic hot water.

As first mentioned, hot water is the most important segment of houses in Japan for the energy saving. We will continue the measurement, analysis and experiment for the truly effective conservation methods.

Acknowledgements

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Presentation of Authors

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Development of the Calculating Method for the Loads of Water Consumption in Restaurant

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Abstract

The purpose of this study is to develop a new calculating method for water supply demands in restaurant.

It is difficult to clarify the characteristic of water supply demands and to estimate its volumes in each faucet and cooking equipment in restaurant because the water usage, in each operation or cooking equipment, is various and complicated. However, it is possible to get the data of water consumption in a whole kitchen easily and to clarify the characteristic of water supply demands there.

The authors have advanced the development of calculating method for the time series loads, such as daily, hourly, and instantaneous loads by using a computer. We have proposed the method that applies the unit model as the water consumption of one flat in an apartment, at the CIB/W62 symposium (S. Murakawa, 2002, 2003). Applying the view of a unit model, it is possible to prospect the loads of water consumption in restaurant.

In this paper, the measurements of water consumption were carried out in 21 restaurants, and the basic data on the store characteristics were offered by the management company. First of all, the method of the numerical analysis for a large data recorded the volumes of water consumption in every one- minute over a year was studied. Secondly, the relationship between store characteristics and number of customers was analyzed. In addition, by analyzing the measurement data of water consumption, the calculating unit model of water usage in the kitchen was set up. The time series loads in the restaurants were calculated by using the method that applied the Monte Carlo Simulation technique, and the precision of results were studied as a comparison with the measurement data. As the results, it was shown that the calculating method was effective in restaurants.

Keywords

Water Consumption, Monte Carlo Simulation, Restaurant

1. Introduction

As the calculating method for water supply demands in the buildings of various types, the authors have developed the method and have suggested a part of them, as a case study of apartment houses, on the 28th and 29th International Symposium of CIB/W62, Iasi (Rumania), Ankara (Turkey) [1, 2]. The method is to estimate the demands in the time series such as daily, hourly, and instantaneous loads. The accurancy of applying the Monte Carlo Simulation technique was proved by the calculation of the demands in the time series. Furthermore, the flat unit model, as one flat water supply demands summed up the each fixture usage in a flat, was suggested.

In this paper, the water consumption in the 21 restaurants is studied. It is difficult to clarify the characteristic of water supply demands and to estimate its volumes in each faucet and cooking equipment in a restaurant. However, applying the view of a unit model, it is possible to estimate the loads of water consumption in the restaurants.

2. Outline of the investigation

2.1 Outline of the building

The measurements of water consumption were carried out in the 21 restaurants which are placed in the complex commercial building (that has department, hotel, hall etc.). The outlines of the complex commercial building and the restaurants are shown in Table 1 and Table 2. These restaurants have various floor areas from 66.5 to 781.9 [m2]. Most of the restaurants, except restaurant B and D, use the city gas for the kitchen's heat sauce. Restaurant B and D use the electric power. Also, the most of the restaurants individually use the instantaneous water heater by gas for the hot water supply system.

2.2 Outline of the measurement

We measured water consumptions in each restaurant by setting up water meters to the main pipelines. Pulses from water meters (10L/pulse) were recorded by one minute interval as water consumptions. The measurements were carried out from April 1, 2002 to May 12, 2003.

Table 1 - Outline of the complex commercial building

Location	Hiroshima city
Building use	Department, Hotel, Hall, Restaurant etc.
Lot area	21800 [m^2]
Total floor area	166000 [m^2]
Scale	Hotel zone : 33 stories, 2 basement Commercial zone : 12 stories, 2 basement
Structure	Steel structure (A Part of structure and besement are steel encased reinforced concrete.)
Cold water supply system	Gravity water supply (A part of water supply system is pressurization system)
Elevated tank	For drinking water : 90 [m^3] ×1, For non-drinking service water : 70 [m^3] ×2

In addition, the data of daily water consumptions from April 1, 2000 to March 31, 2002, the daily number of customers from April 1, 2000 to March 31, 2003, and the the store characteristics, such as floor area, number of employees, number of seats, and so on, were offered by the management company.

Table 2 - Outline of the restaurants

Restaurant (food type)	Floor area [m^2]	Kitchen area [m^2]	Number of seats [Seat]	Number of employees*1 [Person]	Kitchen ratio*2	Opening time	Closing time	Time-zone		
								Preparation	Rest	Cleaning
A (Japanese (kaiseki))	211.5	61	60	19	0.29	11:00	22:00	7:30-11:00	15:00-17:00	19:30-22:00
B (Okonomiyaki)	109.0	8	60	13	0.07	11:00	22:30	10:30-11:00	(no rest)	21:30-23:00
C (Japanese food)	279.3	84	142	10	0.30	11:00	23:00	10:00-11:00	15:00-17:00	22:30-23:30
D (Seafood big bowl)	66.5	13	31	11	0.20	11:00	22:00	10:00-11:00	(no rest)	21:00-22:00
E (Japanese (Bar))	136.5	60	64	7	0.44	11:00	23:00	9:30-10:45	15:30-16:30	22:00-23:00
F (Chinese food)	472.9	100	275	19	0.21	11:00	22:00	7:00-11:00	15:00-17:00	22:00-23:30
G (Teppanyaki)	172.5	43	36	14	0.25	11:00	22:30	10:00-11:00	15:00-17:00	22:00-23:00
H (Pasta)	96.3	28	50	6	0.29	11:00	22:00	10:00-11:00	(no rest)	21:30-23:30
I (Churrasco)	781.9	170	164	19	0.22	11:00	22:30	10:00-11:00	16:00-17:00	22:30-23:00
J (Korean (Dakkarubi)	330.4	79	116	13	0.24	11:00	23:00	10:00-11:00	15:00-17:00	23:00-24:00
K (Grilled meat)	165.7	77	105	6	0.46	11:00	23:00	10:00-11:00	15:00-17:00	22:00-23:00
L (Buckwheat noodles)	82.7	29	47	16	0.35	11:00	22:00	9:00-10:00	(no rest)	22:00-22:30
M (Wheat noodles)	87.9	36	60	12	0.41	11:00	21:30	8:00-11:00	(no rest)	21:00-22:00
N (Sushi)	115.7	73	72	12	0.63	11:00	22:30	9:00-11:00	15:00-16:30	22:30-23:30
O (Japanese food)	99.2	41	51	10	0.41	11:00	22:30	10:00-11:00	14:30-17:00	22:30-23:00
P (Pork cutlet)	131.2	47	72	7	0.36	11:00	22:00	10:00-11:00	(no rest)	22:00-23:00
Q (Pasta)	413.2	95	200	29	0.23	11:00	22:00	10:00-11:00	(no rest)	21:30-22:30
R (Curry)	158.3	54	86	9	0.34	11:00	22:00	9:30-11:00	15:30-17:00	21:30-22:30
S (Sandwich)	99.2	37	63	14	0.37	11:00	22:00	10:00-11:00	(no rest)	22:00-23:00
T (Omelet)	181.8	22	94	10	0.12	11:00	21:00	8:00-11:00	15:00-16:00	21:00-22:00
U (Vietnamese food)	277.7	64	84	19	0.23	11:00	23:00	9:45-11:00	(no rest)	23:00-25:00

Notes *1 Number of employees is including the number of part-timers.
*2 Kitchen ratio is a ratio of kitchen area to floor area of a restaurant.

3. Analysis of daily water consumption

The relationship between the daily number of customers and the daily water consumptions in restaurant M is shown in Figure 1 as an example. In the figure, the marked legends are shown by Weekday, from Monday to Friday, and Saturday and Holiday, non working day. However, regression line and correlation coefficient are calculated by using all data. On Saturday and Holiday, according to the increase of the number of customers, water consumptions increase compared with those of Weekday. Therefore, both of the items have a strong relationship with each other. Table 3 shows the regression coefficients and the correlation coefficients that were calculated in each restaurant. The regression coefficients “a” that mean the water consumption per day and per customer are variously valued from 4.48 to 35.45 [L/person/day]. The correlation coefficients show the values from 0.312 to 0.870. These restaurants have the characteristics, such as the turnovers which divide the number of customers by the number of seats are quick. In addition, the payment of the customer per person is low. Therefore, the relationship between the number of customers and the water consumptions is strong because the water consumptions per customer do not change largely.

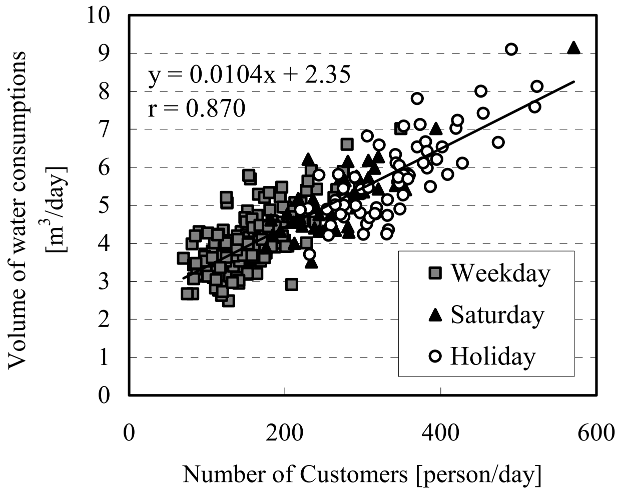


Figure 1 - Relationship between the daily number of customers and the daily water consumptions (Restaurant M)

Table 3 - Regression coefficients and correlation coefficients in each restaurant

Restaurant	The regression coefficients		The correlation coefficients
	a	b	r
A	0.0355	5.24	0.652
B	0.0115	2.94	0.719
C	0.0095	4.02	0.560
D	0.0045	1.48	0.707
E	0.0203	2.30	0.447
F	0.0197	7.53	0.577
G	0.0207	3.32	0.711
H	0.0081	2.23	0.726
I	0.0237	7.99	0.444
J	0.0244	5.33	0.782
K	0.0127	2.20	0.645
L	0.0162	4.12	0.688
M	0.0104	2.35	0.870
N	0.0283	3.94	0.618
O	0.0161	3.42	0.486
P	0.0062	1.96	0.757
Q	0.0093	10.54	0.433
R	0.0166	4.22	0.712
S	0.0170	3.41	0.464
T	0.0164	4.36	0.551
U	0.0054	5.19	0.312

Note : y [m3/day] = a x [person/day] + b

Based on the number of customers and the floor areas of the restaurants, the water consumption units were calculated in each restaurants. Table 4 shows average value, standard deviation and maximum value of the water consumption units per day. The data of regular holiday in each restaurant were excluded by the calculation.

Table 4 - Water consumption units per day

Restaurant	Water consumption per floor area [L/m^2/day]			Water consumption per customer [L/person/day]		
	Average value	Standard deviation	Maximum value	Average value	Standard deviation	Maximum value
A	33	5.4	51	178	84.8	816
B	42	11.5	96	39	15.0	99
C	20	3.4	34	39	11.3	90
D	38	10.2	82	12	4.3	48
E	32	12.6	94	45	18.8	189
F	26	7.7	79	57	21.5	210
G	34	10.6	80	57	25.0	191
H	37	9.9	81	26	9.6	68
I	18	8.2	52	62	32.6	202
J	25	6.7	62	43	16.4	129
K	21	6.8	48	43	23.5	204
L	95	23.7	174	36	8.9	64
M	51	12.6	104	24	6.5	51
N	53	12.7	95	54	17.7	132
O	58	15.5	101	43	13.1	89
P	24	4.5	39	18	4.6	43
Q	32	7.5	53	62	34.4	258
R	42	9.5	76	52	16.6	147
S	57	30.0	218	51	25.9	234
T	55	25.7	143	32	13.3	77
U	24	6.0	58	29	13.6	104

Focusing on the average values, the water consumptions per floor area are almost in the range of value from 20 to 60 [L/m2/day] excluding restaurant L (95 [L/m2/day]). These values are small in comparison with the value of reference [3] (160 - 200 [L/m2/day]). And the water consumptions per customer are almost in the range of value from 15 to 60 [L/person/day] excluding restaurant A (178 [L/person/day]). Most of the restaurant's values are smaller than the value of reference [3] (50 - 60 [L/person/day]).

4. Analysis of hourly water consumption

4.1 The method of the numerical analysis for water consumption data

First of all, the method of the numerical analysis for a large data which recorded the volumes of water consumption in every one-minute over a year was studied. Figure 2 shows a water consumption data on April 10, 2002 (Wed.) in restaurant I as an example.

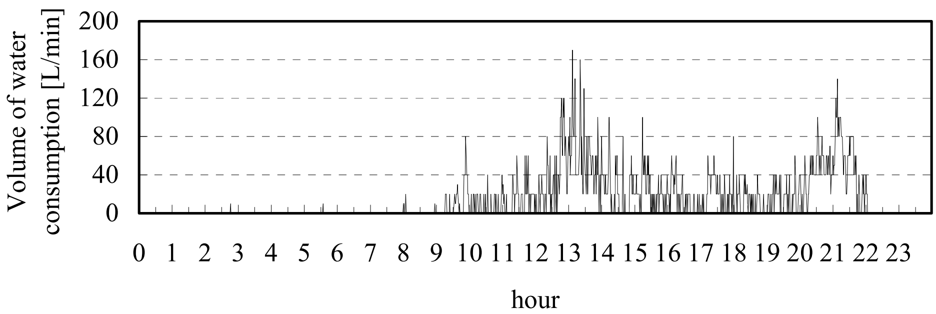


Figure 2 - Measurement results of water consumption (Restaurant I, April 10, 2002 (Wed.))

When the one-minute data are analyzed by a certain interval, the following two cases are considered. As for hourly value, one case is calculating the value by the just interval, for example "7:00 - 8:00". Another case is calculating the value by shifting one minute as the moving average. In this paper, we call the former "the time-zone average", and the latter cases as "the moving average". When the time-zone average value is compared with the moving average value, the maximum of time-zone average value necessarily becomes smaller than that of moving average value. Therefore, the relationship of both average values on the basis of the 5 days water consumption data measured by one-minute interval in the time-zone 7:00 - 24:00 from April 1st (Mon.) to 5th (Fri.) ,2002 was studied. The coefficients of variation were figured up in each restaurant. From the results, 3 restaurants, of which coefficients are the smallest or the biggest or the middle as representative restaurants (restaurant D, F and O), were chosen. Figure 3 shows the ratio of cumulative frequency on the water consumptions in each time-interval; 2, 5, 10, 15, 30, 60 minutes. In the figure, the marked legends show the time-zone average value. The solid lines show the moving value. Table 5 shows the maximum value and failure factor 1 - 50% of the both average values in each time-interval. Compared with the moving average values, the time-zone average values are almost same within the 2 to 15 minute intervals. However, the time-zone average values show the tendency to have a little difference in the 30 and 60 minute intervals. From the Table 5, the difference of the maximum values, such as the time-zone average value and the moving average value, has no tendency by the time-interval. In addition, the values in each failure factor are almost same. Therefore, we decided that the time-zone average value has no problem by using the analysis of the peak value in the certain time interval.

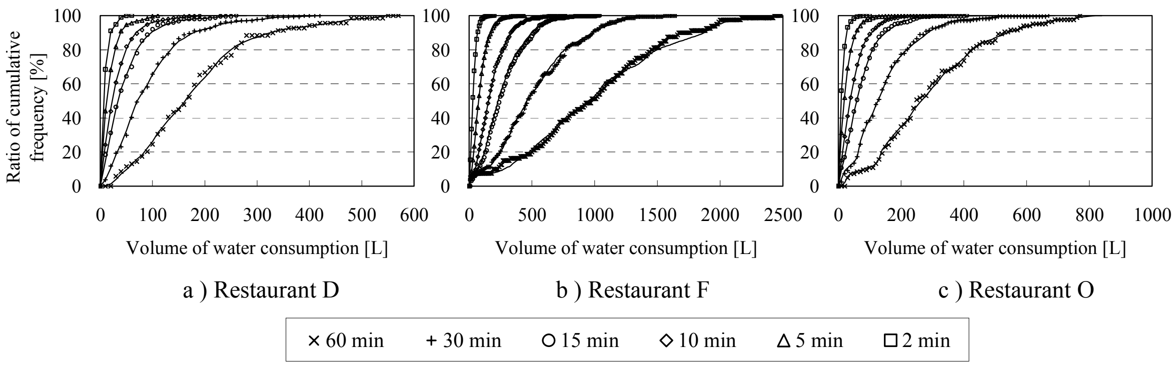


Figure 3 - The ratio of cumulative frequency on the water consumption in each time-interval (Restaurant D, F and O)

Table 5 - The maximum value and failure factor 1 - 50% of the average values in each time-interval

			2 min		5 min		10 min		15 min		30 min		60 min	
			Time-zone avegrege	Moving average	Time-zone avegrege	Moving average	Time-zone avegrege	Moving average	Time-zone avegrege	Moving average	Time-zone avegrege	Moving average	Time-zone avegrege	Moving average
Restaurant D	Maximum [L/min]		30.0	30.0	22.0	24.0	19.0	22.0	17.3	18.7	13.0	14.0	9.2	9.5
	Failure factor [L/min]	1%	25.0	20.0	20.0	20.0	15.0	17.0	15.3	15.3	10.7	11.3	9.2	8.8
		2%	20.0	20.0	18.0	18.0	14.0	14.0	14.0	12.0	10.7	10.7	8.0	8.2
		5%	20.0	20.0	12.0	12.0	10.0	10.0	8.0	8.7	7.7	8.0	7.0	7.2
		10%	10.0	10.0	8.0	8.0	8.0	7.0	6.7	6.7	6.0	6.0	5.7	5.5
		25%	10.0	10.0	6.0	6.0	5.0	5.0	4.7	4.7	4.0	4.3	4.0	4.0
		50%	5.0	5.0	4.0	4.0	3.0	3.0	2.7	2.7	2.7	2.7	2.8	2.8
Restaurant F	Maximum [L/min]		90.0	100.0	88.0	88.0	72.0	77.0	67.3	68.7	51.7	55.0	40.5	41.3
	Failure factor [L/min]	1%	60.0	60.0	58.0	58.0	57.0	57.0	52.7	54.7	44.3	44.7	40.5	38.5
		2%	55.0	55.0	50.0	52.0	50.0	48.0	46.0	46.0	41.7	42.3	36.2	36.7
		5%	45.0	45.0	42.0	44.0	41.0	41.0	38.7	39.3	36.7	38.3	33.2	33.3
		10%	35.0	35.0	36.0	36.0	34.0	34.0	34.0	33.3	33.0	33.0	29.5	31.3
		25%	25.0	25.0	24.0	24.0	25.0	24.0	24.7	24.0	24.3	23.3	23.0	23.5
		50%	15.0	15.0	16.0	16.0	16.0	16.0	16.0	16.0	15.7	15.3	16.3	15.8
Restaurant O	Maximum [L/min]		50.0	50.0	42.0	42.0	34.0	41.0	27.3	34.7	22.3	23.0	12.8	14.0
	Failure factor [L/min]	1%	30.0	30.0	24.0	24.0	20.0	20.0	17.3	18.0	17.0	16.3	12.8	12.8
		2%	25.0	25.0	22.0	20.0	17.0	17.0	16.7	15.3	15.0	14.3	12.7	12.0
		5%	20.0	20.0	16.0	16.0	14.0	14.0	12.7	13.3	11.7	11.3	10.3	10.7
		10%	15.0	15.0	12.0	12.0	11.0	11.0	10.0	10.7	9.3	9.7	8.8	9.0
		25%	10.0	10.0	8.0	8.0	7.0	7.0	6.7	6.7	6.7	6.7	6.8	6.8
		50%	5.0	5.0	4.0	4.0	4.0	4.0	4.0	4.0	4.3	4.3	4.2	4.5

4.2 Hourly water consumption

The investigation on the number of customers was carried out at 3 restaurants on August 14th, 2002 to clarify the relationship between the hourly number of customers and the hourly water consumptions. The ”Going in and out time ” and the number of customers at the representative restaurants were recorded by an investigator and a video camera which was set close to the entrance. Figure 4 shows the hourly fluctuation of the number of customers and the water consumption. In each restaurant, the peak hours of customer occur at the time-zone of 12:00-13:00. However, the peak hours of water consumption are various because the cooking process is different in each restaurant. Table 6 shows the number of customers, the volumes of water consumption and the ratio of water usage in each process time-zone. At the preparation of cooking time-zone, the ratios of water consumption for the daily values are 16 [%] in restaurant E, M, and 24 [%] in restaurant F. At the cleaning time-zone of restaurant F, the volume of water consumption is small comparing with the other restaurants. At the service time-zone, the volumes of water consumption per customer are different between the lunch time and the dinner time in each restaurant. Therefore, the hourly water consumption has little reference to the number of customers in the time-zone. The hourly fluctuation of water consumption receives the influence of cooking process and routine work.

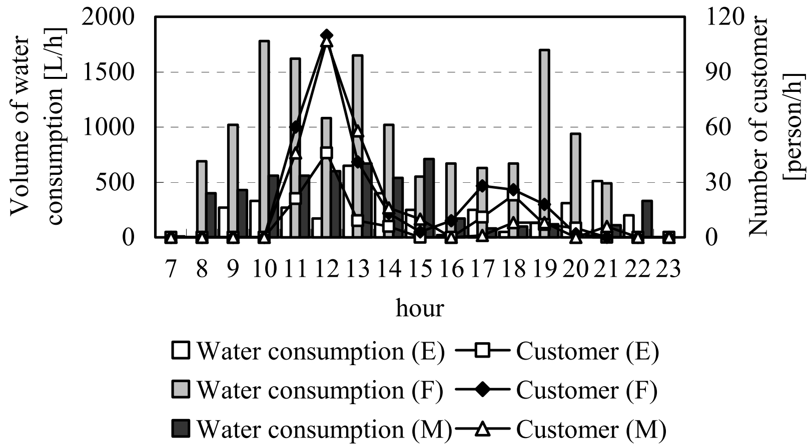


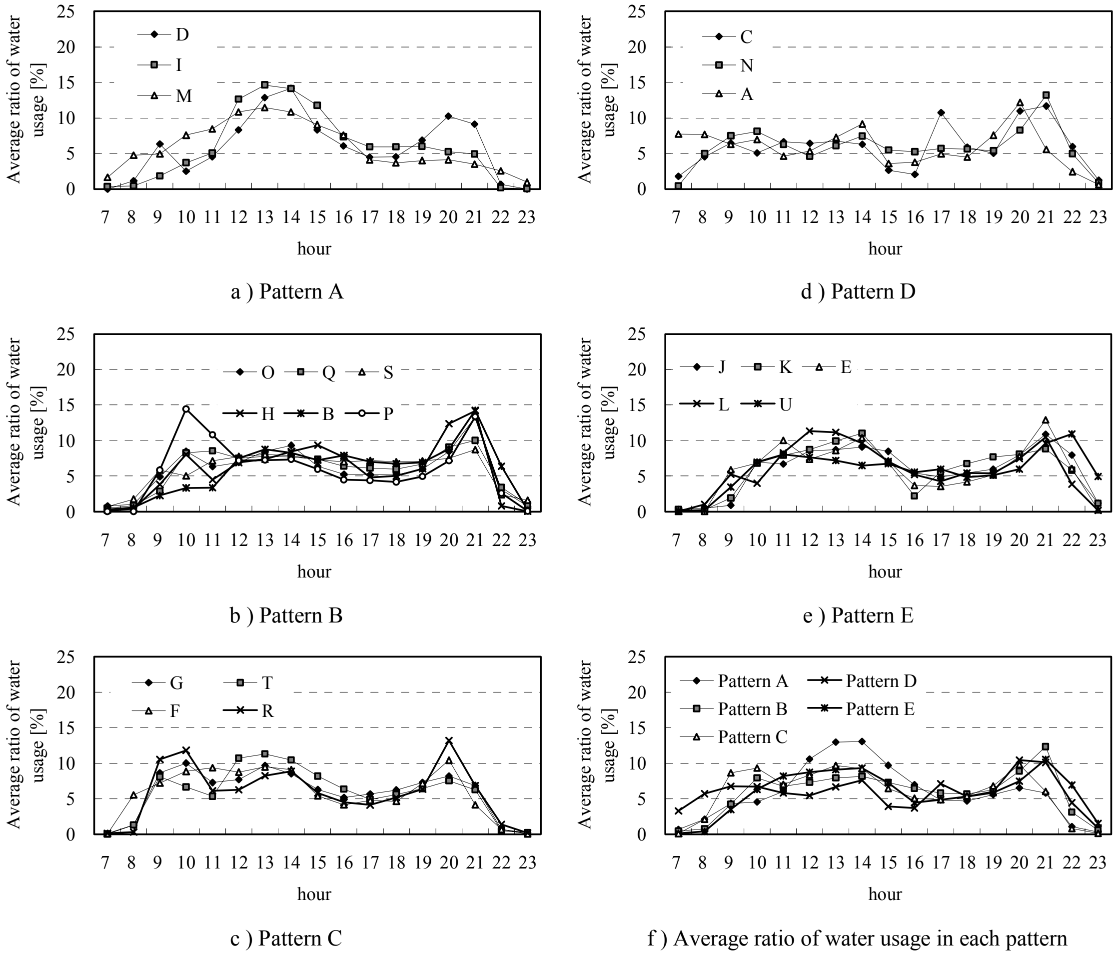
Figure 4 - Hourly number of customers and hourly water consumptions

Table 6 - Number of customers, volume of water consumptions and ratio of water usage in each process time-zone

Time-zone	Number of customer [person]			Volume of water consumption [L]			Ratio of water usage [%]		
	E	F	M	E	F	M	E	F	M
Preparation	0	0	0	600	3500	840	15.7	24.0	15.6
Service (lunch)	82	224	227	1720	5370	2930	45.1	36.9	54.4
Rest	0	0	0	30	0	0	0.8	0.0	0.0
Service (dinner)	46	86	27	750	5650	1180	19.7	38.8	21.9
Cleaning	0	0	6	710	50	440	18.6	0.3	8.2

4.3 Type of the fluctuation pattern for hourly water consumption

As for the calculation of water demands in time series, it is important to typify the fluctuation patterns characterized by the cooking process and routine work in each restaurant. Based on the data of time-zone 7:00-24:00 on “Holiday” in 2002, the fluctuation patterns for hourly water consumptions were studied. The fluctuation patterns of 21 restaurants were shown as the ratio of water usage that divided the hourly volumes of water consumption by the daily volumes of water consumption. The patterns were classified to 5 types by cluster analysis. Figure 5 a)-e) show the restaurants which belonged to the fluctuation patterns of the 5 types in each. Figure 5 f) shows the average ratio of water usage in each pattern. In this paper, we advance to set up the calculating model on the basis of these 5 patterns.



Note : Hourly average ratio of water usage is a percentage to the total water consumption for 17 hours

Figure 5 - The fluctuation patterns of average ratio of water usage

5. The model for calculation

5.1 Behavior of water usage

Calculating the volumes of water consumption in restaurant, it is necessary to set up the condition for water usage model by the worker's behavior in the kitchen . In this paper, the kitchen unit model as the aggregate of some fixtures in the kitchen is set up by using the same idea, such as the flat unit model for cold and hot water consumption in the apartment houses. The Monte Carlo Simulation technique is applied, as in the calculation of apartment houses and office buildings. Therefore, the calculating condition was studied by one-hour time interval, and the average of flow rate, the average of duration time and the frequency of water usage in each time-zone were calculated. Figure 6 and Table 7 show the method of analysis for the behavior of water usage in the kitchen. From the data of water consumption measured by one-minute interval as shown in Figure 6, we decide the change of the behavior of water usage by checking the change of the volumes of water consumption. In other words, when the water flows the constant volume per minute through several minutes, the behavior of water usage continues through the time zone. When the volume of water consumption changes, the behavior finishes or a new behavior startes. We calculated the average of flow rate, the average of duration time and the frequency of water usage in each time-zone as shown in Table 7.

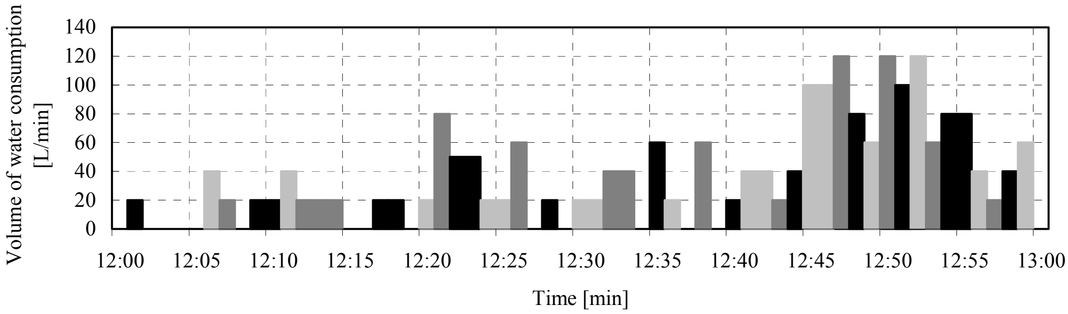


Figure 6 - The method of analysis for the behavior of water usage in the kitchen (Measurement results of water consumption per one minute)

Table 7 - The method of analysis for the behavior of water usage in the kitchen (Calculation for average of flow rate and average of duration time)

Time	[hour]	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12		
	[min]	1	6	7	9	10	11	12	13	14	17	18	20	21	22	23	24	25		
Volume of water consumption [L/min]		20	40	20	20	20	40	20	20	20	20	20	20	80	50	50	20	20		
Cumulative frequency of water usage [time]		1	2	3	4		5	6			7		8	9	10		11		Frequency of water usage [time]	11
Flow rate [L/min]		20	40	20	20		40	20			20		20	80	50		20		Average of flow rate [L/min]	31.8
Duration time per frequency [sec]		60	60	60	120		60	180			120		60	60	120		120		Average of duration time [sec]	92.7

5.2 Analysis of the calculating condition

Figure 7 shows the average of flow rates and the average of duration times in each time-zone as an example of restaurant A. The flow rates are about 15 [L/min] and the duration times are 90-100 [sec] in each time-zone. In the other paper [4], we confirmed that the results which were calculated under two models of 17 conditions in each time-zone and one condition as average of daily time-zone;7:00-24:00, were similar. Therefore, we decided to apply the average value of 17 time-zone as the calculating condition in each restaurant by thinking the simplification model. Figure 8 shows the average flow rates and the average duration times in each restaurant. The average flow rates are various because the floor area and cooking equipment are differed. However, the behavior of water usage on certain fixture did not have big difference. Therefore, we decided the standard values for calculation from the data of some restaurants where the floor scales were small and its water consumptions were small. As the results, the standard models were set up as follows. The average flow rate is 13 [L/min] and the average duration time is 95 [sec], from the data of restaurant D, H, M and S. On the basis of these values, the frequency of water usage was calculated by dividing the daily volume of water consumption by the volume of water consumption per frequency (13 [L/min] x 95 [sec] / 60 [sec]).

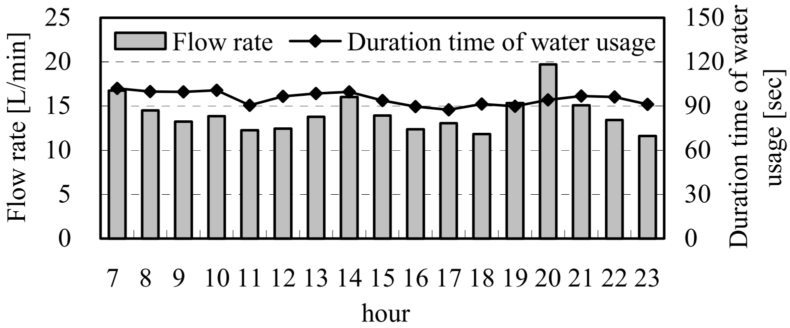


Figure 7 - Average of flow rates and average of duration times in each time-zone (Restaurant A)

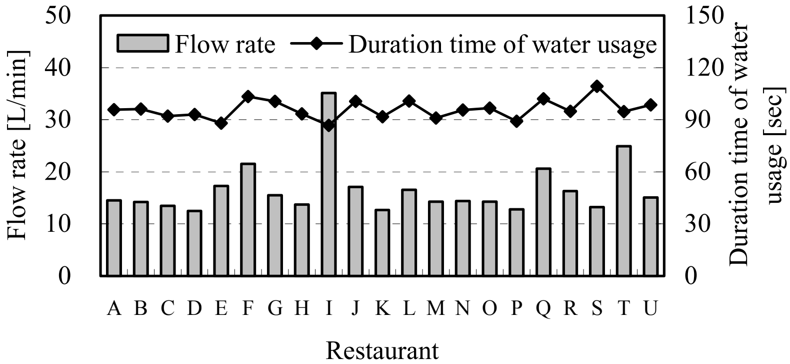


Figure 8 - Average of flow rates and average of duration times in each restaurant

6. Simulation of water consumption in the restaurants

6.1 Calculating model of the restaurants

Table 8 shows the calculating model of the restaurants on holiday. The frequency of water usage per day is divided into the each frequency of hourly time-zone by using the 5 fluctuation patterns of water usage, shown in Figure 5 f), as the model of frequency. The distributions of flow rate and duration time are adapted by the hyper exponential distribution, shown in Figure 9.

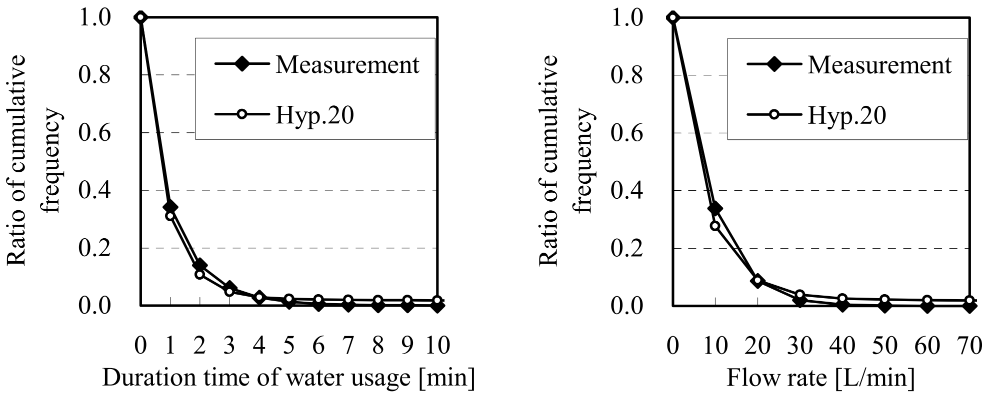


Figure 9 - Ratio of cumulative frequency of the duration time and the flow rate

Table 8 - Calculating model of the restaurants on holiday ; on Sundays including the national holidays

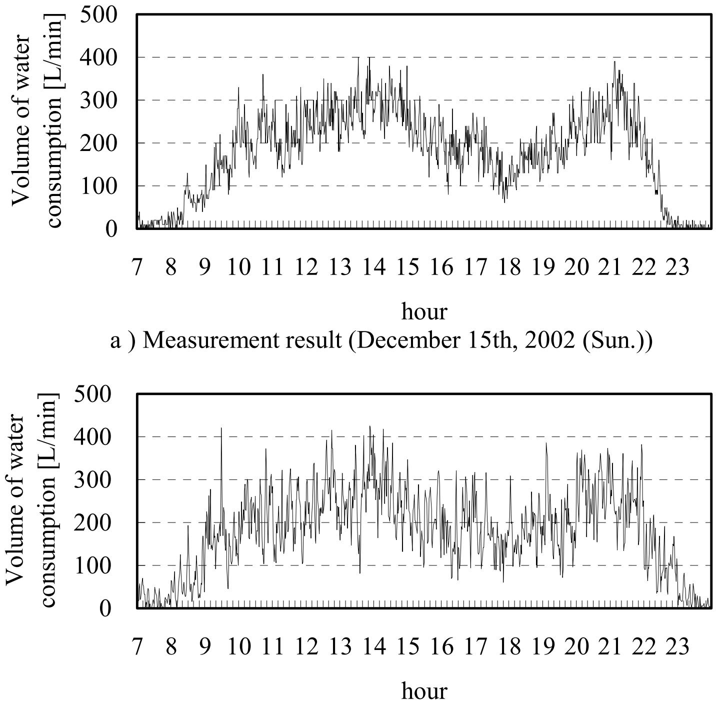
Restaurant	Duration time of water usage [sec]		Flow rate [L/min]		Frequency of water usage [time/day]	Volume of water consumption [L/day]	Frequency model
	Average	Distribution	Average	Distribution			
A	95	Hyp.20	13	Hyp.20	347	7142	D
B	95	Hyp.20	13	Hyp.20	279	5740	B
C	95	Hyp.20	13	Hyp.20	276	5684	D
D	95	Hyp.20	13	Hyp.20	157	3232	A
E	95	Hyp.20	13	Hyp.20	243	4992	E
F	95	Hyp.20	13	Hyp.20	699	14381	C
G	95	Hyp.20	13	Hyp.20	369	7599	C
H	95	Hyp.20	13	Hyp.20	219	4510	B
I	95	Hyp.20	13	Hyp.20	880	18121	A
J	95	Hyp.20	13	Hyp.20	511	10525	E
K	95	Hyp.20	13	Hyp.20	220	4529	E
L	95	Hyp.20	13	Hyp.20	457	9399	E
M	95	Hyp.20	13	Hyp.20	278	5725	A
N	95	Hyp.20	13	Hyp.20	338	6956	D
O	95	Hyp.20	13	Hyp.20	300	6170	B
P	95	Hyp.20	13	Hyp.20	187	3853	B
Q	95	Hyp.20	13	Hyp.20	719	14794	B
R	95	Hyp.20	13	Hyp.20	394	8103	C
S	95	Hyp.20	13	Hyp.20	305	6282	B
T	95	Hyp.20	13	Hyp.20	680	13997	C
U	95	Hyp.20	13	Hyp.20	362	7444	E

6.2 Results of the calculation

On the basis of calculating model in each restaurant, shown in Table 8, the simulation for water consumption in 21 restaurants was carried out hourly interval through a day; the time-zone of 7:00-24:00. The number of simulation trials for an hour was set up one hundred times.

As for the fluctuation of water consumption per one minute through a day, Figure 10 shows a measurement result on December 15, 2002 and a calculation result as an example. As compared with the measurement values, the calculation values have the wide range of fluctuation and the coefficients of variation are large in the time-zone of 7:00-21:00. However, in the time-zone of after 21:00, the coefficients of variation on the measurement values are large because there are various cases of the closing time on each day.

Figure 11 shows the instantaneous maximum floor rates and the failure factor 0.1%, 0.2%, 1% of measurement results and the failure factor 0.1%, 0.2%, 1% of simulation resuluts in each hourly time-zone. These values were calculated as the total of 21 restaurants. The maximum values of measurement results in each time-zone are changing within the range of the failure factor 0.1-1% of simulation results. When we predict the instantaneous flow rates by the simulation, we should regard the failure factor 0.1-2 % as the maximum value because the maximum value of simulation is too large for the maximum load of water consumption according to the trial numbers of simulation.



a) Measurement result (December 15th, 2002 (Sun.))

b) Simulation result

Figure 10 - Measurement and simulation results

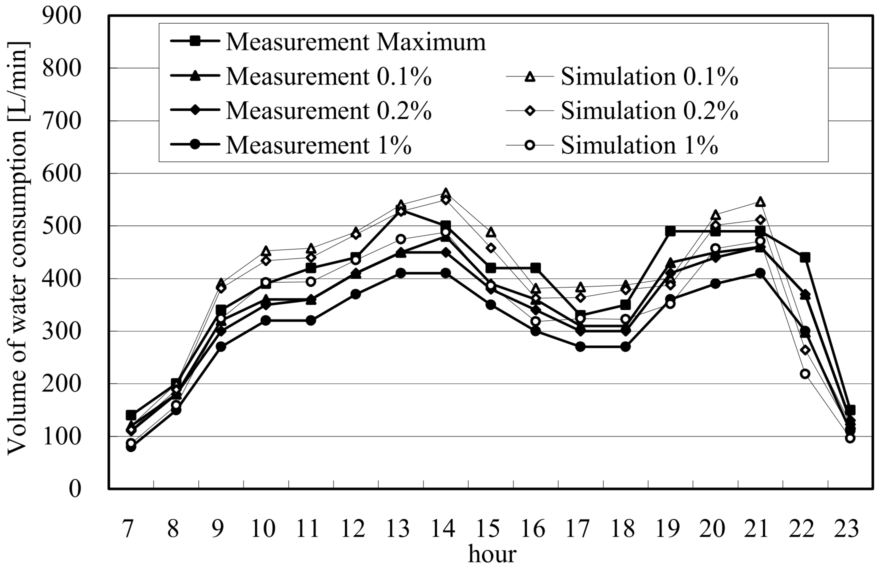


Figure 11 - Instantaneous maximum flow rate

As for the hourly water consumption, calculated as the total of 21 restaurants, Figure 12 shows the average+3σ (σ: standard deviation), average+2σ, average value of measurement results and the failure factor 1%, 5%, average value of simulation results. The value of failure factor 1% of simulation results is almost same with average+2σ of measurement results. As for the average values, the simulation values exceed a little at the time-zone of 20:00-22:00, however the simulation values are almost equal to the measurement values.

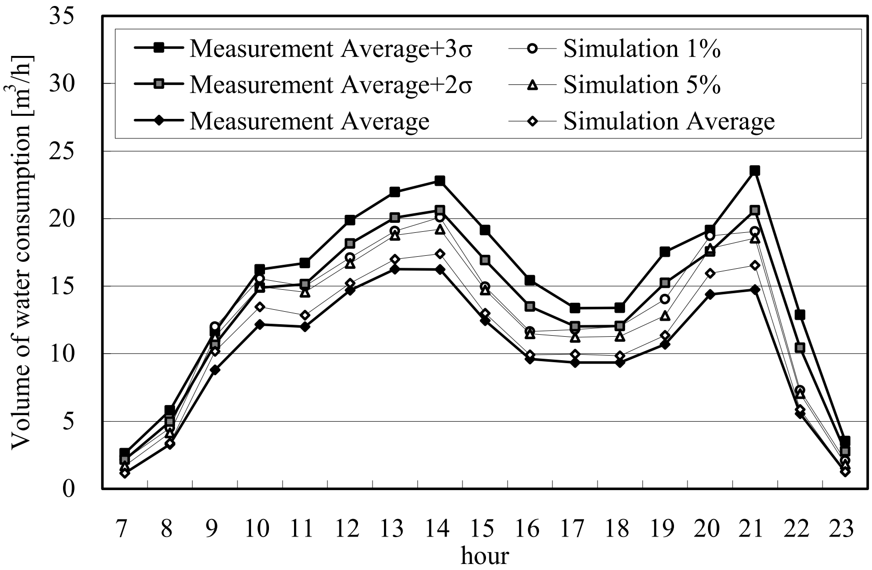


Figure 12 - Hourly water consumption

Table 9 shows the measurement values and the simulation values of the daily water consumption calculated as the total of 21 restaurants. As for the average values, the simulation value has large volume of 7% on the measurement value. As for the maximum values, the average+3 σ value of simulation results is near to the 5th large value of measurement results on 52 days. From the relationship of the average values and the maximum values, the calculating technique is useful in the practical range to estimate of water consumption in the restaurants.

Table 9 - Daily water consumption

	Average [L/day]	Standard deviation [L/day]	Maximum [L/day]	Minimum [L/day]	Average+3σ [L/day]	Number of samples [day]
Measurement	171982	17363	221970	132780	224072	52
Simulation	184366	3733	191578	176422	195567	100

7. Conclusion

In this paper, the authors suggested a calculating method of water consumption loads in restaurant by using the Monte Carlo Simulation technique.

First of all, we carried out the measurement of water consumption in 21 restaurants for one year or more.

Secondly, the hourly number of customers was measured in 3 restaurants. On the basis of these data, the relationship between the water consumption and the number of customers was analyzed. Also, based on the data of holiday in 2002, the fluctuation patterns for hourly water consumption were studied. The fluctuation patterns of 21 restaurants were classified to 5 types by cluster analysis.

In addition, the calculating model in restaurant was set up as the kitchen unit model based on the same idea to apply the flat unit model in apartment houses.

Finally, the results estimated by the simulation model were compared with the measurement values. It was clarified that the kitchen unit model is useful and convenient to deal with the complex water usage in the kitchen. Furthermore, the calculating technique is useful in the practical range to estimate of water consumption in restaurants.

Acknowledgements

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Development of the Calculating Method for the Loads of Cold and Hot Water Consumption in Office Building

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Abstract

The purpose of this study is to develop a calculating method for cold and hot water consumption in office building.

It was proposed that the calculating method which applied the Monte Carlo Simulation technique for the loads of cold water consumption in a office building at the last CIB/W62 symposium (H. Takata, 2003)[1]. The paper was analyzed by the results of a questionnaire and measurement investigation carried out in IN building.

The detailed measurement was carried out at other two office buildings (D building and F building). The volumes and temperatures of cold and hot water consumption in the hot water service rooms were separately measured from the toilets in D building. The volume of water consumptions in each sanitary fixture in the toilets and the hot water service rooms were measured in F building. In addition, the frequencies of each fixture usage were recorded in the both buildings.

In this paper, the characteristics of water usage in the hot water service rooms were clarified by analyzing the time series loads, such as daily, hourly, instantaneous loads of water consumption, the temperature of hot water usage, the frequency of water usage, and the duration time of water usage. Also, the occupation times, the consumption and time of water usage per occupation were analyzed as for the sanitary fixtures in the toilets. Under the results of analysis, the calculating model including the temperature of water usage and the ratio of hot water usage was set up. Furthermore, the simulation for calculating the time series loads was carried out. As the result, the applicability of calculating technique in office building was verified by comparing the values of measurement and simulation.

Keywords

Cold and Hot Water Consumption, Monte Carlo Simulation, Office Buildings

1. Introduction

The development of calculating method for cold and hot water consumption based on the fixture usage has advanced. The method applies to the Monte Carlo Simulation technique. The idea of calculating method was described by S. Murakawa in the paper presented at the CIB/W62 Symposium held in Iasi, Rumania, 2002[2]. In another paper presented at the CIB/W62 Symposium held in Ankara, Turkey, 2003[1], we proposed the calculating method of water consumption loads in office building's toilet and hot water service room. However, in that paper, hot water consumption and hot water temperature were not covered. In addition, there are only a few papers studied the cold and hot water consumption in hot water service room.

In this paper, we show the results of the measurement that were carried out in toilets and hot water service rooms. On the basis of analyzing the measurement results, we set up the calculating model including the hot water consumption in the office buildings.

Finally, we estimate the loads of cold and hot water consumption and confirm the effectiveness of the calculating method.

2. Outline of the investigation

2.1 Outline of the office buildings

The investigation was carried out for three office buildings located in Hiroshima City, Japan. The outlines of the buildings are shown in Table 1. IN building's outline was shown in the proceeding of the CIB/W62 symposium last year, it is left out. The 8th, 16th, 17th floor in D building and the 3rd, 11th floor in F building were selected as the objects of investigation. There are a male toilet, a female toilet and a hot water service room on each floor of the buildings.

Table 2 shows the number of office workers in each period of the investigation. In case of D building, the 8th floor is occupied by the branch office of certain corporation, and the 16th and 17th floor are occupied by the stations of certain head office organization. In case of F building, the 3rd floor is shared by 4 tenants and the 11th floor is shared with 2 tenants.

Table 1 - Outline of the office buildings

	D building	F building
Location	Hiroshima-City, Hiroshima, Japan	
Building use	Office room, Show room, Restaurant, Tearoom, Underground substation	Office room, Restaurant
Lot area	3,415.21m^2	2,036.79m^2
Building area	1,713.93m^2	1,423.11m^2
Total floor area	24,609.51m^2	18,256.39m^2
Scale	20 stories, 2 basement	14 stories, 1 penthouse
Cold water supply equipment	Few stories Gravity water supply Break tank 121m^3, 1 tank	Potable water Water supply pump Receiving tank 31m^3, 1 tank
	Highrise stories Water supply pump Intermediate gravity tank 28m^3, 1 tank	Non-potable water Water supply pump Break tank 71m^3, 1 tank
Hot water supply equipment	Central and individual system	Individual system
	Water source heat pump (waste heat utilization)	Electric water heater for basin, 30L
	Electric water heater for hot water service room, 40L	Electric water heater for hot water service room, 48L
	Electric water heater for kitchen, 5000L, 1tank	Instantaneous water heater for kitchen

Table 2 - Number of the office workers

	D building						F building			
	Male [person]			Female [person]			Male [person]		Female [person]	
	8F	16F	17F	8F	16F	17F	3F	11F	3F	11F
winter	23	54	55	14	5	8	66	38	8	10
spring	21	54	55	17	5	8	66	38	8	10
summer	21	54	55	18	5	8	66	38	8	10
autumn	21	54	55	19	5	8	66	38	8	10

As for the hot water supply system in D building, the hot water is heated by the waste heat from the substation located at the basement in the building and is supplied with the temperature of approximately 30°C. In the hot water service rooms, the hot water is reheated by the individual electric water heater. There are the individual electric water heater at each toilet basin and at each hot water service room in F building.

2.2 Outline of the investigation about the office worker's presence

To grasp the state of office worker's presence, investigation was executed. The questionnaire investigation for the office workers was carried out at D building. The office workers cooperated in the investigation for three consecutive days; Tuesday, Wednesday and Thursday, in four seasons. The workers checked off the oneself state of presence every 30 minutes from 7:00 to 24:00 in a sheet prepared to each one. In F building, the number of people who go in and out the floor was recorded by investigator from 8:00 to 18:00. We recorded the cumulative number of people of each gender every 5 minutes on the investigation paper.

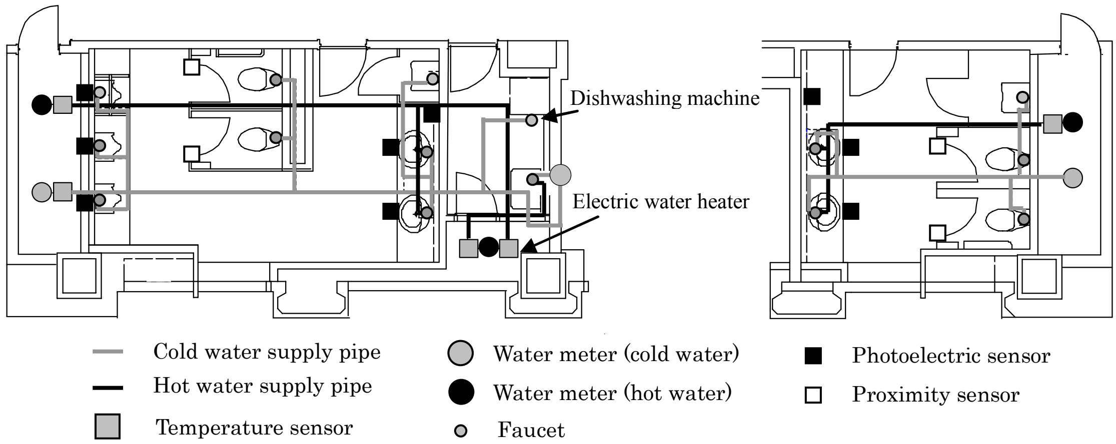
2.3 Outline of the measurement

The same measurement method executed in IN building was applied to D building and F building. Figure 1 shows the cold and hot water supply pipelines and locations of the meters and the sensors for measurement.

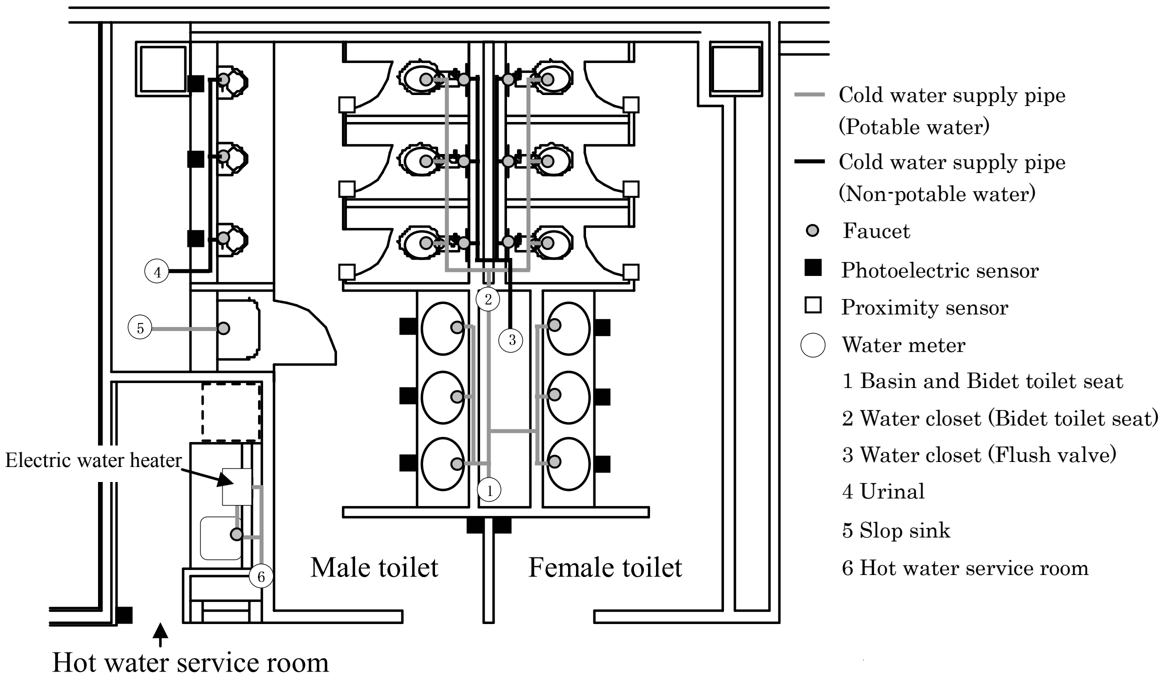
As for the measurement of cold and hot water consumption and cold and hot water temperature in D building, the measurement were executed for 4 or 6 weeks in each season; winter, spring, summer and autumn. In F building, the water consumptions were measured from June 2002 to February 2004.

The cold and hot water consumptions were measured by setting up water meters to the cold and hot water supply pipelines. At the water supply lines of D building's male toilets, the cold water is supplied to water closets, urinals, basins, slop sink and dishwashing machine, and the hot water is supplied to basins. In D building's female toilets, the cold water is supplied to water closets, basins and slop sink, and the hot water is supplied to basins. In F building, the water supply pipelines are connected to each kind of fixtures, the water consumptions are individually measured in each pipeline.

At the hot water service room, D building's sink is installed with a single-lever mixed faucet and F building's sink has a single lever mixed faucet with a hot water supply faucet.



a) D building



b) F building

Figure 1 - Ground plan of the toilets

As for the measurement of the frequency in each fixture usage, photoelectric sensors and proximity sensors were set in each fixture and on the doorway of the toilets. The sensors respond to the user of fixtures and toilets. In addition, the frequencies of water usage at D building's basins were measured by the water-flow switches. The period of the measurement is 2 weeks in each season.

In this paper, the objects of analysis are shown as the 4 week's data including 2 week's data that the frequency of fixture usage was measured in each season.

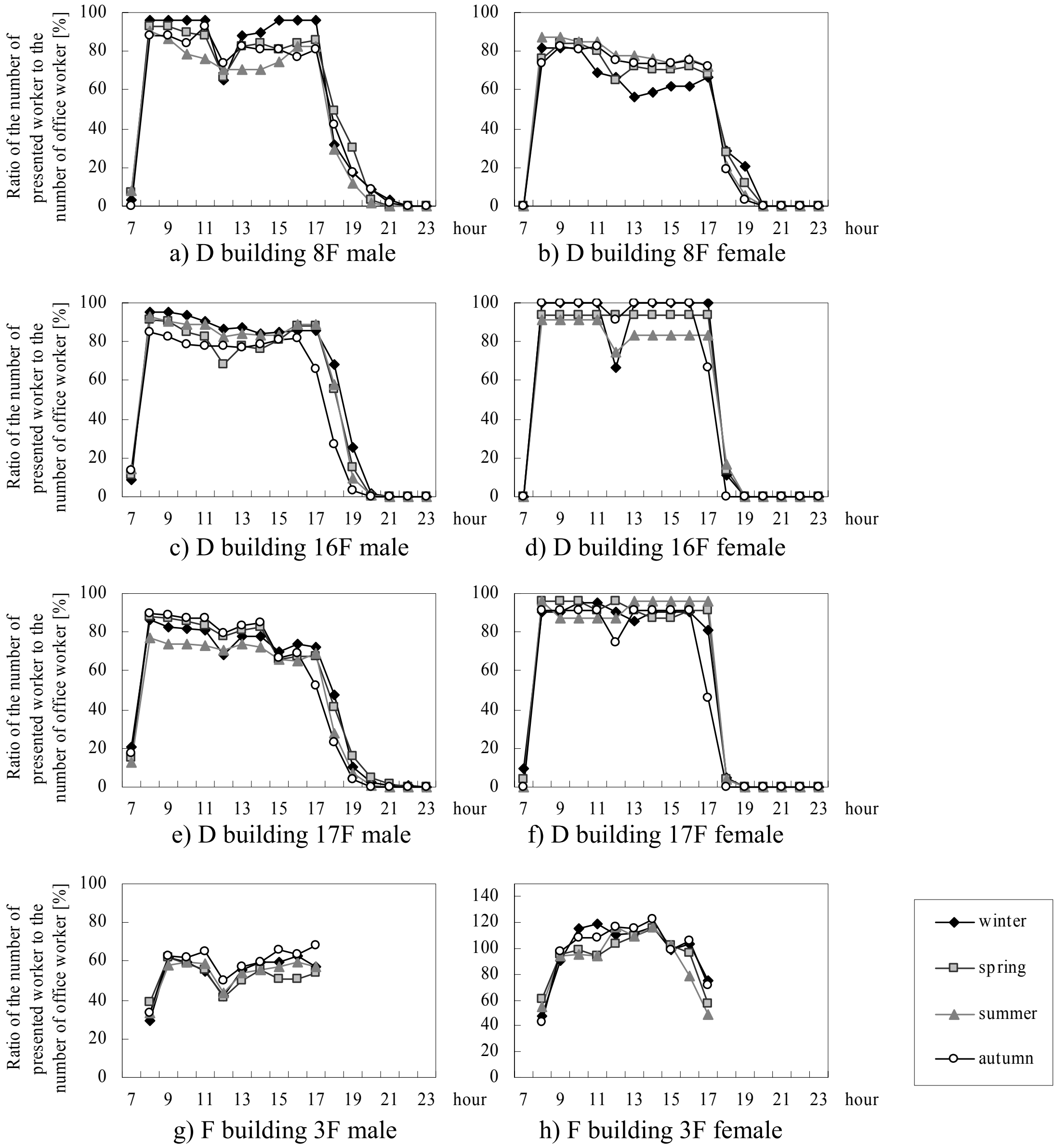
The volumes of cold and hot water consumption, the cold and hot water temperature and the frequency of fixture usage were recorded by one minute interval.

3. Results of the investigation and measurement

3.1 State of the office worker's presence

Figure 2 shows the hourly ratio of the number of presented workers out of the all office workers on each floor. Female's ratios are higher than male's ratios on the time-zone of 8:00-18:00 on each floor except the 8th floor in D building and the 3rd floor in F building. However, male's ratios are higher than female's ratios on the time-zone after 18:00 because some of male workers work overtime.

The number of female's workers of F building's 3rd floor is a few, 8 persons, therefore the ratios in hourly time-zone sometimes exceed the value of 100%. Because,



a) D building 8F male
b) D building 8F female
c) D building 16F male
d) D building 16F female
e) D building 17F male
f) D building 17F female
g) F building 3F male
h) F building 3F female

Figure 2 - State of office worker's presence

the corporation which occupy the 3rd floor also occupy the other floors from 4th to 8th floor and the visitors come from other floors for the meeting and so on.

On D building’s 16th and 17th floor, the work closing hour became 30 minutes earlier from October to February. Therefore, the ratios of the time-zone of 17:00 - 18:00 in autumn are small. However, the ratios of that time-zone in winter are not small because the overtime work increases at the end of the fiscal year.

3.2 Cold and hot water consumption in the hot water service rooms

There are a sink and a dishwashing machine in each hot water service room of D building. In this chapter, the volumes of cold and hot water consumption in hot water service room are shown as the volumes of cold and hot water consumption at the sink except the dishwashing machine.

As for the water consumption used at hot water service room’s sink, we define the following terms.

“Single cold water consumption” means the independent cold water consumption. “Mixing water consumption” means the water mixed with the cold and hot water. “Single hot water consumption” means the hot water consumption independently. “Total hot water consumption” means the sum of “Mixing water consumption” and “Single hot water consumption”. “Total water consumption” means the sum of “Single cold water consumption” and “Total hot water consumption”. “Ratio of hot water usage” means the proportion of “Total hot water consumption” in “Total water consumption”. “Ratio of single hot water consumption” means the proportion of “Single hot water consumption” in “Total hot water consumption”. “Mixing water temperature” means the temperature of “Mixing water consumption”.

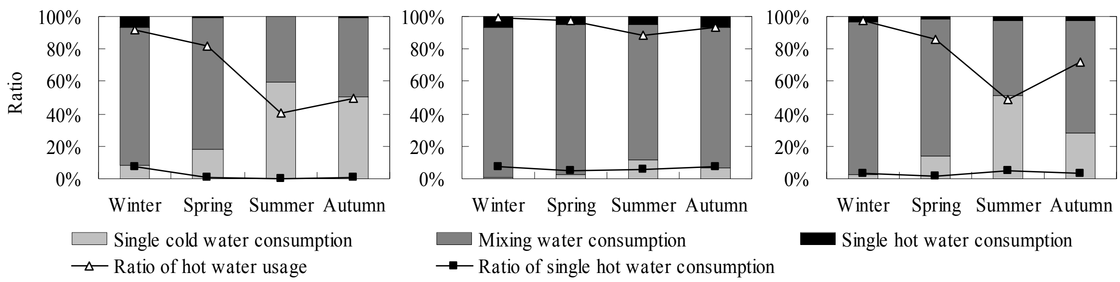
Table 3 shows the daily total water consumption. The 16th floor’s values in D building are the largest value among the 5 floors, and the range of fluctuation between each season is large. The 8th floor’s values in D building that have the smallest number of worker are the smallest value among 5 floors, and the range of fluctuation between each season is small. As for the values of each floor’s consumption per 10 hours and per worker presented at the office, the values in each floor are 2.5 - 6.5 [L/10h/person]. As compared with the results in the previous studies, the values are lower than the past results 7.5 ± 3.8 [L/10h/person] [3]. As this cause, it is thought that the tea servers at D building’s each floor and the convenience store by F building have influenced to reduce the volume of water consumption for drinking.

Figure 3 shows the constitution ratios of each usage to “Total water consumption” of D building in each season. At the hot water service room of D building, “Ratio of single hot water consumption” is low through a year, because the sink is installed with a single-lever mixed faucet. “Ratio of hot water usage” tends to be high in winter and low in summer. As for the 16th floor, “Ratio of hot water usage” is high through a year.

Figure 4 shows the hourly water consumptions in each floor of the buildings. The values are calculated as the average values in the measurement period. The fluctuation tendencies have no difference between winter and summer in every floor. However, the fluctuation pattern of winter differs from other seasons on the 11th floor of F building. As this cause, it is thought that the cleaning hour was shifted by changing the cleaning company. The hourly water consumption reaches to the peak on the time-zone of 16:00 - 18:00 on each floor of the buildings. In D building, the hourly consumptions on

Table 3 - Daly water consumption in each hot water service room

			Average	Standard deviation	Maximum	Minimum	Average
			[L/d]	[L/d]	[L/d]	[L/d]	[L/10h/person]
D building	8F	winter	102.0	10.6	117.6	76.1	2.8
		spring	97.8	23.9	140.5	62.6	2.7
		summer	95.8	13.4	119.0	63.7	2.5
		autumn	98.5	15.8	139.9	78.3	2.6
	16F	winter	354.3	154.9	828.9	146.5	6.5
		spring	267.3	68.4	483.7	130.7	5.2
		summer	297.3	68.8	415.2	187.8	5.6
		autumn	309.5	34.5	388.8	239.0	6.4
	17F	winter	189.2	33.4	260.7	138.0	3.6
		spring	172.5	29.9	229.6	106.7	3.2
		summer	160.7	23.6	206.3	110.1	3.2
		autumn	169.8	44.3	291.0	104.8	3.1
F building	3F	spring	208.8	45.9	300.0	146.0	4.8
		summer	220.4	65.2	396.0	141.0	4.8
		autumn	212.4	45.6	317.0	131.0	4.2
		winter	176.8	48.0	307.0	98.0	3.6
	11F	spring	182.3	34.7	258.0	128.0	—
		summer	187.9	54.6	302.0	98.0	—
		autumn	173.1	41.6	240.0	86.0	—
		winter	220.1	40.3	296.0	162.0	—



a) D building 8F b) D building 16F c) D building 17F

Figure 3 - Constitution ratio of "Total water consumption"

the time-zone of 8:00 - 9:00 are also large. There are small peaks on the time-zone of 12:00 - 13:00 on the 8th and 16th floor. As for the 16th and 17th floor, the peak time-zone is different in each season, because the working time closes 30 minutes early in autumn and winter. Furthermore, as for the electric water heater of the 11th floor in F building, the electric heater is set in order to supply water automatically in the tank at 4:30 on every Monday.

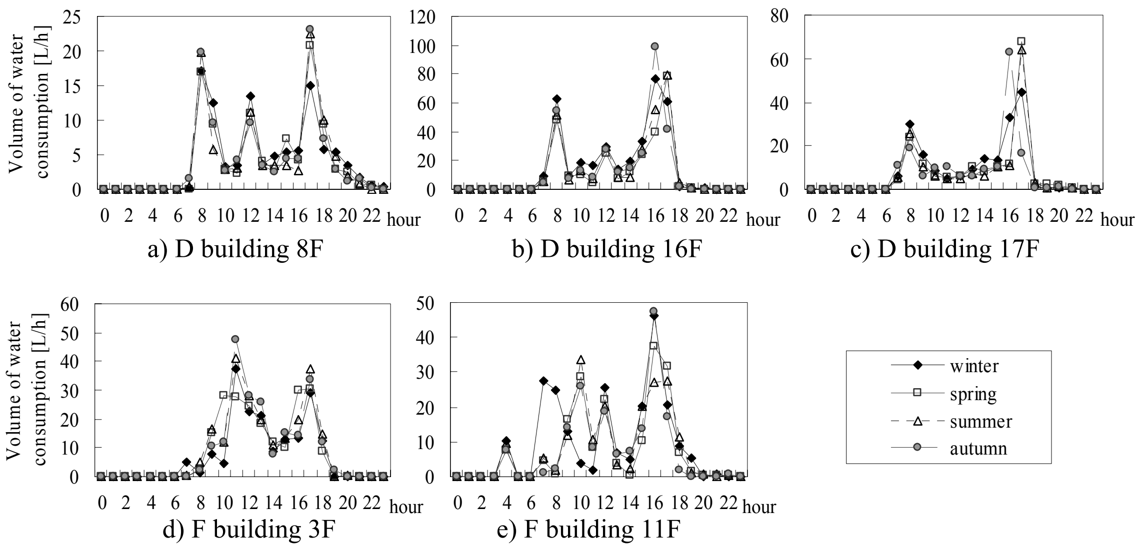


Figure 4 - Hourly total water consumptions in each hot water service room

3.3 Cold and hot water temperature in the hot water service rooms

The results of the analysis on cold water temperature, hot water temperature and "mixing water temperature" are shown in this section.

Table 4 shows the average values and the distributions in each water temperature. These temperatures are calculated based on the values measured by one minute interval when water was used. The setting temperature of electric water heater was 75°C on the 8th floor, 64°C on the 16th floor and 60°C on the 17th floor. The hot water temperature at the 8th floor is lower about 10°C in comparison with the setting temperature because the hot water consumption is little and the hot water temperature fall on the time-zone when nobody uses the hot water. As for the mixing water temperature, the values of the 8th and 16th floor tend to be high in winter and low in summer, but the values of the 17th floor are almost same in each season.

Table 4 - Cold and hot water temperature in each season

		winter	spring	summer	autumn
Cold water temperature [°C]		10.0	17.7	22.6	20.2
Hot water temperature [°C]	8F	66.6	63.8	61.2	62.7
	16F	63.0	63.4	63.4	64.4
	17F	56.1	54.5	53.2	54.8
Mixing water temperature [°C]	8F	38.4 Erl.8	34.3 Erl.12	32.3 Erl.20	33.4 Erl.12
	16F	38.3 Erl.16	37.7 Erl.20	36.7 Erl.17	36.7 Erl.14
	17F	28.0 Erl.13	28.2 Erl.17	29.1 Erl.29	29.6 Erl.20

3.4 Usage of each fixture in the toilets

In this section, the results of measurement in 3 buildings are shown as the fixture usage in the toilets.

In Figure 5, the frequency distributions of the occupancy time in each fixture are shown as the ratio to the total frequency. Table 5 shows the average values and the distributions of the occupancy time in each fixture. The frequency distributions and the average values are almost same in each floor and in each season. Therefore, Figure 5 and Table 5 show the results of calculating as the total of all the floors and all the seasons.

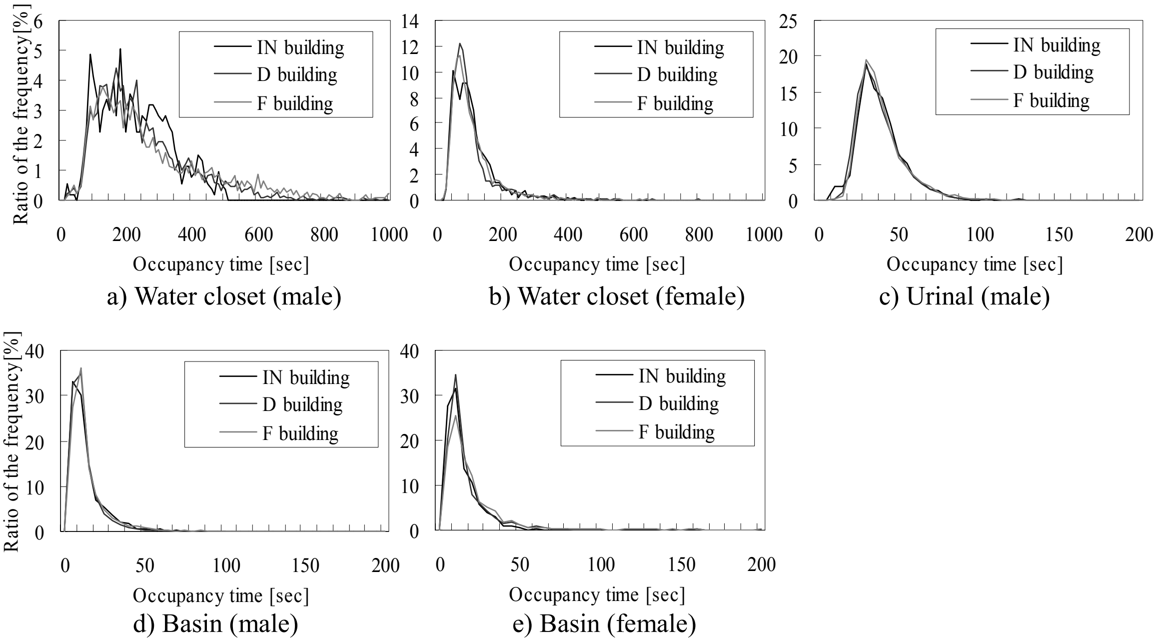


Figure 5 - The frequency distributions of each fixture's occupancy time

Table 5 - The average occupancy time and the distributions of each fixture

	Male			Female	
	Water closet	Urinal	Basin	Water closet	Basin
	[sec/frequency]	[sec/frequency]	[sec/frequency]	[sec/frequency]	[sec/frequency]
IN building	243.2	37.1	12.6	106.1	13.6
	Erl.4	Erl.7	Hyp.2	Erl.3	Exp
D building	248.9	36.7	10.8	109.7	15.2
	Erl.3	Erl.7	Exp	Erl.2	Exp
F building	292.5	37.6	12.6	106.8	21.9
	Erl.2	Erl.7	Exp	Erl.3	Hyp.3
Average	261.5	37.1	12.0	107.5	16.9
	Erl.3	Erl.7	Hyp.2	Erl.3	Hyp.2

The measurement of the volume of water consumption at slop sink was done in F building. Figure 6 shows the duration time per frequency and the flow rate of the slop sink. And Table 6 shows the average duration time and flow rate. The distributions and the average values have some differences on each floor and in each season. However,

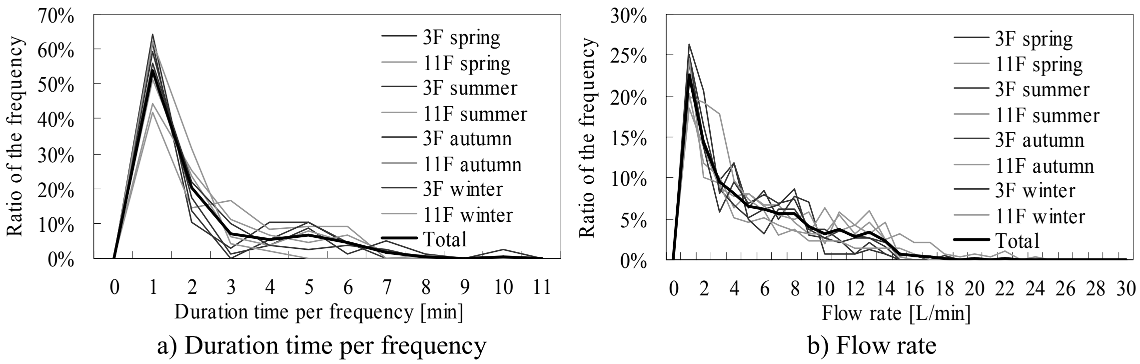


Figure 6 - Water usage at the slop sinks

Table 6 - The average duration time and flow rate

	3F				11F				Total
	spring	summer	autumn	winter	spring	summer	autumn	winter	
Duration time per frequency [min]	2.0	2.2	2.6	1.9	2.7	2.3	2.4	1.5	2.2
Flow rate [L/min]	4.3	4.7	5.0	4.1	5.5	5.6	6.6	4.3	5.2

we considered that these differences were influenced by the behavior of cleaning worker. Therefore, we apply the distributions and the average values calculated by the total data of all the floors and all the seasons for the calculating model.

As for the water usage at the basin in toilets, the detail measurements ware carried out in D building. Table 7 shows the frequency of water usage, water consumption and duration time on each floor and in each season in D building. These values were calculated on the basis of water consumption measured when simultaneous usage didn't occur. These values are shown as the water usage per person when one person occupies the basin and pours out water. The average flow rate of basin was chosen by 5 [L/min]. Therefore, we calculated the duration time of flowing out based on the water consumption divided by 5 [L/min].

4. Simulation of water consumption in the office buildings

4.1 Calculating model of the office buildings

We set up the calculating model in each water usage of fixtures installed in the toilets and hot water service rooms. Table 8 shows the calculating model of the office building's toilet and hot water service rooms. Each value is set up based on the results of investigation in the office buildings and the model of railway station's toilet [4]. The operation times of a flashing valve for water closet depend on the ability of fixtures. Therefore, we set up the operation time based on the results of investigation at the 16th floor in D building. And also, the ratio of water usage was set up based on the results of investigation on the same floor. As for the hot water service rooms, the 3 models; "Mixing water model", "Single hot water model" and "Single cold water model" are set up as the model of water usage. And the 4 cases concerned with time-zone are set up on duration time and the flow rate in each model. The mixing water temperature, the hot water temperature and the cold water temperature are set up in order to divide the mixing volume of water consumption into the hot water consumption and the cold water consumption each.

Table 7 - Water usage at the toilet's basins

			Average	Standard deviation	Maximum	Minimum
Frequency of water usage [frequency]	Male	winter	1.38	0.96	8	1
		spring	1.34	0.87	13	1
		summer	1.38	1.17	15	1
		autumn	1.31	0.92	13	1
		all	1.35	0.98	15	1
	Female	winter	1.60	1.17	8	1
		spring	1.43	1.02	11	1
		summer	1.55	1.08	12	1
		autumn	1.54	1.21	11	1
		all	1.51	1.10	12	1
Water consumption [L]	Male	winter	0.49	0.47	5.68	0.03
		spring	0.43	0.32	3.49	0.03
		summer	0.45	0.40	5.49	0.03
		autumn	0.42	0.31	3.43	0.03
		all	0.45	0.37	5.68	0.03
	Female	winter	0.51	0.36	2.48	0.00
		spring	0.45	0.33	3.27	0.07
		summer	0.47	0.35	2.93	0.13
		autumn	0.49	0.50	5.34	0.10
		all	0.48	0.38	5.34	0.07
Duration of water discharge [sec]	Male	winter	5.91	5.67	68.18	0.37
		spring	5.19	3.87	41.87	0.37
		summer	5.44	4.83	65.88	0.37
		autumn	5.08	3.77	41.17	0.37
		all	5.35	4.46	68.18	0.37
	Female	winter	6.24	4.25	29.71	1.96
		spring	5.45	3.99	39.28	0.79
		summer	5.70	4.24	35.17	1.57
		autumn	5.87	6.05	64.05	1.18
		all	5.71	4.56	64.05	0.79

Table 8 - Calculating model as an example of the office buildings

a) Toilet

		Male				Female		
		Water closet	Urinal	Basin	Slop	Water closet	Basin	Slop
The model of arrival	The ratio of arrival [person/min]	Set in each times						
	(Distribution)	Exp.						
	Frequency of fixture usage [frequency/person/day]	0.76	6.06	6.75	-	5.36	14.52	-
	Ratio of water usage	1	1	0.95	1	1	0.62	1
	Number of fixtures	2	3	2	1	2	2	1
The model of occupancy	Duration of occupancy [sec]	260	37	12	-	110	17	-
	(Distribution)	Erl.3	Erl.7	Hyp.2	-	Erl.3	Hyp.2	-
The model of water volume	Duration of water discharge [sec]	6	9	5.5	130	8	6	130
	(Distribution)	Exp.	Erl.10	Exp.	Hyp.5	Exp.	Exp.	Hyp.5
	Flow rate [L/min]	120	30	5	5.5	120	5	5.5
	(Distribution)	Erl.6	Erl.10	Erl.10	Exp.	Erl.6	Erl.10	Exp.
The model of operation	Fixture operation [time]	1.86	1	1	1	1	1	1

b) Hot water service room

	Mixing water				Single hot water				Single cold water			
The ratio of arrival [person/min]	Set in each times											
(Distribution)	Exp.											
Frequency of fixture usage [frequency/person/day]	1.31				0.24				0.17			
Time-zone	7～9	12	16～18	other	7～9	12	16～18	other	7～9	12	16～18	other
Duration time per frequency [sec]	166	126	173	120	81	60	96	92	63	67	62	71
(Distribution)	Hyp.2	Hyp.2	Hyp.2	Hyp.2	Hyp.16				Hyp.30			
Flow rate [L/min]	3.12	3.10	4.33	3.01	0.92	0.62	3.23	1.46	0.54	0.33	0.59	0.97
(Distribution)	Erl.2	Exp.	Exp.	Exp.	Exp.				Exp.			
Temperature [°C]	38.3				63.0				10.0			
(Distribution)	Erl.16				-				-			

Figure 7 shows the average frequency of fixture usage and water usage per hour and per worker as a percentage to the total frequency for a day based on the results of the 16th floor in D building. By inputting the other conditions such as the number of workers and the ratio of number of male and female, we can calculate the volume of the water consumption in each fixture. In this simulation, the number of workers at the 16th floor in D building was used.

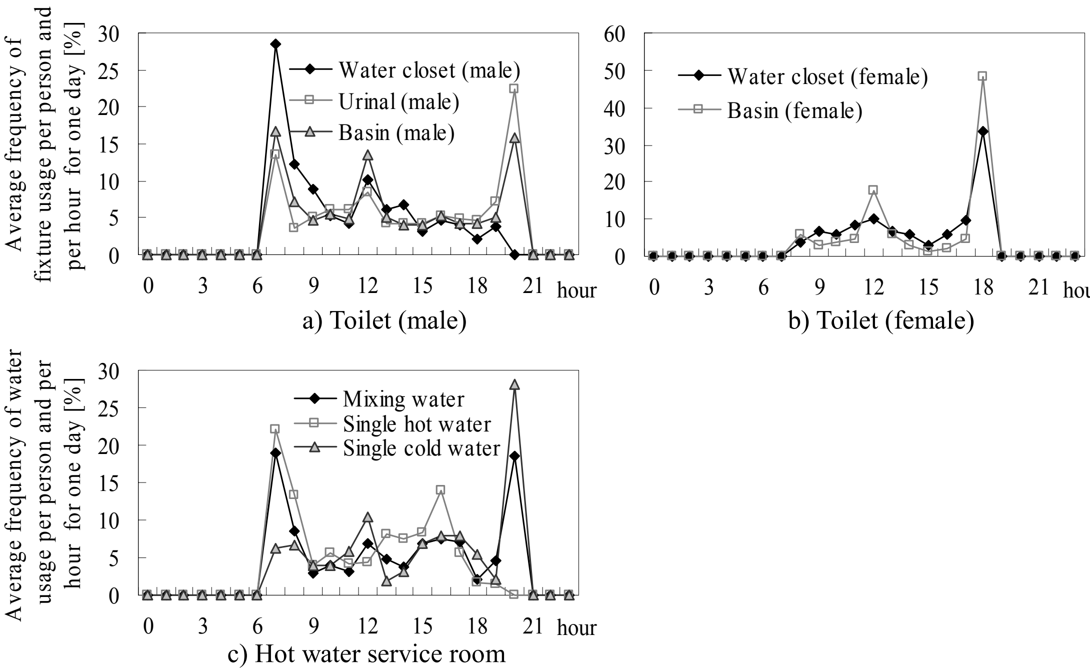


Figure 7 - Calculating model for the average frequency of fixture usage as an example of the office buildings

The simulation is carried out every hour from 7:00 to 24:00. The number of simulation trials for one hour is set up for one hundred times. In D building, the cleaning of fixtures is carried out on the time-zone of 8:00 - 9:00. Therefore, we set up the frequency of fixture usage on this time-zone to add the number of frequency for cleaning fixture.

4.2 Results of the calculation

The loads of water consumption are output at one-second interval by the simulation. The volumes of water consumption per minute are calculated as the volumes for 60 seconds. As for the instantaneous maximum flow rate, we had proposed to apply the values of one-minute interval on the apartment houses in the CIB/W62 Symposium, 2002[2]. The possibility of applying the values of 60 second interval for the instantaneous maximum flow rate, not only on that of apartment houses but also on that of office building, is shown at the CIB/W62 Symposium, 2003[1]. In this paper, the value of 60 second interval for the instantaneous maximum flow rate is considered as the same way as before.

As mentioned above, the cold water for the dishwashing machine is supplied from the water supply line of male toilet in case of D building. In this calculating model, the conditions of dishwashing machine are not considered. Therefore, on the measurement results in this section, the specific volume such as the dishwashing machine usage on the time-zone of 17:00 - 19:00 in male toilet is excluded from the daily and hourly volumes of water consumption.

Figure 8 shows the instantaneous flow rates calculated by the simulation and the values of measurement as the water consumption in male and female toilets. In this figure, the failure factor 0.1%, 0.2%, 1%, 2%, 5% of simulation results, and the instantaneous maximum flow rates and the failure factor 0.1%, 0.2% of measurement results are shown in each time-zone. It is difficult to divide the instantaneous flow rate into the toilet and dishwashing machine usage. Therefore, the values of the time-zone of 17:00 - 19:00 were excluded from the comparative analysis. There are 60 samples per one-trial, so the total of 100 trials has 6000 samples. When we predict the instantaneous maximum flow rate on the basis of simulation, the maximum value which can occur rarely will be too large. Therefore, it is appropriate that the instantaneous maximum flow rate is chosen between 0.1% - 2% of the failure factor. The maximum flow rate and the failure factor 0.1% and 0.2% of measurement results are plotted between the failure factor 0.2% - 2% of simulation and between the failure factors 0.1% - 1% of simulation in male toilet and female toilet respectively.

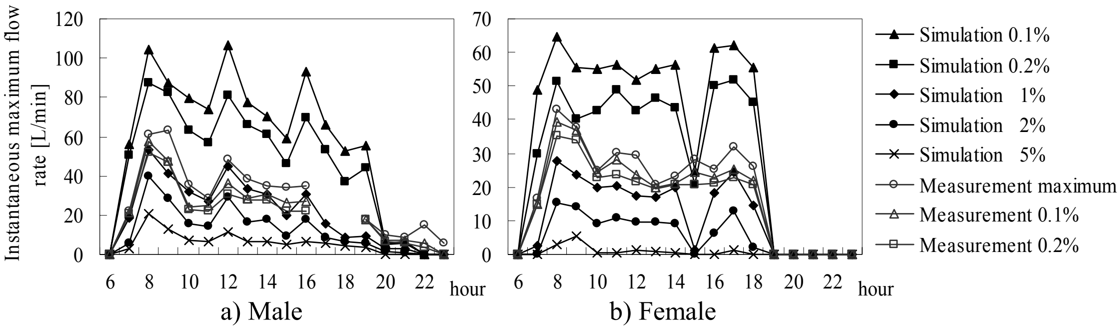


Figure 8 - Instantaneous maximum flow rates of the toilet

Figure 9 shows the instantaneous flow rates calculated by the simulation and the values of measurement in each failure factor about the hot water service room. Compared with these results, the simulation values of failure factor 1% or more large percent are almost same to the instantaneous loads of the measurement.

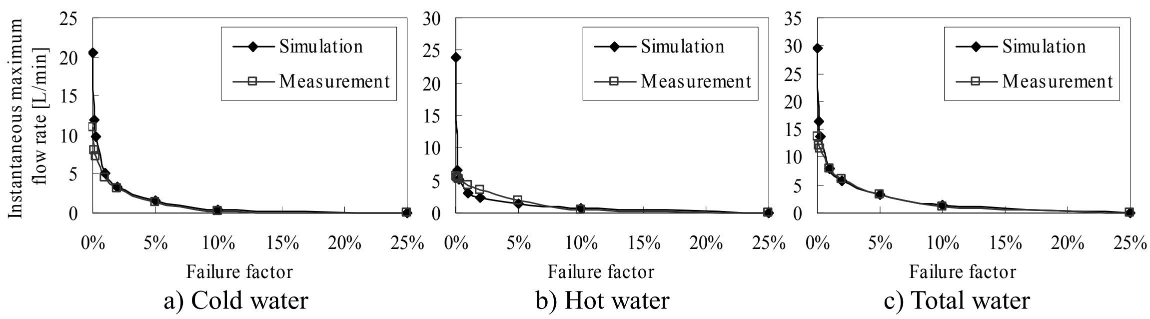


Figure 9 - Instantaneous maximum flow rates of the hot water service room

Figure 10 and 11 show the hourly volume of water consumptions calculated by the simulation at the toilet and the hot water service room. The measurement values of hourly total water consumption are shown in these figures too. The simulation values of total water consumption are almost equal to the measurement values in each time-zone. The hourly peak values occur on the time-zone of 8:00 - 9:00 in male and female toilet, and on the time-zone of 16:00 - 17:00 in hot water service room. The peak time-zones of toilet are influenced by the water closet usage in each peak time-zone. However, the cleaning of fixtures is also carried out in the time-zones. Therefore, some of water consumptions in the peak time-zones are used for cleaning of fixtures.

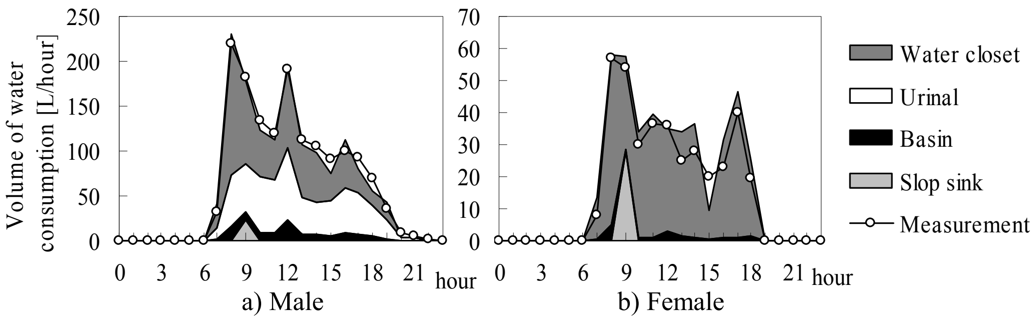


Figure 10 - Hourly consumption of water of toilet in each fixture usage

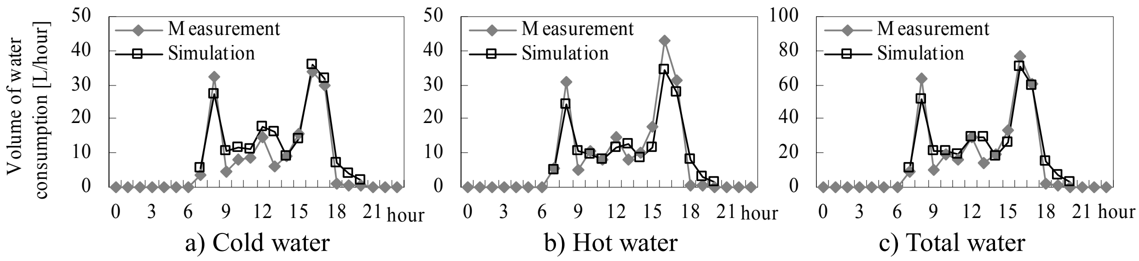


Figure 11 - Hourly consumption of water of hot water service room

Figure 12 shows the measurement values and the simulation values of daily water consumption in the toilets and the hot water service room. As the results of toilets, the male toilet and female toilet in each, and the total of them are shown. As for the hot water service room, the cold and hot water consumption and the total of them are shown. The simulation values of water consumption are almost equal to the measurement values, and the range of fluctuation between the simulated results is almost same to the range of measurement values.

5 Conclusions

In this paper, we studied about a calculating method for the loads of cold and hot water consumption in the office building's toilet and hot water service room by using the Monte Carlo Simulation technique.

First of all, the investigation concerning the workers was carried out to clarify the hourly ratio of the number of presented workers to the number of all office workers in each season.

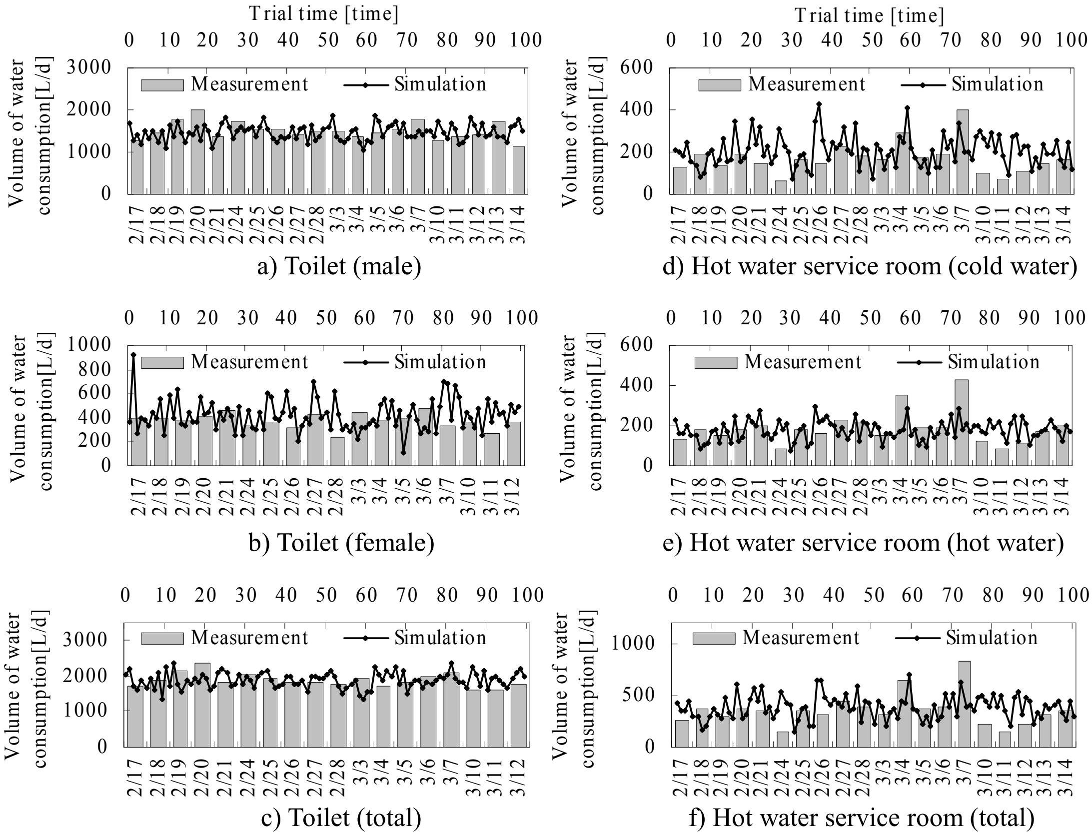


Figure 12 - Daily consumption of water

Secondly, the measurements of water consumption, temperature and frequency of fixture usage were carried out in the toilets and hot water service rooms to clarify the actual conditions of water usage and fixture usage in the office buildings.

Next, the calculating model of water usage in each fixture was set up based on the values of measurement and the results of previous studies.

Finally, the loads of water consumption were calculated from 7:00 to 24:00 by using the calculating method applied the Monte Carlo Simulation technique. The maximum flow rate of measurement values was plotted between the simulation values of failure factor 0.1% - 2%. The hourly and daily values of simulation were almost equal to the values of measurement. Therefore, the calculating method proposed in this paper is useful to estimate the loads of cold and hot water consumption in the office buildings.

Acknowledgements

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Main author presentation

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Original Water Supply and Heating Systems in a 14th Century Bath: Çukur Hamam in Manisa, Turkey

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Abstract

Today historic baths deserve more detailed research on the characteristics of their water supply and heating systems in terms of efficiency, sustainability, economy and capacity. In this paper, to discuss these characteristics, the original water supply, surface-water discharge and heating systems of "Çukur Hamam" in Manisa (Turkey) are examined in a limited extent. Çukur Hamam, dated to the 14th century, represents the general characteristics of its period, whereas the water supply system providing natural pressure by arranging various levels remains as a unique example. In this presentation, design principles, architectural elements and their construction techniques will be discussed with special references to water supply, surface-water discharge and heating systems.

Keywords

Çukur Hamam; water supply system; surface-water discharge system; heating system; *su haznesi*; *künk*; *kurna*; *tüteklik*.

1 Introduction

The bath tradition in Anatolia extends far back to antiquity. When the Turks arrived in Anatolia, they were confronted with the bathing tradition of Romans and Byzantines. They were inspired by and preferred to build on existing cultural, architectural, technological patrimony and achieved a unique synthesis by adding their own bathing tradition, which had its shape according to Muslim concern for cleanliness and for water usage. This synthesis is known as Turkish bath or so called *Hamam*. The architectural and technological features of *hamam*s are closely interrelated, to get optimum use of water and heat sources. This is the main design principle behind of the water supply and heating systems of *hamam*s.

1.1 General Features of *Hamam*s

*Hamam*s are mainly composed of three sections: changing section, bathing section and service section. (In Roman baths, changing section is called frigidarium while bathing section is composed of tepidarium and caldarium.) In early examples, there existed an additional space between changing and bathing sections, which was composed of toilet(s) and a cell. It is explained as a space providing control of heat transfer between cold and hot rooms. In later examples, it was replaced with a shaft, which is located between cold and hot sections; toilet(s) and cell become part of the bathing section.

1.1.1 Changing section (soğukluk, soyunmalık, camekan, camegah)

This section is used for the purposes of changing clothes, waiting and resting. It is usually the largest among all the other spaces. The main entrance to the *hamam* is from this section directly or from a preliminary entrance space attached. The space is illuminated by a lantern (*fener*), placed on the middle of dome or timber roof. A small pool (*şadırvan*) is placed under the lantern, on the center of the space, for cooling. There are also benches (*seki*) surrounding the space and in some examples, the walls are adorned with niches.

1.1.2 Bathing section

It is composed of two main sections: *ılıklık* and *sıcaklık*
Ilıklık section is the space, where the body is gradually adapted to heat, before entering hot rooms. It is usually composed of a main space, toilet and a cell (depilatory room). The main space is illuminated by skylights on the dome. The walls are surrounded with *seki*s in most examples.
Sıcaklık is the bathing section, which is composed of a central space surrounded by iwans (*eyvan*) and cells (*halvet*s). The alternatives in the composition of *eyvan*s and *halvet*s create variety in plan schemes. The skylights on the dome illuminate the central space and *halvet*s while ones on the vaults illuminate the *eyvans*. There is a bench constructed of marble slab (*göbektaşı*) in the central space, which is the hottest section of the *hamam*. There are also stone basins (*kurna*) for bathing.

1.1.3 Service section

It is composed of two service spaces: water tank and furnace (*külhan*)
Water tank lies along one side of the *sıcaklık* section. It has a connection to the *sıcaklık* by a small window and steps just behind, for the purpose of access for maintenance and control. There is a boiler (*kazan*) in the middle of the water tank to heat water.
Külhan serves dual function of heating the hypocaust and the *kazan*. It is located behind the water tank and placed on the same axe with the *kazan*.

2 Çukur Hamam in Manisa

Çukur Hamam that will be introduced with its water supply, surface-water discharge, and heating systems is in Manisa, at western Turkey. It is located on the slopes of the

Mountain Spil, in the vicinity of the antique castle of the city. The *hamam* lays north-south direction, parallel to the topography. Because of the slope, the west wall of the *hamam* is below the ground.
Çukur Hamam is a public bath, dated to 14^{th} century (1360s), Principalities Period (Saruhanoğulları Principality). It is one of the few examples that have survived from the period until today. The *hamam* is a part of a complex, which is composed of a mosque (Ulu Cami), a tomb and a madrasa, donated by İshak Çelebi. Today, it is in a ruined condition as being out of use.

Figure 1 – General view of *hamam*

Figure 2 – *Sıcaklık* space of *hamam*

This single story massive building is constructed of rubble stones in walls and bricks in superstructure, transition elements and openings (doors, windows, niches). Marble stones are also employed at floor coverings, on the corners of exterior walls and as architectural elements. Interior surfaces of the walls are plastered with lime plaster while exteriors are exposed. As superstructure, rooms in square plan are covered by domes while vaults cover the *eyva*ns, water tank and toilet. Today, vaults and dome of *soğukluk* and main space of *ılıklık* sections are still standing but the rest are collapsed.

2.1 Methodology

The restoration project of Çukur Hamam was prepared within the graduate course in the Restoration Department, METU, in the spring of 2003. The *hamam* was documented by using the traditional measuring techniques (optical distance measurement method, hand measurement, and documentation with photograph). The measured survey was drawn in 1/50 and 1/20 scale.

2.2 Plan

Çukur Hamam is composed of *soğukluk, ılıklık*, *sıcaklık* sections and service spaces. The main spaces are square while service spaces are rectangular in plan. (figure 3)
Soğukluk (room A), a width of 7.25 m, is entered through an arched opening at south façade. The walls are adorned with a serious of rectangular niches. There are also *seki*s in front of the walls. According to the written sources, there was a *şadırvan* in the center of *soğukluk* but it was removed in the recent past.
Ilıklık is composed of three rooms. The space functioning as a passage between cold and hot spaces (room B1) measures 3.20 m in width at the west and 2.87 m. in width at the south. The toilet is set off from the room B1 by a brick parapet wall. Main space (room

B2), a width of 4 m, is surrounded by *seki*s along the three walls. There are also two niches on the south and west walls. Depilatory room (room B3) is a width of 2.80 m.
Sıcaklık has a centralized plan scheme; the central space is surrounded by four *halvet*s and four *eyvan*s. *Halvet*s (room C2, C4, C6, C8) are located at the corners of *sıcaklık*, which are a width of 2.85 m. They are the hottest rooms in the *hamam*. *Eyvan*s (room C1, C3, C5, C7) are a width of 2.70 m. At the central space (room 9), there is an octagonal *göbektaşı*, 7 *kurna*s and a pool.
Water tank (room D) is a rectangular space, 2.6 m wide and 10 m long. It is connected to the room C7 by a window, 0.65 m wide and 0.97 m height.

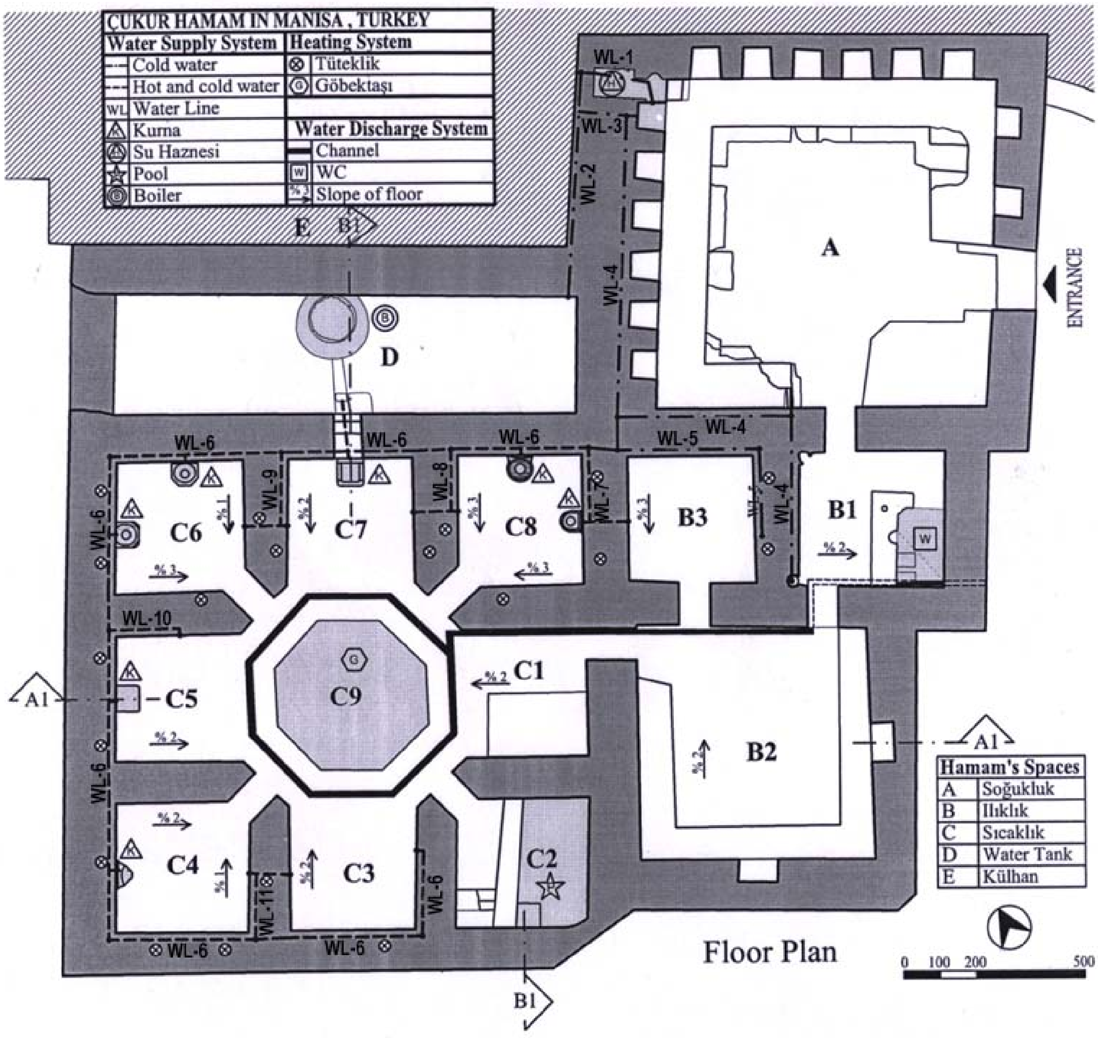

Figure 3 – Plan of Çukur Hamam

3 Water supply, surface-water discharge and heating systems of Çukur Hamam

The investigation on water supply, surface-water discharge and heating systems of Çukur Hamam aims to document all data including design principles, architectural elements and construction techniques, as a part of the restoration project of the *hamam*.

In this paper, the water supply system is defined by means of distribution of hot and cold water, levels and slope for an effective water flow, providing balance of water pressure before the distribution of water, and architectural elements of the system. As a drainage system, only surface-water discharge system is observed in Çukur Hamam. Finally, heating system is defined by means of vertical and horizontal flow of smoke under floor and walls, multi-use of heating source for both heating water and spaces and architectural elements of the system.
As a methodology, measurements are taken in relation to a reference line (±0.00) established along the walls by using traditional techniques. During the documentation phase, the traces of water supply system on the walls allow us to make some comments about hot and cold water supply systems circulated round the *hamam*. The architectural elements of the water supply system are mostly in-situ. Moreover, the floor covered by the deposits is cleared that allows us to measure the slope of water discharge system. Furthermore, the vertical hollows in walls (*tütekliks*) as a part of the heating system are observed both inside the *hamam* and on the roof. Unfortunately, there is no information about the most important elements of heating system, *külhan* and the space (*cehennemlik*) under the floor of *sıcaklık* and *ılıklık* sections because they are below ground and inaccessible. Finally, these three systems are documented in 1/20 scale drawings and photographs.

3.1 Water supply system

The investigation of water supply system can be broken down into two parts, a consideration of the question of how water is fed into Çukur Hamam and second, a consideration of how water is circulated in it.
First, there has originally been an aqueduct in the form of a channel, which supplied water from the mountain. The channel is on the south of the Çukur Hamam, passing approximately 5 m distant from the *hamam*. Possibly the water fed by the channel should enter Çukur Hamam from the north-east corner of the *soğukluk*.
Second, there are two water supply systems in Çukur Hamam that distribute cold and hot water by terracotta tubes (*künk*). The continuous and vertical systems are embedded inside the wall and carry water with the force of gravity down and around the *hamam*.

3.1.1 Cold Water Supply System

Cold water supply system connects to the main water source by a vertical *künk*, which distributes water on three horizontal lines in two levels. The first water supply system starts on +0.79 m level and the other systems start on +0.72 m level. (Figure 3 and 4)
The first water system (WL-1), composed of *künk*s at +0.79 levels, runs vertically along the deep niche (*su haznesi*) at the north-east corner of the room A. The system in the niche works as an inverted siphon; the pressure of the water coming from the main water source is balanced before it is distributed to the *hamam*. The excessive water is discharged from the main supply system by a drain at the base of corresponding niche.
The second system (WL-2), connecting the main water source to the room D (water tank), runs along the north exterior wall of room A between +0.72 m and +0.36 m level.
The third system is connected to the main water source at +0.72 m level. It distributes water first to the *soğukluk* section and then to the rest of the *hamam*. There are two water lines, here. The first line (WL-3) that supplies water for the *soğukluk* section has an outlet on the surface of back walls of niche, adjusted to the *su haznesi*. The second

line (WL-4) runs first the north and west walls of room A and then along the north wall of room B3. The system, 14.09 m long, has a slope of 3.5%. The water is discharged from the toilet.

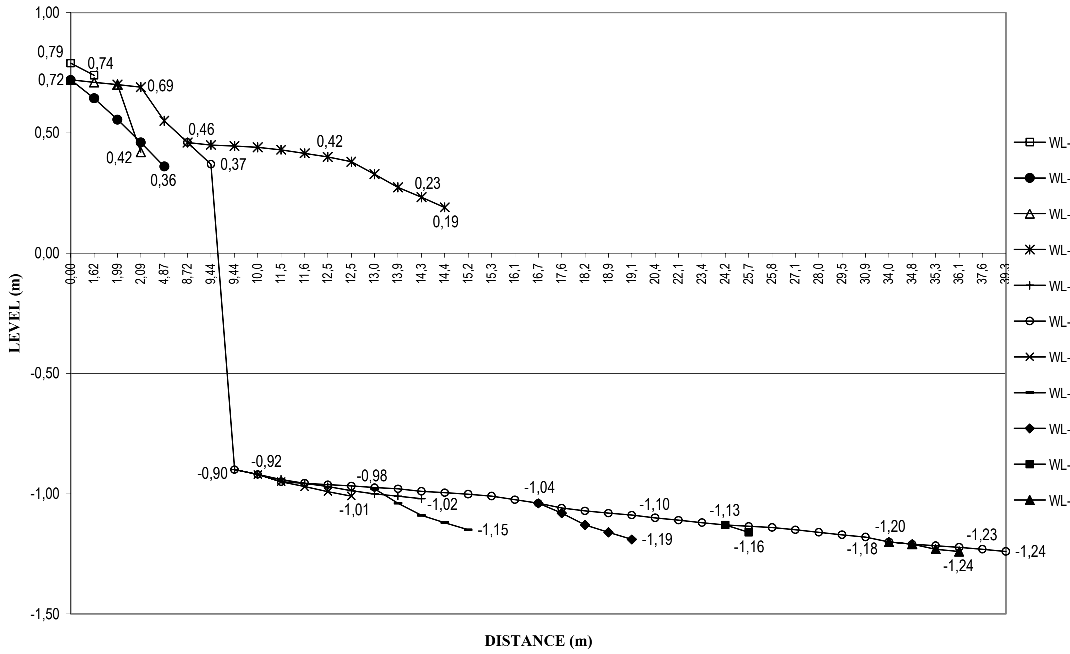

Figure 4 – Cold water system

Two water lines (WL-5 and WL-6) are connected to the WL-4 at the north-east corner of room B3 by a vertical *künk*, running between +0.37 m and -0,90 m levels. The WL-5, 4.98 m long, runs along the east and south walls of room B3 and has a slope of 2%. There is no trace of any water outlet or *kurna* in this room.

The WL-6 supplies cold water for the hot spaces, which runs along the east, north and west exterior walls of the *sıcaklık*. The water line is approximately 29.88 m long and constructed in a minimum efficient slope (1%). There are five sub-systems (WL 7- 11) passing along the interior walls in the *sıcaklık*, which are fed by WL-6. The lengths of these systems vary between 2.10 m and 2.45 m.

3.1.2 Hot Water Supply System

The hot water supply system is constructed using in the same principle; the pipe composed of *künk*s runs inside the walls of *sıcaklık* section, parallel to the cold water supply systems but on a lower level. It differs from the cold water supply system by means of the heating of water (figure 5). The water collected in the water tank (room D) is heated by the fire set directly beneath the *kazan*, which is fixed on the floor of the tank, on the center of the plan, above the heat source. From the room D, with forces of convection and gravity (slope), heated water is fed to room C7 at –1.20 level.

The hot water carried from the water tank is distributed in two continuous hot water supply systems lay on north-south direction; the first one supplies hot water for room C8 and B3 while the second supplies water for the rest of the sıcaklık. The first water line is 7.75 m long and the slope of the system is approximately 0.77%. The second line is 23.95 m long and the system lies in the same slope. There are also sub-water lines (WL 7-11), which carry hot water to the other outlets of the *sıcaklık* section.

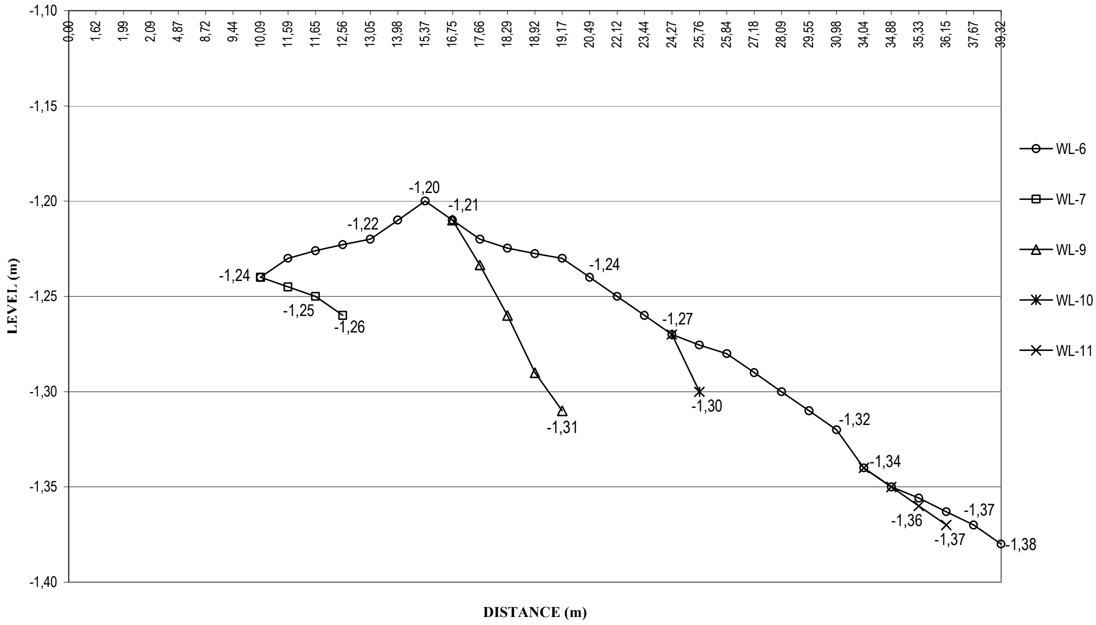

Figure 5 – Hot water system

3.1.3 Architectural Elements of Water Supply System

The water supply systems of Çukur Hamam are composed of *su haznesi*, *künk*s, *kurna*, pool, and *kazan* as architectural elements.

Su haznesi:

The north-east corner of the room A is adorned by two niches, one next to other. The deeper niche is named *su haznesi* because possibly a waterspout should be restored here (figure 6). The space is 65 cm wide, 160 cm long and 72 cm in height. It is constructed with bricks in the vault on the façade and cut stones in the walls and ceiling. The second niche is 65 cm wide, 60 cm long and 90 cm height. There is a basin with a drain at the bottom of the niche. The outlet, 15 cm in diameter, of WL-3 is set into the face of the wall, in the center of the back wall.

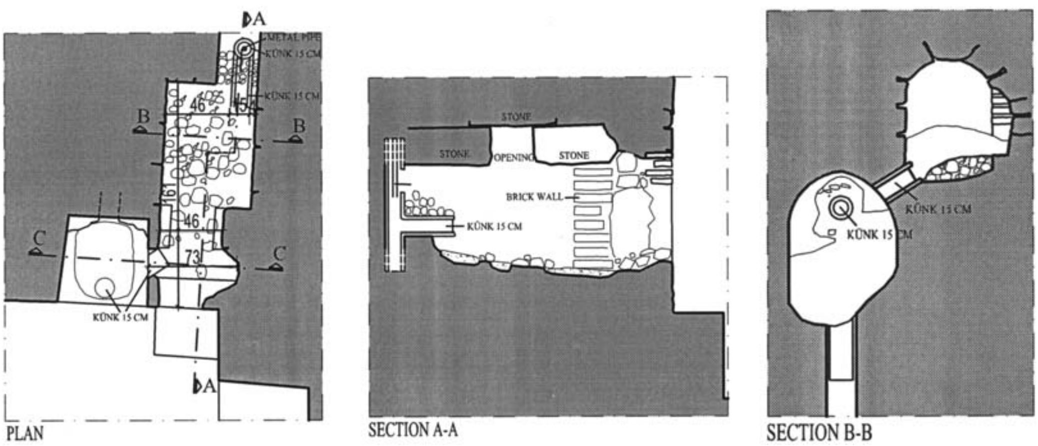

Figure 6 – Detail of *su haznesi*

Künks:

The *künk*s observed in Çukur Hamam are made of terracotta and generally have conic sections (figure 7). They are produced in standard dimensions as unit elements: the examples in the hot rooms (room B3 and room C1-C9) are 29 cm long and a width of 14 cm-10 cm at the ends of conic *künk*s. The examples in room A are larger in diameters, which are preliminary to the others within the water supply system. In some examples, lead pipes in 4 cm diameter are installed inside the *künk*s (examples in room A and C7). The *künk*s are approximately 8 cm inside from the surface of rubble wall and embedded in the thickness of the mortar with an efficient minimum slope. Instead of rubble stone, a course of brick is laid flat above the *künk*s because brick is installed easily comparing to the rubble stone. The mortar between the surfaces of cold and hot water pipes provide insulation for heat loss or transfer as well as prevent any kind of water leakage.

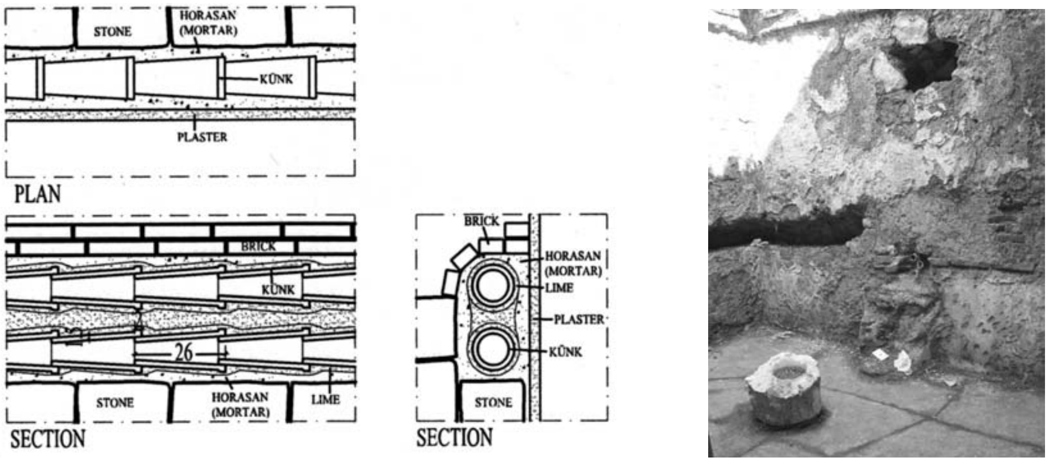

Figure 7 – Detail of *künk*

Kurna:

There are 7 *kurna*s in Çukur Hamam, located in the *sıcaklık* section (figure 8). However, the water outlets and traces on the walls indicate more *kurna*s in the *sıcaklık* section and room B3, which were removed in the recent past. In original plan, there are generally 3 *kurna*s in each room and they are located in the center of the walls. Each *kurna* has two outlets for hot and cold water. Moreover, the water capacity of each *kurna* is approximately 0,02 m^3.

Figure 8 – Detail of *kurna*

Pool:
The pool, 150 cm wide, 285 cm long and approximately 150 cm height, is not a part of the original plan of room C2 (figure 9). The original kurnas were removed and it was placed against the north wall of the room. The base of the pool is covered with deposits so the water outlet or drainage system is not observed.

Kazan:
The *kazan*, as an element of hot water supply system is set 70 cm below the floor of water tank, on the center of the plan, above the heat source. The circular metal, 100 cm in diameter, was removed (figure 10).

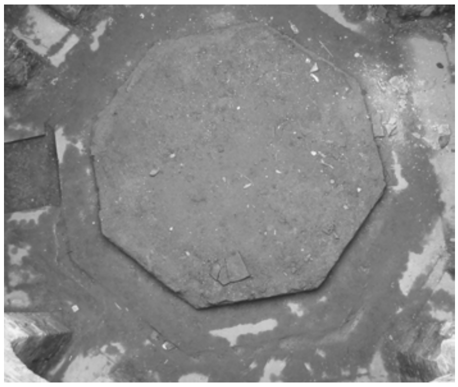

Figure 9 – Pool **Figure 10 – Water Tank** **Figure 11 – *Göbek taşı***

3.2 Heating system

Çukur Hamam is heated by hot water steam and smoke. Heating by steam happens when the hot steam, coming out of the hot water tank, flows to the *sıcaklık* section through the window of room C7 or when hot steam rises from the *kurna*s during the bathing. Smoke heating is done by the hypocaust system, which is defined as the circulation of smoke through the *cehennemlik* and *tütekliks*, which heats floor and walls of the *hamam* (figure 12).
During the field study, *külhan* and *cehennemlik* were not examined but there is a certain amount of information about *cehennemlik* in the sources. Smoke produced by the *külhan* (room E) flows first inside the vaulted channels under the floor of room D and then circulates round the *cehennemlik*. The floor of the hypocaust is supported by pillars (0.60-0.80 m on centers) and creates a suspended floor, approximately 1.00 m in height. The floor itself is constructed of two layers of stone (marble slabs in 5 cm thick and slate stone slabs in 6 cm thick) with a layer of mortar. The pillars are constructed of square bricks, 23 cm wide and 4 cm thick. The bricks used between slate stones and pillars have larger surface to reduce the surface pressure.
During the field study, 16 *tütekliks* are observed in the *sıcaklık* section and room B3, three of them open to the roof (figure 13). The *tütekliks* on the exterior walls are 50 cm inside the wall surface and approximately 25 cm in diameter. The *tütekliks* in room C4, C5 and C6 indicates that originally, there are two *tütekliks* on the exterior walls of each rooms. The *tütekliks* on the interior walls are 35 cm - 40 cm inside the wall surface and approximately 20 cm in diameter. There are two *tütekliks* on the interior walls, each of

them are close to the wall surface of one room. *Tütekliks* are constructed as a hole inside the massive rubble stone walls but there are *künks* inside two *tütekliks*

It is possible to say that *tütekliks* as elements of heating system is designed to support hot water supply system in Çukur Hamam, and details are produced to interrelate water supply and heating systems. Besides heating, *tütekliks* on the exterior walls provide control of heat loss or transfer while ones on the interior walls keep hot water circulates at a certain temperature inside the *hamam.*

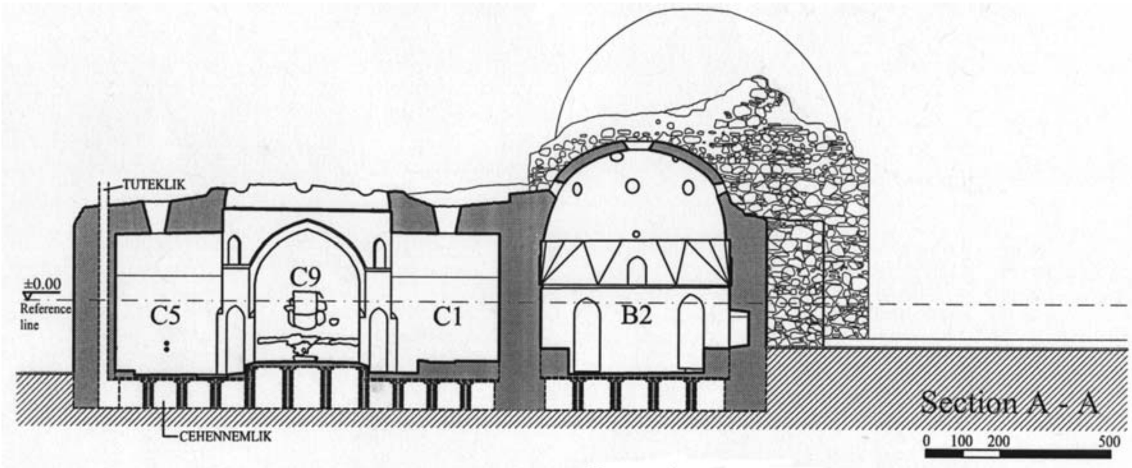

Figure 12 – Section A-A

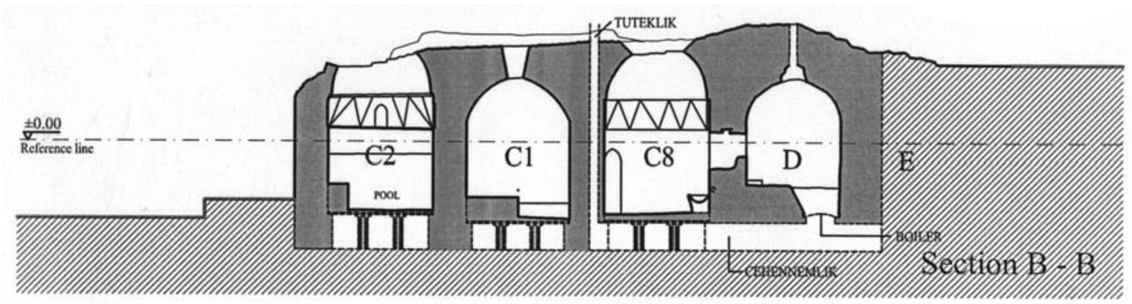

Figure 13 – Section B-B

3.3 Surface water discharge

In Çukur Hamam, only the surface-water discharge system is observed. The waste water flows on the surface of floor, which slopes from *sıcaklık* to *ılıklık* sections in 2% or 3% incline. The marble floor slopes to the door opening in the *halvets* while it slopes to the central space in the *eyvans*.

By the slope of floor, the waste water is collected and directed to the open channels on the floor, which are 14 cm wide and a depth of 4 cm. The open channel first circuit rounds the octagonal *göbektaşı*, approximately 0.47 m far from the *göbektaşı* (figure 11). Then it runs along the east wall of room C1 and B2 as a line and run beneath the sill of the doorway, connecting room B2 to B1. The floor of rooms B2 and B3 slope to the channel in 3% slope. Finally waste water runs below the floor of B1 by a pipe in 20 cm in diameter. The traces in the toilet indicate the exact position of the main drainage pipe, which is located along the north wall of the toilet.

4 Conclusion

Çukur Hamam is an example for 14th century bath, which attains original characteristics of water supply and heating systems with most of their components. Studying this building is important not only for history of architecture and conservation of cultural heritage but also for today's architectural practices for giving inspiration and the chance to utilize the experiences collected in centuries.
The water supply and heating systems of Çukur Hamam served for 700 years as a consequence of rational solutions in its design. This study is sort of a pre-study, which defines heating and water supply systems in Çukur Hamam as an example but not define efficiency, capacity and economy of these systems. Thus this study can possibly provide bases for other research approaches, from many other disciplines, in the future.

5 Acknowledgement

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PUMPING FOR IASI WATER SUPPLY

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Abstract

This document presents proposed solutions and results obtained after a study carried in reference to *the upgrading of three staged pumping water supply and adjacent water storage within Iasi City's water supply system*. Goal of this study was the increasing of the supply's capacity and enhancing its global efficiency. This is to be achieved by re-equipping the pumping stations, mounting proper delivery mains and rationing the system's compensation capacity, that is not running pumps during the power consumption peak periods.

Study has been carried by considering the forecasted water demands, the analytical characteristics of the system, the pumps' maximal reference efficiency and, respectively, the mains' optimal diameters.

Keywords

Energy consumption, water supply, distribution system.

1. Preamble

Within a water distribution system the pumps are the main power consumers, hence a strive to abate power consumptions is perfectly justified when comes the time to upgrade existing facilities. Considering this, efforts must be focused towards the directions below:

- Reviewing the conceptual design of the pumping stations
- Enhancing pumps efficiencies
- Implementing continuous adjustment of pumps speeds (variable speed drives) instead of the discontinuous one which is mostly used within existing pumping stations (i. e. parallel connection of pumps drived at constant speed, valve adjustments, etc.)

Taking into account the *increasing of power tariffs* (power costs represent circa 20÷40% of the delivered water's price), the effectiveness of such a program is conditioned by:

- Correctly assessing the demand for drinking water
- Conceiving a system able to ration the pumpings and to decrease down to the strict necessary the specific power consumptions related to pumping
- Operating facilities on the basis of an optimal algorithm in order to fulfill the consumers' demands and, in the same time, minimizing the total annual average operating expenditures

The document below presents the method used and main results obtained for the project of upgrading a main water supply within Iasi City's drinking water distribution network (having three pumping & storage stages).

Study considered the next goals:

- Increasing system's operational capacity in order to provide a nonstop drinking water supply towards the upper areas of Iasi City
- Rationing the power consumption in pumpings in order to decrease operational costs
- Increasing operational safety in order to enhance quality of water supply
- Decreasing impacts upon environment

2. Technical diagram of the supply

System provides water distribution of urban areas having populaces of circa 275.000 inhabitants, and located in the city's upper areas.

Water flow of 1200-1500 l/s, is transferred by gravity from source by a 120 km long pipeline towards the Pacurari complex, located at the entrance of the city.

2.1. Existing situation

Sector *Păcurari–Aurora–Mijlociu–Breazu*, which is object of this study, is by itself a water pumping supply and, according to diagram 1, it comprises:

Păcurari complex

- ***Receptor water tanks (from Timişeşti source)*** :
    - 5000 m3 tank which receives water carried by Main 1 (Dn 600, 300 l/s)
    - 2x10000 m3 tanks, receiving waters carried by Main 2 (Dn 1000, 1200 l/s).
- ***Păcurari pumping station***, fitted with two pumps having the characteristics below:

- 1+1 EP 12 NDS Ø 460 mm / 1482 r.p.m., which transfers water from Main 1, 5000 m3 tank Păcurari towards 2x3500 m3 tanks Aurora, by a Dn600 pig iron main, 1410 m long (designed parameters: Q = 300 l/s, H = 66 m)

- 2+1 EP 18 NDS Ø 670 mm – 982 r.p.m., which transfers water from Main 2 from the 2x10000 m3 tanks in Păcurari towards the 2x10000 m3 tanks at Aurora, via an OL steel Dn1000 main, 940 m long (designed parameters: Q = 1200 l/s, H = 64 m).

Păcurari complex is fully processing the water coming from the Timişeşti source providing within the SYSTEM the water supply towards superior pressure areas as it follows:

- Area IV - supplied populaces: 10.000 residents + 30.000 commuters;
  Qmax day = 14000 m3/day; Qhourly max = 1250 m3/day; Qie = 2x25 l/s; Qii = 2x5 l/s; from Mijlociu PS and Breazu tanks
- Area II - supplied populaces: 60.000 inhabitants
  Qmax day = 41000 m3/day; Qhourly max = 1300 m3/day; Qie = 2x25 l/s; Qii = 2x5 l/s; by gravity, from Mijlociu tanks
- Area I - supplied populaces: circa 215.000 inhabitants;
  Qmax day = 123000 m3/day; Qhourly max = 6300 m3/day; Qie = 3x70 l/s; Qii = 3x5 l/s; by gravity, from Aurora tanks

Aurora Complex

- ***Aurora storage-compensation tanks***
  - 2x3500 m3 tanks, are receiving flows from Main II, and subsequently are to supply (via new pumps) the upper distribution areas (that is area II and area IV)
  - 2x10000 m3 tanks, for compensation and gravity supply of flows for pressure area I

Between 2x10000m^3 tanks and 2x3500 m^3 tanks there is a Dn 300 connecting main which transfers a 80 l/s flow via two pumps (1+1 CRIŞ 200 / 1450 r.p.m.)

- ***Aurora pumping station*** equipped with the pumps described below:
  - 1 EP 12 NDS Ø 390 mm / 1481 r.p.m. + 1 EP CERNA 200 Ø 330 mm / 1450 r.p.m. + 1 EP 12 NDS Ø 430 mm / 988 r.p.m.,
  - transfers flows from Main 2 towards the 2x4000m^3 tanks at Mijlociu via a Dn 400/600 delivery main, 165/823 m long, at a head of 30…46 m.

Mijlociu Complex

- ***Storing-compensation tanks***– 2x4000 m^3 which are:
  - Supplying by gravity the pressure area II
  - Supplying by pump the pressure area IV
- ***Mijlociu pumping station*** equipped with the pumps below:
  - 1 EP 9 NDS Ø 460 r.p.m. / 1481 r.p.m. + EP CRIŞ 125-2950 r.p.m. + 12 NDS Ø 430 mm – 1489 r.p.m., and is supplying the area IV networks (Copou district, counter-tank system).

Breazu Complex

- ***Breazu terminus tanks (compensation) – 2x2000 m3***

As regards the system's technical condition it is to be stated the following issues:

- Power specifically consumptions for water pumpings variate from a PS to another, depending on the adopted pumping schedules, the pumps' ages and the operating schemes, as it follows: Păcurari II = 3,9…5,1 Wh/m3/m…esPăcurari I = 4,0…4,1 Wh/m3/m, esAurora = 3,8…6,0 Wh/m3/m, esMijlociu > 4,7…6,5 Wh/m3/m. Recorded figures are higher compared to those which may be achieved with new generation and properly operated and maintained pumps (i. e. es < 3,5Wh/m3/m) ;
- Water is pumped in a quasi-continuous manner, 24/24, which overlaps the peak periods upon the load curves of the power grid (when power tariffs are 3 times higher)
- Timisesti source's maximal flow (source located within Moldova river's hydrographical basin) is assessed to reach 1,750–1,820 m3/s, figure which exceeds the system's transfer capacity, in its current arrangement
- Water's high quality and the possibility to use gravity transfer towards Pacurari tanks is a perfect justification for a project able to increase system's transportation capacity

2.2. **Analyzed alternatives**

In order to increase flows distributed from the Aurora, Mijlociu and Breazu tanks, upgraded facilities must allow the pumping, via existing route (fig. 2) of the daily average volumes provided by Timişeti & Verşeni sources towards the Păcurari tanks, that is $Q_{day}^{T\&V} = 155.000\ m^3/day$.

The relative location of the four facilities and their existing plant allowed us to consider several technological alternatives for this water supply (Fig. 1):

- A combined arrangement, providing an unique pumping on the Păcurari-Aurora sector (Fig.3)
- Three distinct arrangements, of which one (a direct one) envisages the suppression of Aurora PS. These technical alternatives are shown in Figures 4, 5 and 6, on which pumped flows are indicated. Water will be transferred during a running period decreased down to 17 hours per day. Also there are shown the daily transferred volumes (currently and forecasted) and also the necessary compensation volumes. Between brackets are shown figures that might be reached if the increasing of the Timisesti source's flows would be achieved in the future.

For each of the envisaged arrangements and subsequently to the assessment of PS's characteristics, it results:

- <u>The "combined" arrangement (C):</u> Although attractive in terms of possibility to concentrate all pumpings within Păcurari complex, on a unique facility, this alternative is not worthy to be developed. The reason is that this arrangement would mean the transfer of 80% of the carried volumes under a head being with 10 m superior compared to the necessary one, fact imposed by the transfer conditions for the remainder of 20%. Hence, unrational ands costly power consumptions

- The "separate-direct" arrangement (S2): Is also put out of discussion because the increasing of hydro-dynamical head on the outlet of Pacurari 1 PS (up to 100m) would make mandatory the changing of the commercial class for the mains used on route 1 Păcurari-Aurora-Mijlociu. Therefore huge investment costs.
- The "separate" arrangement with a re-pumping scheme via the Aurora PS (S1b): Means an increasing with circa 50% of flows transferred on Main 1 (Dn 600), which will automatically lead to an increase with over 220% of head losses. Hence this would make compulsory to have in Pacurari 1 PS a much more powerful pump. This fact would make mandatory the re-configuration of power supply, and, therefore, extra costs.
- The "separate" arrangement which would pump flows between the Aurora 2 tanks and the Aurora 1 tanks (from which the Aurora PS's pumps are drawing)–S1a: This scheme is demanding minimal changes to be carried upon existing infrastructure and allows the best enhancing of system's economical and power consumptions characteristics, with a minimal investment.

Considering the above mentioned issues is to be retained the S1 arrangement as an optimal solution for upgrading the Păcurari-Aurora-Mijlociu-Breazu water supply. Main technical features of this scheme are shown in Fig. 4.

3. Operating conditions

Operating conditions for the system are dictated, mainly, by flows drawn by active consumers at a given time and their distribution towards the network. By the other hand other issue that has an influence id the operational arrangements used within pumping stations.

System's operating condition is to be assessed through flows recorded on the tanks' outlets. These figures reflect the tanks' compensation function. Considering this factor it appears clear that the Aurora 1 tanks (2x3500 m^3) - in which stored water has insignificant variations - operate practically as suction tanks for the PS.

Tanks' functioning depends on the way that compensation is provided for the difference between input flows (transferred by gravity in Pacurari complex and by pumps in the other tanks) and those distributed towards active consumers present in the network (by gravity for Aurora 2, Mijlociu and Breazu or by pump for Mijlociu-Copou-Breazu)

The hourly variation of stored water volumes during the two main periods which occur during the tanks' operation (that is, filling and draining) is determined by the hourly variation of distributed flows (depending on the specifics of deserved area) and by the manner in which the tank is supplied (continuously, at a quasi-constant flow, or discontinuously, on a period T_{supp} <24 hours per day).

In order to increase the necessary compensation volumes in different operating conditions (for the current situation and, as well, for the future optimized configuration), considering the information stated above, there have been calculated the hourly average relative flows distributed from the tanks of each complex and the hourly average relative flows of their supply (in different pumping arrangements, the relative compensation volumes, the hourly variations and cumulated values), and, also the effective average flows entered in the system from Timisesti source.

Calculations for compensation capacities have been completed in an analytical manner, distinctively for each situation.

Parameters of the studied system will be described by the mean of a comparison of its specifically parameters, with homologous orientative values, indicated by textbooks for urban centers, depending on the number of inhabitants.

Analysis' results have been arranged as document sets, issued for each system's complex, which comprise:

- A table with the hourly distributed flows (absolute and average values) - hourly averages on the assessed period; relative diagrams for flow hourly variation of distributed/input flows
- A table with the cumulated hourly values for the relative distributed volumes and of those which supply the tank in several operating conditions
- A table and the relative necessary compensation volumes diagrams for several assumptions

4. Pumping power consumption

Depends upon the global pumps' efficiency and upon the transferred water volumes in the reference period.

If the optimal pumps are adopted and if all system's components are properly reinforced, pumping's specific power consumption for the studied supply can be brought to the figures shown in Table 1.

Table 1 - Optimal values for pumping's specific power consumption

PD	Păcurari 1	Păcurari 2	Aurora 1	Aurora 2	Mijlociu
E_s^{opt} [Wh/mc]	235...255	190...215	94...102	53...80	225...240

Total power specific consumption for water distribution will be those shown below, considering these conditions:

- For distribution from Aurora complex: $E_{sDAurora}^{opt}$ = 190...215 Wh/mc;
- For distribution from Mijlociu complex: $E_{sDMijlociu}^{opt}$ = 330...370 Wh/mc;

- For distribution from Breazu complex: $E_{sDBreazu}^{opt}$ = 555...673 Wh/mc.

5. Admissible peak pump stopping durations and pumping power costs

Depending on existing compensation capacities, these durations of pump stoppings on peak periods variants from a complex to another, depending on daily transferred water volumes, according to data from Table 2:

Table 2 - Admissible peak pump stoppings durations for existing compensation capacities

Complexe	Păcurari		Aurora		Mijlociu	Breazu
Tank	2x10000	5000	2x10000	2x3500	2x4000	2x2000
Existing situation	7	7	7		7	7
Forecasted 1	6	5-6	5-6		5	7
Forecasted 2	4-5	4-5	0		5-6	4-5

For the three assumptions regarding the daily transferred volume (Q_{day}), power cost has been determined as a function of the peak pump stopping duration (to be beared in mind that the power's binomial tariff depends of the supply voltage).

If upgradings are completed (that is decreasing the pump running periods on power grid's peak periods), within limits admitted by existing compensation capacities, pumping power cost have values shown in Table 3. Table shows also how the pumping influences the price of distributed water (PI factor).

Table 3 - Power cost for pumping on Păcurari-Aurora-Mijlociu-Breazu water supply

Water Route	Păcurari-Aurora 1	Păcurari-Aurora 2	Aurora - Mijlociu	Mijlociu-Breazu
PC [Lei/m3]	354...369	348...360	201...207	426
PI[Lei/m3]		348…360	555...576	981...1002

6. Estimated savings

If pumps are to be operated outside the power grid peak area, savings earned will correspond to the difference of cost for consumed power compared to the situation when pumps are nonstop operated (NSO). These are proportional with the daily transferred water volumes and with the pumps peak cut-off period (o_v), which is admissible for existing compensation capacities. Existing tanks' storage capacities lead to figures shown in Table 4. Hence, the usefulness of this investment, especially for Păcurari 1 PS, Păcuran 2 PS and Mijlociu PS.

Table 4 - Peak pump stoppings duration and possible savings (DCP) [thou Lei/yr]

Complex		Păcurari		Aurora		Mijlociu
PS		PS1	PS2	PS	IP	2x4000
Current situation	o_v [hrs]	7	7	7	7	7
	DCP	704,2	2573,7	677,9	162,4	633,1
Future situation	o_v [hrs]	6	6	5	7	7
	DCP	1558	4760	340	1756	1115

7. Conclusions and proposed measures

Results of study made proof of possibility to optimize existing system in terms of power consumption and economical efficiency.

It is mandatory to replace old pumps with new-generation pumps with high efficiencies closing to reference figures (83...88,9%), depending on the pump's nominal flow.

In order to optimize the pumping's global efficiency at each stage it is compulsory to resize the pumps' communication mains, in order to achieve optimal transfer velocity (matching the optimal power and economical efficiencies for pump transfer).

If existing mains are to be replaced with new mains having an optimal diameter matching flows which are to be transferred after upgrading, the recovery durations for the general investment will have very different values.

Hence, rational measures to be implemented are: keeping the Dn600 and Dn1000 diameters on the two mains of the Păcurari-Aurora route; using Dn600 mains on the whole Aurora-Mijlociu route; reinforcing the main that connects the Aurora 2 tanks to the Aurora 1 tanks, up to a Dn500; reinforcing the Mijlociu - Breazu supply up to a Dn500.

Water pumping power consumption depends on the facilities' global efficiency and on the transferred water volumes during the reference period. If a system is properly designed and operated this factor do not depend on the duration of the peak pump stoppings. If optimal pumps are adopted and system is properly reinforced, specific power consumptions can be abated down to the figures shown in Table 1.

Global specific power consumption for water distribution will decrease with 190...215 Wh/mc, that is being with circa 21% lesser than the current consumption - for Aurora complex; 330...370 Wh/mc, that is being with circa 20% lesser than the current consumption - for Mijlociu complex; 555...673 Wh/mc, that is being with circa 16% lesser than the current consumption - for Breazu complex.

Duration of admissibile peak pump stoppings for existing compensation capacities variates from a complex to another, depending on the daily transferred water volumes - see Table 1.

Power cost for pumping varies depending on the pumps' stopping duration and on the binomial tariffs.

Savings earned by running pumps outside the power grid's peak areas is practically proportional with the daily transferred water volumes and the duration of pumps' stopping period allowed by the existing compensation capacities. Volumes of the tanks existing within the system lead to figures shown in Table 2.

Proposed measures in order to optimize this pumping supply are those shown below:

	Goal	Proposed measures		
		New investment	Replacements rehaulings	Operation
Păcurari PS	- rationing of pumping power consumption - optimizing hydraulic resistance on PS communications - providing an optimal versatility of pumps to the variable demands of the network	- providing SCADA modern control and automation devices (rationing of operating costs)	- replacing old pumps with new ones having η_p>85/88% - replacing delivery mains, collectors, communications, suction mains having Dn_{opt}	- valves on delivery/suction fully opened - survey of operating status - automation function of flow and head on PS delivery
Supplies	- optimizing supply's hydraulic resistance - providing an anti-surge system (depressive stage) - maximal safety and reliability	Reinforcement: - ref. IP Aurora: L=80m, Dn300 - main UAI-Breazu: L=2200m, Dn300 - interconnecting "Petru Poni" Dn1000 mains for supply-distribution	Replacing: - ref.SP Aurora: L=200m, Dn400 with Dn600 Valves for overpressure, aeration, air purge	- line valves fully opened
Storage	- peak pump stoppings (full use of compensation capacities)	-interconnecting the Aurora tanks	- on the future perspective: increasing the compensation capacity	- line valves fully opened
Aurora & Mijlociu PS	- rationing of pumping power consumption - optimizing hydraulic resistance on PS communications - providing an optimal versatility of pumps to the variable demands of the network	-SCADA	-replacing old pumps with new ones having η_p>85/88% - replacing delivery mains, collectors, communications, suction mains having Dn_{opt}	- valves on delivery/suction fully opened - survey of operating status - automation function of flow and head on PS delivery

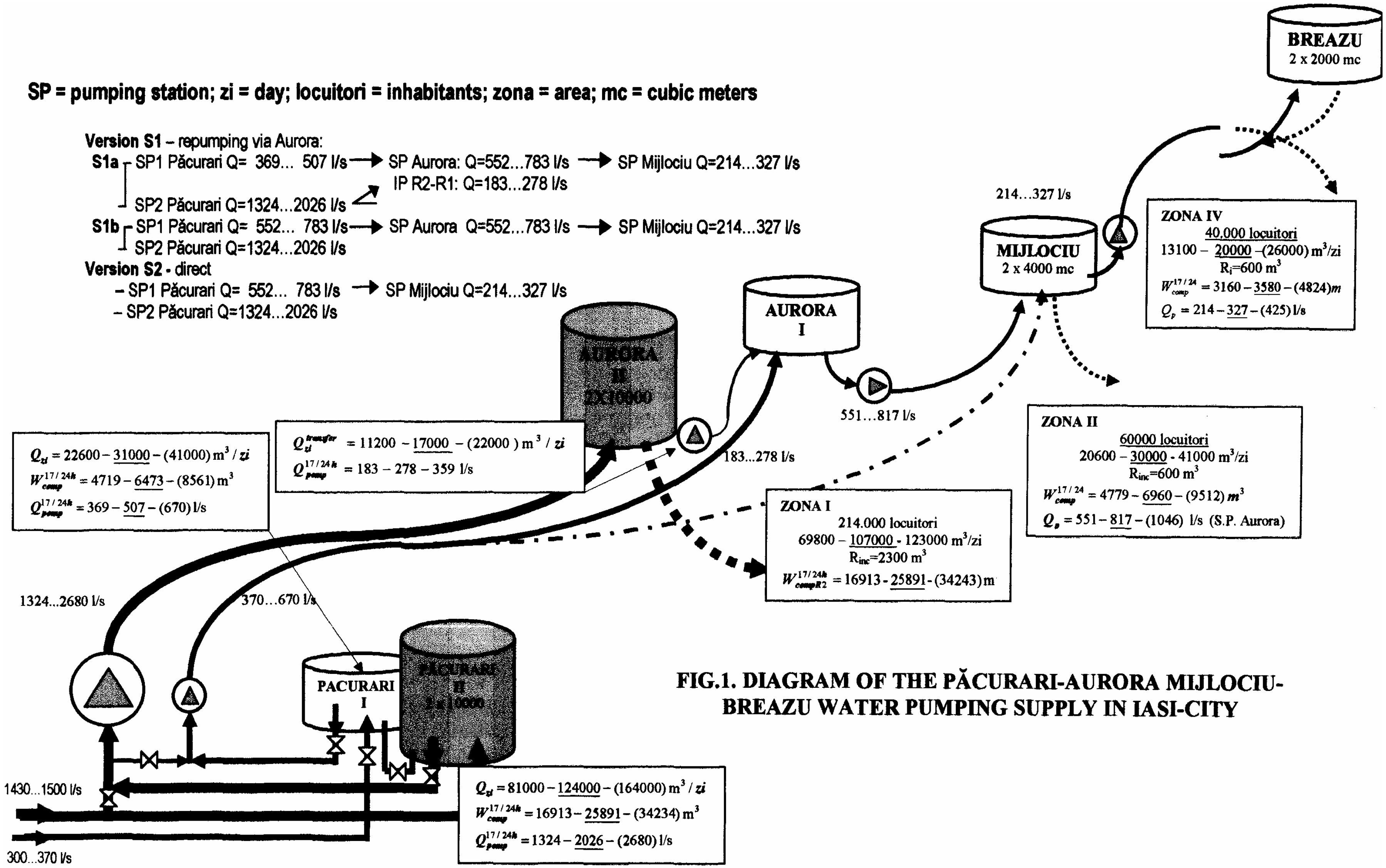


FIG.1. DIAGRAM OF THE PĂCURARI-AURORA MIJLOCIU-BREAZU WATER PUMPING SUPPLY IN IASI-CITY

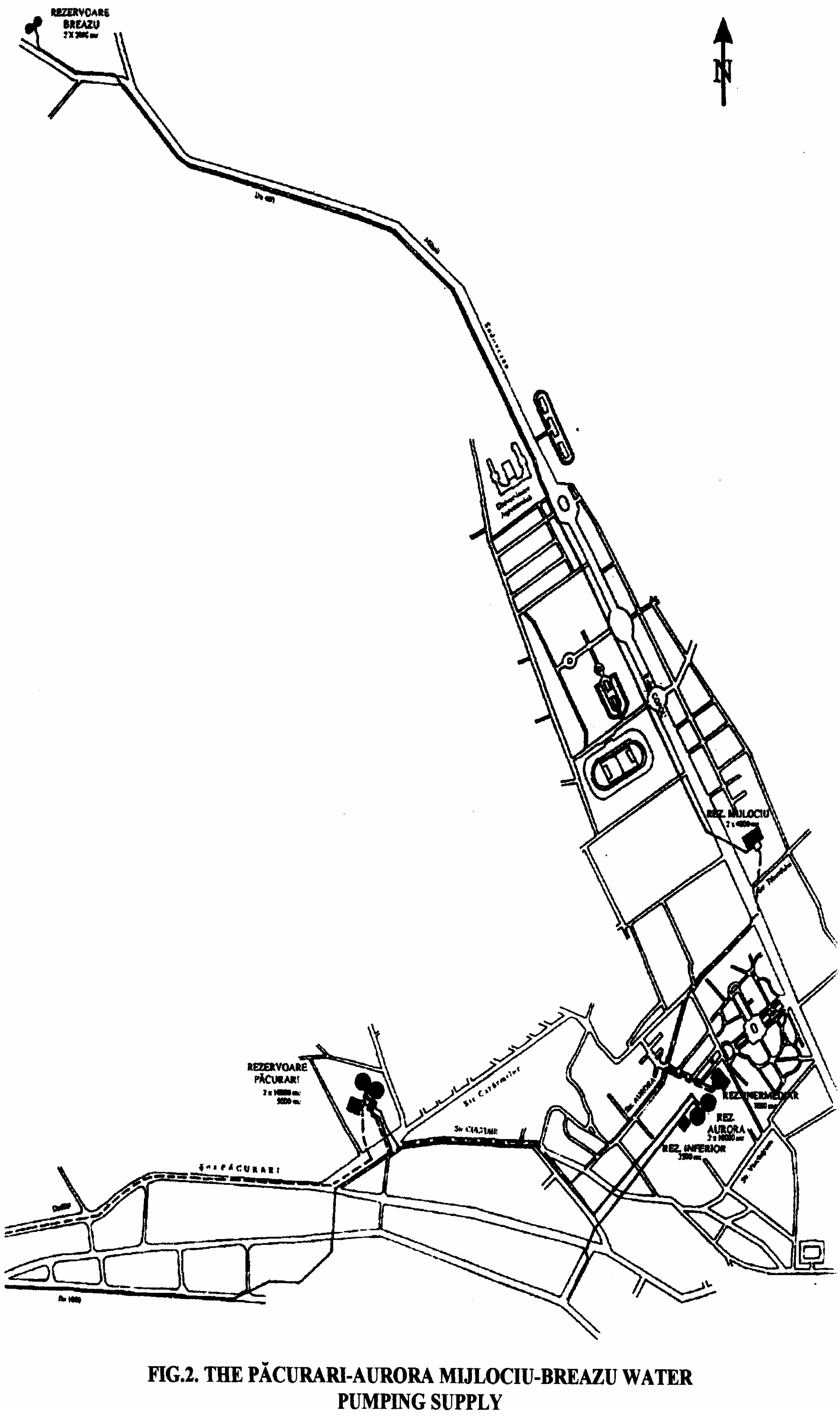


FIG.2. THE PĂCURARI-AURORA MIJLOCIU-BREAZU WATER PUMPING SUPPLY

System demands

Nr. crt	Pumping st.	Pumped flow [l/s]	Head [m]	Head losses [m]	Total head [m]	Pumps' Reference head
1	S.P. Păcurari	1693-2533-3350	40,0…61,0	6,6…10,1	47,0…72,0	67,0
3	S.P. Aurora	551-817-1046	17,0…22,0	5,0…8,0	22,0…30,0	26,0
5	S.P. Mijlociu	214-327-425	50,0…55,6	7,5…8,0	58,0…63,0	60,0

SP = pumping station; zi = day; locuitori = inhabitants; zona = area; mc = cubic meters

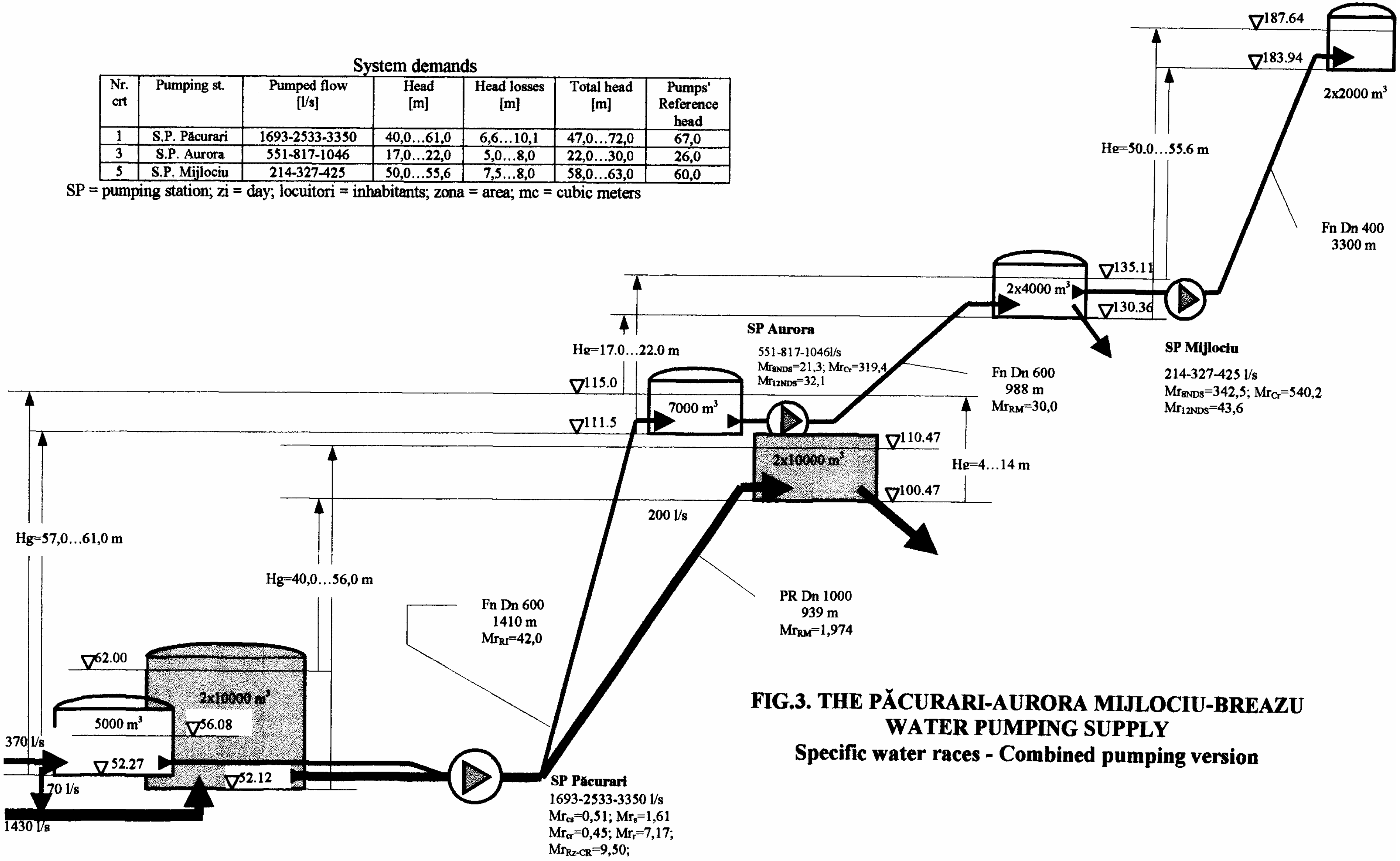


FIG.3. THE PĂCURARI-AURORA MIJLOCIU-BREAZU WATER PUMPING SUPPLY
Specific water races - Combined pumping version

System demands

Nr. crt	Pumping st.	Pumped flow [l/s]	Head [m]	Head losses [m]	Total head [m]	Pumps' Reference head
1	S.P. Păcurari 1	369-507-670	57,0…61,0	6,6…10,1	63,0…71,0	67,0
2	S.P. Păcurari 2	1324-2026-2680	40,0…56,0	7,7…10,1	47,7…66,1	57,0
3	S.P. Aurora	551-817-1046	17,0…22,0	5,0…8,0	22,0…30,0	26,0
4	I.R.P. Aurora	183-278-359	4,0…12,0	3,0…5,0	7,0…17,0	12,0
5	S.P. Mijlociu	214-327-425	50,0…55,6	7,5…8,0	58,0…63,0	60,0

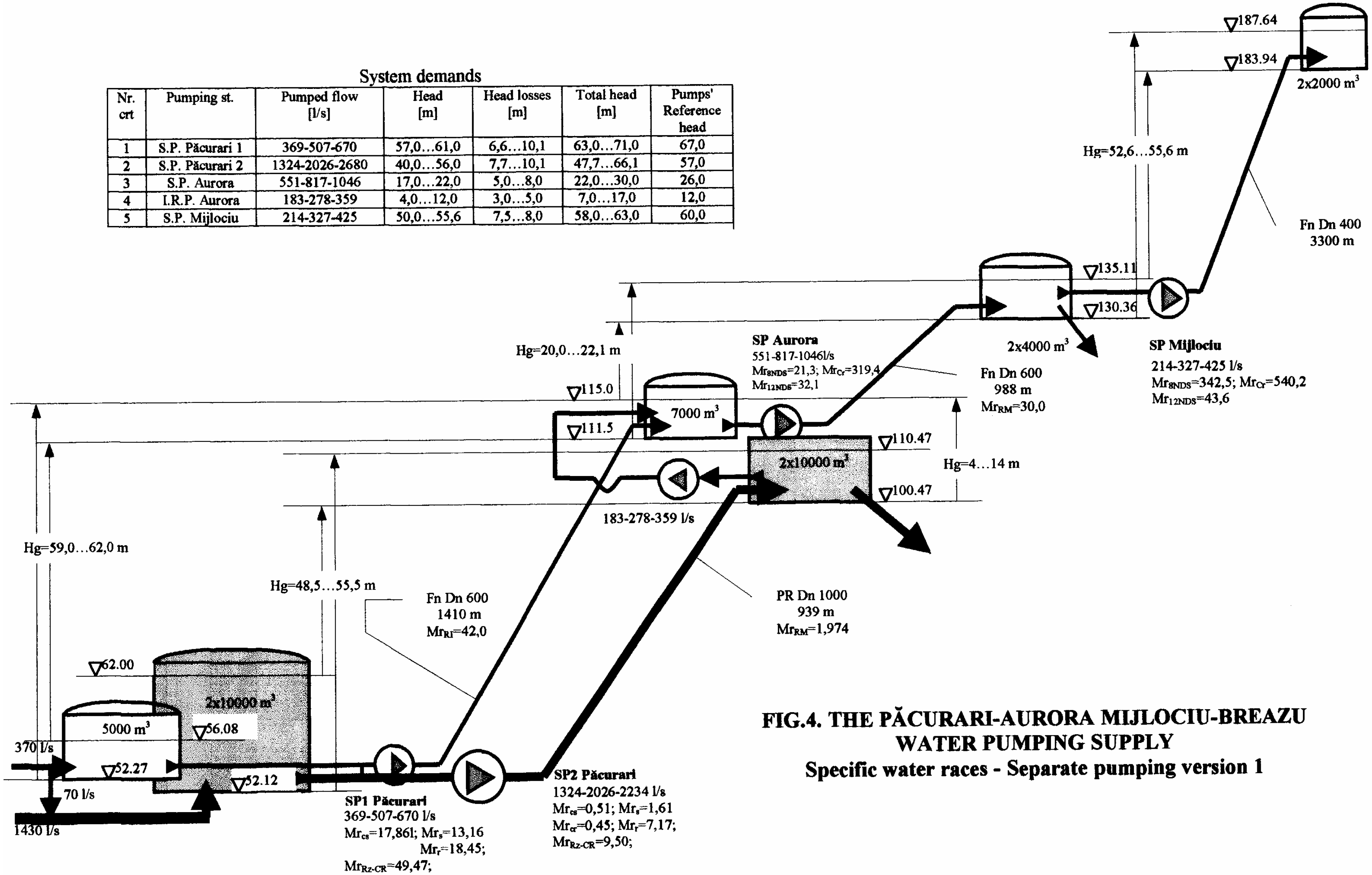


FIG.4. THE PĂCURARI-AURORA MIJLOCIU-BREAZU WATER PUMPING SUPPLY
Specific water races - Separate pumping version 1

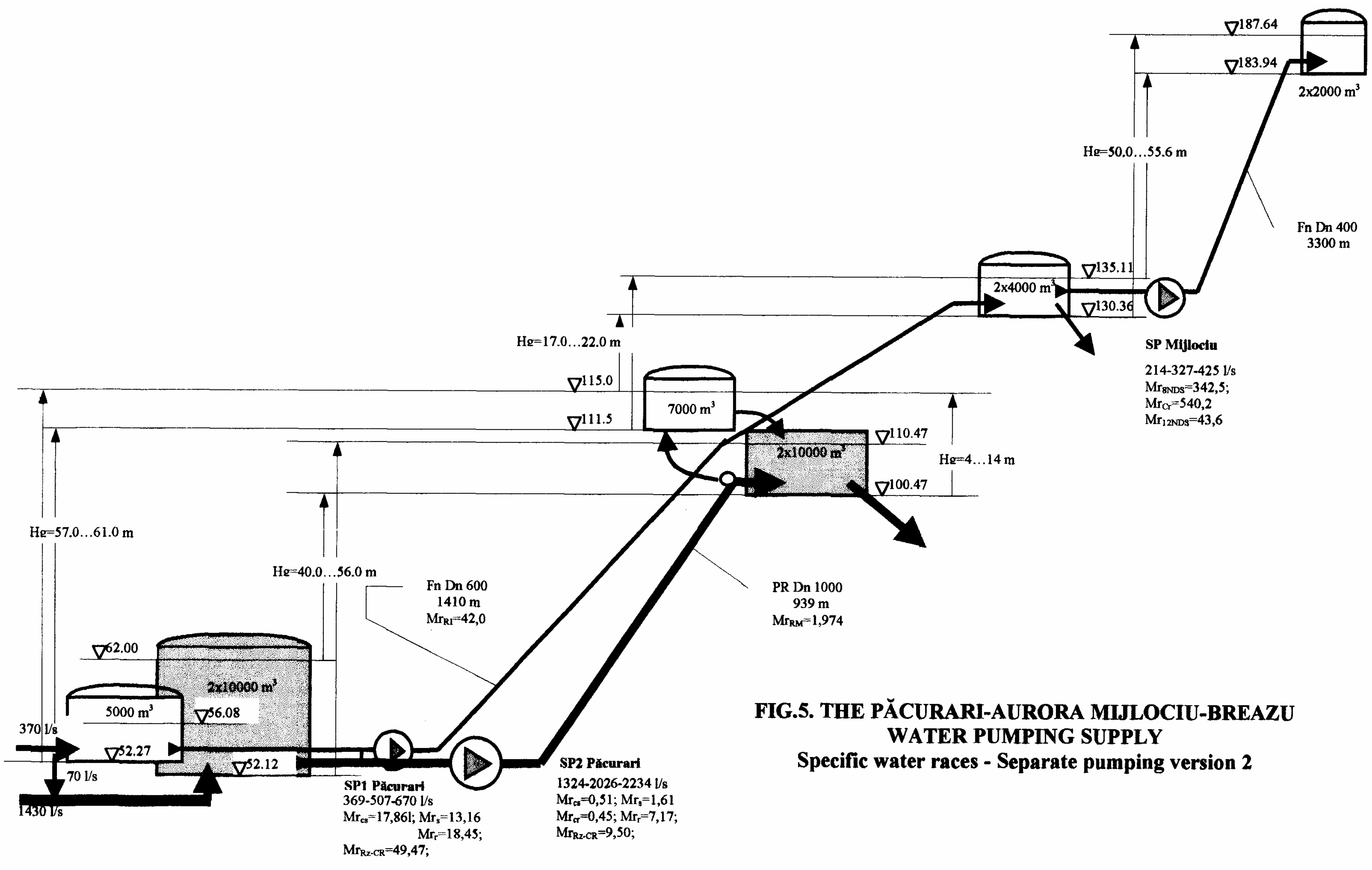


FIG.5. THE PĂCURARI-AURORA MIJLOCIU-BREAZU WATER PUMPING SUPPLY
Specific water races - Separate pumping version 2

System's demands

Nr. crt	Pumping st.	Pumped flow [l/s]	Head [m]	Head losses [m]	Total head [m]	Pumps' Reference head
1	S.P. Păcurari 1	1693-2533-3350	57,0…61,0	6,6…10,1	63,0…71,0	67,0
2	S.P. Păcurari 2	1324-2026-2680	40,0…56,0	7,7…10,1	47,7…66,1	57,0
3	S.P. Mijlociu	551-817-1046	17,0…22,0	5,0…8,0	22,0…30,0	26,0

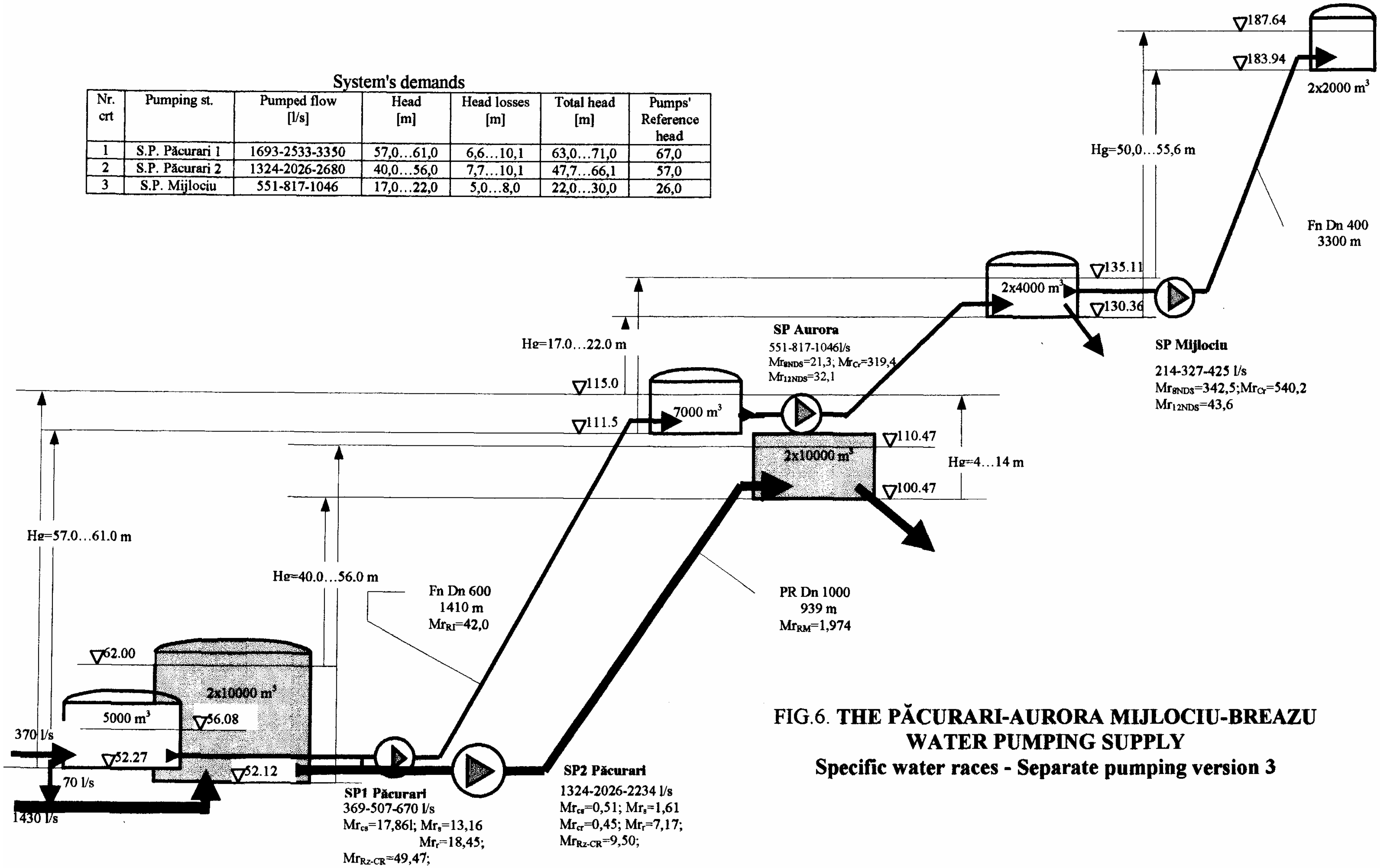
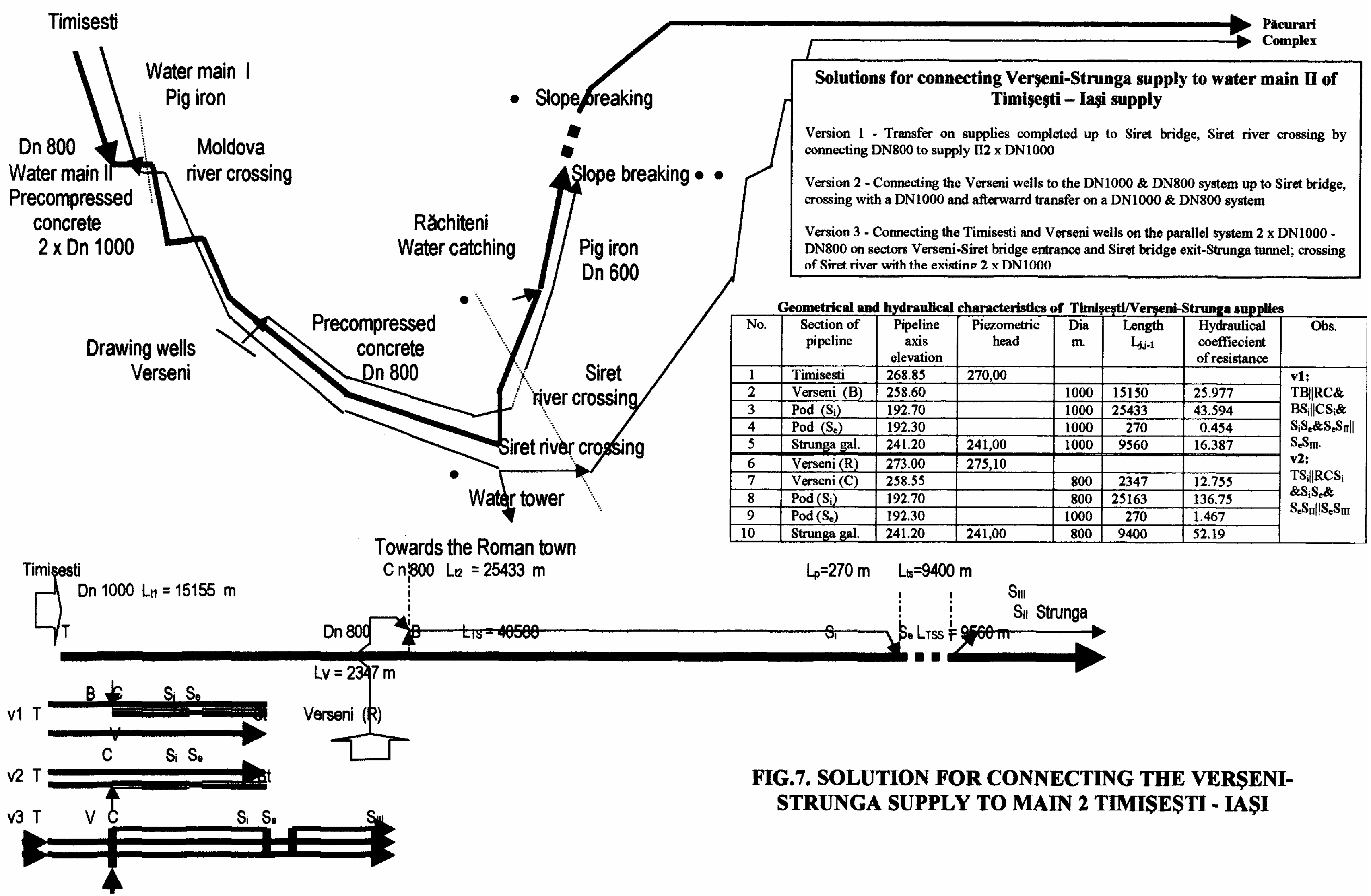


FIG.6. **THE PĂCURARI-AURORA MIJLOCIU-BREAZU WATER PUMPING SUPPLY**

Specific water races - Separate pumping version 3



Solutions for connecting Verşeni-Strunga supply to water main II of Timişeşti – Iaşi supply

Version 1 - Transfer on supplies completed up to Siret bridge, Siret river crossing by connecting DN800 to supply II2 x DN1000

Version 2 - Connecting the Verseni wells to the DN1000 & DN800 system up to Siret bridge, crossing with a DN1000 and afterwarrd transfer on a DN1000 & DN800 system

Version 3 - Connecting the Timisesti and Verseni wells on the parallel system 2 x DN1000 - DN800 on sectors Verseni-Siret bridge entrance and Siret bridge exit-Strunga tunnel; crossing of Siret river with the existing 2 x DN1000

Geometrical and hydraulical characteristics of Timişeşti/Verşeni-Strunga supplies

No.	Section of pipeline	Pipeline axis elevation	Piezometric head	Dia m.	Length $L_{j,j-1}$	Hydraulical coeffiecient of resistance	Obs.
1	Timisesti	268.85	270,00				v1:
2	Verseni (B)	258.60		1000	15150	25.977	TB‖RC&
3	Pod (S_i)	192.70		1000	25433	43.594	BS_i‖CS_i&
4	Pod (S_e)	192.30		1000	270	0.454	S_iS_e&S_eS_{II}‖
5	Strunga gal.	241.20	241,00	1000	9560	16.387	S_eS_{III}.
6	Verseni (R)	273.00	275,10				v2:
7	Verseni (C)	258.55		800	2347	12.755	TS_i‖RCS_i
8	Pod (S_i)	192.70		800	25163	136.75	&S_iS_e&
9	Pod (S_e)	192.30		1000	270	1.467	S_eS_{II}‖S_eS_{III}
10	Strunga gal.	241.20	241,00	800	9400	52.19	

FIG.7. SOLUTION FOR CONNECTING THE VERŞENI-STRUNGA SUPPLY TO MAIN 2 TIMIŞEŞTI - IAŞI

8. References

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2) *Optimizarea funcțional-energetică a aducțiunii prin pompare Păcurari-Aurora-Mijlociu-Breazu din sistemul de alimentare cu apă a municipiului Iaşi*, CC 514P/15.06.99 - 9885/17.06.99, Univ. Tehnică Iaşi.
3) *Retehnologizare şi automatizare stații de pompare Păcurari, Aurora şi Mijlociu Iaşi* – S.F.Pr.nr.9957/99

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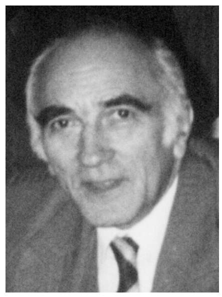

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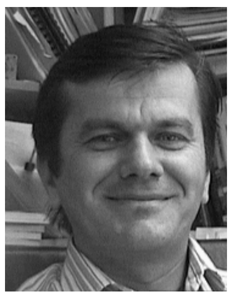

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Selection and Evaluation of Appropriate Sanitation Systems in Rural Egypt.
Case Study in Sohag Governorate, Upper Egypt

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Abstract

Maintaining social justice for every one in Egypt is one of the most important duties of the government, and in this thought maintaining health and well being for individuals has been considered in Egypt's Basic Legislation. Wastewater is one of the greatest environmental problems in Egypt, where more than 3000 local villages and sub-villages with a total population of about 25 millions have no facilities of wastewater treatment and/or wastewater collection. To provide these villages with the required facilities of wastewater collection, treatment and disposal, some of evaluation and selection tools must be done starting with selection of villages with high priority, selection of suitable sanitation system and ending to the implementation of the most eligible system in terms of technical and economical eligibility. Governorate of Sohag GOS was selected to be a case study of this study. It is located in Upper Egypt, 467 km south of Cairo, consists of 11 central units, 10 cities, 51 local units, 270 mother villages and 1217 small villages. Total population is 3,113,012 capita, 78% of them live in rural areas, and 67% of them need sanitation facilities and suffering from lack of infrastructure utilities and economic plans.
The main objective of this study is producing of selection tool as well as a simplified computer program to assist in choosing suitable sanitation systems for different villages depending on a technology selection leading to a single or group of options for the sanitation technologies as well as economical comparison between the selected options to get the most economical option. The selection of sanitation options was based on the state-of-art technologies for different components of the system. Moreover, this study assists in determination of the preference factors to get the villages' priorities for implementation. The proposed selection tool and the developed software was tested for a group of villages in GOS and proved successful and simple applicability.

Keywords

rural sanitation; wastewater treatment and disposal; on-site systems; sewerage systems; drainage; Egypt.

1- Introduction

The selection of a sanitation system for specific community in rural and semi-urban areas became a hard task for the decision makers in Egypt. Considering the major change in the community pattern and continuos shift from rural to semi-urban and to urban patterm makes the selection of the most suitable system for the wastewarter collection, treatment and disposal a dynamic process. This justifies to a great extend the importance of having a simple and flexible tool for selection of such sanitation system. Accordingly, it is worth to mention that the selection tool developed in this study is not for rural sanitation or on-site-sanitation rather than a tool able to deal with different patterns of communities covering rural, semi-urban, or small towns. The following paragraphs will present some litrature related to the topic of the paper. This would be a step ahead to the presentation of the methodology and results of this research.

An increasing proportion of surface and ground water resources in Egypt is polluted mainly due to inappropriate disposal of municipal wastewater, infiltration from onsite sanitation facilities, and excessive use of fertilizers and pesticides in agriculture. Due to the shortages in agricultural water, reuse of wastewater has become unavoidable. Community wastewater management services in Egypt evolved in three phases. During the first phase, wastewater services were provided to large cities and urban centers. In the second phase, currently underway, wastewater collections services and some treatment works were provided to secondary towns. The third phase, now being considered, will provide wastewater services to smaller towns and communities.

It has been argued that water supply and sanitation in Egypt have a considerable effect on child mortality. For instance Ali et al. (1990) find that access to clean water and adequate sanitation decreases child mortality. According to the World Bank (2002) there is an annual average loss (cost) of 0.8 percent of Egypt's Gross Domestic Product (GDP) due to diseases and mortality primarily affecting children, caused by lack of access to safe water and sanitation.

More than 95% of the Egyptian rural-areas are not provided with wastewater collection and treatment facilities. There are about 4000 Egyptian rural-areas with a population ranging from 1000 to 20000 capita. The wastewater produced from houses in these rural areas is mainly treated in septic tanks. Communities without municipal water range between 23 and 36 percent. As concerns the lack of sanitation, the coverage is between 6 and 17 percent. The former communities rely on unimproved water supplies (e.g., wells, rivers, ponds, canals and unprotected springs) and the latter on unimproved sanitation facilities as holes in the ground, bushes and other places where human waste is not contained to prevent it from contaminating the environment. Communities with improved water and sanitation do not all have the same services. It should be noted that the functioning or the improvements in sanitation facilities also depends on its connection to a sewer system. However, only some of the urban households have access to sewer systems.

To meet the demands for water and wastewater services in the next decade, Egypt will have to invest 5-7 billion US$, which is well above the available national resources (USAID, 2002). Providing rural areas in Egypt with water supply (more than 98% of rural areas in Egypt have water supply) has resulted in an increase of wastewater production, which increases the urgent need for proper facilities for wastewater collection and treatment.

1.1 Strategy

1.1.1 Problem and the objectives

Domestic water use in small communities increased due to the general rise in the standards of living. Accordingly, waste generation increased. There is a need for re-evaluation of the environment scenarios, water resource and wastewater drainage systems with a view to the totality of the system and with proper analysis of the flow of water and wastewater. The role of the engineer is to make available to society as many technical options as possible – and to put these options into the proper perspective in relation to the objectives Planners and decision makers typically favor conventional wastewater management systems which are water intensive and especially costly when applied to small communities. Commonly used onsite wastewater disposal systems (cesspits or percolation pits) fail to protect the water resources and environment because of their poor design, lack of maintenance and increased loading and development densities. Application of holistic but decentralized management approach and the use of low cost sewerage are more suited to the socio-cultural and environmental circumstance in small and semi-urban communities.

1.1.2 The Guiding Principles

Adequate and effective wastewater services for small communities in small communities must be developed within the following principles in order to meet the intended benefits:

1. Solutions should be tailored to the social, cultural, and economic circumstances and application of simple blue prints should be avoided. The household and community environments must be protected. Solutions must be cost effective and affordable to the community and national economies.
2. Wastewater is part of the total water cycle and it should be managed within the integrated water resources management processes. Management of wastewater must be holistic and should be based on careful consideration of waste generation, transportation, treatment, and reintegration.
3. Pollution must be contained and the domain in which wastewater is managed should be kept to the minimum practicable size (household, community, town, city, catchments) and wastes diluted as little as possible.

For the development of sustainable wastewater concepts, the prediction of additional environmental impacts, of social and economic aspects must be integrated into the decision-making process. Most of the investigations were focused on the comparison of specific technologies and the determination of the best alternative for one single site, not necessarily being the optimal solution for the whole area or governorate. Therefore, a methodology for the assessment of wastewater management strategies on a governorate level is important to be developed. From that perspective, all the benefits as well as the negative effects may be included in the comparative assessment of different alternatives.

2. Wastewater System Alternatives

Most Urban growth is taking place in informal settlements where government is unwilling or unable to provide wastewater services. Effective wastewater treatment is so expensive that is rarely achieved in practice, particularly in the fast urban centers of developing countries. The sewerage system must be effectible and adequate enough to receive different types of wastewater discharges. In the following dome of sewerage systems techniques:

2.1 Improving onsite wastewater system:

Onsite wastewater disposal systems present a sound method of household wastewater systems in communities where the development density is low, land is available for system construction, and where soil and groundwater conditions permit system use. Onsite systems must be designed for pollution control and recovery of resources. Improved design, construction, operation and maintenance of onsite systems are essential. Reuse of treated gray water in non-potable water uses such as household landscaping, gardening, and toilet flushing is now promoted in many of developing countries.

2.2 Conventional centralized wastewater system:

Conventional sewerage is expensive and water intensive and therefore its application for small communities cannot be justified. Conventional sewerage cost 80-90% of the entire wastewater collection and treatment (Otis R., 1996). Wastewater management can be made affordable only if significant reduction in wastewater collection can be achieved. The conventional sewerage system and treatment works can be provided to the highly developed and densely populated commercial and residential centre of the community.
A World Bank review of sewerage investment in 8 capital cities in developing countries found that costs range between US$ 600-4000 per capita (1980 prices) with a total household annual cost of US$ 150-650 (Mara D., 1996). The conventional sewerage systems are more costly in small communities. Because of their size and layout, small communities do not enjoy the economies of building large systems. Moreover, the per household cost of sewers in a town of 500 is three times the cost for a city of 100,000 (USEPA, 1992a). Conventional sewerage systems are designed as waste transportation

systems in which water is used as the transportation medium. Reliable water supply and a consumption of 100 l/c/d are basic requirements for problem free operation of conventional sewerage systems. Conventional sewerage is not appropriate for small communities where water supply is intermittent and only limited amounts of water are available. Conventional sewerage dilutes fecal matter and spreads pollution to a larger environmental domain.

2.3 The Decentralized System:

Decentralized wastewater system implies managing wastewater as close as practical to where it is generated and to where its potential beneficial reuse is located. The wastewater management system for a community may comprise several smaller subsystems for collection, treatment and reuse. The size of each subsystem is determined by the administrative, drainage boundaries, and other prevailing social and economic conditions. Decentralization is receiving increased attention from wastewater professionals and researchers because of its potential for cost reduction, efficient management, reduced environmental hazards in case of accidents; more reuse opportunities and many other advantages (Venhuizen D., 1997b; Otterpohl et al, 1997; Butler and MacCormick, 1996). Decentralization requires the choice of efficient and affordable wastewater treatment technologies which can be placed close to the human settlements without causing nuisance to the community.

2.4 The non-conventional sewerage systems

The settled sewerage and the simplified sewerage are appropriate for small communities. These sewerage systems are well tried and robust offering the same benefits and convenience as conventional sewerage at much lower cost and less demand on water for their operation. The two systems offer opportunities for long-term and large scale solutions enabling faster and sustainable expansion of wastewater services as concluded by an international conference on low cost sewerage in (Mara D., 1996), a round table on innovative experiences from Latin America in sanitation for the urban poor in July 1998 (UNDP – World Bank, Water and Sanitation Programme 1998) and a regional workshop on wastewater management for small communities in the Eastern Mediterranean Region (WHO-CEHA, 1998).

2.5 Settled sewerage:

Settled sewerage is a sewerage system that is designed to receive only the liquid portion of household wastewater. Solids are removed in an interceptor tank which is part of household connection. The clarified effluent flows by gravity into the sewers, which are designed as gravity fluid conduits. The settled sewerage costs are quite low in comparison to conventional sewerage mainly due to shallow excavation depths, use of small diameter pipe work (commonly 75-100 mm PVC) and simple inspection chambers.

Settled sewerage is commonly used in Australia, the United States, Columbia, Nigeria and Zambia. The systems is also termed small bore sewers, small diameter gravity sewerage (SDGS) in the USA, solids free sewerage in Columbia, septic tank effluent drainage (STED) in South Africa, and common effluent drainage in Australia. Settled sewerage is appropriate for low-density residential and commercial developments such as small communities and residential developments around urban areas where it is used as alternative to the more costly conventional sewerage. It is also appropriate for areas that already have septic tanks but where the soil no longer accept all the septic tank effluent and can also be used as a means to upgrade onsite systems.

2.6 Simplified sewerage:

Simplified sewerage is a wastewater collection system that is designed to receive all household wastewater. It is essentially similar to conventional sewerage, but without any of the latter's conservative design features. Costs are low, and can even be lower than on-site sanitation. The low costs of simplified sewerage are due, as in the case of settled sewerage, to shallow excavation depths, small diameter pipe work and simple inspection units in place of large manholes. In Brazil, it is serving more than one million people. The largest area of application is in the capital Brasilia with more than 400,000 clients representing all social and income levels (Nazareth P, 1998). The system is increasingly being used in Africa and Asia. Simplified sewerage is most appropriate in high-density, low-income housing areas where there is no space for on-site sanitation pits or for the solids interceptor tanks of settled sewerage. Unlike conventional sewerage systems, the non-conventional settled and simplified shallow sewerage are not water intensive and therefore they are more suited to the condition of small communities.

The low-income urban areas which are densely populated but use very little water can be served by shallow sewerage system. Treatment processes can be tailored to the quality of the wastewater generated from each separate subsystem. The use of settled and simplified sewerage systems becomes appropriate not only for small communities but also in sections of larger communities if the decentralized approach is adopted.

3- Methodology

The main tasks under this study were performed through four steps and can be categorized as follow:

3.1 Assessment of the existing situation of water and wastewater facilities:

Data was collected and assessed refering to population, water supply systems, wastewater facilities, wastewater quantities, wastewater qualities and future plans, feasible sanitation systems and geo-technical studies.

3.2 Set the strategy of the Wastewater system Design:

The following steps have been used for development of the proposed selection tool: Determine System design Strategy including Preliminary system screening, Wastewater characteristics, Initial Site Evaluation, Preliminary screening of disposal options, System Selection, Detailed site evaluation procedures, and Selection of most appropriate system. This would be a step ahead to the System Design and Management

3.3 Hydrology and Geotechnical Zoning of Sohag:

The groundwater, sub-soil water, and the soil formation have great effect on some of wastewater system options in terms of treatment and disposal especially those depending on the on site treatment and disposal. Therefore, it was a must to survey both the hydrology and geotechnical characteristics of the Sohag governorate to facilitate the selection process of such options.

3.4 The Selection Matrix:

To propose specific options for collection, transportation, treatment, and disposal of wastewater, factors affecting the selection of wastewater system are the character sites, wastewater quantity and quality, land availability, and available technologies. The proposed selection tool and the followed criteria based on the scientific background for the eligible wastewater options and the specific Condition of Sohag was explained. The proposed selection matrix covers the possible / feasible options against the potential site conditions and design parameters. The wastewater options were divided into three groups: collection, treatment, and disposal. The collection group includes collection tanks, transportation by evacuation trucks, small bore sewers, simplified sewerage system, and conventional sewerage system. The treatment group includes the on-site sanitation options as well as other treatment systems including lagoons systems, suspended growth as well as attached growth systems. The third group, disposal, includes discharging to an existing sewerage pumping station or wastewater treatment plant, soil aquifer disposal, discharging to an existing agricultural drain after treatment without violating the environmental regulations, and reuse in irrigation to cultivate trees as a source of wood. The idea of selection was based on the scientific background of the available technologies suitable for the target communities. For the ease of the selection process, the decision was made to do the selection of the technology by elimination of the invalid options for the specific conditions for specific community. The output of such process would be a single or (group) of technical option (s) to be economically assessed and make the final selection based on the economical assessment considering the capital as well as the operating costs. Figure (1) illustrates the parameters and the possible options for the wastewater system components.

Wastewater System Selection Matrix

Parameter		Actual Data	collection / conveyance				Treatment					
			C. tanks	Trucks	SBS	Convent	ST/PT	ST/CP	ST/CWL	ST/ SP1	SP2	AS
Total Population	<500											
	<1000											
	<5000											
	<10000											
	>10000											
Water Consumption (l/cap/day)	<50											
	<75											
	<100											
	>100											
Availability of Land (m2/per)	<1.0											
	1-2											
	>2											
Distance to Existing/Planned WWTP (Km)/PST	3-5											
	>5											
Groundwater Supplies	Artesian											
	Gravity											
Soil Conditions												
Top Soil Formation	Sand/Gravel											
	Clay											
	rock											
Level of GWT	<2.5 m											
	>2.5 m											
Nearby Drain	<1km											
	>1km											
Land reclaimation	yes											
	No						Selection Matrix					
Feasible or Valid Options												
Specific Cost (LE/person)												
FINAL SELECTION												

Legend:
C.Tank: Collection Tank ***CWL: Constructed Wetland*** ***PST: Pumping Station***
SBS: Small Bore Sewers ***SP: Stabilisation Ponds*** ***WWTP: Wastewater Treatment Plant***
ST: Septic Tank ***AS: Activated Sludge*** ***Invalid Option***
PT: Percaulation Trench ***AAFBR: Anaerobic Fixed-bed Reactor***
CP: Cesspool ***TF: Trickling Filters***

Notes: 1) Fill in actual data, hide invalid raws, and identify the valid option. 2) Based on cost comparison and specicifc site circumsta

Figure (1) The Proposed Selection Matrix

4. Results and Discussions

4.1 Survey and Analyses

4.1.1 Results related to water Consumption and Wastewater Discharges

Survey of the present situation of collection and disposal of waste water in all villages of Sohag has been done by a questionnaire form. Wastewater Collection and Treatment Questionnaire is including: village name, location, population, No. of families, area, climate condition, hydrological records, sanitation measures, water source and water supply system, depth of ground water table, type of underground layers, sources of wastewater produced, type of waste waters, treatment system used (if any), point of discharge, Per capita wastewater production, soil permeability, type of sewerage system, and wastewater analysis. The most important information related to water consumption and wastewater discharges for the governorate of Sohag GOS was demonsrated in table (1) and figure (2).

Table (1) Water Consumption and wstewater Characteristics for GOS

Water Consumption(l/c/d)		Average loads in rural wastewater (g/c/d)					
<1000 capita	50-95	COD	BOD_5	SS	TN	PO_4	Oil and grease
1000-5000	75-100	120-210	60-83	65-75	13	7	10-15
>5000	90-105						
Total needed hydraulic load for WWTPs (m^3/d)		560,000		Total organic load for (kg/d)			333167
				Suspended solids for (kg/d)			254567

4.2 Soil Properties

4.2.1 Hydrology of Sohag Governorate

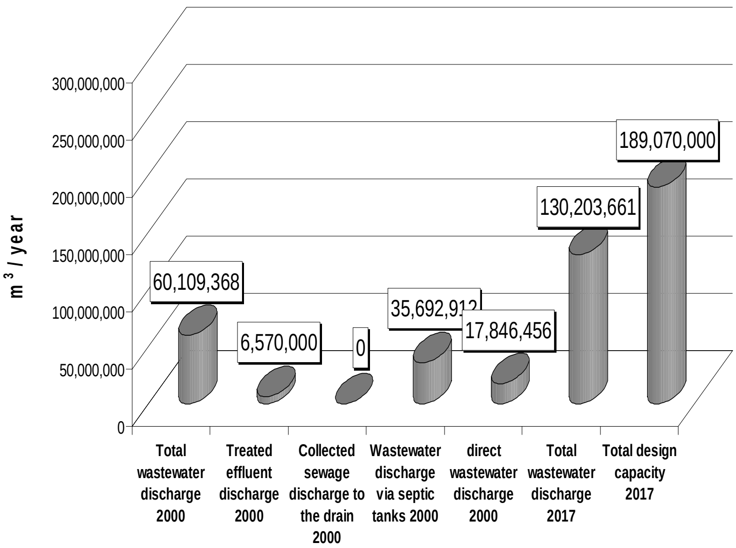
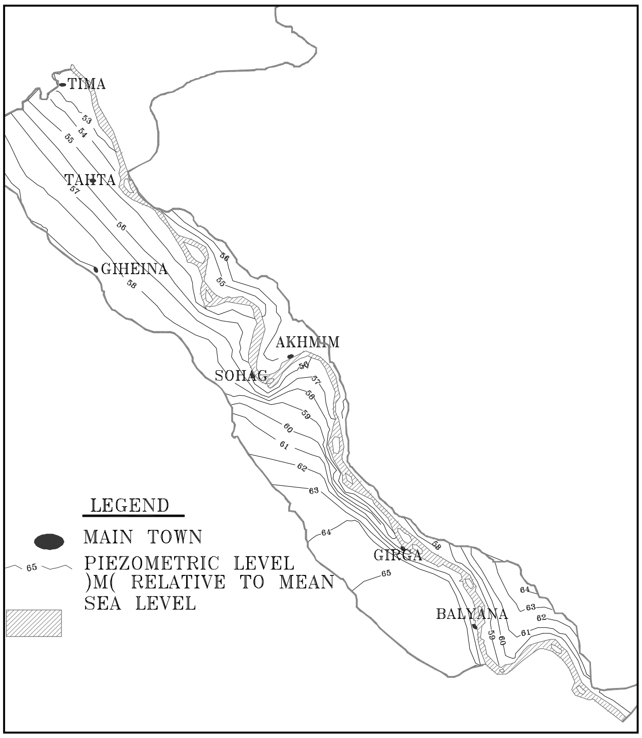


Figure (2) Wastewater Discharges Distribution in GOS

The aquifer is composed of sand and gravel with clay lenses. The maximum thickness of the aquifer is about 250 m at the center of the Nile valley, reaching 50 m at the border. The depth to the groundwater in the alluvial plain varies from one locality to another and is affected by the ground elevation, the level of water in the canals, the water level in the aquifer in addition to many other local factors. Generally, the depth to groundwater ranges between 0.5 m to 6m in the Nile valley and between 8 m to more than 25 m on the border of the valley (Abu El Ella, 1992). Figure (3) shows a contour map of the ground water elevation in the Pleistocene aquifer (Faid, 1990). From this Figure, it can be seen that the groundwater elevation varies between 65 m at the south to 53 m at the north.

4.2.2 Geotechnical Zoning of Sohag Governorate

The geological and hydrological studies of the governorate given in the previous sections, complemented by the available geotechnical data, are used to develop a geotechnical zoning map of the governorate. Figure (4) shows the zoning map of the inhabited area in the governorate. As stated before, the zonation in this map was made based on the results of the geological study and the available geotechnical data. Whenever discrepancy between the results of the geological studies and the available geotechnical data occurred, the zonation was made based on the available geotechnical data since it gives more detailed consideration of formation of the top soil layers. Thus, the borders of the zones in this map are slightly different than what exist in the geological map since they were modified based on the available geotechnical data. The zonation in this map was made considering the soil formation within the top 15.0 m (the depth covered by most of the available boreholes). As seen in Figure (4), the inhabited area in the governorate has been divided into six zones.



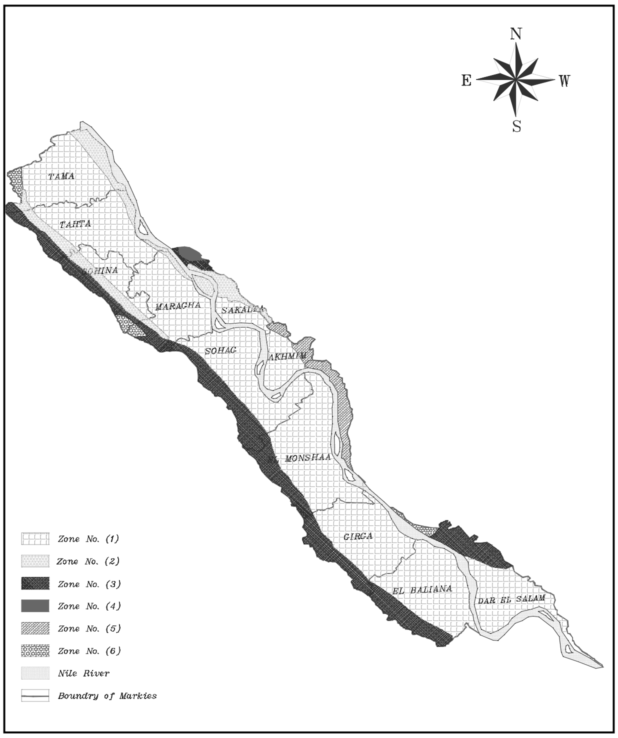


Figure (3) Hydrological Map of GOS **Figure (4) Geo-technical Zoning of GOS**

4.3 Application of the proposed Selection tool

The following criteria have been used to select te target villages as a step ahead to the selection of the most urgent pilot village. To facilitate the application and close monitoring, all target villages for this study should have the following conditions: Near to the city of Sohag, Base map and survey drawings must be available, close to the mother village, having social and local active organizations, ready to share the project cost (house connections), sever shortage in wastewater services, does not included in the national wastewater plans, possibility of treated effluent reuse.

4.3.1 Setting Priorities

Thirteen villages have been chosen as target villages among larger number of villages. These villages were selected based on the selection criteria of the target villages. To determine the priority of implementation, it was necessary to set certain factors and weight for each factor to score the priority of each village. The factors controlling the priority are:

no of beneficiaries, no of households, architectural and structural conditions oh buildings, conditions of water supplies, standard of living, health aspects, social and local activities, project cost, possible extension to accommodate discharges from other villages, and availability of maps. Base on that, the results of prioritization process were concluded with score for each village determining the implementation priority.

4.3.2 Selection of wastewater System components

The starting point of the system selection for a community is the specific parameters and site conditions of the pilot village. The developed selection matrix was designed to simplify the selection and the evaluation process. The matrix includes the required data for each parameter. Based on the scientific background and the specific conditions of the pilot village, the valid options of each component were identified. For the ease of application and analysis of such matrix, a computer program was developed with several subroutines for each to identify the options and cost effectiveness.

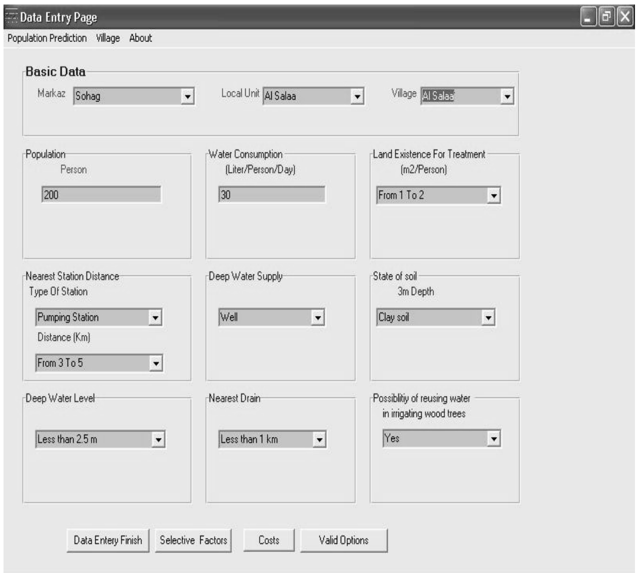


Figure (5) Data Entry Page

The final results of the selection process are the possible options for each wastewater component. Then, the final selection between the valid options was based on the technical and economic eligibility for each option. Figures 5, 6, and 7 illustrate some demonstrations for the developed computer program for data entry, valid options, and cost estimates, respectively. For the pilot village the selected wastewater system components are shown in figure (8). The selection includes the system components for collection & transportation, using simplified sewerage system, treatment using stabilization ponds, and reuse of treated ww in cultivation of woods farms (more than 50 acres).

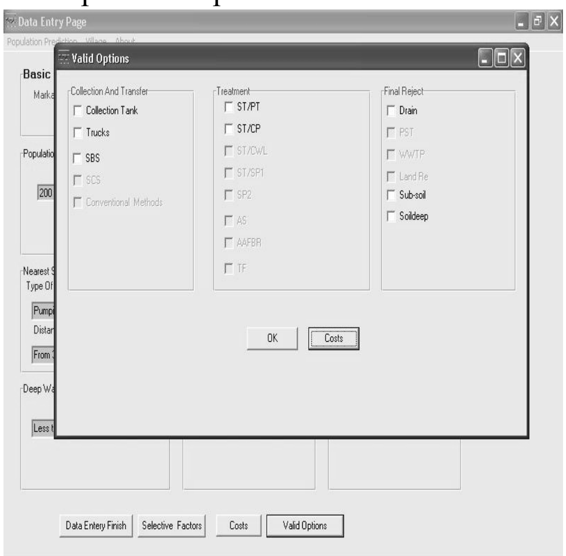


Figure (6) Valid Options Page

The results obtained from this study could be summarized as the following:

1. Simple and easy to operate and update, a computer based selection tool was designed and tested considering technical, economical, environmental, and social aspects as well as community participatory approach.
2. A strategy to set implementation priorities was developed for technically eligible and fair selection in case of limited financial resources. Determination of preference factors and villages' priorities depending on evaluation of No. of beneficial, population density, No. of houses, house connection, living standard, health state, cost, and social acceptance.
3. The Geotechnical zoning of GOS was developed and divided into six zones according to the soil formation and structure based on the available soil bores in different area of the governorates.
4. The proposed technique was tested for a group of villages to set priorities and select a pilot village. Then the selection matrix based on the elimination of the invalid options using the developed computer program was applied to identify the most appropriate options for the wastewater system components in terms of technical and economical aspects.

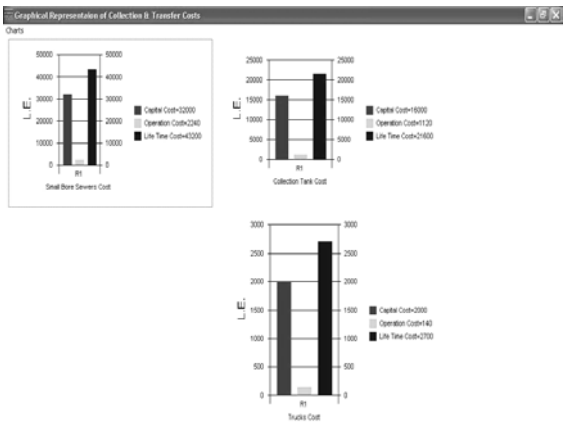


Figure (7) Cost Estimates Page

	First Stage El Hagarsa village ○ Collection ○ Pumping ○ Treatment (1st Stage)	Second Stage El kawamel & A Gharib villages ○ Collection ○ Pumping ○ Treatment (2nd Stage)
Collection	Simplified Sewerage System	Simplified Sewerage System
Transportation	Main Pumping Station	Secondary Pumping Station
Treatment	Stabilization ponds	Stabilization ponds
Disposal and Reuse	Reuse in Cultivation of Wood trees (Local Contribution)	

Figure (8) The WW system components for the pilot village

5. Conclusion

The study proved the possibility of setting and successfully applying the proposed strategy of ww components selection as a helpful and simple technique for evaluation and selection of the most appropriate technical / economical options in the rural areas in Sohag Governorate. Also it is considered as a starting point to touch the actual need of wastewater systems for each village depending on its conditions and preference according to specific criteria for implementation priority. Based on the results obtained for the sanitation system options, a master plan for the rural sanitation systems could be developed considering the context of the national plans. Then, the system design can be prepared for the most preferable options to achieve the village's need as a part of Sohag rural development program considering the sustainability of the project by setting the appropriate system management.

Acknowledgments

The authors introduce their respect to the team participated in this study as a part of Sohag rural development program. Although the study philosophy and concept was developed by Dr. Hisham S.A. Halim *(the first author)* as the principal investigator of this study, the authors highly appreciate and thank the geotechnical department and the centre of Civil engineering and research at Faculty of Engineering, Cairo University for their great support to prepare and finalize the study. Finally, the authors feel very grateful to the project management team from GOS for their support during preparation of the site work.

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The need for certification in the field of water distribution systems

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Abstract

The Quality of Water intended for human consumption is in Europe regulated by a Directive. This regulation is implemented in member states and defines the quality at the point of use, which means that the building actors have now a responsibility towards the user. Furthermore, recent legionella cases have shown the sensitivity of water distribution systems to bacterial ingress. All these factors lead to a new approach of water distribution systems in terms of design, installation, commissioning and maintenance. Design shall include a good calculation of flow rates so that temperatures are at any point high enough in order to prevent bacterial growth, and that no dead legs favours corrosion processes. Installation shall be carried out so that the material's choice is respected and their assembly correctly made. Commissioning and maintenance may include disinfection which is to be practiced with a good knowledge of chemicals used and materials. More and more users ask for a diagnosis of installations inside buildings. There is a necessity for an evaluation of these different operations. This paper shows how, in France, these operations can be controlled and how certification helps to the improvement of water distribution systems inside buildings and, as a consequence, the quality of distributed water.

Keywords

Drinking water, certification, water distribution systems, water regulations, sustainable development.

1 Introduction

Running water at every level in a building was a modern comfort criteria, still written, for example, on some multistorey buildings realised in Paris during the 19th century. Water distribution systems exist now in all buildings and are today banal installations. Comprising just the essential, they have during years fulfilled their function : to put at the occupant disposal a water with potable quality. The achieved functions were to provide drinking water, to prepare food, to wash, to provide bathroom and WC flushing cisterns with water. Water quality can today be non stable, sanitary and comfort requirements are increasing, the research of low installation and maintenance costs is everywhere. Therefore, water distribution systems have to be adapted, modified and improved. This paper is a review of these evolutions and of the possibilities of a control of the systems and of contributors working for operating and maintenance.

2 Traditional systems in buildings

Water distribution systems are traditionnaly made of galvanised steel pipes (usually in collective use) and of copper for smaller diameters (mostly in individual flats or individual houses). Lead is today forbidden for realising water distribution systems, because of sanitary reasons, but it still exists in many of them. When using good quality materials and carrying out the installations according to professional instructions, these materials had a satisfactory behaviour during years.
Some cases of copper pitting in cold water have lead to the elaboration of a more severe European standard, thus reducing the number of corrosion damages. On the contrary, galvanised steel is still presenting pathologies, and its use in waters with particular quality requires a water conditioning. Its repair uses more and more synthetic materials, which can also be the origin of scaling phenomena.

3 The new requirements

The new requirements in the field of water distribution systems in buildings are at the same time of regulatory level in order to protect the consumer's health, and of sociological character in order to follow an increased request of comfort and well-being.

3.1 Regulations

Water distibution is regulated in Europe according to European Directive 98/83/CE. This directive introduces a very important change in the field of water distribution systems : the drinking water quality is now defined at the point of use, and no more at the point of delivery in the building. The result is that the different building actors are now involved in the respect of water quality and the owner or the contributors in charge of maintenance have the responsibility of this water quality. Furthermore, the important reduction of lead content in drinking water will lead to replace most of existing lead pipes. New materials can be used, introducing new connecting techniques, and eventually internal pipe coatings.

Problems appeared these last years with the development of pathogenic bacteria in water distribution systems have lead to the publication in France of regulatory documents authorising some disinfection techniques : thermal schock or use of authorised disinfectants with their usage conditions and their compatibility with the materials installed in the system.
The protection of drinking water systems against backflow (private systems may contain chemicals used for water conditioning) is also regulated as wel as the contact of materials with water, requiring an acceptance certificate.

3.2 Comfort evolution

The evolution of the society has lead at the end of the 20th century to an increase of the water consumption (up to 200 litres per person and per day). This request was corresponding to the search of an increased comfort and well-being at home, with an increase of the number of showers and baths, and a more intensive use of washing machines. Multifunction shower cabinets also appear on the market. The result is insufficient hot water productions, installations with a too low pressure or flowrate. On the contrary excessive flowrates can induce erosion corrosion phenomena on materials subject to this. More and more installations are also equipped with water softeners, also corresponding to this comfort requirement, comfort of skin in contact with soft water, and elimination of scaling problems.

3.3 Water saving

The logic of sustainable development leads to the study and realisation of techniques in order to save the potable water resources. Amongst these techniques, an example is the double flush mechanisms for WC cisterns, taps with stroke or flowrate limitation, as well as recommandations to users about leakages or maintenance of systems. Sometimes in contradiction with comfort evolution which is energy and water consuming, these measures correspond to a drinking water consumption stabilisation, or even a consumption reduction.

Some contradictions appear with this logic of water saving when it is necessary to proceed to installation flushing, for example after long stagnation periods in order to reduce metallic ions content in water or during thermal shocks used for disinfection. Rain water reuse for certain installations leads to a reconsideration of designing water distribution systems in buildings.

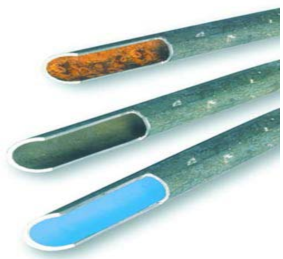
3.4 Technical evolution

The considerable progresses in organic chemistry during last decades, have lead to the arrival on the market of polymeric materials which have also invaded water distribution systems technology, particularly the technology of pipes. Formulations compatible with drinking water have appeared and reduced the market of metallic materials which reputation had suffered from corrosion problems.
The most employed ones are PVC, PB, PE, XPE, PP and PVCC. Their connection is realised either by gluing, polyfusion or electrofusion assembling, or mechanical assembling which makes the technology accessible to non professionnal actors.
The advantages of these materials are the chemical resistance and the absence of corrosion. Their disadvantages are greater expansion coefficients, appearance, and gas permeation. This last characteristic poses no problem of oxygen permeation in water distribution systems, but can lead to difficulties when pipes are installed inside technical rooms containing solvants for example. An evolution towards multilayer materials; with an aluminium layer, appears.
Still less developped in France, stainless steel appear, principally as renovation material (replacement of lead or of corroded pipes) and thanks to the mechanical assembly technique. Choosed with good compositions, they are not affected by corrosion in drinking waters. They particularly develop in buildings like hospitals, where however its connection by soldering requires the competences of a specialist.

Without necessarily using new piping materials, connection techniques also change, either under the influence of regulations (replacement of tin-lead soldering materials by tin-silver soldering materials) or due to market evolutions, especially the developpment of DIY market (mechanical connections for copper for example).

Scaling phenomena in new pipes has been widely studied leading to the observation that also materials non subject to corrosion are subject to scaling, sometimes intensively. After the first period of use, all materials, covered by a first layer, behave in the same way towards scaling and biofilm formation.

The coating technique of pipe inner surface in water distribution system shall also be cited. This technique, initially developed for lead pipes, in order to eliminate the direct contact with drinking water, has expanded for renovating corroded galvanised steel pipes.



4 Design, operating and maintenance of installations

4.1 Technical guide

In France, design, operating and maintenance of water distribution systems are the object of official rules written in a so called technical guide. In such a document, the choice of materials, the way to assemble them together, the operating conditions (pressure, temperature, flow rate) are described.

4.2 Maintenance of systems

Neglected during a long time, maintenance of water distribution systems are now better taken into account. Regulation refer to them now, especially for water conditioning systems. A regular check of disconnection devices, pressurisation devices, control pipes and water heaters is requested.

4.3 Evaluation, diagnosis of systems

Evaluating the condition of water distribution systems has always been a difficult operation, because it is only really possible when the installation is out of function, mostly during openings following damages. Making continuous observations, and predict the condition of an installation has during a long time been made via visual observation of control pipes. Now, electrochemical sensors for corrosion and scaling appear, permitting a continuous check of the evolutions at inner pipe surface in real installations in use. A new job of diagnonis expert develops, usually studying the water distribution system in its whole. The great number of informations collected when anlysing a system needs new data anlysis techniques.
In fine, evaluations should lead to design recommandations, because it is more obvious today that an installation, well calculated, well conditioned, where no dead leag exist and where temperature is correct at any point is not subject to corrosion, scaling damages or bacterial growth.

5 Certifications attached to water distribution systems

5.1 The need for certification

All the above mentioned evolutions lead to the necessity of having a control on the different actions during operation and maintenance of water distribution systems. In France a third party certification exists, which is for the owner, or the person responsible for drinking water quality at user's tap, a guaranty of good practice and correctly carried out operations.

5.2 The reference documents

The certification is based on reference documents which can be of different nature.

5.2.1 Standards :

- materials or product standards (copper tubes, hot dip galvanisation, …)
- device standards (softeners, chemical dosing pumps…)

- implementation standards

5.2.2 Technical agreements :

Products or precesses for which no standard has been written can be covered by a technical agreement. It is for example the case for pipes made of synthetic materials or water treatment processes.

5.3 The corresponding certifications

5.3.1 NF certification

It corresponds to the products where a standard exists (copper tubes, taps, PVC pipes; polyethylene pipes, regeneration salts for softeners, for example). This certification is based on regular product and quality systems in factories controls.

5.3.2 CSTBat certification

It corresponds to the products under a technical agreement (Other sysnthetic material pipes, adhesives, multilayer pipes for example). This certification is also based on regular product and quality systems in factories control.

5.3.3 CSTBat Service certification

It corresponds to a process certification and is today applicable to water conditioning processes, softeners maintenance and water systems disinfection. It is deliverd according to the ability of a company to carry out the process correctly, as defined in the certification rules. It will soon be also applicable to water systems diagnosis. For water conditioning process, this certification is based on :

- technical agreement of the conditioning chemical, with quality control of the product and of the factory.
- regular control (usually once a year) of installations where the process is operated, with water analyses and corrosion and scaling controls, conformity to design specifications written in official technical guides.

Sanitary hot water installation

Checking a control pipe

6 Conclusions

During the last ten or twenty years, water distribution systems have totally changed, passing from simple installation to a more sophisticated system. In parallel, the complexification of regulatory systems in many countries lead to new responsibilities and the necessity of more controls during operating and maintenance, in order to keep permanently up to the occupant's tap the quality of potable water. A panel of certifications is existing in France, and gives to the owner or responsible person the guaranty that each contributor has correctly carried out his job.

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Title : Real World Testing of Drain Line Carry

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Abstract

In the United States, there are a number of standards that determine the operations of water closets and the subsequent disposal of waste water and bulk waste through the sanitary drainage piping system. Working in conjunction with these standards are various local and state plumbing codes that mandate additional minimum standards affecting installation and final operational aspects of these fixtures. Size of drain line pipe, types of drain line pipe material, pipe installation slope and attachment to new or existing infrastructure all must be properly integrated to assure the proper movement and disposal of waste water.

Over the years, technology has advanced and engineering and design of plumbing systems has continued to evolve. In addition, there are environmental considerations regarding the assurance of safe drinking water and future water supply that now mandate, for example, the amount of water that will be used to discharge through a water closet. Programs such as LEED, Leadership in Energy and Environmental Design and the development and engineering of high performance and self-sustainable buildings has all combined to require new protocols and better "real world" testing of all water use fixtures.

Of considerable concern are retrofit situations utilizing modern ultra low flow water closets (ULFWCs) installed on older infrastructure systems. New engineering and design provides for the integration and creation of efficient and effective piping and plumbing systems. Anecdotal evidence indicates that retrofitting modern fixtures on 25 and 50 year old systems creates serious negative affects on overall performance.

Current testing by the American Society of Plumbing Engineers Research Foundation (RF) has begun to analyze and examine just one of the variables: drain line carry of waste and waste water as a function of ULFWCs. As lower volumes of water are being utilized in ULFWCs to remove wastes from the bowl, it becomes intuitively obvious that the ability of the sanitary drainage system to move waste sufficiently will be affected.

The current test installation and protocols utilize an accurate and a fully functional plumbing system. Accommodations have been made to permit measurement and visual inspections of the interior of the drainline. Initial operational design factors are establishing benchmarks, identifying the variables for the standardization and statistical consistency required for accurate measurements. Factors being reviewed include the decision for and/or creation of the test bulk media, ULFWC waste water discharge curves and waste transport in sanitary piping systems.

The testing apparatus utilizes variable sanitary drainage piping system material (e.g., polyvinyl chloride (PVC) and cast iron) in different diameters (e.g., 3" and 4") and slopes (e.g., 1% and 2%), requires each ULFWC to be properly mounted with a sealing ring and incorporates apparatus to permit the testing of vented versus non-vented systems.

Initial results have provided some tantalizing data.

1. Finding a realistic test bulk media has become a crusade unto itself.
2. Regardless of the test media, the differences in the roughness coefficient for new coated cast iron and new PVC have profound effects on the travel distance of test bulk media.
3. Vented and non-vented plumbing systems affect the discharge flush curves of ULFWCs.
4. The different discharge flush curves of the ULFWCs have a significant affect on the travel distance of test bulk media in the various piping systems.

Keywords

bulk media
discharge curve
drainline carry
ULFWC – Ultra Low Flow Water Closets
waste transport distance

Introduction

As a result of the United States of America Energy Policy Act of 1992, the maximum volume of water mandated for one flush of a water closet was reduced. Originally using 3.5 gallons or more, the maximum volume of water now allowed by this act is 1.6 gallons of water per flush. Ultra Low Flow Water Closets (ULFWCs) is the name given to water closets complying with this legislation. Although this move was made to improve the efficient use and conservation of water, the original ULFWC performance fell short of properly flushing with a 1.6 gpf volume of water thus projecting a negative connotation to not only the plumbing industry but the general public as well. Over the years, technology has advanced and engineering and design of plumbing systems has continued to evolve. Today, there are many ULFWCs on the market changing the negative stigma of low flow flushing capabilities.

Additionally to the Act of 1992, the United States has a number of standards that determine the operations of water closets and the subsequent disposal of waste water and bulk waste through the sanitary drainage piping system. Standards have been created to ensure the health and welfare of the public by setting procedures and minimum requirements for testing equipment, materials, and fixtures. ANSI (American National Standards Institute) A112.19.6 and ANSI A112.19.2 are two such standards directly related to testing ULFWCs. Solids removal, rim wash, dye rinse, water consumption, and hydraulic characteristics are tested to identify if the bowl clearance for a ULFWC complies with the standard. Working in conjunction with these standards are local and state plumbing codes mandating additional minimum standards affecting installation and final operational aspects of these fixtures. Drain line size, piping material, pipe installation, slope, and attachment to new or existing infrastructure all must be properly integrated to ensure the proper movement and disposal of waste water.

As a result to ensure new water closets are functioning properly with respect to lower volumes of water, analysis and examination of just one variable: drain line carry of waste and waste water as a function of ULFWCs has begun by the American Society of Plumbing Engineers Research Foundation. Research includes the following: Bulk media development and testing, bowl clearance, waste transport, testing, and findings to date.

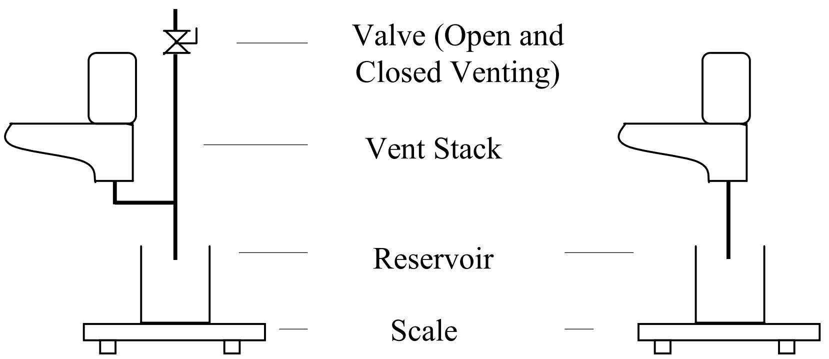
Objectives

Prior to beginning the set-up, testing, and all research, a clear concise set of objectives is was set in place. The following is a list of objectives identified for the research study:

- The test installation and protocols must utilize an accurate and a fully functional plumbing system to simulate as close to realistic situations as possible.
- The bulk media with which to test ULFWCs requires research and must replicate real situations to the best of its capacity. Developing a reusable and comparable media for testing has been be a study within itself.
- A baseline, of flush curves, to compare water closets, needs to be established and identify variables for the standardization and statistical consistency required for accurate measurements.
- Determine the performance of a variety of water closets based upon waste transport performance and categorize their results based upon their individual flush curves.

Set-Up

Two test rigs were constructed. The first test rig consisted of ULFWCs and a reservoir mounted on a scale to discharge into directly. Both open and closed venting were part of the test set up (See Figure 1). The second, ULFWCs properly mounted on a test stand providing sufficient vertical height to connect waste piping to the sealing ring at the water closet's discharge waste pipe connection and run 100 feet of waste piping at the prescribed slopes. The most common waste piping systems are polyvinyl chloride (PVC) and cast iron and were thus utilized as the sanitary drainage piping system materials for testing. Minimum waste pipe sizes connected to any water closet (WC) are 3 inch and 4 inch diameters and were chosen to test. Each piping set up is to be tested at ¼-inch drop per foot (2%) and 1/8-inch drop per foot (1%) slopes. Apparatus permitting testing drainline carry with vented and non-vented systems were incorporated into the set-up for both test stand configurations. (See Figure 2 for the second test stand set-up).



a. Open and Closed Venting Configuration

b. Straight Pipe/Direct Discharge

Figure 1: First Test Rig Configuration

Bulk testing media

Human Waste

Finding a realistic test bulk media has become a crusade unto itself. To determine a media to represent human waste as close as possible, properties must be examined. Characteristic traits such as: Mass, specific gravity, content make-up, decay rate after discharge, and types (or categories) of stools are identified.

It was determined that the typical stool resulting from an American diet will have an average mass of 120 grams and a maximum of 250 grams. Containing 75% water, the remaining portion is made of 1/3 living cells, 1/3 dead cells, and the rest is indigestible material from the diet.[1] Fiber and excreted biliary compounds fall into the category of indigestible material.

Figure 2: Second Test Rig (Test Stand) Constructed at the Energy Systems Laboratory at Texas A&M's Riverside Campus

Depending upon the type of stool discharged into the bowl of the ULFWC affects the decay rate and possible adhesion to sanitary piping walls after discharging from the bowl. According to research conducted in 1976 at the Bristol School of Medicine, there are a variety of stool types. Based upon this research, the school has developed a scale called The Bristol Stool Scale, which categorizes stools into 7 types. (See Table 1).[2]

Table 1: Bristol Stool Scale	
Type 1	Separate hard lumps
Type 2	Sausage-like, but lumpy
Type 3	Sausage-like, but with cracks on surface

Type 4	Sausage-like, smooth and soft
Type 5	Soft blobs with defined edges
Type 6	Fluffy pieces with ragged edges, mushy
Type 7	Watery, no solid pieces

At this time, decay rates for human stools after discharging into an ULFWC and leaving the bowl is still under research. Undoubtedly, the stools listed above will play some role in transport distance based upon their type. Additionally, possible smearing on the waste piping wall is an important factor which little is known. These are all critical factors in determining how waste travels through the sanitary piping.

Paper Waste

To crumple or fold, that is the issue of the tissue. There have been many unofficial studies done on this topic. But, what seems to be apparent is that the line is split closely down the middle. According to a study done by Kimberly-Clark in 2000, percentages of tissue wadding versus tissue folding people are confirmed. The research found 40% of the 1,012 people studied wad or crumple toilet tissue. Even more interesting than that, whether one-ply- or two-ply-toilet paper is used, the total 4.5 in. x 4.5 in. squares used is still the same. Averaging between 5.6 to 8.6 sheets of toilet tissue per visit to the bathroom. Not only did Charmin find the average sheets used per visit from their study, but added that a total of 57 sheets were used per day per person.

However, another online survey titled, "Paper Use Survey", was conducted through the web site *Poopreport.com*. The survey found out from 45 responses that an average 24 squares of toilet tissue were used during each visit to the bathroom. Although this survey was by no means scientific, it does provide an insight into the magnitude of paper being utilized. To date, no tests at Texas A & M University (TAMU) have included any paper during flushing.

Noticing the difference between the studies shows the dramatic variance in results. Connecting toilet paper use to the Bristol Stool Scale is almost mandated by the large differential. If more of the 45 people from the, "Paper Use Survey" experienced Type 5 or Type 6 stools from the scale, the need for more toilet tissue per visit to the bathroom would be speculated. Future testing using toilet tissue has been recommended to be 63 squares. This was the top end of the survey results and provides full range of potential experiences for the North American population.

Simulate Waste Media

ASME (American Society of Mechanical Engineers) Standard A112.19.6 defines current testing standards for the hydraulic performance of ULFWCs. Polypropylene balls are used to represent the human waste to be removed from the bowl in this standard.

Performance of the ULFWC is based upon 100 balls and the ability of the water closet to clear a minimum of 75 balls when the water closet is flushed with 1.6 gallons of water. The density of polypropylene balls may be more than sufficient to study the power of the flush for a water closet. But, when it comes to carrying media through the waste line after exiting the bowl of the water closet, the balls do not work well in comparison to human wastes. The balls are lightweight and round. In addition to the slug of water, the slope of the piping could potentially allow the balls to continue to roll and be carried far enough to pass any performance test established.

Food, sponges, wads of paper, bean curd, and processed soy products are all materials that have wound up being used as bulk media substitutes for human waste in one independent test or another. A bulk media needs to be reusable to reconstruct tests equivalent to the next and consistent with actual waste characteristics to provide accurate results. Otherwise, testing that does not convey real data is worthless.

Media types considered for evaluation in this research include: Silicon (smooth/encased and tacky cylinders), Latex, DriWater, Play Doe, Gak, a mixture of cornstarch and water, and "water wigglers". Most of the materials did not have reusable qualities or parallel the human stool. In the case of the silicon cylinders, the combination of smooth and tacky media got stuck in the trap of the ULFWCs and virtually became cemented to the waste piping walls after dropping out of the discharged water slug. Ultimately, the test piping had to be disassembled in order to pry the media from its final resting place. Although foam latex may be similar in volume, the density was not homologous with a human stool and would become lodged in the water closet trap way.

Dri Water is a gel-like substances used as a time released plant watering system. Made of 75 percent water, the characteristics of feel and flexibility are right. Unfortunately, durability was not sufficient. During each flush cycle of the test performance sequence, 15 percent of the product was lost. The residual of products considered did not perform adequately, except for one.

The material of choice upon which the measurements for this test are based is a "water wiggler". The Sponge Bob Square Pants™ children's pool toy has proven to have a comparable mass (250 grams for two "water wigglers") to the maximum stool of the American diet. Furthermore, the density (70 pounds per cubic foot) and size (one and one-half inched in diameter by fours inches long) is commensurable to the human stool. (See Figure 3.) A final determination how the "water wiggler" compares with true human waste has not been completed, however, valuable data has been found and indicates how waste transport through a piping system can be correlated to a specific ULFWC discharge curve. "Water wigglers" have proven to be a reasonable working media to date, but efforts to find a better bulk media substitute continue.

Figure 3: Sponge Bob™ Water Wiggler

Bowl clearance

According to the Environmental Protection Agency (EPA), there has been very little difference shown in the field and laboratory studies over the last thirteen years regarding the incidence of clogging and multiple flushes between 1.6 gpf and 3.5 gpf toilets.[3] Thus, bowl clearance has been an issue long before 1.6 gpf water closets were introduced.

There is still continued debate about the volume of water to be used in a water closet. ULFWC bowl clearance is improving as manufacturers come out with better technology for each new generation of water closet.

Waste transport

Most manufacturers use bowl clearance as a selling point to their product. Waste transport is just as important of an overall issue and often overlooked by some manufactures. Of considerable concern are retrofit situations utilizing ULFWCs installed on older infrastructure systems. New engineering and design provides for the potential to integrate and create efficient and effective piping and plumbing systems. However, confirmation of effects of new technology such as ULFWCs and other water efficient plumbing fixtures on existing systems are still needed. As the push for lower volumes of water becomes greater, ASME A112.119.6, which governs the performance requirements for water closets, must be met. The standard reads, in part that"The average carry *(transport)* distance… shall be forty feet or greater."[4]

Testing

Discharge curves

The initial testing of the apparatus was done to establish discharge curves for each ULFWC. Using the first test rig configuration and water without toilet paper or bulk media, measurements were taken continuously through the entire flush cycle of the water closet. The data collected is correlated to discharge rate and time in Figure 4.

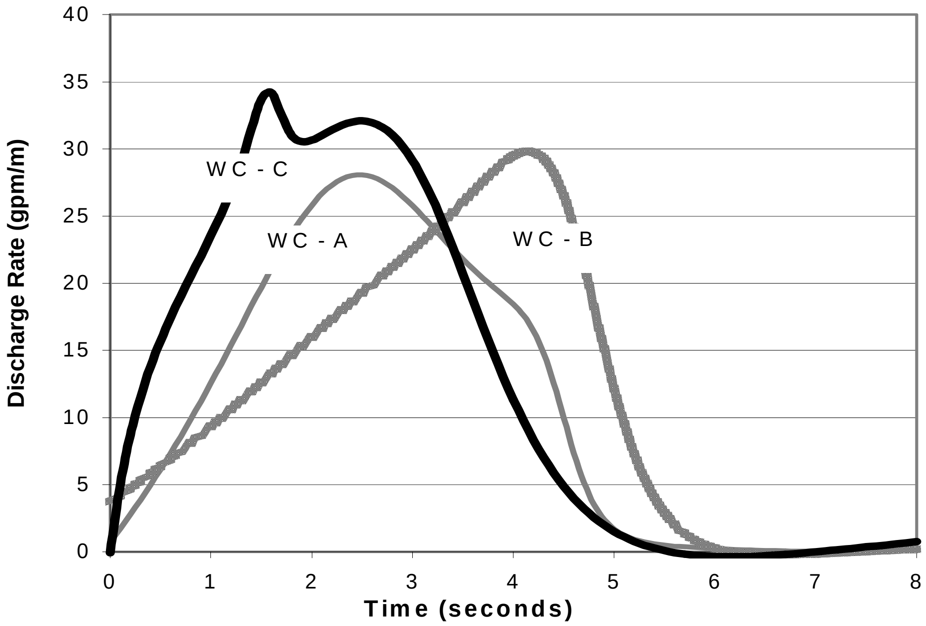


Figure 4: Three Distinct Flush Curves

From Figure 4, WC-B represents a water closet with a slow late peaking flush. Conversely, WC-C peaked early thus indicating an early discharge of water from the bowl within the entire cycle of the flush.

For each water closet tested thus far, three variations of the test were conducted. Scenarios taken into consideration to establish discharge curves were: open venting, closed venting, and direct discharge into the reservoir (See Figure 5). It was determined from the data, there is not a significant difference between discharge curves, for each water closet, due to vent position or a direct discharge from a straight pipe.

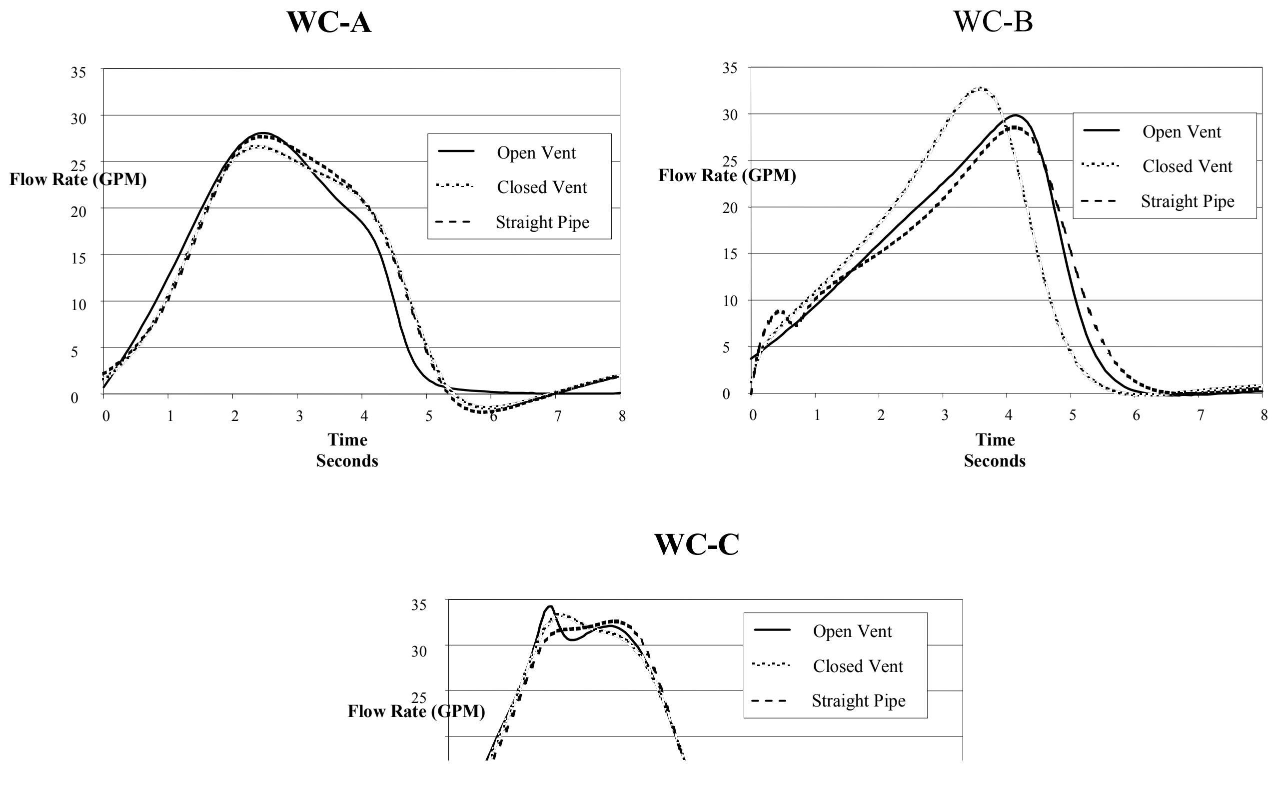


Figure 5: Three Different ULFWCs Discharge Curves
Under Open Venting, Closed Venting, and Direct Discharge Conditions

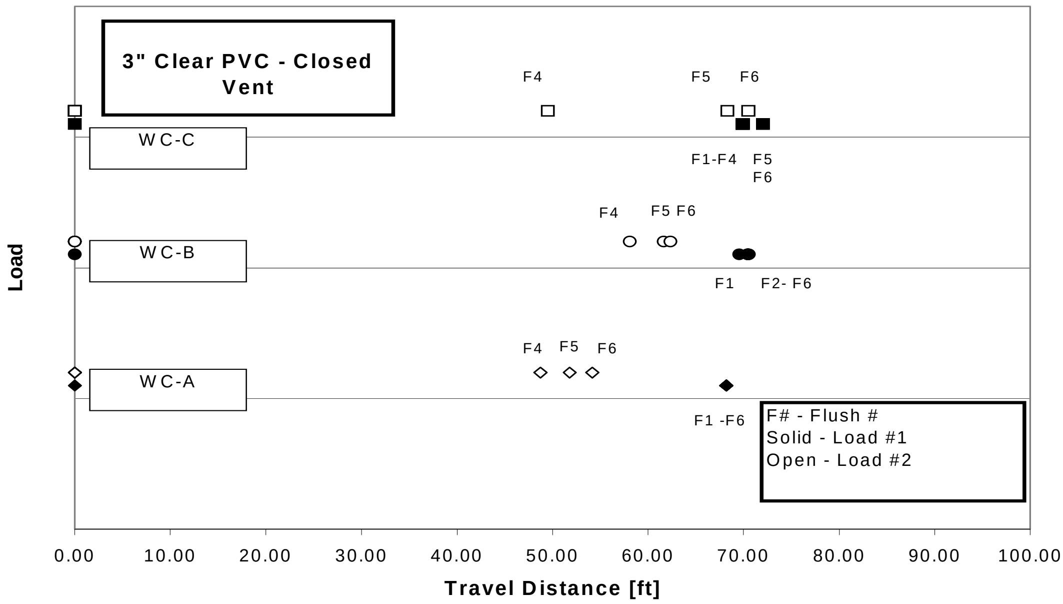
Water drainage systems, multiple plumbing fixtures and related vents, come into play when connected together. Discharge curves will respond differently in this configuration. At this time, no testing or protocol has been developed for water closet flush curves in a multi-fixture system.

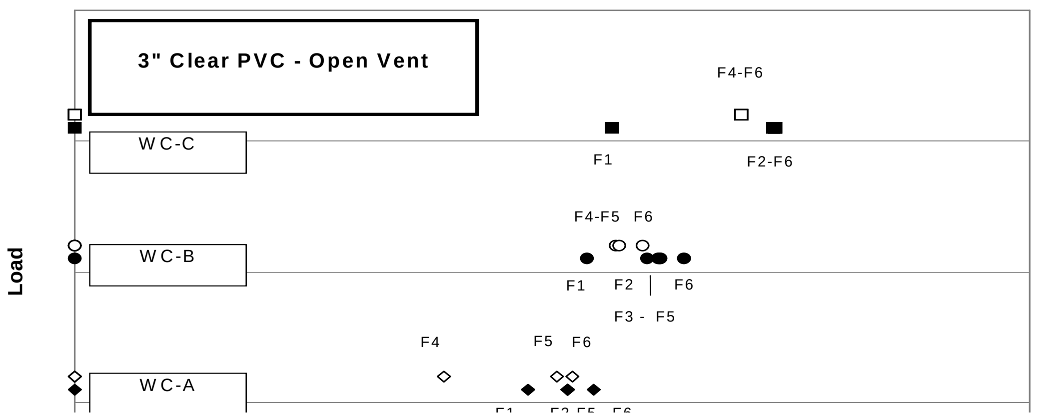
Waste transport

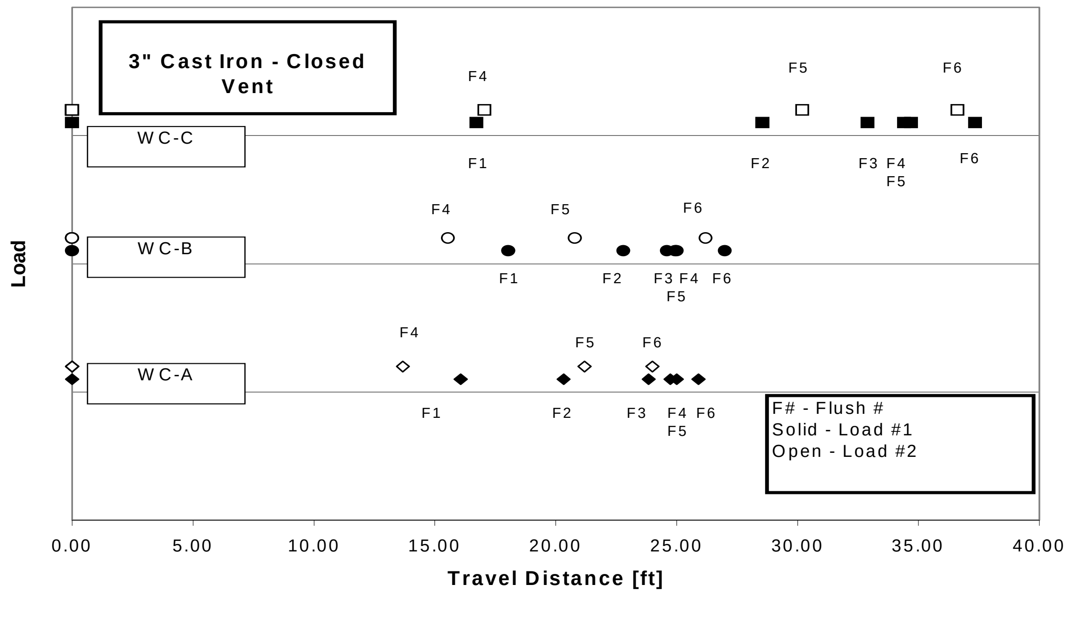
Moving on to the next phase of testing for the ULFWCs, entailed using the test stand (rig number two), the bulk media (water wiggler pool toy), and sloping the waste piping 1/8-inch per foot. Table 2 represents the procedure for which each water closet was tested. A duration of five minutes was established (held) between each flush of the flush sequence.

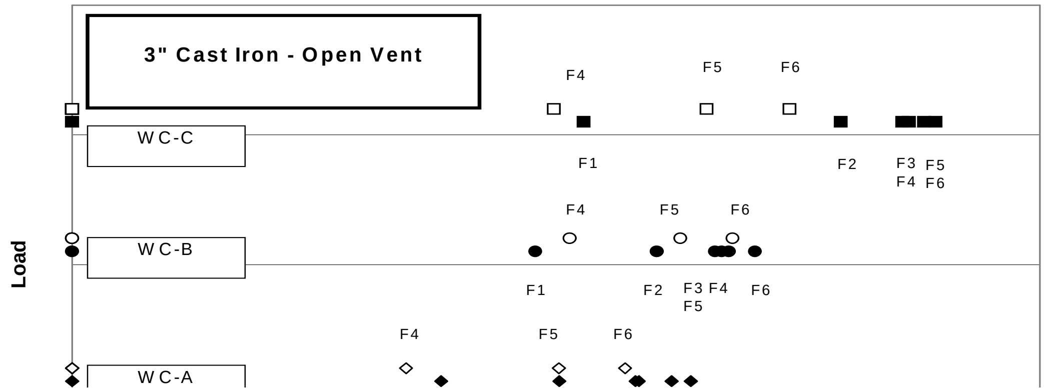
Table 2: Waste Transport Performance Flush Sequence		
Flush Number	Flush 0	Wetting Flush
	Flush 1	Load #1
	Flush 2	Wetting Flush
	Flush 3	Wetting Flush
	Flush 4	Load #2
	Flush 5	Wetting Flush
	Flush 6	Wetting Flush

Testing procedures were repeated for both an open and closed venting system for each ULFWC. Results for the 3-inch PVC and 3-inch cast iron pipe tests are represented in figures 6a-6d.



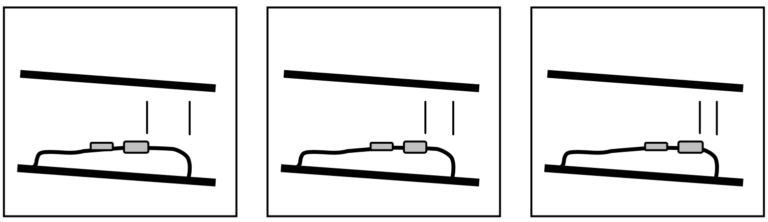



3" Cast Iron - Closed Vent
F4
F5
F6
WC-C
F1
F2
F3 F4
F5
F6
F4
F5
F6
WC-B
F1
F2
F3 F4
F5
F6
F4
F5
F6
WC-A
F1
F2
F3
F4 F6
F5
F# - Flush #
Solid - Load #1
Open - Load #2
Load
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
Travel Distance [ft]


3" Cast Iron - Open Vent
F4
F5
F6
WC-C
F1
F2
F3 F5
F4 F6
F4
F5
F6
WC-B
F1
F2
F3 F4
F5
F6
F4
F5
F6
WC-A
Load

Findings
The water closets fell into three flushing categories. The categories are labeled as: Early peak short duration, linear ramp, and long peak. The best performance, to date, was found to be early peak short duration. It was observed that when a large volume of water is capable of exiting the tank and discharged into the bowl early in the flush cycle, it caused the water to have a greater impact force on the contents in the bowl.

A correlation between media location in the water slug and flushing category was verified in the 3-inch clear PVC piping. A visual inspection of the media immediately after discharge from the bowl confirmed that the media rides nearer the front of the water slug for an early peak short duration flush (see Figure 7).



WC-A	**WC-B**	**WC-C**
3.5 Second Time Lag Between Load #1 Behind Front of Water Slug	3.25 Second Time Lag Between Load #1 Behind Front of Water Slug	2.5 Second Time Lag Between Load #1 Behind Front of Water Slug

Figure 7: Position of Water Wiggler on Water Slug 10 Feet in 3" PVC Pipe From Discharge for WC-A, WC-B, and WC-C

Additionally, the media was found to travel further distances when it was located nearer the front of the water slug. In all cases tested (3-inch PVC, 3-inch cast iron, 4-inch PVC, and 4-inch cast iron both open and closed venting) the early peak short duration discharge curve (WC-C) out performed the other two discharge curve categories. See Table 3 for a summary of travel distance results for 3-inch PVC and 3-Inch cast iron.

Investigation of the effective roughness for PVC and cast iron paralleled the findings thus far. Table 4 gives the values for PVC and cast iron. In the case of each discharge curve category, the travel distance through the 3-inch PVC was greater. It has been hypothesized by some industry sources that as the aging process begins in a piping network, the effective roughness for most piping converge to the same value. Further research and investigation are required to confirm not only the validity of this claim, but the new effective roughness value.

Table 3: Summary of Results for Load #1

Position after Flush 1 and Flush 6

		WC-A		WC-B		WC-C	
		Initial [ft]	Final [ft]	Initial [ft]	Final [ft]	Initial [ft]	Final [ft]
3" PVC	Open	47.45	54.35	53.65	63.80	56.25	73.40
	Closed	68.20	68.20	69.50	70.50	69.90	72.05
3" CI	Open	13.35	22.40	16.75	24.70	16.75	37.35
	Closed	16.08	25.90	18.05	27.00	18.50	31.23

Investigation of the effective roughness for PVC and cast iron paralleled the findings thus far. Table 4 gives the values for PVC and cast iron. In the case of each discharge curve category, the travel distance through the 3-inch PVC was greater. It has been hypothesized by some industry sources that as the aging process begins in a piping network, the effective roughness for most piping converge to the same value. Further research and investigation are required to confirm not only the validity of this claim, but the new effective roughness value.

Table 4[5]: Effective Roughness of Conduit Surface

PVC	0.00005 ft
Cast Iron	0.00085 ft

Conclusion

Continuation of this research goes on as new ULFWCs are donated or purchased. It is the intention of the Research Foundation to test approximately 200 plus water closets in this phase of the study. It is also the intention of the Research Foundation to publish the results of this study in the form of categories of Flush Curves vs. Drainline Performance. It is not the intent of the Research Foundation to publish the manufactures names and model numbers of the products used in this study. This study is being conducted for the purpose of providing the ASPE membership with data that they will be able to use in their day-to-day system design efforts. It will be the design engineer's responsibility to interpret the data and use the water closets that fit into the flush curve required for each project.

Acknowledgments

Dr. John Bryant, Associate Professor; Greg White, Research Assistant, Texas A&M University, College Station, TX, USA

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Presentation of Author (s)

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Water Closet Tests Survey, Limit Impacts and Variations

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Abstract

Waste load solids materials for water closets acceptance testing were applied in fixed and varied solids quantities in two U.S. and Canadian projects. Results were compiled to apply in water conserving applications from the relative ranking. One set used increasing loading of sponge solids and crushed paper loads in an expanded "Flush Performance Index" or "Clog Index" extraction weighting scoring system. Relative performance comparisons include incomplete extractions for weighting performance. The other approach applied cylindrical test media (from extruded bean curd) at increasing loading increments for total extractions. Acceptance set achievement of total extraction in two of three tests to move up to the next loading. Added loading increments established maximum extraction total loading (MaP) value. Less than 250 gms extracted were considered unacceptable. Data from the same model WCs with both methods did not demonstrate correlations; distinctive differences in methodology applied were probable cause. A research goal for data comparisons and correlations remains open-ended unless detailed basic (raw) data are provided by the investigators.

Keywords

Performance criteria, test evaluations, standards, waste test media, water closets

1 Introduction

Waste solids extraction and drain pipe transport continues to be a major concern in evaluation of low flush volume water closets (WCs). Laboratory testing for solids extraction vary in national plumbing regulatory requirements that apply differing test methods. There is lack of agreement by knowledgeable specialists for suitable test media loads. A need remains for standard test material specifications of uniform/reproducible properties and dimensional tolerance limits. Specificity is required for measurement confidence and testing reliability. Reproducible test results and statistical validity determinations are essential constraints not practiced.

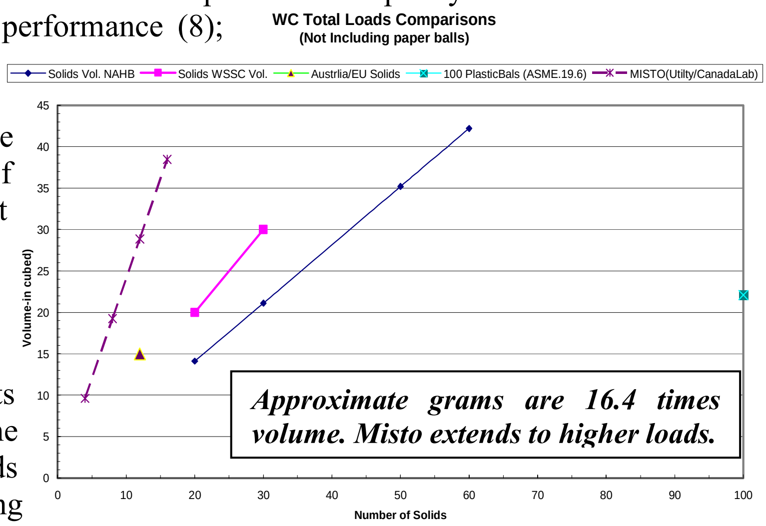
Detailed data reports and applications for incomplete extraction acceptance (1, 2) or discards for partial extraction (3) compete with total extractions (although valid tests are dropped when lesser performance occurs). Statistical validation procedures are not set for acceptance criteria that accounts for a limited extent of incomplete extractions. Partial extraction(s) limits in pass/fail requirements could project improved characterization to anticipated usage. Discussion of skewed data distribution(s), typical of WCs extraction for acceptance criteria in standard requirements for solids extraction testing (2) indicated statistical considerations.

Requirements for representative test media materials from actual waste discharge contents are feasible from reported field measurements (4). Realistic pass/fail criteria from credible evidence would be accomplished. Also, essential input is required from field usage WCs, with known failures or acceptable performance. Environmental Protection Agency (EPA) and American Water Works Association (AWWA) are undertaking establishment of a labeling program (Water Star, similar to existing Energy Star) for water/energy conserving fixtures and appliances (appliances require energy information labels in the U.S.); however, no similar WCs information is required to assist selection by consumers, plumbing engineers or specifiers.

Two different projects with differing materials and loadings as well as methodologies for waste solids extraction performance criteria are discussed. One applied sets of solids, either of sponge ‘sinkers’ or ‘floaters’ (not combined loads) with added crushed paper that included partial extraction weighting for evaluations (5, 6, 7). The other (14) used progressive loadings of extruded cylindrical bean paste solids and required two of three complete extractions in order to advance to the next loading sequence for a progressive WCs performance ‘Maximum Performance (MaP)’ scale based on total solids extractions.

1.1 Test Media

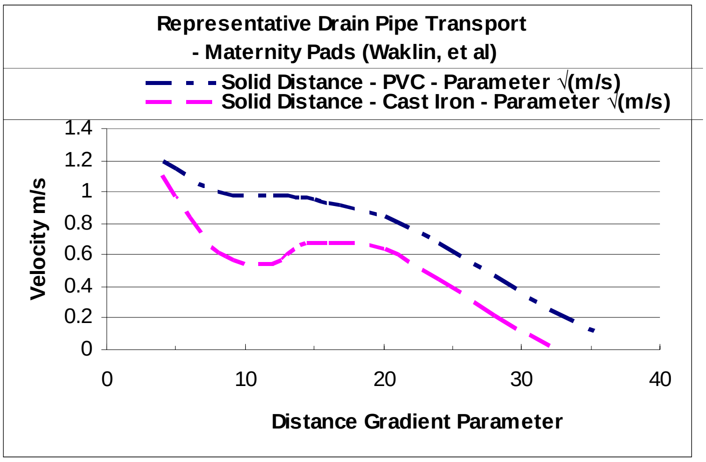
Extraction materials volumes and numbers are shown in the figure (paper ball small volumes not included). ASME standard plastic balls specify distinctive differences for WC waste extraction performance (8); other data do not show such effects since only complete extractions are required. Large numbers of balls may cause apparent added loads due to constrained (entrapped) water volumes at interstices adjacent to body contacts that limits initial flow at start of the flush (prior to solids dislodgment) as a retarding inertial effect to be overcome.



Load materials applied include plastic balls, paper towels, sponges, water filled cylinders (pliable encapsulations), extruded bean paste cylinders. Combined material loads are designated ‘mixed media’. Some tests imply waste solids transport in drains with all solids removal required and specify clear water only in the latter portion of the profile for drain transport (3, 7). Transport from clear water flush tail for waste carry in the drain has not been verified. In (1) plastic balls 40 ft average transport test distance is required (despite overlooked ball rolling effects).

1.2 **Configuration for Water Closet Solids Extraction Testing**

Vertical downward WCs outlet outflow into open collection device is usual configuration of solids extractions test rig. That is not representative of building drainage systems that requires a turning fitting attached to horizontally pitched branch drains pipes. The turning causes flow and solids dynamics deceleration effects from fittings as shown from maternity pads test data (9) for initial deceleration with re-acceleration from the turning effects and pipe friction attenuation for smooth and rough pipes/fittings. The turning fitting reduces momentum in transition from vertical to nearly horizontal direction that requires reacceleration by the WCs surge wave; wall friction attenuation reduces velocities.



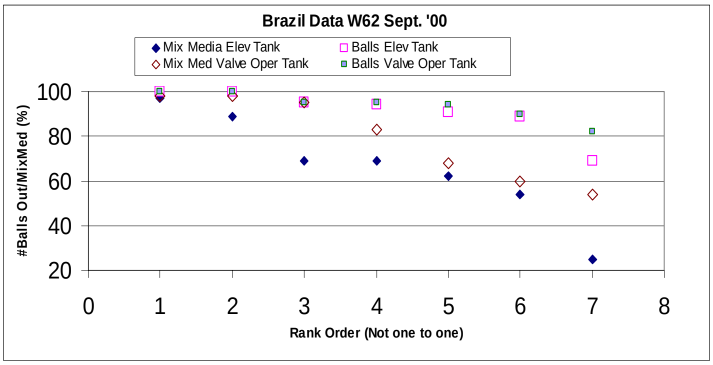
Difficulties arise for controlling factors for replication on solids extraction variables of discharge surge water energy, solids location in the water discharge rate profile, and energy collision exchanges. No extraction test evaluations have been reported for influences from pipe fittings turning models into drains with solids. WCs to drains reports stress only transport distances (10, 11) but are without details of fitting losses for radius, materials, angle change, diameters. A need exists for research on fittings (decelerations, collisions) impacts that may reduce discharge capability. None of the factors can be simulated with open air vertical outlet discharge tests. Other neglected factors in waste load testing representations require user loading data input and research from real installations (4) include:

- Distributions of floating and non-floating solids;
- Solid waste size distributions;
- Varieties of mixed components/materials;
- WC installation norms for testing configurations; representations of horizontal drain elements applied in installed WCs drainage and venting systems;
- Further effects of drain pipe wall materials, friction factors for limitations on solid waste transport and surge wave attenuation in piping;
- Realistic waste transport requirements in standards and design methods;

- Implied clear water latter discharge verification of presumed transport.

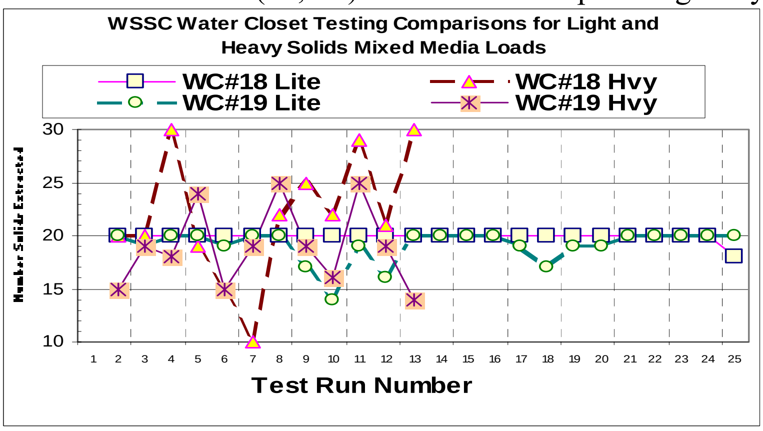
2 Conventional Resources

Averages applied to test data restrict further analyses for test materials applications or representative loading(s) and integration of field experiences are then almost impractical. Average typical overall decreasing test performance data (12) does not reveal media representations adequacy for evaluation of loads and materials; user realities that are missing leave many uncertainties for test load materials evaluation. Only feedback from user experiences in controlled test programs can introduce comparative evaluations. Although consistent data trends (and ignored) appear in laboratory testing little confidence for validity or conclusions is possible without actual field data experiences. An example is that current U. S. standard (1) with plastic balls requires acceptance criteria at 75 % extraction (on average). No label information is provided so that selective distinctions for actual test extraction performance levels can be applied in choice of WCs.



2.1 Mixed Media

Mixed media loads in Washington Sanitary Suburban Commission (WSSC) test series were undertaken to develop plumbing code changes for drainage pipe sizing of plastic and cast iron drains (10, 11). Two different specific gravity sponges (natural sinkers, synthetic floaters) as light loads while heavy loads included four baby-wipes. Light loads were 20 synthetic and natural sponge cubes; heavy loads were 26 synthetic and natural sponge cubes with four baby wipes (total 30 items) applied to 18 low flush volume WCs plus 2 WCs of 3.5 gal flush. Inconsistencies from heavy load test performances data were demonstrated and not applied in the final drain sizing developments. For light loads 14 of the 18 WCs yielded repeated discharge of all solids for 24 individual tests and were applied with confidence to pipe sizing for adequate solids transport.

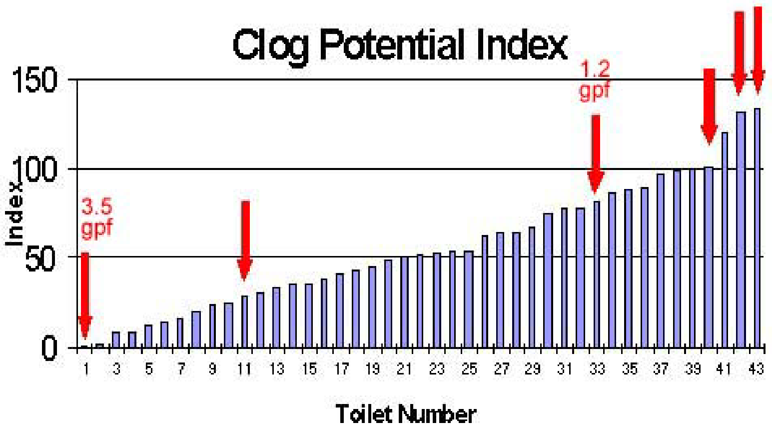


2.2 "Clog Index" a Partial Extraction Alternative

A WCs "Clog Index" introduced a scoring method with mixed media (floating and weighted sponges [(0.8x0.8x1.1) in, (20x20x28 mm)] and four paper balls) were applied. Partial extractions and user field data (5, 6, 7, 13) applied for weighting performance determinations coupled to a 'WCs Survey' of consumer satisfaction and problems. Categorization of acceptable or unacceptable usage in homes into the ranking criteria protocol introduced impacts from frequent clogging (inability to remove solids). A numerical score "Clog Potential Index" sets extraction flush level comparisons from laboratory data for "complaint and satisfactory toilets". The clog potential performance index indicates ability to flush increasing amounts of bulk media and uniquely includes specific partial extractions.

2.2.1 Test Media Challenge

Floating and sinking sponges were separately set at five challenge levels: I, II, III, IV, and V, with 7, 10, 15, 25, and 30 sponges respectively, and four paper balls. The "Clog Index" provides **rankings** for media not discharged in initial flush in all the series. A 'zero' represents no test media remained in the bowl. Increasing test data scores indicate extent of incomplete extractions. Performance was assessed relative to acceptable field performance. Arrows designate used field WCs 33, 40, 42 and 43 reported for frequent clogging problems. Toilet 33, evaluated twice (incorrectly adjusted in-service condition at 1.2 gallon per flush (gpf), had reset proper 1.6 gpf) designated WC 11. Toilet 1 is 3.5 gpf reference that owner reported satisfactory performance.



2.2.2 Application

Test WCs for loads (24 half sponges and 10 paper balls) varied from –30 % to +30 % from basic amount in user complaint and newly purchased WCs. Effective performance levels for A and C were judged despite scoring non-zero clog index value results. Consistent failures occur for B (clog index 132); N, fails consistently above basic load. Lower clog index toilets pass at +20 % indicating the importance of introducing field experiences into performance requirements.

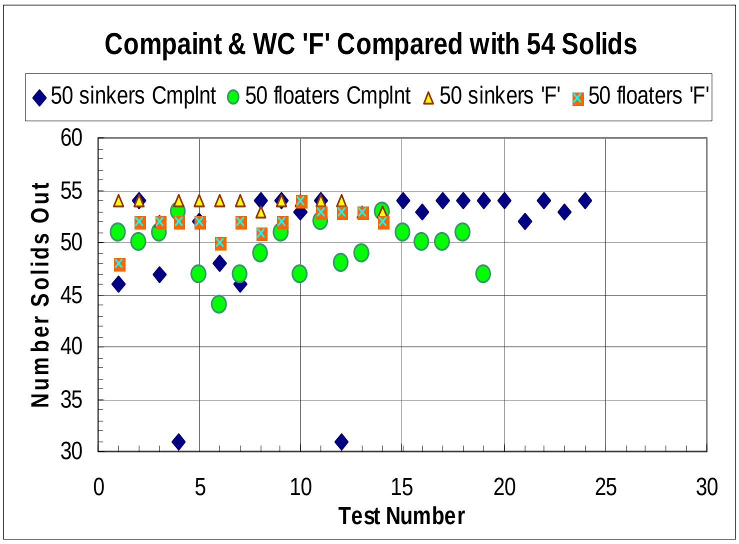
Failure Outcomes (High Clog Indices) for Five Replicate Evaluations

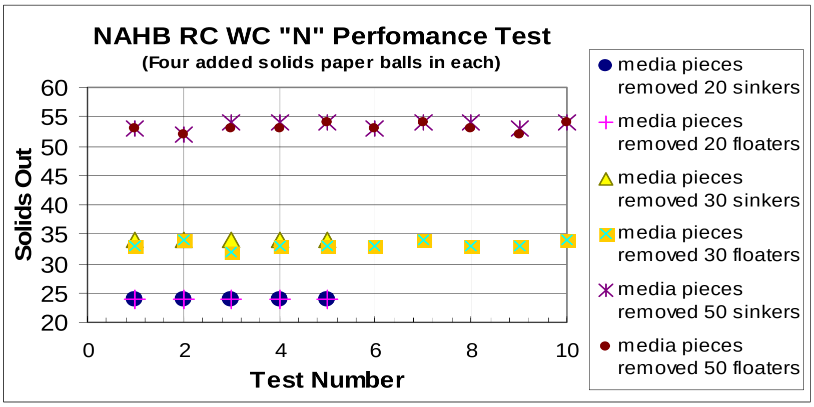
Toilet	-30%	-20%	-10%	Base	+10%	+20%	+30%	Clog Index
B complaint	**1**	**1**	**4**	**5**	**5**	**5**	**5**	**132**
N complaint	**0**	**0**	**0**	**0**	**2**	**2**	**5**	**101**
A new	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**41**
C new	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**20**

3 CLOG INDEX EXTENDED COMPARISONS

3.1 WC Data Comparisons

Extension of the 'Clog Index' to broader testing required more than five repeat tests for solids extraction since convergence data criteria were imposed. From those data the 'complaint' water closet (Cmnplnt) indicates wide variability from extraction testing with the 50 solids and 4 crushed paper balls (13). A reasonable basis is shown for troubled extraction performance. Performance distinctions become apparent from data comparisons. Data for repeat test performance, as "N", displays reproducible consistency for total extractions of that unit. These tests present a rational evaluation method with the solids applied and should have consideration potential for adapting to applications in standards. The final ranks charting for relative performance indications of the 52 WCs were published with model manufacturer and identification.





3.2 Clog Index Type Tests and Recommendations

▪ **Combined** tests with sinkers and floaters with crushed papers loads are required to evaluate mixed test media in realistic applications for determining performance; testing loads of 54 solids (possibly to 64 solids as in this series, not shown here).
▪ 'Floater/sinker/paper' **combined loads** comparisons with separated loads tests.
▪ Tests with other national standards materials in the same WCs are required. A large number of tests need to be conducted (say, seven) could establish assurance and confidence in media comparisons.
▪ Drainline transport tests, as A112.19.6 standard configuration with vent should be conducted for drain carry and impacts on drain blockages with low flush volume WCs. Emphasis on impacts from turning elbows should be part of the series.

4. NEW CONSIDERATION - MAXIMUM PERFORMANCE (MaP)

The recent project 'Maximum Performance' (MaP) evaluations applied **total load extraction** performance comparisons (14). Canadian (CSA) and U.S minimum standards (ANSI/ASME) WCs certification requirements have not assured user satisfaction with WCs in water utilities rebate programs. Those WCs allow incomplete extraction and lack labeling to enable performance capability distinctions between higher and lesser performing WCs to be made. Selective information labels, as required for energy appliances, are necessary to inform users, installers, consumers, do-it-yourselfers, plumbing engineers or local regulatory authorities.

Testing criteria set **total solids extraction** flushing performance for 80 WCs with 6 l (1.6 gal) flush and less. Pass/fail criteria required all solids extracted in two of three attempts. Average fecal load, 250 gm benchmark level (from British medical study - *Variability of Colonic Function in Healthy Subjects*) set a lowest required performance. Soybean extruded paste materials solids (assumed human waste properties) with crushed toilet paper balls were used. Those were formed in a 7/8-inch (22mm) die, cut into 50-gram specimens, approximately 100mm (4 in) length. Progressively larger loadings (in 50-gram increments) were successively introduced until complete extraction was not achieved; then the prior loading was set as the limit.

WCs evaluated, to the same test protocol, included: (i) groups of production models (two samples of each) purchased 'off the shelf'; (ii) group of single samples, manufacturer provided or prototype models. The report presented final rankings, organized by relative load levels, from two of three tests to attain complete extractions. Identifications presented model and manufacturer, in ranked order, from the lowest to best performing WCs for load ranges from 250 gm to 900 gm. Excerpted information and charts from the report are reproduced in the following pages.

5 WCs DATA RANKINGS COMPARISONS

Comparisons of the data for the same model WCs in reports for the Clog Index and MaP test methods were made to determine if test correlations of bean paste solids and sponges with paper crushed balls appear. For the same model WCs published rankings a numerical order scale (from 1 to higher numbers) was introduced for the highest load level (best performing) achieved in MaP evaluations; similarly, for the best Clog Index performance (i.e., score of **both sets sinkers and floaters**). The value 1 indicates best; higher ordered numbers progressively represent lesser total extractions or partial extraction increases, depending on each test procedure criteria. A limited number of same WCs (name/model) data sets were available; the separation of floaters and sinkers test data was not possible. Failure bean paste tests category applied when unable to achieve 250 gm as the minimum total extraction; those were identified as unacceptable (notation applies to horizontal scale only). The authors proposed that "many agencies and municipalities may consider the results of MaP testing when evaluating WCs models for to subsidies or rebates". Publicity is expected to improve models performance (current and those not previously tested or improved by MaP testing.

3.1 Flush Performance

The ability of a toilet to completely remove waste in a single flush without plugging or clogging is considered by many to be one of the most important test criteria. The flush performance test was conducted by loading the fixture in 50-gram increments of soybean paste until the toilet model failed to pass 100 percent of the media in two of three attempts. Four loosely crumpled balls of toilet paper (six sheets each) were included in each test. The toilet paper used in testing had the following specifications: single ply toilet paper conforming to ASME A112.19.14–2001, section 3.2.5.1.2. All tests were completed at 50 psi static supply pressure. The minimum level of acceptable performance in terms of loading for this project was set at 250 grams (as identified in Section 2.2).

Figures 1, 2, and 3 illustrate the maximum solids loading that each model was able to successfully clear from the bowl in a single flush in at least two of three attempts. **Figure 1** illustrates toilet models that failed to clear the benchmark of 250 grams, while **Figure 2** shows models that cleared between 250 and 500 grams (up to twice the minimum benchmark). Finally, **Figure 3** illustrates models that cleared greater than 500 grams (i.e., more than twice the benchmark of 250 grams). Results for the 44 toilet models were as follows:

- Flushed less than 250 grams: 20 models
- Flushed 250 to 500 grams: 13 models
- Flushed in excess of 500 grams: 11 models

Figure 1 – Models Clearing Less than 250g

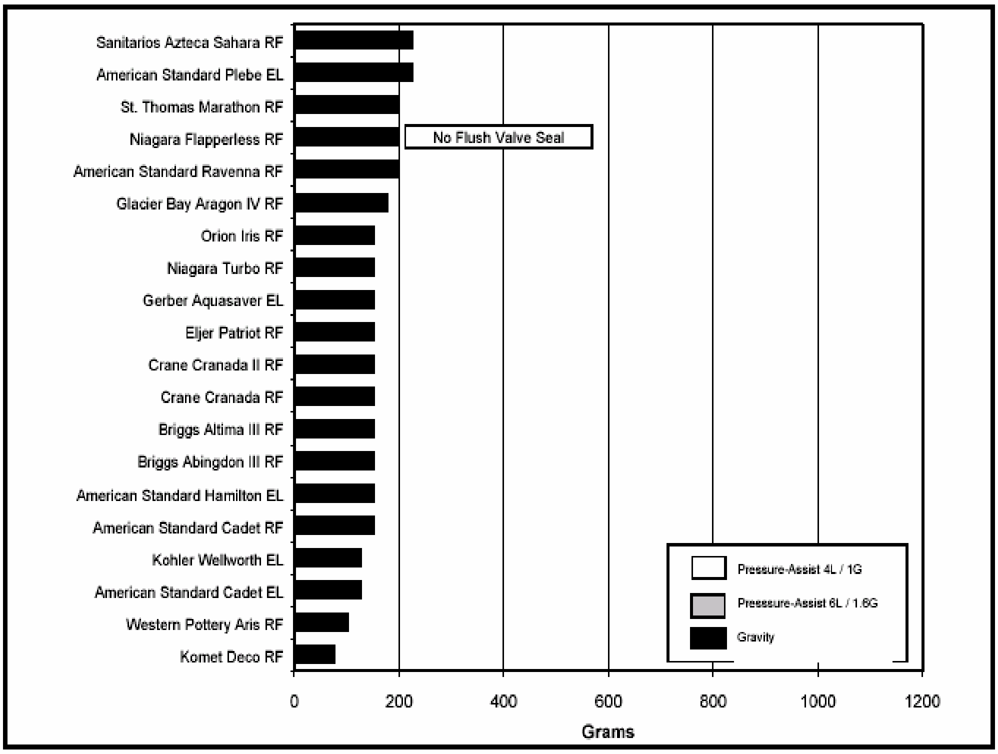


Figure 2 – Models Clearing Between 250g - 500g

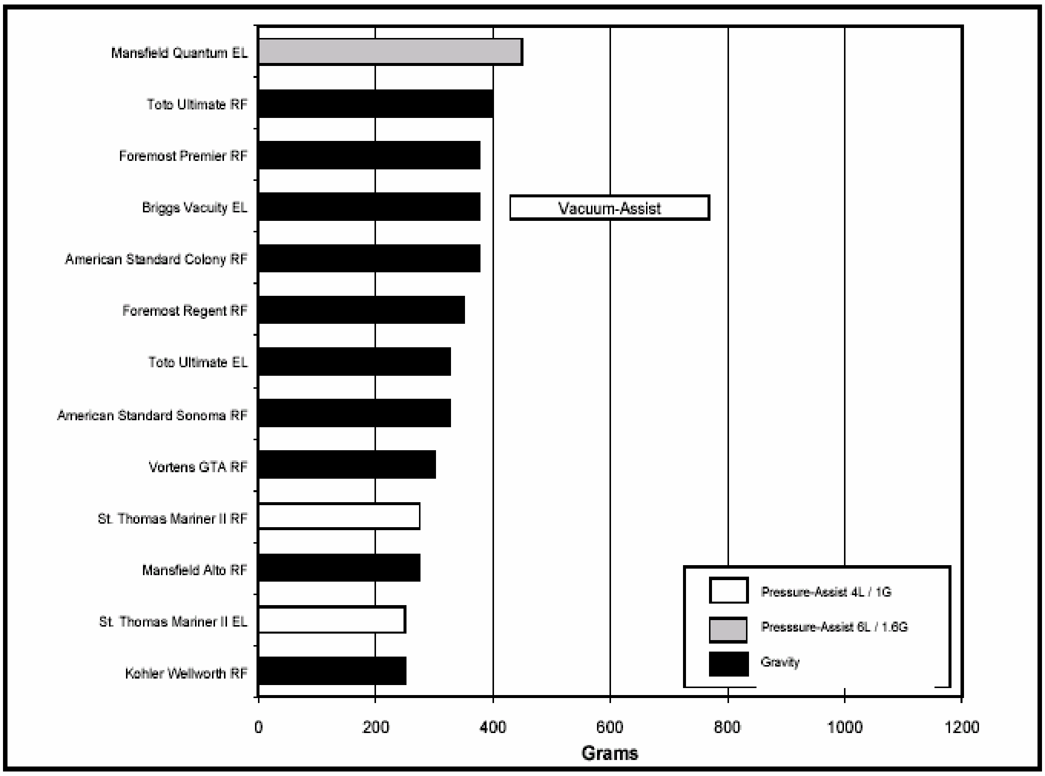
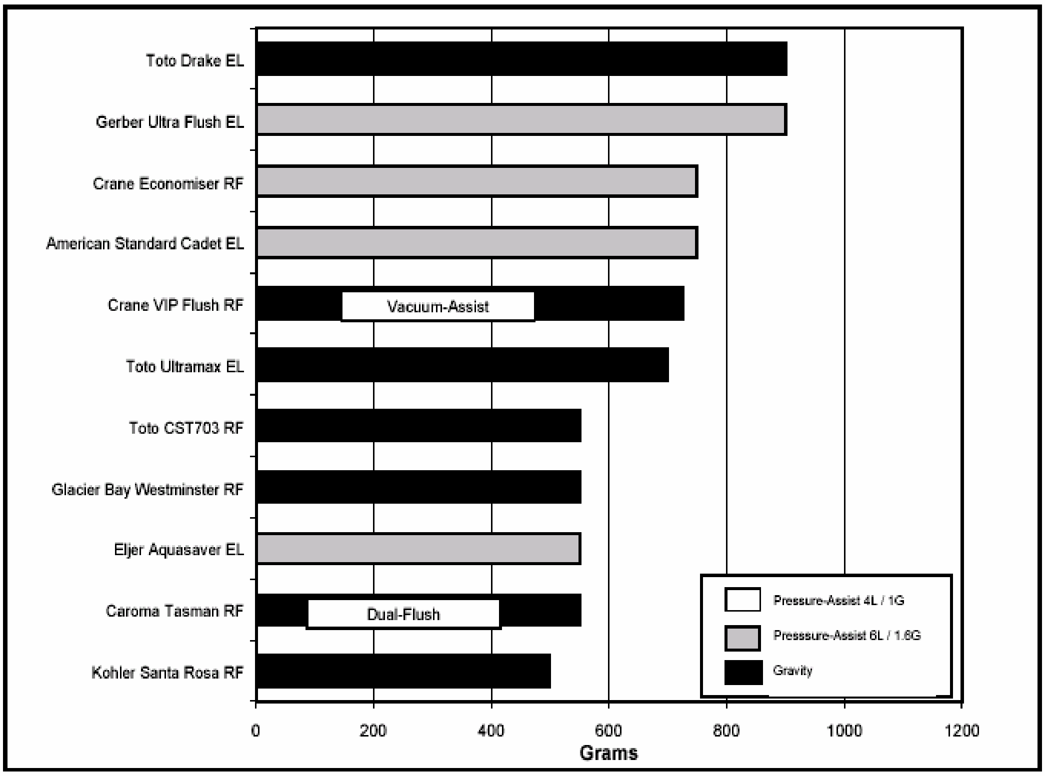
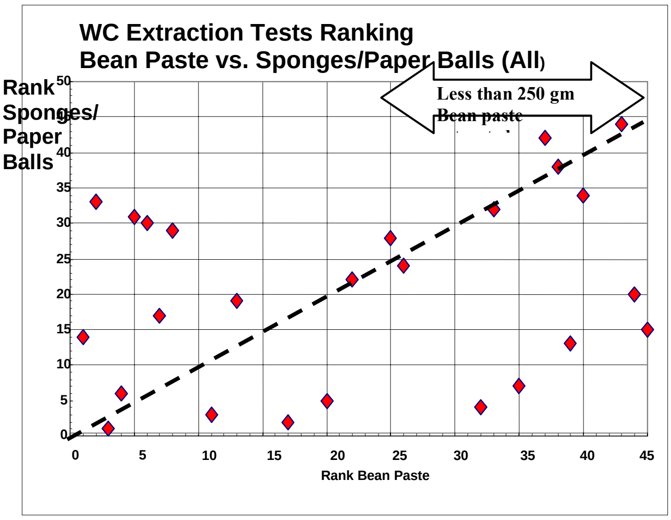


Figure 3 – Models Clearing Greater Than 500g



The lack of correlations from each method is apparent, however, lack of trends can be deceptive since test criteria for sinkers and floaters have no corresponding analogue with bean paste test criteria for total extractions only. Perplexing and contrary indications are shown from comparisons of each set of tests for better performance of the same model (i.e., those with lower numerical values). Higher performance in one test procedure appears with a contrary corresponding indication for poorer performance ranking display from the other series method. Those apparent contradictions indicate the need for detailed data as essential to have available separate data from floaters (greater difficulty to extract) and sinkers. Comparisons could then be more meaningful from similar testing conditions. Since no failure criterion are imposed in Clog Index data (that applies an additive scoring method for each solid not extracted) the proper ranking order may need revision. MaP increased extraction loads ranking is based solely on demonstrating total extraction results. It is necessary that comparable data comparisons from detailed data information should be available. MaP failure levels (below 250 gms extracted) have no corresponding Clog Index distinctions.



Manufacturing differences in performance of the same WCs (by model) cannot be entirely dismissed. Other differences may be due to insufficient tests with bean paste loadings and also that no distinctions are made when two of three tests are necessary to show complete extraction (note: two of three tests allowed for total extraction condition means one-third failure of trials occurrence, as compared from each of two tests all solids were extracted). Detailed data sets to provide a more rational basis of comparisons, e.g., sinker type tests alone; total clearance identified for three bean paste tests, whether the same or different WCs were tested in both procedures. MaP test report gave indication of wide variations since 45% of purchased models (off the shelf) failed to achieve 250-gram performance criteria despite achieving required criteria for 75 % average clearance in U.S. national standards. Also, another indication was that some WCs did not clear 100g, while another neared 900 gms. Consequently, actual test data details, rather than only a final summary, are an essential need. Requests for added details of data sets were unsuccessful.

Tests with brine mixtures and conductivity measurements for change-out showed all models performed well so such a method could not be an indicator of solids extraction performance. Testing of adjustable 2-inch (50mm) flapper replacements illustrated many were not always functional or adequate for presumed performance. Some cannot be installed on all toilet models although indicated for serviceable installations.

No replacement of non-standardized flappers or pressure-assist tanks, or interfering existing trim, was found that prevented replacement flapper operation or as impossible to adjust to rated flush volume. Projections of flapper five year lifetimes and 25 years for WCs suggest replacements may not promote water savings and subsidies for flapper replacements by agencies may find it not worthwhile.

6 Conclusions

Two WCs test methods data from different approaches for laboratory test methods and materials were discussed and comparisons illustrated. Unique aspects from sets of Floaters and Sinkers solids in a 'Clog Index" method and a Maximum Performance "MaP" method were compared for extraction performance testing determinations of the same WCs models. No correlations between those data could be determined. Introduction of weighting scores from compounding test loads data included partial extractions into ranking scores in a 'Clog Index". Introduction of user WCs field experiences were applied into ranking scored performance criteria. For maximum performance (MaP) method series of sequenced increased loadings of discrete samples of extruded bean paste cylinders were applied. A ranking method was applied to all data for only total load extraction as determined in the test series. Both methods demonstrated sequenced loads impacts from laboratory test performance.

Comparisons of test results with different varieties of solid waste media did not demonstrate correlations that could link the findings for the same model WCs. Different acceptance criteria may have been a fundamental basis that prevented test comparison correlations. Each method of varied loads representations may be useful simulations for usage conditions but that remain unanswered; portents of user variability in actual usage conditions simulation was not validated. The research need remains unfulfilled that establishes performance capabilities form laboratory testing.

Tests of user field installed WCs (returned for laboratory evaluations) are necessary feedback for laboratory evaluations was shown by Clog Index procedure. Standards and code developers should consider and evaluate expansion from both concepts for improving evaluation methods. Plumbing engineering for water conserving systems and design of drain-waste-vent (DWV) systems and water conservation efforts require assurance and confidence in WCs performance evaluations. Test materials, mixed media composition and any other solids that are necessary for laboratory test methods remains an open issue. Little effort has been expended for realistic testing simulation of loadings.

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SOUNDSPOTSIM
Instrument to predict the level of noise resulting from sewage pipes in buildings

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Abstract

The law and regulations in various countries make demands on the level of noise in rooms in a building. In The Netherlands the requirement is 30 dB(A) for the room of an adjoining apartment. Principals often make even heavier demands such as 25 dB(A) or even 20 dB(A).

Sewage pipes, especially standpipes in shafts produce such a noise level that additional measures are required. Manufacturers of sewage systems and manufacturers of material for shaft walls, each in their own way try to meet these requirements by producing silent sewage pipes, pipe insulation, whisper clamps, insulation of shaft walls, and so on.

In their communicatives they present favourable values for sound reduction as measured by their own company. These values are the result of individual measurements and it not always becomes clear how these values have been defined. Besides, there exists a possible interaction between the various parameters.

That is why the installation field (Uneto-VNI), the field of wall material (NBVG) and six manufactures of pipes (Wavin, Dijka, Geberit, Tersia, IZEG and Walraven), under the supervision of ISSO, have joint forces by carrying out measurements under equal conditions.

The internationally renowned consultant Peutz carried out these measurements in accordance with the European standard. They will also develop a spreadsheet to predict the noise level in a space that adjoins the duct shaft, by putting in the relevant parameters. For now this spreadsheet tool is called 'Soundpotsim'.

Keywords

Noise level reduction, standpipes in shafts, silent sewage pipes, pipe insulation, whisper clamps, insulation of shaft walls.

1 Introduction

In the Netherlands, the demands made on the level of noise in rooms in a building are becoming more and more important. Nowadays the building envelope has to meet strict requirements to suppress noise produced by traffic. Furthermore, noise produced by installations has to be restricted, which results in for example the use of silent taps, insulation against impact noise of sanitary appliances, lower flowvelocities in waterpipes and smart placement and division of sanitary rooms. Besides, we have to deal with sewagepipes that may, be it briefly, produce an interfering noise.

Manufacturers of sewagepipes anticipated this by introducing silent pipes that, due to a larger mass, reduce the level of noise. They also developed sound insulation materials to dress the pipes and special clamps to reduce the impact noise.

The sewage pipes in a space are generally connected to standpipes, that run underneath the other spaces, often in a shaft.

The sound insulation values of pipes, pipe-insulation and shaft wall materials separately have already been calculated. The research by Peutz was mainly focussed on the interaction between the pipematerial, pipeclamps and shaft. Almost all available pipe- and the most important wall-materials have been tested under equal conditions in a research so that a comparison could easily be made.

In our opinion this research remains unique for Europe or even the rest of the world.

2 The research

2.1 The organization of the research

First of all insight had to be gained into the noise radiation of various bare sewage pipe systems. These were measured at different discharge flow capacities. Also measured to this effect was the flushing of a closet to determine to which constant flow it could be compared. Furthermore measurements were taken of two different standpipes (sound proofing and non sound proofing pipe material) with a repositioning 2 x 45°.

Vibration level measurements in the same arrangement were taken to determine the impact of clamping on the noiselevel. The vibration level was measured at four different points on the back wall (175 kg/m^2) where the pipes were positioned. On the basis thereof the radiated construction noise level was calculated.

Subsequently shaft walls were built around two different sewagepipes and the noise radiation of the sewagepipe was then measured again. To this effect various shaft wall materials and measurements were employed.
Additionally the influence of the placement of sound absorbing material in the shaft wall was researched.
The influence of pipe insulation materials had earlier been researched by Peutz.

The arrangement for measurement is according to the Arrangement for measurement of sound level according to prEN 14366:2002 “Laboratory measurement of noise from waste water installations”
Figure 1 shows the principal of measuring and figure 2 the arrangement for measuring the bare pipes and figure 2 for measuring the pipes in the shaft.

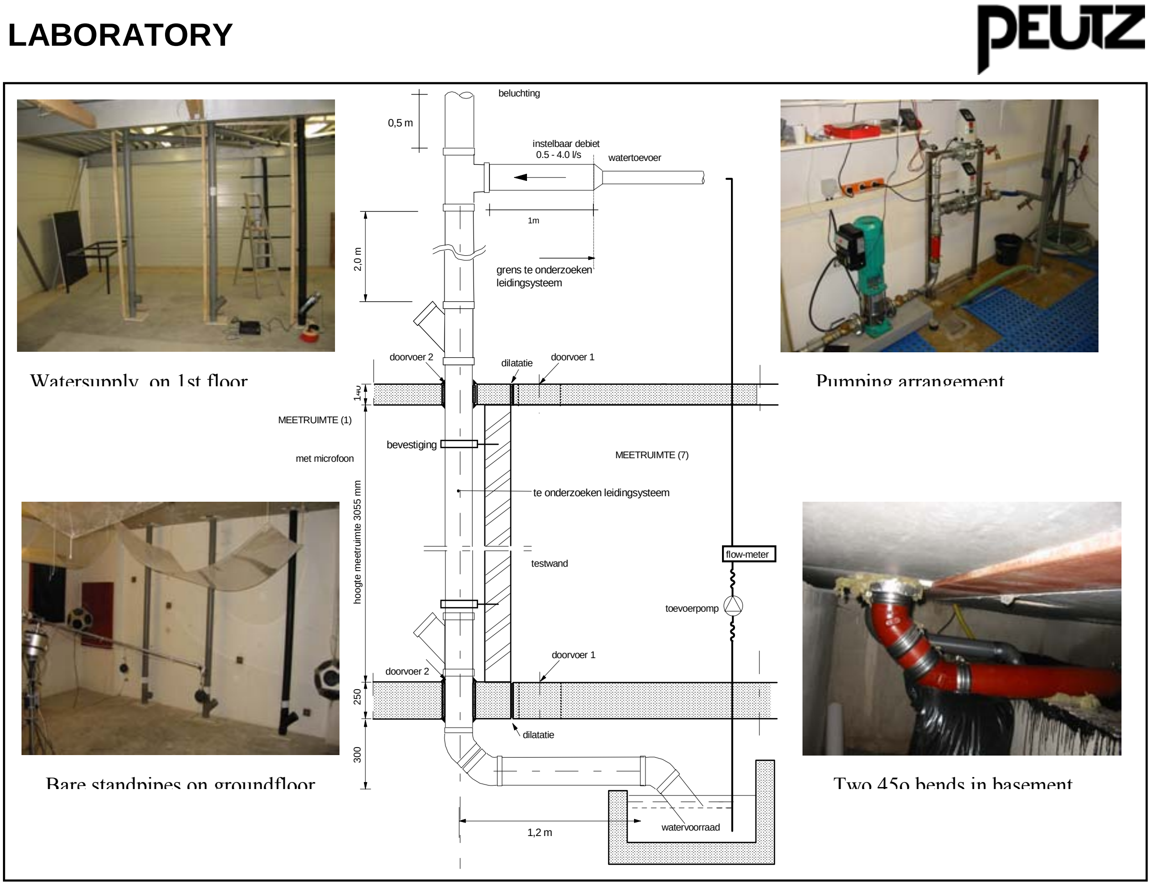
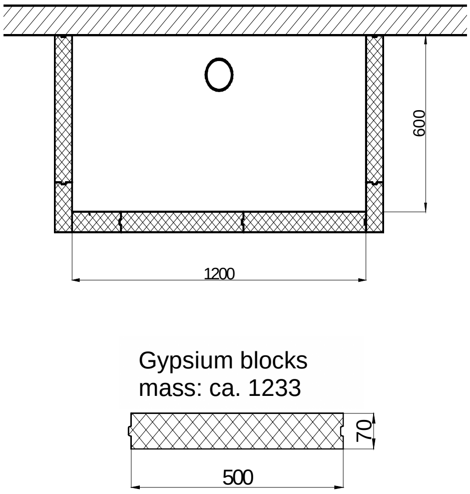


Figure 1 – Arrangement for measurement of bare pipes.

STANDPIPES IN SHAFT



Varian

Sewagepipe:
- type : PP heavy
- massa :3,47 kg/m
- ∅ inside : 99 mm
- ∅ ouside :110 mm

Varian

Sewagepipe:
- type :PVC light
- massa :1,22 kg/m
- ∅ inside :103 mm
- ∅ ouside :110 mm

Clamps:

Figure 2 – Arrangement for measurement of pipes in a shaft.

2.2 Results

Table 1 presents an overview of the results of measurements of the bare sewagepipes at a flow of 3 l/s. Table 2 shows the calculated impact noise levels resulting from the vibrations of the back wall.

No.	Pipe material	Mass [kg/m]	D/d [mm]	L_n [dB(A)]	Influence of repositioning 2x45^o [dB(A)]
1	PVC NEN-EN 1329	1,22	110/103	58	+ 9
2	PE80 NEN-EN 1519	1,45	110/100	58	-
3	PP NEN-EN 1451	1,51	110/102	56,5	-
4	PP with filling material	1,85	110/104	54,5	-
5	PE with filling material	3,49	110/98	54,5	-
6	PP with filling material	3,47	110/99	52	+ 6
7	Cast iron NEN-EN 877	9,8	111/99,5	51	-

Table 1 – Radiated noise level of bare discharge pipes at a flow of 3 l/s (noiselevel equal to toilet flushing).

No.	Pipe material	Clamps	$L_{n,construction}$ [dB(A)]
1a	PVC NEN-EN 1329	None	21,5
1b	PVC NEN-EN 1329	Steel	30,0
1c	PVC NEN-EN 1329	PVC	29,0
1d	PVC NEN-EN 1329	Special-2	25,0
2a	PE80 NEN-EN 1519	Special-1	28,0
2b	PE80 NEN-EN 1519	Special-2	28,0
3	PP NEN-EN 1451	-	-
4a	PP with filling material	Special-1	26,0
4b	PP with filling material	Special-2	26,0
5a	PE with filling material	Special-1	31,0
5b	PE with filling material	Special-2	28,0
6a	PP with filling material	Special-1	27,0
6b	PP with filling material	Special-2	23,0
7a	Cast iron NEN-EN 877	Special-1	31,0
7b	Cast iron NEN-EN 877	Special-2	28,0
* *Special-1 = noise reducing clamp unbranded* *Special-2 = special noise reducing clamp*			

Table 2 – Calculated construction noise levels of the back wall of 175 kg/m^2.

Table 3 shows the results of measurements of the radiated noise levels at different kinds of shafts for pipe/clamp combinations 1a, 1b and 6a. The shafts have been varied in material, measurements and amount of sound absorbing material (none, 1-sided, 2-sided and 3-sided and 4-sided)

Shaft material	**Absorption-material**	**Size**	**Pipe and clamps**		
		[mm x mm]	1a: PVC no clamps	1b: PVC steel clamps	6a: PP heavy special-1 clamps
No shaft	-	-	58	58	52
Gypsium blocks	None	1200 x 600	-	31,5	27,5
Single plasterboard	3-sided	1200 x 600	-	28,5	24,0
Double plasterboard	3-sided	1200 x 600	-	28,0	24,0
Cavity wall	3-sided	1200 x 600	-	28,0	23,5
MDF*	None	1200 x 600	42,0	-	-
MDF	3-sided	1200 x 600	28,5	-	-
MDF	None	600 x 600	41,0	-	-
MDF	3-sided	600 x 600	29,5	-	-
MDF	None	330 x 455	40,0	-	-
MDF	3-sided	330 x 455	29,5	-	-
MDF	None	345 x 620	41,0	-	-
MDF	1-sided	345 x 620	36,0	-	-
MDF	3-sided	345 x 620	33,0	-	-
MDF	4-sided	345 x 620	30,5	-	-
MDF+12,5 mm Plasterboard	None	345 x 620	39,0	-	-
** Medium Density Fibreboard*					

Table 3 – Radiated noise levels of standpipes in shafts.

2.3 Conclusions

1. The difference between the airborne noise radiation of bare sewage pipes is maximally 7 dB(A). Cast iron is best and light PVC is worst.
2. The reduction of the airborne noise radiation as a result of pipeinsulation is 0 to 20 dB(A), depending on the cellstructure, its mass and the top coating (results of earlier researches by Peutz).
3. A repositioning of 2 x 45^o in a standpipe presents an disadvantageous influence of maximum 9 dB(A) (at light PVC) and minimally 6 dB(A) (at heavy PP).
4. The use of sound proof clamps results in a reduction of the construction noise level of about 3-5 dB(A) (this has still to be checked).
5. The influence of the placement of noise absorbing material in the shaft shows an influence of 5 to 13 dB(A) on the noiselevel in the room, depending on the amount of insulation material applied (based on mineral wool thickness 40 mm)
6. The size of the shaft has a maximum influence of ca. 2 dB(A) on the noise level in the room. A small shaft gives better results.

The sum total of the influences of the various noise reducing facilities is not easy to calculate. A computer calculation model is required.

2.4 The computer calculation model

This computer program (soundspotsim) is still in the making. The calculation model will be composed as follows:

No.	Noise reducing facilities	Noise pressure level dB(A)
1.	Starting point noise radiation of a standpipe made of a certain pipematerial under laboratory conditions	
2.	Correction repositioning	
3.	Correction drop	
4.	Correction flow capacity	
5.	Correction diameter	
Sum total technical components	Σ	
6.	Insertion loss pipe insulation	
7.	Insertion loss shaft wall	
8.	Correction measurements of shaft	
9.	Correction absorption material in shaft	
10.	Correction positioning of shaft	
Airborne sound level to be expected $L_{l'n}$	Σ	
11.	Calculated impact soundlevel under laboratory-conditions	
12.	Correction clamping	
13.	Correction mass of back wall	
Impact sound level to be expected $L_{l'n}$	Σ	
Predicted total sound level in a standard room	Σ	

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6 Presentation of Author

Oscar Nuijten is currently working as a project co-ordinator with ISSO (Institute for the Study and Promotion of Research in the field of building services) in Rotterdam, The Netherlands where he is responsible for the realisation of technical publications in the field of sanitary and gas installations in buildings.

RAINWATER HARVESTING IN A RESIDENTIAL TALL BUILDING IN THE CITY OF SÃO CARLOS, BRAZIL

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ABSTRACT
The uncontrolled growth of the urban centers, and the changes in daily habits of the city population started to ergs the perspectives of a worldwide water crisis.
It starts to become necessary to reduce the daily demand of potable water. From the actions that can be taken, the technological ones detach because they allow the reduction and doesn't changes habits of the users.
The rainwater harvesting is one good alternative to the rational use of water, especially because it works in two different fronts. It reduces the amount of water needed and reduces the effect of the paved areas, being that way, a non structural action to urban drainage
This research has the main goal to study the feasibility of the rainwater harvesting in residential tall buildings, of seven floors, of a local construction company. In this case, the rainwater will be used to non-potable purposes in the community area of the building.
It will be analyzed the changes in the construction methods that is used to the construction company as well quality issues that may cause any concern to the use of rainwater. At the end, it will show de financial analysis of the enterprisement.

Key words: civil construction, rational use of water, rainwater harvesting

1. Introduction
Lately, the cities have been trough an uncontrolled grown that brings serious consequences, especially in developing countries, where this growth is not followed by the necessary infrastructure.
So, this way, many public services become precarious, being more difficult to live in large urban centers. Public transportation, healthy care, sanitation, etc are samples of the problems that, nowadays, disturb the urban lives.
One of these problems that are causing worries of everybody is the water crisis. The lack of potable water is disturbing cities in different parts of the world, since it is essential to human living. In cities, like São Paulo for example, the water used is already collected 60 Km from where is used. This causes the increasing of the price.
Besides the water crisis, the cities are suffering with drainage problems. The drainage

net doesn't follow the city's growth, causing inundation in storms. The inundations can cause damages in economical and healthy order and disturb psychologically the population that becomes fearful of possible disasters in any precipitation.
This way, the rainwater harvesting ergs as a technology that promotes the rational use of water. It substitutes the potable water used in activities where it isn't necessary to use it, substituting it by treated rainwater. This technology is also a non-structural drainage method.
Rainwater harvesting is an ancient technology, known by many thousand of years. According to Gould; Nissen-Petersen (1999), there are cisterns, as the ones in the Negev Desert, that are dated 2000 Before Christ.
With the development of the civilization, the use of rainwater harvesting had been forgotten. Its use was just restricted to areas where there weren't plumbing water. But, this development, allied with the population growth, caused the water crisis that nowadays disturbs the entire world. So, in the beginning of this Century, the rainwater harvesting takes an important roll in the water conservation methods.

2. Objectives

2.1 General Objective
To collaborate with the improvement of the rainwater harvesting technology trough the study of its use in a type of building, contributing to the rational use of water.

2.2 Specific objectives
1) Study of rainwater harvesting systems and analysis of national and international experiences.
2) In a case study, analyze and comparer the coldwater and rainwater plumbing systems, designed with and without the rainwater harvesting,,, so it would be possible to:
   - Verify possible changes that the implementation of a rainwater harvesting system will bring to the work routine of a middle size construction company in the city of São Carlos;
   - Establish standard procedures to elaborate projects that use this kind of system;
   - Characterize some problems related to the rainwater quality that may happen;

3. Methodology
It will be shown the methods used to obtain the results of this research.

3.1 Bibliographical research
To guarantee the highest number of cases studied, it was done an ample research in many different searches such as: thesis, internet websites, books, Conference preceding, periodic articles, national and international standards and talks and chats with technicians that already had used this technique.
This research had has its goal to clear up the Idea of the rainwater harvesting as well as the knowledge to the best technique to the rainwater harvesting system in the type of building used.

3.2 Studies about the pluviometrical indexes of the region

There was a study of the pluviometrical indexes of the region of São Carlos to allow a more precisions sizing of the cistern. To do that it was analyzed the daily pluviometric data of the city of São Carlos/Brazil, given by the Weather Station of the CRHEA/USP.

3.3 Development of the model

Through the examples studied and analyzed, it was created a model of a system applied in thy type of building chosen. With that, it was possible to create a standard model to the use of project with same objectives, even in different types of building.

3.4 Study of Case

The model created was applied in an enterprisement of a middle size construction company of the city of São Carlos. Trough the availability of the company, it was recognized the steps of design and execution of the cold water and rainwater Plumbing systems of this, allowing, a new design that use rainwater harvested in activities where potable water isn't necessary in the common areas of the building.
Besides that, it occurred studies in the necessary changes in the constructive process of the company to use the method proposed.
At last it was studied financial feasibility of the enterprisement.

4. Rainwater harvesting system

4.1 Initial considerations

During this research, it was recognized many types of rainwater harvesting system, used around the world. At his research, it could be watched a large numbers of systems, used in different situations. Some of these systems were really simple, consisted of leaves of some trees (as the banana trees) and clay vase, and some were very sophisticated, consisted of many devices such as UV disinfection light, filters, etc.
In the United States, for example, there are system installed in, at least, fifteen states and American territories such as: Alaska, Hawaii, Washington, Oregon, Arizona, New México, Texas, Kentucky, Ohio, Pennsylvania, Tennessee, North Carolina, Virginia, West Virginia and American Virgin Islands, estimating more than half off million people in theses states that use rainwater to non-potables uses (KRISHNA, 2003).
Other Country where rainwater harvesting highlights is Germany. Although recent, there are more than one hundred companies that produce devices to theses systems. The main company installed, in the last tem years more than 100.000 thousand cisterns, what give us a total installed volume over 600.000 cubic meters. (HERRMANN; SCHMIDA, 1999).
In France, according to De Gouvello et al (2003), the development of rainwater harvesting technique started in the last years, especially in one family residential building, and now stars the use in collective use buildings such as schools, residential tall buildings, stadiums, garage and malls. There are, today in France, especially in the North of the Country, a total of thirty-eight buildings that use or will use rainwater harvested from their roofs.
Japan is other country where the rainwater harvesting takes an important part. Japan is an island, poor in natural resources, especially about potable water. Because of that, many actions take place to promote the rational use of water. There are many types of buildings that use rainwater harvested from rooftops to non-potable activities such as toilet flushing and water the garden. One example is the Sumo Domes. The Domes in

Tokyo (built in 1983), Fukuoka (built in 1993) and Nagoya (1997) and Nagoya) have some commons characteristics such as: big structures in urban area, large collected areas, especially when compared to the skylines (ZANZEM et al, 2003).
It can be noted a great variety of types of system, used in different situations. These differences aren't just restricted to the type of use this water will have but to the amount of resources it's used. In developing countries it's more common to find simples systems. In developed countries the systems are more sophisticated, with worries about quality and quantity issues.
This way, the devices that is part of a rainwater harvesting system was classified in:

a) Essential devices – they are the devices that is part of any system, independently how complex is the rainwater harvesting system. They are the collecting area, gutters and downpipes and the cistern.
b) Complement devices – They are those devices that are optional, and it will depend where the rainwater will be used and the amount of financial resources available. Its use is necessary to improve the water quality. Some examples of these devices are: filters, bombs, UV light sterilizer, Carbon filters, roofwash valve, etc.

Like said before, there three elements that can be considered as essentials: collecting area, gutters and downpipes and the cistern.
The collecting area is the device that responds to the harvesting of the rainwater. It's a critical point to the sizing of the system, since it will determinate the amount of water that can be harvested. It´s also critical related to the quality issues, since it is exposed to many kind of contaminations. This contamination can also occur by the material itself. The roof is main type of collecting area, especially when the rainwater harvesting is related to buildings, but here are two other types of collecting area: paved areas such as roads and parking lots and rocks catchments (GOULD, NISSEN-PETERSEN, 1999).
The gutters and downpipes are important to a correct work of the system. These elements are responsible to the transportation of the water to the collecting point (roofs) to the cistern.
The correct sizing of these, following the Brazilian Standards (ABNT, 1989) will reduce chances of lost by flowing out. The constant maintaince can also help reducing those lost.
The last essential device is the cistern. This device is the most important by the financial point of view. It is responsible by 50 to 70% of the total costs of a system, and it's responsible by the quality of water in the point of use.
The cisterns can be built by many types of material such as plastics fiberglass, concrete, Ferro cement, wood, galvanized iron, etc. The choice of a material is important to determinate the costs of the cistern and to guarantee the minimal quality proposed. Macomber(2001) says the choice of a material must be criterius and the material must be inert, avoiding some kind of contamination in the stored water.
Na efficient design of a cistern must look out to issues that guarantee the water quality. This design must regard issues that avoid light and polluents in it. The temperature of the water must be constant during the season so it won't raise seaweed. Besides that, it is necessary to have a maintance and cleanance routine.
The direct contact between men (and animals) with water must be avoided. That's why faucets and bombs must be used always as it is possible. The use of bucket must be avoided. The Figure 1 gives some example of cisterns.

Figure 1 – Examples of some types of cisterns

Many devices can be classified as accessories and some examples of these are: filters, UV light sterilizer, roofwashers, are the most common used. Their use will depend where you are going to use rainwater.

4.2 Rainwater quality

One issue that bring huge worries is the quality of the water harvest and stored, specially when this water will be used in home

In a general way, the rainwater has a good quality being real pure, especially because of the natural distillation that it suffers, during the water cycle in the process of distillation and condensation. But, depending on the region where the system is in it how in real industrialized regions, this rainwater can get some polluents (GOULD; NISSEN-PETERSEN, 1999).

The water quality can be changed by any factors: local climatic conditions, kind of the catchments area and the cistern, if there are accessories, maintance, etc (CUNLIFFE, 1998).

4.3 Cistern Sizing

Like it was Said before, the cistern is the most important device of a rainwater harvesting system and it will determinate the financial end technical feasibility. That is the reason it should have some worries about their sizing.

Before the implementation of a rainwater harvesting system it is necessary to have some data: local precipitation, catchments area, runoff coefficient and the demand of the rainwater.

Most of the methods used to size a cistern consider the dry period, as well as the amount of water that can be collected. What turns different to each other is how the demand is estimated.

The most common method to size cisterns is the Rippl Method. This method regularizes the flown in the cistern to guarantee water during the any period of the year. (TOMAZ, 2003). One example of this method can be found on Table 1.

Table 1 Example of a cistern sizing using the Rippl Method

Months	Average rain (mm)	Demand(m3)	Catchment area (m2)	Rain volume (m3)	Rain surplus (m3)	accumulated difference (m3)
January	260,93	10,2	350	73,06	62,86	0
February	210,99	10,2	350	59,08	48,88	0
March	153,25	10,2	350	42,91	32,71	0
April	68,63	10,2	350	19,22	9,02	0
May	46,93	10,2	350	13,14	2,94	0
June	28,90	10,2	350	8,09	-2,11	-2,11
July	20,68	10,2	350	5,79	-4,41	-6,52
August	19,77	10,2	350	5,54	-4,66	-11,18
September	52,00	10,2	350	14,56	4,36	-6,82
October	127,36	10,2	350	35,66	25,46	0

November	167,85	10,2	350	47,00	36,80	0
December	256,89	10,2	350	71,93	61,73	0
Total	1414,17	122,4		395,97		

Source: Siqueira Campos et al (2003)

In this case, the highest accumulated difference is 11, 18 m^3, that will be adopted to the volume of the cistern. In plans like that it can simulate any situation desired.

5. CASE STUDY

It was made an analysis of the rainwater catchment in a residential tall building in the city of São Carlos, Brazil. This choice was made randomly according to the availability of the construction company.

After that it will be described the rainwater harvesting system used, characterizing all the components of it. This system will allow the use of rainwater in the common areas of the building, in activities where can be used non-potable water (toilet flushing, and the garden faucets).

5.1 Description of the building

The Paul Klee Residential is a tall building built by the AVR Construction Company. This building has 7 floors, and three kind of apartments the first one, called 01 has one sleeping room, and one bathroom. The total area is 28,50 m^2. The second (02) has sleeping room and 2 bathrooms, with total area of 68,11 m^2. The last one (03) has three sleeping rooms, three bathroom and total area of 122,30 m^2.

In the first floor has four apartments 02 e three 01. The second until sixth floor has four apartments 02 and four apartments 01. In the last floor there are four apartments 03.In the firs floor there are gym room, party room, me and women WC, swimming pool and rest area.

5.2 Original Plumbing systems

As goals established to this paper, the cold water and rainwater plumbing systems are the ones that should be studied, since they are the ones that will be changed.

There are four reservoirs to cold water. All of them have 10 m^3 and are built with fiberglass. Two of them are in the first floor and two in the last one. All the tubes are PVC and sized by Brazilian Standards (ABNT, 1998).

The apartment 01 has the following consumption points: 1 toilet, 1 shower, 1 hygienically shower, 1 faucet, 1 sink, 1 filter, 1 washing machine, 1 tank and 1 dishwasher.

The apartment 02 has the following consumption points: 2 toilets, 2 showers, 2 higienical showers, 2 faucets , 1 sink, 1 filter, 1 washing machine, 1 tank and 1 dishwasher

The apartment 03 has the following consumption points: 3 toilets, 3 showers, 3 higienical showers, 3 faucets , 1 sink, 1 filter, 1 washing machine, 1 tank and 1 dishwasher and one point to the swimming pool.

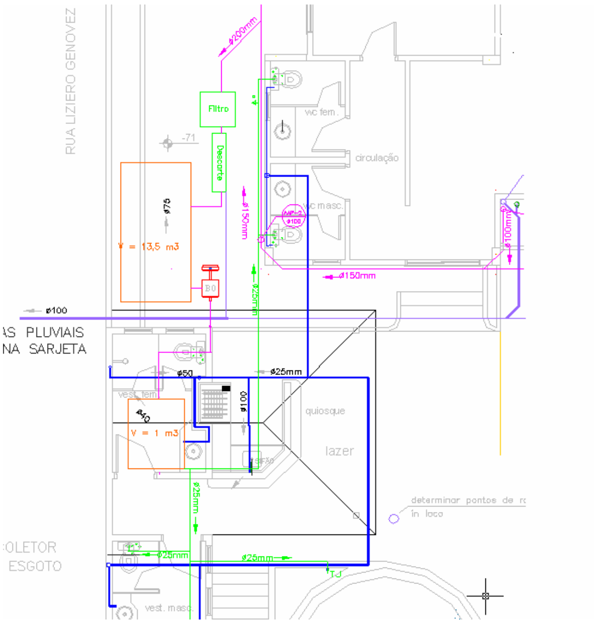
The other plumbing system modified is the rainwater. The original one collects the water ad through it out in the streets. There are 20 downpipes that collects water from the rooftop. Eight of them also collect water from the balcony.

The gutters are made from Aluminum and have sized with 25 x 15 cm. Both the downpipes and gutters are sized by the Brazilian standards (ABNT, 1989).

5.3 Rainwater harvesting plumbing system

It was necessary some changes in the original one designed so it would be possible to

harvest and use rainwater.
The most important changes are related to the construction of the cistern and the pipes to take the water to the cistern and from the cistern to the consumption points. It will be necessary to have 8 more downpipes to separate the water collected in the rooftops from the water collected in the balcony. This is essential because the water collected in the balcony, as well, in the parking lot, have many polluents such as greases, detergents, etc.
This way, there will be 2 different rainwater plumbing system: the first one is the one that have the tubes that will take water from the rooftop to the cistern. With that the following downpipes will be part of this system: AAP1, AAP2, AAP3, AAP4, AAP7, AAP8, AAP9, AAP10, AAP11, AAP12, AAP13, AAP14, AAP15, AAP16, AAP17, AAP18, AAP21, AAP22, AAP23 E AAP24.
The second system is the one that will be responsible to take the water collected in the balcony and in the parking out the building to the drain at the streets. The following downpipes will be part of this system: AP 3, AP 4, AP 7, AP 8, AP 17, AP 18, AP 21, AP 22.
With that, it can isolate the rainwater that can be stored to the one that will be discarted. In the new design plants, the first will be represented by the magenta color and the second by the purple color. All the tubes were sized by Brazilian Standards (ABNT, 1989 and ABNT, 1998).
After the harvesting and before the storage, the rainwater will have to go through some physical treatment. There are a filter and a roofwasher that will discart the firs 200 liters of the first rain. These devices are similar to the one shown in Siqueira Campos et al (2003)
The water in the cistern is bombed to a reservoir of 1000 liters, trough a pressure pump of ½ Cv. After that, it feeds the toilets of the party room and the resting area, and the garden faucets by gravity.
The system is, in an abbreviated way, shown in the Figure 2.



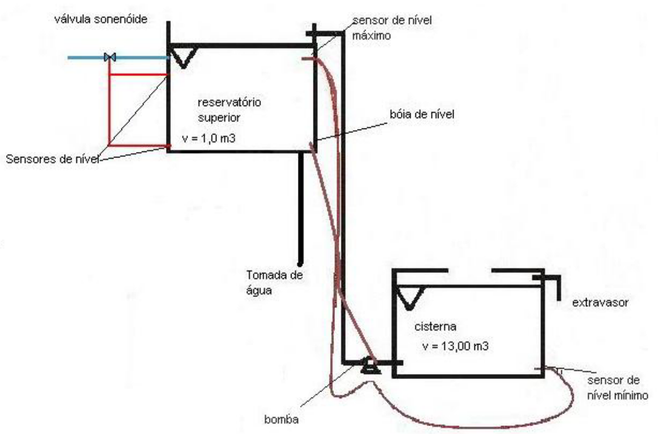
Rainwater harvesting plumbing system

Rainwater sewage system

Rainwater Distribution System

Cold water plumbing system

To guarant e dry time work, it will have solenoid valves and level sensors that will feed the potable water automatically when there is no rainwater in the cistern. The pumping lay out is represented in the Figure 3.



Rainwater harvested

Potable water

Figure 2- Representative example of the rainwater supply

5.4 Cistern sizing

Before size the cistern, it’s necessary to know the pluviometrical behavior of the region where the system is in it. So, it should obtained monthly and daily average, day and year of biggest rain and other informations that can help to clear the behavior up. In Table 2 and 3 there are some of these parameters found to the city of São Carlos, describing its pluviometrical behavior.

Table 2 Pluviometrical datas of the city of São Carlos

Highest daily precipitation (01/07/1999)	118 mm
Average of the highest daily precipitation of the year	77,88 mm
Highest monthly precipitation (janeiro/1983)	554 mm
Year of the highest precipitation (1983)	2487,3 mm
Year of the smaller precipitation (1994)	1180 mm
Annual average precipitation	1515,7 mm
Standard deviation of the annual precipitation	272,8091mm

Source: Adaptaded from the data given by CRHEA-USP

Tabela 5.1 Monthly precipitation data of the city of São Carlos

	Highest	Lowest	Average	Standard deviation
January	554,00	92,80	258,08	108,10
February	523,30	57,10	206,25	99,82
March	403,50	31,60	176,30	94,04
April	167,50	6,00	80,81	47,30
May	240,20	1,60	70,55	51,70
June	168,00	0,00	43,38	46,42
July	119,30	0,00	29,64	31,75
August	145,50	0,00	36,47	41,33
September	286,70	0,00	76,94	57,70
October	279,40	38,00	125,41	63,61
November	351,70	28,20	161,02	72,33
December	435,80	84,00	250,85	91,57

Source: Adaptaded from the data given by CRHEA-USP

It's worthy to say the sizing mustn't be by the worst or for the better case. It's known that average shows unreal situations.

That's why it was used a year-to-year sizing verifying the volume obtained with monthly and daily data. By the Rippl Method, it can be said that smaller is the interval highest is the precision of the sizing. To this paper, the daily data will be enough.

This way, using a demand o f 7, 27 m^3/ month and the catchment area of 630 m^2 and a runoff coefficient of 0,85, it was gotten a large number of values, allowing choosing the one that represents the best feasibility .the values are found on Table 4.

Table 4 Volumes and efficiency of the adopted system

Volume calculated by monthly average	0 m^3	27%
Volume calculated by daily average	0,60 m^3	49%
Volume calculated in the worst year with monthly data	17,74m^3	99%
Volume calculated in the worst year with daily data	22,02 m^3	100%
Volume calculated in the best year with monthly data	0 m^3	27%

Volume calculated in the best year with daily data	6,24 m^3	90%
Volume calculated in the average year with monthly data	7,20 m^3	91%
Volume calculated in the average year with daily data	12,58 m^3	80%

Trough the analysis of theses results and the situation of the system adopted, as well to optimize the construction of the cistern, the volume chosen was 10,00 m^3 , being 9,00 m^3 in the cistern and 1,00 m^3 in the reservoir above the restrooms, that will supply water to those by gravity. This volume has 95% of eficiency.

The cistern will have an extra volume of 4,5 m^3 to help in urban drainage. This volume will reduce the amount of water during the heavy storms. This value was adopted from the Table given by Tucci apud Fendrich (2002).

6. Results and discussions

6.1 Changes in the design process and execution routine

During the design process , it didn't happen any important changes in it. Excluding the sizing of the cistern, where it is necessary to have specific knowledge as the Rippl Method and the pluviometric behavior, all the sizing followed Brazilian Standards usually used as ABNT(1998) and ABNT(1989). It took some cares to guarantee the water quality ,such as the separation of the water that comes from the rooftop of the water that comes from the balcony and parking lots, the use of a roofwasher, filter, etc. Other cares were taken to make the mantaince easier.

It can be noticed that it wasn't used the inspection boxes, frequently used in theses cases. These boxes were a point of contamination, what could prejudice the quality of the water stored. To substitutes these Box it was chosen the inspections Ts, that would do the same thing without contaminate the water.

The changes in the cold water plumbing system were restricted only to the tubes that go to the toilet of the common areas and the garden faucets. Those points were feed by public water. From now on this will be feed by the reservoir above the restroom of the swimming pool.

The execution was small and won't bring any radical change in the work routine of the company. The simplicity of the technique,, using procedures usually done it will make easier the implementation of the system. It could be seen that won't be necessary to change the sequence of the activities. The only activities that will be included is the construction of the cistern and the treatment system(filter and roofwasher), but those activities can be fit in any step of the construction.

6.2 Standard procedures to a implementation of a rainwater harvesting system

As you begin , it should realize a study about the pluviometrical behavior , determinating some variable, as show in Table 2 and 3. This analysis will be important to the sizing of some devices.

After obtain those parameters, some cares must be taken in the choice of the collecting area, the kind of material, rationalize the number of downpipes and gutters.

Some of those weren't possible at this design. There were an original design and it was seen to do the changes without interfering in the other systems of the building(such as structure , for example).

The size of gutters and downpipes must be the same when there isn't the rainwater harvesting system. The choice of the material must be to one that is inert, just as in the catchment area.

The cistern will depend the material that it is made of. It can be used the cisterns done

"*in loco"* or the ones industrialized. The choice of the material must follow the same rule of the elements said before. When built in the construction site, some cares must be taken to guarantee the structural safety.
The cistern sizing must be criterions just like said before. There many methods that can allow a good sizing. The Rippl Method, used in this paper, worked just fine, especially when used daily data. To help urban drainage, it suggests the use of an additional volume to keep the water longer in the building during heavy storms.
The execution of the plumbing system must follow the standards procedures use in any plumbing system. The tubes that are being used by the water that goes to the cistern or come from de cistern must have different colors to distinguish from the original ones.
It should be established some procedures to mantain and clean the devices that make part of the rainwater harvesting system. This maintance and cleance will help the system to work as desired. The gutters, donwpipes, cistern, filters, and other elements must have an often espection and maintance contributing to the improvement of the water quality and quantity. These procedures must be put in the user's guide.

7. CONCLUSION

The Xxi Century starts with serious problems in the water supply around the world. In many countries this scarcity is already a reality. This way is necessary a serious rational use of water to guarantee water to everybody.
From the actions that can promote the water conservation, the technological ones seems to be the most efficient since they have results quicker and don't change drastically habits of the users. Of Course the economical and educations actions are important to reduce the amount of water used.
From the technological action, the rainwater harvesting highlights because reduce of the amount of potable water used and help other problem that disturbs the population of big urban centers: the urban drainage.
Ancient technique, the rainwater harvesting spread around the world in many situations, as a way to guarantee the supply of water or to contribute to conservation of water. This technique has at its main advantage the flexibility, adapting to any situation.
Although, there are some paradigms that is over this technique. The first one is the lack of knowledge of the system. It can be noticed the simplicity of the devices that make part of it, as well the sizing of those, just being necessary to promote the knowledge in the technical staff and in the society.
Other paradigm refers to the water quality. Culturally, this source of water can be rejected. In normal conditions of the atmosphere, the rainwater quality is good. When it falls down, it has contacts to many kinds of polluents , in the rooftop, in the gutters and downpipes, tubes and in the cistern. But, when you have a well-done design, with some devices that guarantee the quality this water can be used, especially in non-potable activities. Many researches , around the world can guarantee that.
The third and last paradigm is the cost. In many cases studied the cost analysis seems to be good, especially in a perspective of increasement of the price of potable water for the next years. Some actions that will be soonly obligated to help drainage, will reduce the cost of this system too.
To develop this technique it's necessary some government financial aids. There are many countries , such as Germany, United States, Japan and Australia that already have this support. This is necessary because the advantages of an implementation of a system like that, don't occur just to the user but to all the society around.
The construction Company can use system like that in their building as a way to make

their sales easier and build their image as a company worried about social issues. This certainly will contribute to the marketing of it.
Besides that, it's necessary to standard some procedures,trhough regulamentations that would make easier the control of this construction, as well, their maitance.
It hopes that, from now on, this technique has a development, as the society consicetization increases.

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Rainwater Discharge from Green Roofs

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Abstract

In the context of sustainable construction, green roofs* are considered as being a possibility for improving the water balance in urbanized areas, i.e. by reducing the amount of rainwater discharged within the sewer. However, about the in Belgium commercialised systems, little information was available on the real rainwater discharge and on the quality of this water. In order to get a better view on these issues, the Belgian Building Research Institute monitored from June 2002 till December 2003, 9 commercially available roof gardens of different composition, together with 2 traditional roofs, all having dimensions of about 7.5 m by 1 m and exposed to the outdoor climate.
The study demonstrated that green roofs reduce considerably the amount of rainwater discharged into the sewers. They also have a tempering effect on the peak flows in case of storm showers, which allows the design of drainage systems with reduced diameters. Because of the specificity of the roofs the discharge factor needed for this calculation must be measured. A method for this measurement was identified. The study also showed that the water discharged by green roofs must be considered as polluted and needs treatment before being able to be used in the building.

Keywords

Green roofs, roof gardens, rainwater discharge, sustainable construction

1 Introduction

Green roofs and roof gardens are multilayer constructions with on the top a vegetation layer. Some typical compositions are indicated in the figure 1. They incorporate intensive and extensive roofs. Intensive roofs allow creating roof gardens with even large trees, while extensive green roofs are not designed for public use. Green roof systems are not a new concept; in fact they can be traced to the hanging gardens of Babylon, one the Seven Wonders of the World. Green roof systems are actually promoted as a sustainable building technology for urbanized areas, because of the presumed advantages they provide, e.g.:

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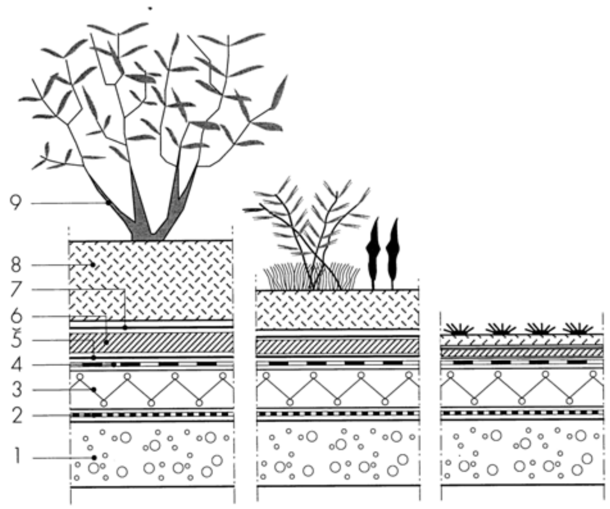
* also written as « greenroofs »

- They improve the energy efficiency of buildings by slowing building heat gain and loss.
- They optimise the indoor climate by keeping the building cool during summer and by improving the acoustical characteristics of the roof.
- They allow to improve the urban water management: by enlarging the amount of rainwater returned into the atmosphere mainly through the evapotranspiration of the plants and hereby lowering the amount of water drained rapidly away by the sewers; by reducing the frequency of combined sewage/stormwater overflow events which pollute seriously rivers and streams; by reducing the flooding frequency in some of the lower parts of the public drainage system; and by reducing the amount of contaminants brought by the rainwater into the receiving surface waters as a result of the filtering effect of the green roof layers; this filtering effect also improves the ability to use the water within the building, eg for rinsing WCs.



1:structural support
2:vapour barrier
3:thermal insulation
4:waterproofing membrane
5:root barrier
6:drainage layer
7:filter membrane
8:growing medium or substrate
9:vegetation

	intensive roofs		extensive
Depth of substrate(m)	>0.25	0.1 – 0.25	<0.1
Green load (kg/m²)	>400	100 - 400	30 - 100

Figure 1 – Green roofs: typical compositions

As these advantages were not clearly demonstrated for the typical green roofs used in Belgium, BBRI was requested to study 9 such roofs with respect to these supposed advantages.

2 The monitoring campaign

2.1 Description of the roofs

Besides the 9 commercially available green roofs, also 2 reference roofs were considered: one with a naked waterproofing membrane and one where the membrane is covered with about 50 mm of gravel with a diameter between 4 and 30 mm. These 11 roofs, with a surface of about 7.5 m² each, were located side by side on top the main office building at the BBRI test centre. Their characteristics are indicated in table 1. The structural support had a slope of 2%, causing a lengthwise drainage of the roofs. The water of each roof was evacuated by an outlet in the middle of its lowest side, connected to a closed vertical pipe DN 125 with a length of 3 m, where the volume of accumulated water is measured with a pressure gauge. Automatic discharge is provided when the water reaches its maximum level, by opening a valve.

2.2 The monitoring campaign

The thermal behaviour of the roof complex and the rainwater discharge of each roof were monitored continuously from June 2002 till May 2003.

Table 1 – Composition of the green roofs tested at BBRI

roof n°	drainage layer:	Filter:	substrate	vegetation
	Type; thickness (bottom up)			
1	Reference roof with 50 mm gravel covering			
2	Felt covered with a cup-shaped PE-sheet (with a water capacity of 3 l/m²), filled with expanded clay pellets; 30 mm	Felt; 5 mm	Peat; 40 mm	Extensive vegetation: mainly sedum and moss
3	Mats of curled PE-wires covered by a felt; 20mm		Mineral pellets; 80 mm	
4	Mats of foamed PUR-flakes; 30 mm	PE-felt (ie. mats of non woven PE-fibres); 5 mm	Mixture of pozzolana, peat and composted bark; 50 mm	
5	Mats of curled PE-wires, covered by a felt; 15 mm		Potting compost; 20mm	
6	Agglomerated expanded PS-pellets; 65 mm	PP-felt; <1 mm	Potting compost; 140 mm	Intensive vegetation: spindle tree, broom, tormentil,…
7	Expanded clay pellets; 30 mm Felt; 15 mm Expanded clay pellets; 70 mm	Felt; 15 mm	Potting compost mixed with expanded clay pellets; 200 mm	Intensive vegetation: ground ivy, lavender, honeysuckle, strawflower,…
8	Cup-shaped expanded PS panels (water capacity : 13 l/m²); 54 mm	PP-felt: 2 mm	Mixture of mineral (lava pellets) and organic (potting compost, peat, …) materials; 80 mm	Extensive vegetation: mainly sedum and moss
9	Cup-shaped PVC sheets (water capacity : 5 l/m²); 20 mm	PP-felt; 2 mm	Mixture of mineral (lava pellets) and organic (potting compost, peat, …) materials; 40 mm	
10	Extruded polystyrene panels; 80 mm	PP-felt; 15 mm	65 mm	
11	Reference roof with naked membrane.			

Punctually, from April till December 2003, samples of the water discharged by the roofs and of the rain were analysed bio-chemically. Afterwards the roofs were also submitted to artificial showers with constant intensity, in order to evaluate their hydraulic

response. In situ, on some real roofs, the acoustical performance was measured. The research made also a comparative study of some current methodologies for evaluating the root-resistance of roofing membranes.
Only the results related to the rainwater discharge, i.e. the hydraulic behaviour and the water quality will be discussed in this paper.

3 The hydraulic performance

3.1 Long term rainwater discharge

The total volume of rainwater discharged by the different roofs, during the different seasons, is indicated in table 2 for the period from 23/06/03 till 24/05/03.

Table 2 – Volume of rainwater discharged by the different roofs (l/m²)

roof		summer	autumn	winter	spring
n°	type	(23/06/02-22/09/02)	(23/09/02-23/12/02)	(24/12/02-20/03)	(21/03/03-24/05/03)
2	Ext (40 mm)	83	152	229	29
3	Ext (80 mm)	148	170	238	40
4	Ext (50 mm)	135	176	243	39
5	Ext (20 mm)	142	180	250	51
8	Ext (80 mm)	154	181	230	48
9	Ext (40 mm)	153	181	249	51
10	Ext (65 mm)	157	169	234	43
6	Int (140 mm)	74	112	220	7
7	Int (200 mm)	87	120	220	13
1	Ref: gravel	214	200	237	83
11	Reference	226	230	256	122

More telling is to look to the long term discharge-ratio, i.e. the ratio between the volume of water discharged by a roof and the volume of water discharged by the naked reference roof n°11, expressed as a percentage: figure 2. From this figure it is clear that the retention-effect of the green roofs depends upon the season: the retention is important in spring (discharge ratio only 6-51%) and less important in winter (discharge ratio between 86 and 98%).
But also the type of roof is influencing the long term discharge of green roofs:

- In general one can say that the thicker the substrate, the lesser is the discharge ratio; this trend can be seen on figure 3. On yearly basis one can conclude that the extensive roofs retained about 30% of the total rainfall, whereas the intensive roofs (6 and 7) retained about 50%.
- But a low discharge ratio can also be realised by having an appropriate composition of the roof, as is illustrated by roof n°2 -which has a substrate of only 40 mm - where the good performance is probably linked to the combination of different layers with a water-retention ability at the level of the drainage, i.e. the cup-shaped PE sheet, its underlying felt and the pellet filling of the sheet.

It’s thus obvious that it is impossible to characterise the retention effect of green roofs by one single value usable for all types of green roofs.

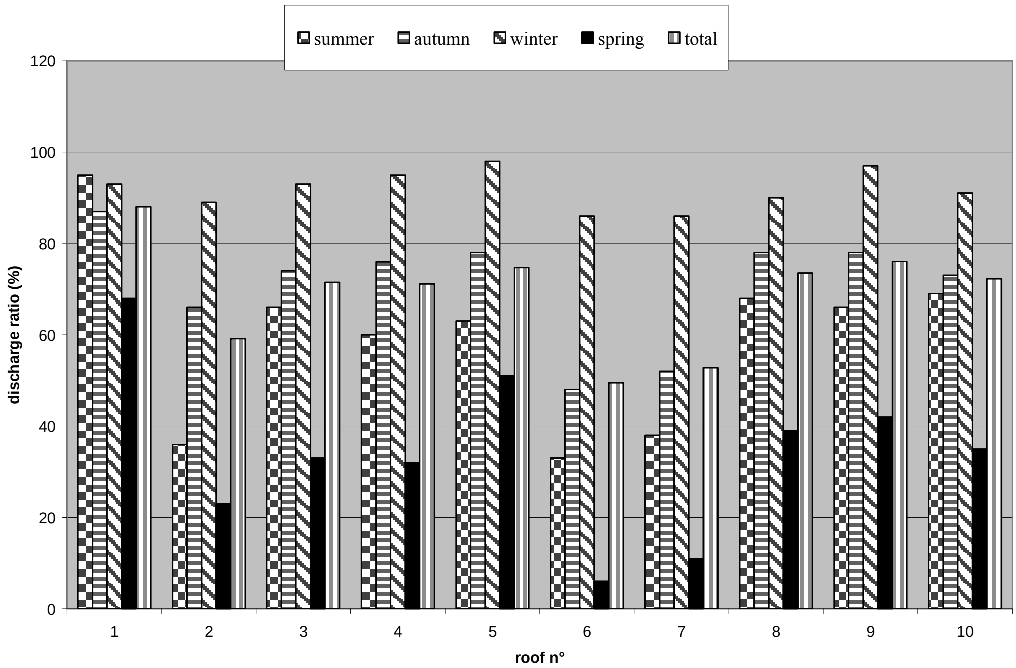


Figure 2 – Long term discharge ratio of the different roofs

3.2 Stormwater discharge

3.2.1 Discharge under a thunderstorm

During the monitoring of the roofs, some days occurred with storm showers. The discharge of the roofs during such a storm is presented in figure 4.

With respect to the naked reference roof 11 we see that the green roofs have a peak flow discharge which is later in time and less intense. This effect is clearer illustrated in the figure 5:

The naked reference roof n°11 has a peak flow rate of 0.832 l/min.m² at 14.32.

The extensive green roof n°2 has a maximum discharge of 0.433 l/min.m² at 14.40, which means a decrease to 52% of the naked roofs' flow rate and a delay of 8 minutes with respect to the time of the peak flow of roof 11.

The intensive roof n°7 has a peak flow of only 0.221 l/min.m² at 14.48, ie a decrease to 26% and a delay of 16 minutes.

It is obvious from these measurements, that the reduction in peak flow rate, as well as the time delay, depend upon the type of green roof and we see that in some cases they can be considerable.

3.2.2 Establishing discharge factors for green roofs

A reduction of the rate of flow to be drained away from a roof means a drainage system with reduced diameters.

The European standard EN 12056-3 [1] for roof drainage proposes to calculate the flow rate (Q) discharged by a roof, with the formula:

$$Q = r*A*C \quad \text{- (l/s)}$$

Where r is the rainfall intensity (to be chosen by each country), in (l/s.m²); A is the effective roof area (m²) and C is the discharge factor, to be chosen by each country, (-). It is thus through the discharge factor C that the attenuating effect of green roofs on the peak flow can be introduced in the calculations. However, the European standard does not give any value for this C-factor. In Germany some values where proposed in their draft standard DIN 1986-2 of 2001 (table 3).

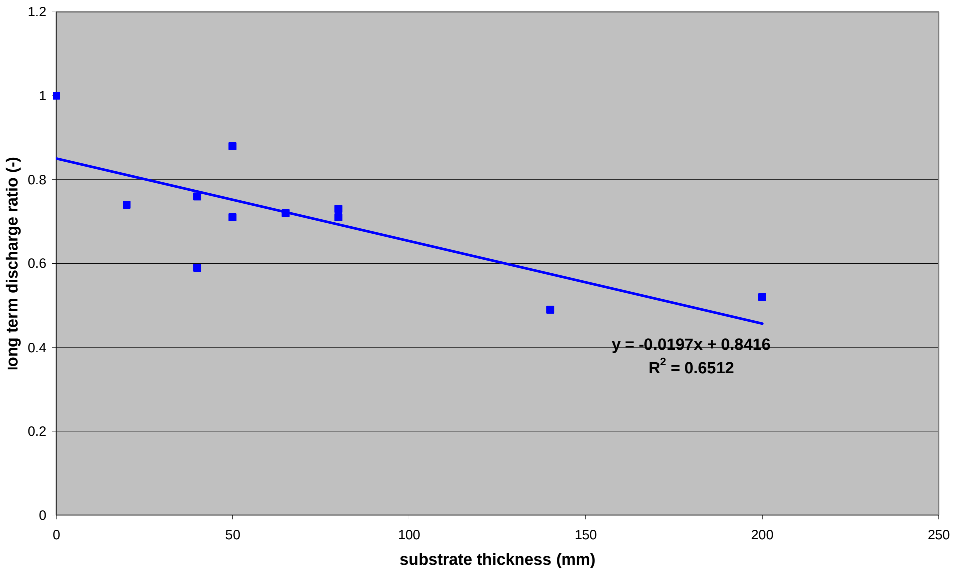


Figure 3 – Relation between the long term discharge ratio and the thickness of the substrate

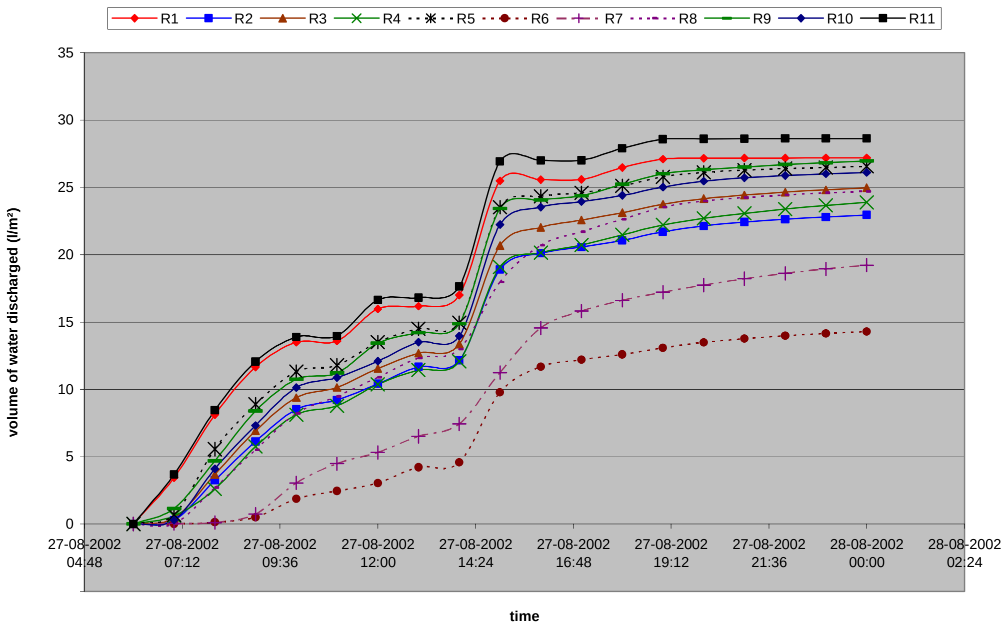


Figure 4 – discharge during storm
(storm shower at 14.32)

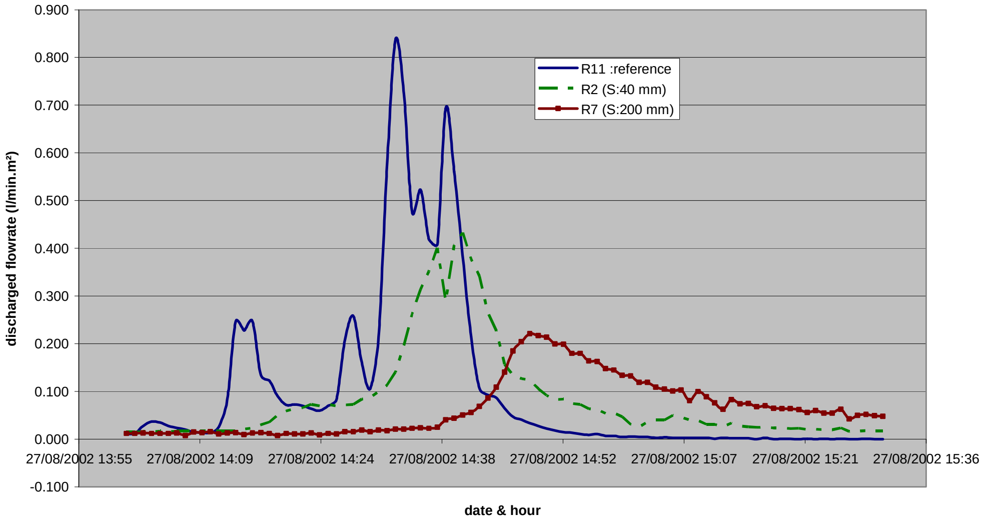


Figure 5 – Discharge flow rate of roofs 2,7 and 11 during a storm shower

They also propose a methodology for measuring these factors [3]. Hereto they measure the volume of water discharged over a period of 30 minutes, by models of green roofs with a width of 1.25 m, a length of 10 m and a slope of 2%, while submitting them at the beginning to a 15 minutes shower with a constant intensity of 0.03 l/s.m² (sprinkling). The discharge factor is then calculated as the ratio between the maximum measured discharge flow rate and the sprinkled flow rate. Before doing the test, the roof is saturated by sprinkling at 0.03 l/s.m² until there is for 10 minutes a constant discharge flow. This approach implies that the Germans consider a shower of 0.03 l/s.m², with 15 minutes duration, as being their design shower. In Belgium such a shower happens once every 250 years.

Table 3 – German proposal for discharge factors for green roofs [2]

Substrate thickness (mm)	**Reduction factor(*)**
20-40	0.7
60-100	0.6
100-150	0.4
150-250	0.3
250-500	0.2
>500	0.1
(*)for slopes up to 5%	

At BBRI, a first attempt was made to evaluate the discharge factors for the studied green roofs. We adopted hereto a slightly different method (table 4), using a sprinkling installation as shown in figure 6. The reason for this different way of working was

- that we wanted to be nearer to a worst case scenario, ie. simulating a situation where the roof is already discharging water when a storm shower occurs (cfr. fig.5);

- that we actually have a discussing in the country, about the rainfall intensity to adopt for the above calculation according to EN 12056-3: 0.0167, 0.025 or 0.033 l/s.m².

Table 4 – Determination of reduction factors: sprinkling scheme adopted by BBRI

Phase		**action**
1	saturation	Constant sprinkling at 0.033 l/s.m²(*)
2	rest	No sprinkling (***)
3	High intensity	Constant sprinkling at 0.033 l/s.m² (**)
4	rest	No sprinkling (***)
5	Medium intensity	Constant sprinkling at 0.025 l/s.m²(**)
6	rest	No sprinkling (***)
7	Low intensity	Constant sprinkling at 0.0167 l/s.m²(**)
(*) up to when there a noticeable flow rate during 10 minutes (**) up to when there is a constant discharge flow rate during 10 minutes (***) up to when there is no noticeable discharge flow rate anymore for 10 minutes		

Measuring of the accumulated volume of water discharged and sprinkled, gives results as presented in figure 7. This allows the calculation of the discharge factor C, as defined in the German method above, i.e. the maximum flow rate, recorded 15 minutes after starting the sprinkling, divided by the sprinkled flow rate: see table 5.

Table 5 –Discharge factors measured by BBRI

Intensity	**Green roof n°**								
(l/s.m²)	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
0.033	0.89	0.57	0.53	0.87	0.86	0.75	0.90	0.92	0.96
0.025	0.95	0.86	0.81	1	0.88	0.58	0.67	0.91	0.98
0.0167	0.99	0.96	0.50	0.93	0.94	0.29	0.81	1	0.90

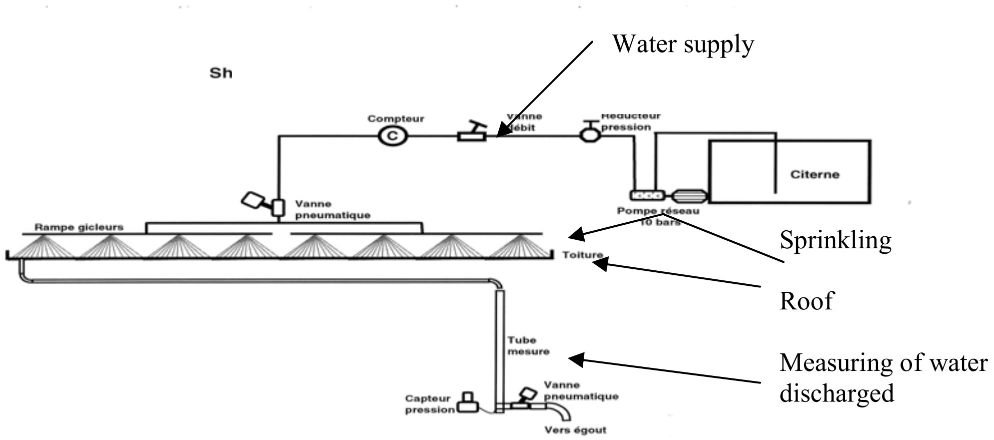


Figure 6 - Measuring discharge factors : principle scheme

In case a roof is fully saturated, the discharged flow rate equals the sprinkled flow rate and the C-factor would be equal to 1. If the C-factor is less than 1 for the high intensity sprinkling, one should then await a lower C-value for the lower sprinkling intensities. This seems not to be the case when looking to table 5: in many cases there is even an increase of the C-factor. This is probably due to the adopted way of working where the tests at the different intensities were conducted each after another starting with the highest intensity, creating full saturation after a while for certain roofs. This means concretely that only the values established for the highest sprinkling intensity might be considered for characterising the roof with respect to a shower a of 15 minutes duration. And also here caution is in order as all roofs were –for the time being- only measured once.

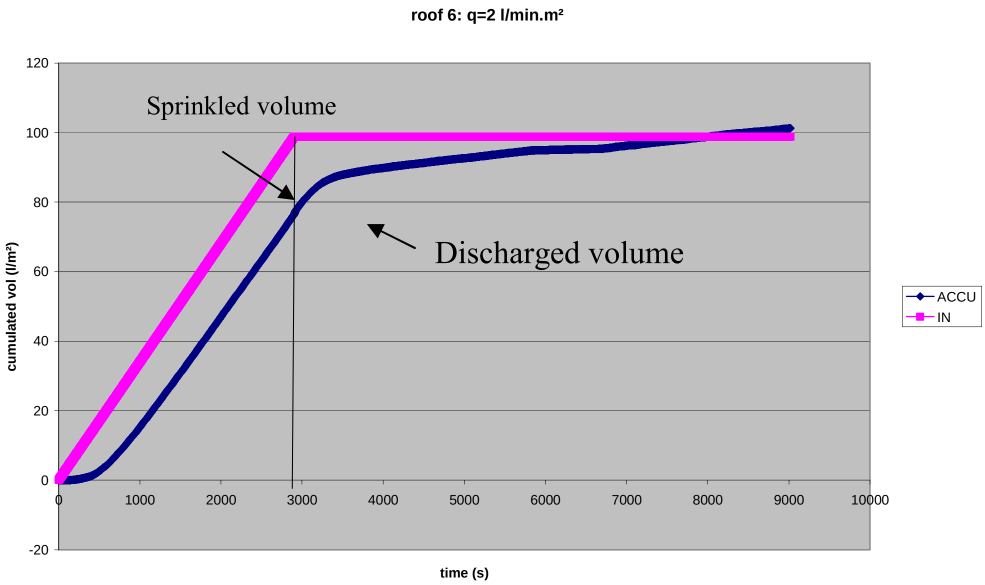


Figure 7 – Volume of water discharged in time by roof 6 (intensive with 140 mm substrate) when sprinkled at 0.033 l/s.m²

Focussing upon the C-values for the 0.033 l/s.m² sprinkling intensity, we can notice (figure 8) that the reduction tends to become more important (C decreases) when the substrate becomes thicker, which seems to be normal. For a green roof with a substrate thickness of 100 mm, the German test gave C-values of 0.83, which fits quite well into our findings. Less coherent is the relation with the German values proposed in 2001 (table 3): the proposed values seem to are a lot more optimistic than those of real roofs submitted to the German “type shower”.
On the other side we also have to notice that for some roofs (especially 3 and 4) not only the substrate thickness is influencing the reduction effect, also the other layers composing the green roof seem to be involved in a significant way, in particular the drainage layer. This means that with for the determination of reduction factors for green roofs, one can not only rely upon the substrate thickness, which implies that this characteristic can only be established with some confidence, by prototype testing. This underlines the necessity of having a reliable standardised methodology, which could be based upon the German approach.

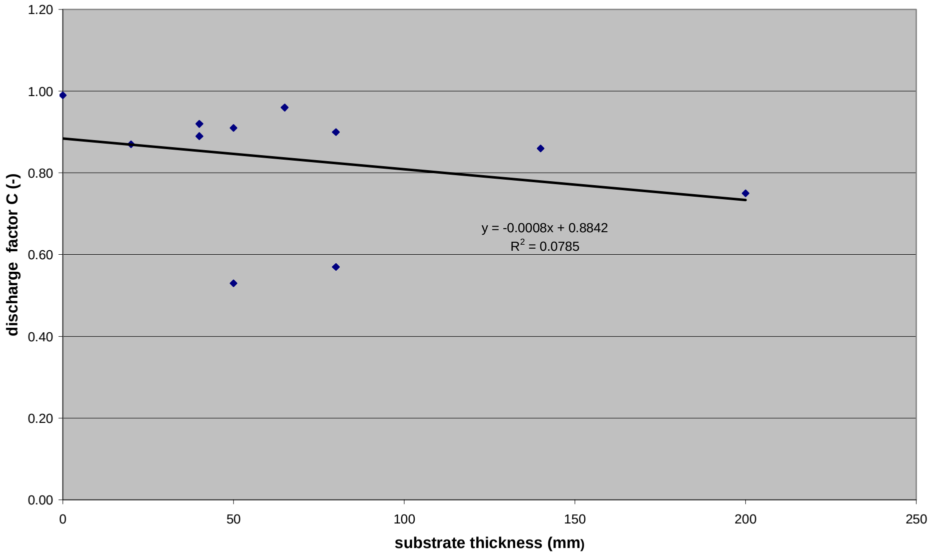


Figure 8 –Discharge factor C: substrate thickness dependency

4 The quality of the water discharged by green roofs

In the course of 2003, ie in the second year of the monitoring, water samples were regularly collected from the different roofs and analysed for different parameters. The aim was to get an idea of the quality of these waters in view of its possible reuse in or around the building. As in Belgium there are no regulations in this context, the choice of the parameters to be analyzed was made after having looked to the parameters considered in different regulations about water, e.g.: surface water for swimming, fishing waters, drinking water, waste water. The mean values for the most important parameters analysed are given in table 6. Looking to the pH, one can say that all green roofs, except n°7, do have a neutralisation effect on the initial acid character of the Belgian rain.

Important is also to underline the fact that the naked reference roof n°11 does have an acidifying effect, which is probably due to the formation of organic acids by the weathering (UV-irradiation) of the membrane material.The claim that the rainwater is "purified" by passing through a green roof is clearly not true:

All roofs do colour the water: most of them deliver a brown liqueur.

The increase, with respect to rainwater, of the conductivity, suspended solids and hardness indicate that a lot of substances are extracted by the water from the green roof, ie there is enrichment, not a filtering.

Also the parameters characterising the organic load (BOD and COD) increase in all cases, indicating pollution by organic matter. One should also notice that the rainwater itself had already an organic charge. The fact that the COD/BOD ratio is quite high for some roofs indicates that, beside organic matters, also oxidizable chemicals are present in the pollution. These products are probably resulting from the fertilizers used on the roofs for the plants.

Except for roofs 2 and 4, there is a certain increase of the number of total germs. Also from the microbiological point of view one can thus not say that the green roofs do improve the rainwater quality.

From this analysis it is clear that the green roofs do influence the quality of the water discharged in such a way that one could speak of pollution. This pollution makes it impossible, in all cases, to use this water directly for flushing WC's or cloth washing. In some cases the water will even not be allowed to be discharged in the surface waters (BOD max 25 mg/l in Belgium), fishing water or swimming water.

Table 6 – Mean quality of the rainwater and of the water discharged by the roofs

parameter	unit	roof n°					
		1	2	3	4	5	6
pH		6.81	7.28	7.22	6.99	6.76	7.34
apparent color	**Pt/Co unit**	67.32	878.19	532.41	350.94	228.58	671.25
conductivity	**µS/cm**	92.9	130.41	207.98	83.82	155.16	273.31
settleable matter	**ml/l**	0.24	0.1	0	0	0.1	0.1
suspended solids	**mg/l**	20.5	9.13	15.53	8.82	9.29	12.27
hardness	**°F**	5	8.01	5.34	4.15	4.15	17.8
COD	**mgO2/l**	24.01	265.25	178.76	100.18	147.6	312.47
BOD	**mgO2/l**	4.5	19.3	29.01	46.1	14.16	46.1
COD/BOD	**(-)**	5.34	13.74	6.16	2.17	10.42	6.78
total phophorus	**mgP/l**	0.06	0.17	0.53	0.08	0.13	3.14
P205	**mgP/l**	0.14	0.21	0.61	3.61	0.21	3.61
SO4--	**mgSO4/l**	14.21	0	1.9	0.15	52.5	86.92
total germs at 22°C	**CFU/ml**	6100	5800	6400	3700	8400	11000
total germs at 37°C	**CFU/ml**	3500	2300	2300	1300	1100	4500
total Coli germs 37°C	**% of pos. samples**	25	25	29	33	33	50
parameter	**unit**	**roof n°**					**rain**
		7	**8**	**9**	**10**	**11**	
pH		5.4	6.52	6.43	6.67	4.89	**5.61**
apparent color	**Pt/Co unit**	46.78	264.9	219.04	250.17	230.55	**23.36**
conductivity	**µS/cm**	1727.8	99.07	87.22	160.93	90.35	**50.87**
settleable matter	**ml/l**	0.15	0	0.1	0.24	0.2	**0**
suspended solids	**mg/l**	37.5	8.9	6.85	12.83	13.9	**5**
hardness	**°F**	5.34	2.37	3.12	4.15	1.78	**1.78**
COD	**mgO2/l**	35.31	99.68	103.15	116.08	106.31	**16.33**
BOD	**mgO2/l**	8.26	5.16	9.15	33.39	9.3	**3.6**
COD/BOD	**(-)**	4.27	19.32	11.27	3.48	11.43	**4.54**
total phophorus	**mgP/l**	0.24	0.06	0.08	15.25	0.16	**0.15**
P205	**mgP/l**	0.35	0.19	0.12	4.46	0.15	**0.09**
SO4--	**mgSO4/l**	1397.5	18.19	11.85	20.68	2.65	**5.4**
total germs at 22°C	**CFU/ml**	12000	9900	9300	10000	13000	**5900**
total germs at 37°C	**CFU/ml**	4700	3900	3500	4100	6200	**4900**
total Coli germs 37°C	**% of pos. samples**	0	17	50	44	67	**67**

5 Conclusions

Green roofs can improve the urban water management by reducing the amount of rainwater discharged into the sewer and by tempering the peak flow. For the design of the drainage system for green roofs, discharge factors must be measured for each type of green roof, no general values can be given. Hereto a standardised method is needed, which could be based upon a German proposal. Green roofs do polluted to a certain extend the rainwater. The reuse of the water discharged by these roofs or their discharge in some environments requires appropriate treatment.

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7 Presentation of Authors

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The French experience in rainwater reuse in buildings for collective use

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Abstract

Collecting and reusing rain water in buildings are increasing in France. Mostly developed during last years in individual houses, it now also concerns buildings for collective use. In spite of the incomplete regulatory frame in France on these topic and the lack of official documents for appreciating validity and durability of installations, the number of equipped buildings increases mostly in the frame of sustainable development realisations. In this context, CSTB carries out since a few years researches aiming at the end to contribute to the definition of prescriptions based on design, execution and exploitation/maintenance of these installations.
During 2003, a first survey has been carried out, consisting in identifying existing collecting and reusing rain water installations in buildings for collective use in France. More than 40 buildings for collective use have been identified. During 2004, this survey was completed and followed by a description and detailed analysis carried out on a sample of the most representative experiences.
The contribution presents a synthesis of this work. Firstly, the different kinds of buildings concerned by this topic are described with the specific spatial adjustments (schools, apartment buildings, industrial buildings, gymnasiums, stadiums, car and bus depots, shopping centres) as well as the different indoor and outdoor uses of the rainwater are also detailed (water closets, car washing, industrial use). Secondly, the technical solutions used in these existing installations to collect the rain (roof, gutters and drain pipe characteristics), to store it (localisation and materials used for the cistern) and to reuse the water, are analysed. Some propositions for a better efficiency of these installations based on the observed installations are developed.

Keywords

Rainwater; water reuse; sustainable development.

1. Introduction: the current situation

Limited for a long time to areas deprived of natural water resources (places such as islands or high mountain shelters…), the collection of rain water in buildings is now developing in France. For a couple of years the sales of tanks dedicated to the collection of rain water (mainly for garden watering) have increased and today, some companies are offering installations and devices allowing the use of rain water for toilets and even sometimes for washing-machines inside houses.
More recently, local communities and companies in charge of building management have become more and more interested in rain water collection. Many seminars are taking place on the subject. College students are writing reports about it. That interest was generated by a double motivation: on one hand, the HQE (environmental high quality) policy which clearly promotes rain water collection; on the other hand, the idea to find new alternatives to the traditional way of managing rain water.
However, a legal element is somewhat slowing down the realization of these projects. According to the current legislation (mainly the Decree 2001-1220 dated 12/20/01, about waters dedicated to human consumption, to the exception of mineral waters, transcription in French law of the European Directive 98/83/CEE) it is hard to determine whether or not a water, that wasn't submitted to the traditional treatment process, can be authorized for a use within the buildings. In its article 1, the Decree states that waters that shall be considered dedicated to the human consumption are "waters that, either naturally or after treatment, are meant to be drunk, used for cooking or other domestic uses…" But what is a "domestic use"? A strict definition would lead to prevent any use of rain water in the building construction business. Such a strict definition would probably be abusive. For instance, the use of rain water in toilets doesn't require a drinkable quality. The consequence of this vague definition: if the devices used in individual houses are not submitted to any type of control, the use of such installations in collective buildings (residential housing, offices, administrations, high schools and other public premises…) requires a preliminary agreement from the DDASS. Without a clear official position in that matter, the rulings of the DDASS vary from one region of the country to the other.
In such a context, at the beginning of the year 2003, the CSHPF (Superior Council for Public Health of France) decided to create a working group in charge of issuing recommendations regarding the use of rain water for domestic uses.

2 Current situation: the CSTB study

It is hard to get an accurate idea of the extent of rain water collection in France. On one hand, it is indeed hard to gather reliable information when, for instance, the devices located in individual houses are not submitted to any control. On the other hand, it is much easier to identity the use of rain water in collective buildings. That was the goal of the CSTB study initiated in 2003, without, however, having the ambition to be exhaustive.

2.1 The different stages of the study

Between July and November of 2000 the French Ministry of Health led an inquiry with the DDASS. The ministry identified less than 10 installations for rain water collection in public buildings. However, the results of that inquiry seemed a bit limited and apparently incomplete.
As a consequence, with the increasing interest of local and regional communities to realize architectural projects involving a section “dedicated to the collection of rain water”, the CSTB, which had been involved in that field for several years (Hilaire, B. et al., 1998; Dérangère, D. et al., 2000), decided to initiate a mission of localization and counting of the different experiments taking place throughout the country for the collection of rain water in buildings for collective use. Identifying and describing existing installations was considered as necessary step to elaborate efficient prescriptions and technical recommendations in this field.
The first stage of the mission was realized in 2003. The first results came from a 4 months study based, not only on the localization of the projects bur also on an attempt to organize the information that had been collected in order to constitute a data base divided in two levels: a general map of the experiments, presented according to several criteria; specific files giving an accurate technical description of the installations when information was available. The information related to this first stage has already been presented (de Gouvello, 2003a).
A second stage was developed in 2004 with the assistance of another student between the months of April and July. The goal was double: first to enrich and update the data base, second to perform a certain amount of inspections of the installations in order to show the different aspects of conception and initiation.

2.2 Map

The map shows the localization of the listed projects, and for each of them the state of the project (realized or to be realized) (see figure 1).
67 projects have been identified: 36 are realized but are in use only for a few years, the 31 remaining are to be realized. These numbers are clearly higher than the number provided by the DDASS survey of 2000 (only 8 existing installations), but also higher than the CSTB survey of 2003 (38 installations realized, 20 to be realized).
Such evolution shows that, in France, rainwater reuse in buildings for collective use is something quite new, with an increasing development dynamic for the last 3 years.
As the map shows, most of the projects identified are located in the north part of the country. France is administratively divided in 96 departments: 2 departments of this area (Nord, Pas-de-Calais) gather more than the third part of the total amount of projects (25 installations, 16 realized). Nevertheless, it is important to notice that this dynamic concerns also other parts of the country: other projects have been identified in 25 different departments (more than 25%).

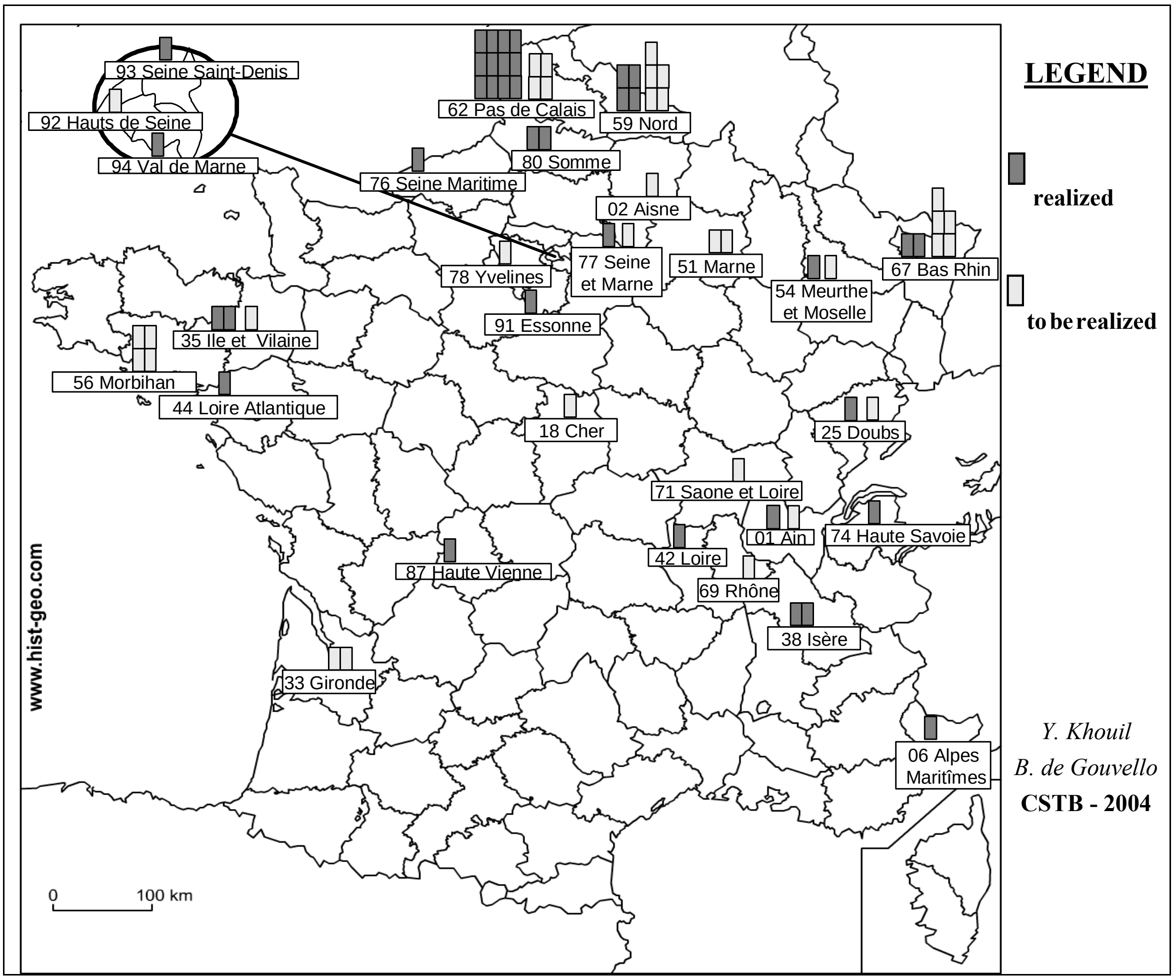

Figure 1 - Map of identified installations

This growing spreading of rainwater reuse projects strengthens the necessity to establish a national regulatory frame in France on this topic, especially for the French health local authorities, who at present have no national criteria to decide whether certain rainwater reuse installations in a building has to be authorized or not.
It is important also to notice that more than half of the total amount of projects were initiated by a local community (region, department, or municipality). That means that local communities seem to be an essential agent to promote and spread this kind of projects.

2.3 Typology of buildings projects

First of all, the rainwater reuse systems apply more to new buildings than to older ones. Nevertheless, at least 10 of the identified projects apply to existing buildings.
The building typology has been defined using the collected information and treating it. The aim of this typology is to describe properly the projects and, at the same, time to aggregate them into several classes, taking into account on one hand the activities within the buildings (especially: function and level of occupation, type of maintenance) and, on another hand, their morphology (especially: size, potential surface for collecting rainwater). The core idea is to target types of buildings for which rainwater reuse is particularly interesting. This approach leads to define 14 classes as figure 2 shows.

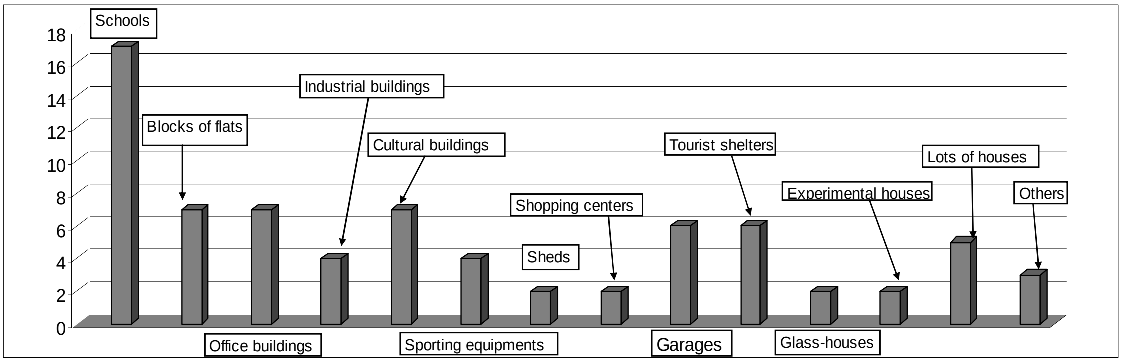

Figure 2 - Types of building projects (2004)

6 classes of building projects particularly stand out.

According to the number of projects, *Schools* is the most important class (17 projects, 10 realized). It can be subdivided into 3 types: grade schools (depending on municipalities), junior high schools (departments) and high schools (regions), being the last category the most important one with 13 projects (7 realized). The region *Nord-Pas-de-Calais* (which includes the 2 northern departments of France) particularly stands out with 6 projects (4 realized). The region decided to generalize the implementation of such installations in all new high school. These first realizations have aroused great interest from other regions and departments or municipalities, which are currently developing rainwater reuse projects in schools.

7 *blocks of flats* projects (6 realized) were identified. 5 were realized a few years ago (between 1996 and 1999). Since then, just one new project has been realized in this category and another one has to be realized, which seems amazingly less than expected. It would be interesting to have an assessment of the 6 projects systems performance to check whether or not this kind of buildings is a good target for rainwater reuse.

7 projects were identified in *office buildings* (3 realized). In most cases, they are administrative buildings. All the identified realized projects are localized in the *Nord-Pas-de-Calais* region. Nevertheless, 3 of the projects to be realized concern other parts of France.

Also 7 projects (with 3 realized) were identified in *cultural buildings*. This category includes auditoriums, libraries, showrooms and village halls from different parts of the country.

6 projects (3 realized) are in *tourist shelters*: rural gîtes, recreational facilities and camping sites.

For the three last categories described, there are more projects to be realized than already realized. This shows the potential of development for these kinds of buildings.

6 projects (4 realized) are garages. “Garage” here means a place where cars are maintained and/or repaired, whether this maintenance is a commercial activity or not.

5 projects (2 realized) deal with *lots of houses*. All these projects are localized in the eastern part of the country. The development of this kind of projects has to be expected elsewhere, due to the evolution of the Urbanism regulation rules.

Finally, 4 projects were identified in 2 other classes, which can become interesting targets for rainwater reuse projects in the future: *industrial buildings*, as the example of Renault-Maubeuge shows (Thomas, J-S. et al., 2002); *sporting equipments* like gymnasiums and stadiums.

2.4 Typology of collected rainwater uses

2.4.1. Main Uses and others

4 main uses of the collected rainwater have been identified (see figure 3).

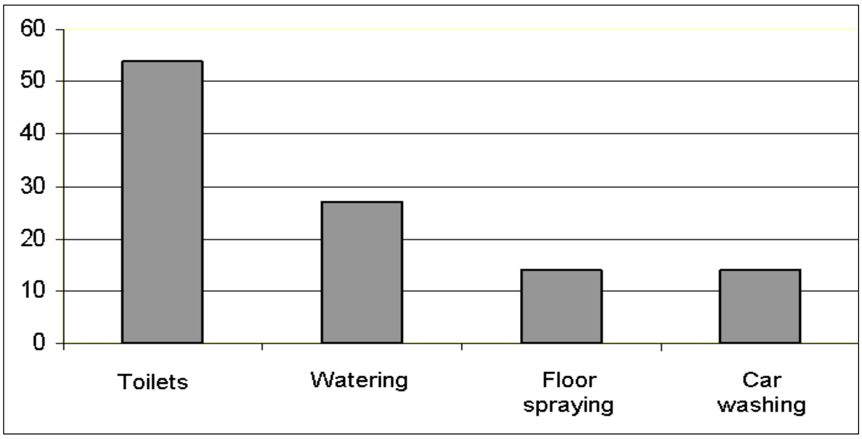

Figure 3 - Main uses of collected rainwater (2004)

Toilets (54 projects): the collected rainwater is used to supply the flush through a specific network. This is the more common use.
Watering (28 projects): the watering is realized using a technical tap, most of the time situated outdoor.
Floor spraying (14 projects): the floors washed are: indoor or outdoor car parks, rubbish rooms, common parts of the buildings,…
Car washing (14 projects): the car washing is realized indoor or outdoor, using a technical tap provided by collected rain water.
Several other identified uses have to be mentioned: industrial uses, glass washing, ornamental lake supplying, fire network supplying, concrete preparing, boat washing, and cooling tower supplying. Although these uses nowadays appear only in a few numbers of projects, they draw potential ideas for future projects.

2.4.2 Indoor and outdoor uses

The uses identified below are indoor (toilets, indoor floor spraying, industrial uses,…) and outdoor ones (watering, outdoor floor spraying, ornamental lake supplying,…). This differentiation is important according to several regulatory questions. Is it possible to have different water networks for different uses within the same building? Does toilet flushing require drinking water quality? Is necessary a tax payment for sewerage in case of rainwater collection?
In many cases (23 of the 67 identified projects) the collected rainwater has 2 or 3 different uses, with a mix of indoor and outdoor ones. Most of the time, the uses combination is: **toilets** + **watering** or **toilettes** + **floor spraying**.
Moreover, there is an obvious relation between the uses and the building projects classes. In schools, blocks of flats and office buildings, the main targeted is toilet flushing (in some cases, cumulated with watering or floor spraying); in garages, the collected rainwater is used to wash cars…

3 Lessons from experiences

3.1 Inspections of installations and in situ experiments

During the last 5 years, about 10 rainwater reuse installations in buildings for collective use were inspected or were in situ experiments watched over by the CSTB (see table 1).

Localization	**Building type**	**Rainwater use**
01 - Meillonnas	**Block of flats**	**Toilets - Floor spraying**
59 - Caudry	School	Toilets – Watering - Floor spraying
59 - Douai	School	Toilets - Watering
59 - Dunkerque	Industrial building	Industrial use
62 - Calais	School	Toilets – Watering - Floor spraying
62 - Loos en Gohelle	Office Building	Toilets
76 - Petit Quevilly	**Block of flats**	**Toilets**
77 - Champs/Marne	**Experimental House**	**Toilets (simulation)**
87 - Limoges	School	Toilets - Watering
91 - Grigny	**School**	**Toilets**
93 - Saint-Ouen	Block of flats	Toilets - Floor spraying

Table 1 – List of inspected installations and experiments in situ
(Experiments watched over by the CSTB are indicated in bold)

The inspection of rainwater reuse installations were realized according to a specific methodology, including the inspection of the technical premises; the identification of all points of use; a roof examination; interviews of the administrative and technical managers of the installation; the drawing of the installation scheme and a brief inspection report including photos.
The information on experiments watched over by the CSTB is more detailed: it includes consumption data and water quality analysis (see de Gouvello, B. et al., 2004)

3.2 Functional description of an installation

Every rainwater collecting and reusing system in buildings can be divided in five *main functions*: rainwater collecting, water refining, storage, water delivering, and signalization and information. Each one of these functions can be possibly subdivided in *elementary functions* to which particular technical devices can be associated.

3.2.1 Rainwater collecting
This main function contains two elementary functions: *collecting* itself (assured by the surface of the building on which the rainwater to be collected falls and flows down) and *conveying* towards cistern (through gutters, drainpipes, manholes and buried pipes).

3.2.2 Water refining
Water refining can be divided in the three elementary functions of *weeding out* (at the head of drainpipes*), water treatment upstream* and *filtration downstream* storage cistern.

3.2.3 Storage

The storage consists in three elementary functions: *storage* itself (high capacity container), *level gauge* (automatic or not) and *storage regulation* (which contains two parts: a contact for tap water and an overflow).

3.2.4 Water delivering

Water delivering can be divided in two elementary functions: *water pressurizing* (pumps and pressurizer), *supplying water* to points of use (pipes).

3.2.5 Signalization and information

The signalization and information function consists in three elementary functions: *differentiation of indoor networks*; *users' protection*; *basic technical information* to help the ordinary operating and maintaining of the installation.

3.3 Comments on inspected installations

It is possible to make some comments on the implementation into practice of the *main functions* and details for some *elementary functions* on the basis of the inspected projects.

3.3.1 Rainwater collecting

The collecting surface preferentially used in the different identified installations is the roof. An additional collecting disposal has been used in one case on parks: this solution appeared to be a source of difficulties, the contents in hydrocarbon being of low compatibility with the use in toilets (even after a clarification tank).

Roofing materials used are: steel or aluminium sheets (the most widely used solution), zinc, stainless steel, copper, tiles, slates, gravelled roofs, flat concrete roofs. In most of the cases, roof materials and shapes are defined by the architect without considerations on possible pollution of rainwater by, which is chosen by the architect. On a same site, rainwater collecting can be realized from a roof made of different materials.

In most cases, no specific cleaning procedure has been defined neither implemented.

3.3.2 Water refining

Gutters and heads of pipes are badly protected. When installed, gratings are usual ones, too wide-meshed to be efficient for rainwater harvesting.

There is no always water treatment upstream storage. Without an efficient upstream water treatment, sedimentation in storage is growing and the storage has to be maintained more frequently.

Several upstream treatments were observed: Clarification tanks or cleaning out, which consist in leaving water to settle in a space, being the water borne solid elements settling at the bottom and the water collected above a certain level only; Wide-meshed sieves (meshes between 2 and 5 mm), which retain elements from water and eliminate them through the public network of rainwater drainage; Self-cleaning filters (tilted grid or whirl filter), which eliminate elements of a significantly smaller size (down to *100-200 μm* according to the models); Tanks for thin filtration (limiting to *5 μm* at the exit), more rarely used because it requires a succession of different layers and also a minimum

of support and maintenance, but offers the advantage of providing storage tank with high quality water, which greatly simplifies the problem of cleaning this tank.
Downstream treatments observed in the inspected installations were: small meshed filters, micro filters and UV lamps.

3.3.3 Storage
The more common types of storage observed are: concrete and metallic buried tanks; underground tanks in PEHD; steel buried tanks; and open air ponds.
Concrete buried tanks are the most common solution. Very often, they are buried under a green area. In cases where it is buried under a road, a specific protection is installed. Metallic tanks are more unusual.
Underground tanks in PEHD are also frequently used. This solution enables to adapt to situations where the excavation necessary for the installation of a buried tank is not possible, either due to a lack of space, or due to building site difficulties. Some of the tanks made of PEHD are modular. Thanks to that specificity these tanks can be installed in battery in cellars once the building construction is finished, the dimensions of each modulus authorizing a motion through the doors.
Open air pond is a relatively marginal solution. It generates problems in terms of water quality, the collected water having to be imperatively filtered before its reuse. However such a solution offers a landscape advantage because it associates a pleasantness function to a strictly speaking storage function.

3.3.4 Water delivering
The number and characteristics of the pumps differs from an installation to another. The pumps are not always chosen according to the characteristics of rainwater.
A lack of maintaining is also noticeable.
Protection against public network pollution is not always assured. The more efficient devices for such function are backflow preventers AA type or BA type, which are installed in some installations.

3.3.5 Signalization and information
Three practices in the domain of signalization can be pointed out.
In the case where collected water is used inside the building, the inner piping system conveying this water is in most cases clearly differentiated from the system conveying public water. This distinction can be made either by painting the pipes of the reused rainwater system in a different color, or by putting every X meters a clear indication (example: *cold non-potable water*).
At the level of points of use located inside as well as outside the building, appears in most cases (but not everywhere) a sign explaining *« non potable water »* or *« hazardous to drink this water»* and/or a pictogram representing a water glass crossed. In a certain number of cases, the use of taps is protected (removable handle, barrel preventing the opening of the tap with single pliers), these taps being only handled with a specific tool.
Finally, it is advisable to point out that in many installations (in particular in blocs of flats), sanitary authorities have required that reused rainwater distributed shall be colored.

4. Conclusion

The collection of rain water in buildings for a collective use is developing in France. The counting and localization realized by the CSTB allows bringing to the fore the different types of buildings (schools, residential buildings, offices …) and uses (toilets, watering, floor and street spraying…) where this idea seems to have a future.
However, today, without a clear legislation regarding the sanitary and technical aspects of the rain water collection, the current projects suffer from many weaknesses. It is urgent to solve these problems and complete the information. The regular inspection of the existing installations will provide us with clues that need to be deepened.

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Authors presentation

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Qualitative and quantitative evaluation of the greywaters reuse in constructions.

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Abstract

The water reuse, is not a new concept and it has been practiced in the whole world has many years. In literature about the subject exemples of diverse forms meet to carry through this exploitation, also the reuse of served waters where the quality is not the main parameter of requirement. The increasing demand for water, is due to the eminent perspective of its scartown, it has made of planned reuse of the water a subject of great importance. In this way, we must consider this reuse as part of more including activity that is the rational or efficient use of the water, which also understands the control of losses and wastefulnesses, and minimize the effluent production and the water consumption. Thus, this work aims at to determine the parameters of quality and amount of leached greywaters in constructions, through analyses, to reduce the consumption and to search the sustainability of drinking waters. To do so, the supplying system of Passo Fundo town, in Rio Grande do Sul, Brazil, are used as case study.

Keywords

Environmental sustainability; greywaters reuse; economy of drinking water.

1 Introduction

A great environmental and sanitary problem of the great urban centers of Brazil, that becomes worse with the time is the urban provisioning of drinking water. According to VESENTINI (1999), the quality of the water that provisions the residences it is so important that, 80% of the existent diseases in the underdeveloped countries are due to the bad use of that water resource. In spite of the expansion of the net of water for urban provisioning in Brazil, she is still insufficient for to growing population of the big ones and averages cities. A portion of the population, especially in the peripheries and poor neighborhoods, it is always to the margin of the net of treated water.

It is known that 97% of the water of the planet is salt water and they are found in the oceans, therefore 3% are only freshwater, and it still needs to discount the glaciers and waters of difficult access. It is also known that the drinking water is draining if. In agreement with several evaluations, Brazil possesses 12% of all superficial fresh water of the planet, and of that total one, 80% are distributed in the Amazon Area and the remaining 20% are distributed in an unequal way by the country, assisting 95% of the population.

One of the evidences that the foreseen shortage is real, and not an exaggeration, is it I number of countries where the standard of living was already overcome capable of being supported by the available water. Countries as China, India, Mexico, Thailand, West of the United States, North of Africa and others areas, are removing of the groundwater more water than the hydrological cycle gets to restore. In Peking, the groundwater, same partially restocked by the rains, it is lowering 1 to 2 meters a year and reports speak about the drain of more than 30% of the wells. In Mexico City the retreat of water of the underground exceeds in up to 80% the capatown of natural replacement. That provokes effects as lowering of lands and collapses of buildings.

If the situation of those countries is difficult and with tendency to become worse, the position of many countries with abundance of water reservations is not less preoccupying. It is the case of Brazil, that possesses plenty of water, however it doesn't know how to use, and it already faces difficulties of provisioning in areas of great population density, as São Paulo City. The country doesn't have sustainability knowledge.

The figure 1, shows the readiness of water in the world, and the decrease in the amount of water, in 1000 m^3 for inhabitant, in each continent in the years of 1950 and 2000:

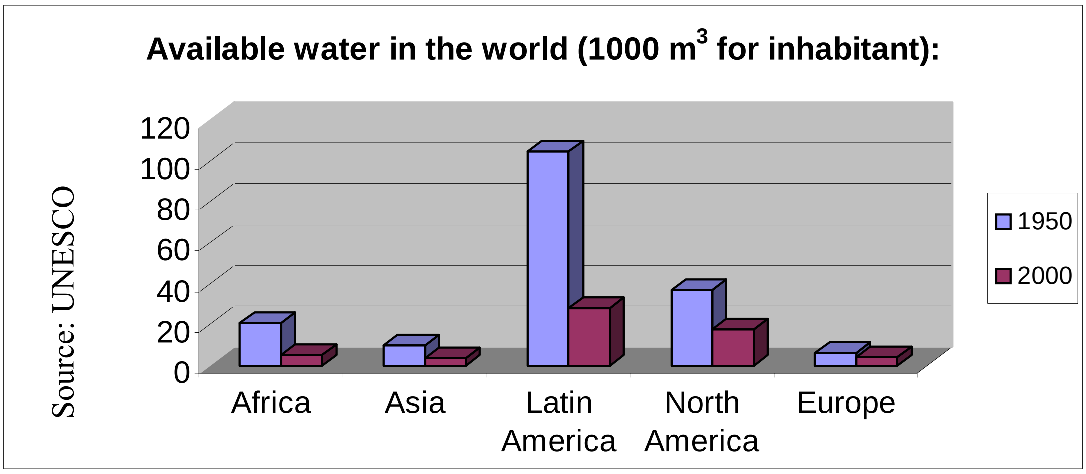

Figure 1 - Available water in the world (adapted of WERTHEIN, 2000).

According to projections of UN (Organization of the United Nations), in 2025 two thirds of the world population - or 5,5 billion people - they will live at places that suffer with some problem type related to the water. A lot of people die every year victims of diseases associated to the lack of water or bad sanitary conditions. Up to 2050, the deficient balances of water resources will be serious in at least 60 countries. At the present time, the half of the six billion inhabitants of the world lacks of water with appropriate treatment, and more than billion people don't have access to the drinking water (BIO, 2001).

The sustainable administration of the waters reuse already generates the economy of water treated, lowering costs, reducing expenses with energy, and it still propitiates the recharge of the groundwater. This work is justified for the economy of the treated water used for ends non noble, through the reuse of discarded waters.

1.1 Water reuse

Water reuse is the re-use of the water, that after suffering appropriate treatment, it is used with different purposes, in order to preserve the water resources existent. It is the use of that substance, for two or more times, recycling that also it happens spontaneously in the nature through the hydrological cycle. In several countries of the world, the planned water reuse is already a solution adopted with success in several processes. The rationalization of the use of the water and the reuse can allow a more maintainable solution. Today it is possible to reduce the pollutant ones at acceptable levels, turning the appropriate water for specific uses through operations and treatment processes.

The Construction Sustainable search the interaction between the human being and the environment, provoking considerable decrease in the degradation, through the use of residues, recycled materials, renewable raw materials, or materials without toxicant components, and technologies that don't cause damages to the environment, becoming a construction ecological correct that looks for your own sustainability.

The main uses of the recycled water would be: the urban use such an as wash of public roads, patios, vehicles, irrigation of green areas, provisioning of sources, bathrooms, fires; for industrial uses, kettles and processing water; in rural environment for irrigation and for groundwater recharge. The water reuse looks for mainly to avoid the consumption of drinking water in procedures where it use is totally dispensable, could be substituted, with advantages besides economical, in the industries and great residential and commercial condominiums. The water originating from sinks, lavatories, showers can be used, without treatment, for discharge of toilets and wash of floors. The black waters original of toilets, it should only be used again for the same ends, after treatment (HESPANHOL, 2003).

The water reuse, for any end, depends on your physical quality, chemistry and biological. Most of the physical-chemical parameters of quality is well understood, turning possible to establish quality criteria that are guiding for the reuse. So that the water can be reused, she should satisfy the recommended criteria or the patterns that have been fastened for the certain use and, for that, it is necessary to know the physical characteristics, chemistries and biological of the residuary waters or polluted.

The great advantage of the water water is the one of preserving the drinking water, reserving it exclusively for the attendance of the needs that demand its potability for the human provisioning. Also the decrease of the demand of the springs of pure water due to the substitution of the source, in other words, the substitution of a water of good quality for other worse, however that contains quality requested for the destiny plan for it. Another important advantage of the reuse is the elimination of discharge of sewers in the superficial waters, so there is a treatment in the water and the resulting products of the process are destined for appropriate places. Also in places where lack of water is very big the reuse solution it can be the best alternative

1.1.1 Greywaters in constructions

Greywater is washwater. The greywaters are those coming of the faucet, lavatories, showers, tanks, sink and washing machines and dishwasher. The water reuse in constructions is perfectly possible, since it is projected for this end, respecting all guidelines be analyzed, in other words, to avoid that the reused water is mixed with the treated water and not to allow the use of the water reused for direct consumption, preparation of food and personal hygiene. For the amount it is recognized that your use, in domestic level is justified. However the necessary quality to assist the foreseen uses should be evaluated strictly, for the sanitary safety's warranty.

Given already published for the relevance of the consumption of water in the construction, it's showing a hierarchy based on the magnitude of the consumption in the intention of identifying priorities of the actions of economy of water, according to table 1:

Table 1 - Consumption of the water in the residential constructions (SANTOS, 2002).

Sanitary equipment	Consumption of water (%)	
	AWWA*	**PNCDA****
Toilet	26,1	5,0
Shower	17,8	55,0
Bathtub	1,8	-
Washbasin and sink	15,4	26,0
Dishwasher	1,4	-
Washing machine	22,7	11,0
Physical losses	12,7	-
Others	2,1	3,0

* **AWWA:** American Water Works Association
** **PNCDA:** Programs National of Combat to the Waste of Water (Brazil).

The actions of rational use are from combat to the waste, as the detection and control of losses of water in the sistema predial, the user's understanding for not wasting water, the use of sanitary equipment economizer of water, incentive to the adoption of the individualized measurement, the establishment of tariffs that inhibit of the waste, between others.

2 Methodology

This research was developed in Passo Fundo town, that is located in the North area of the State of Rio Grande do Sul, south of Brazil (according to figure 2), and with a population of 168,458 inhabitants (IBGE - 2002). On the Basic Sanitation of the town, the exploration of the systems is made by CORSAN (Sanitation Company of Rio Grande do Sul State), in concession form, according to display the table 2 (Municipal Town Hall of Passo Fundo, 2003).

Figure 2: Location of the Passo Fundo town, RS, Brazil.

Table 2 - Data of the basic sanitation of the Passo Fundo town - RS.

Extension of the net of water	540 Km
Assisted population	99%
Volume of water produced	1.320,000 m^3
No. of hydrometers in the net	23,250
No. of connections to the distributing net	36,626
Average of volume of collected sewer:	
Residential	63,934 m^3
Commercial	17,804 m^3
Industrial	30 m^3
Public	2,036 m^3

In the table 2, the sewer volume collected by CORSAN in Passo Fund town, it is equal to 20% of the sewer total produced in the town and now it is thrown without some treatment, directly in the main river that cross the town, Passo Fundo River, that gave name to the town. There are areas of the town where there is not any treatment for the sewer. A project of CORSAN exists in process of an ETE (Station of Treatment of Sewers through Stabilization Lagoons) for the town, that it will begin to work in May, 2005, ETE Araucária, that will treat about 80% of the sewer produced in the town.

The research is based in the rising of data, in the identification of the generating points of water for reuse, in the obtaining of quantitative and qualitative data of the waters, in the knowledge of the different types of treatments of water for a safe and economical choice, according to the following route:

a. A rising of the literature was accomplished on the problem of the contamination of the waters, world and national scenery of that resource, and some reuse examples. A rising was also accomplished about the use, generation and application of the grey and rain waters. Through of these studies, they will be traced guidelines that will contribute in the establishment of general norms that can come to serve from support to the legalization of the sustainable of water reuse in Brazil;
b. Determination the types of residential and commercial constructions for analysis;
c. Elaboration of a questionnaire to look for the volume of greywaters generated in each place, as well as the opinion of Passo Fund society on the reuse of this water that it isn’t drinking;
d. Accomplishment of the collection of the greywaters in the certain buildings, for analysis and classification and reuse possibility. The analyses Physical-chemical and Microbiological of the waters were accomplished at the laboratories of CEPA from *Universidade de Passo Fundo* (University of Passo Fundo – UPF), among them: COD (Demands Chemistry of Oxygen) and BOD (Demands Biochemistry of Oxygen), OD (Dissolved Oxygen), Solids, Nitrogen, Phosphorus, Oils and greases, pH (Potential of Hydrogen) and Surfactantes; Chloride, Phosphate, Nitrate and Nitrite, Alkalinity, Hardness, Conductivity; Fecal and Total Coliform, Bacteria Count, *Escherichia Coli.*. Analyses were also accomplished at the Laboratory of Sanitation of UPF, as Color, Turbidity. All collections and analyses followed the collections of Standard Methods, 20^{th}, 1998.

The control and monitoramento of the water for reuse was accomplished being taken in consideration the physical-chemical and biological parameters recommended by the Resolution CONAMA 20/86 (Brazil), for the Ordinance 1469/MS,2000, for the Ordinance 05/89-SSMA of Rio Grande do Sul and for the Manual Guidelines for Water Reuse of EPA (U.S. Environmental Protection Agency).

The first sample for qualitative analysis of the greywaters was collected in March, 2004, being foreseen more three collections during the year, one in each season. They were collected in apartments, samples that were homogenized and transformed in three types of samples for analysis. The apartments were divided by typology and if it was possessed or it wasn’t possessed children and animals. The *sample 1* was classified by apartment with children, the *sample 2* in apartment with animals, and the *sample 3* apartment without children and without animals. The device for collection of the baths is of PVC of diameter 75mm and volume of 250ml (according to figure 3), and it was placed inside of the box (figure 4) of each bathroom, being collected in the half time and at the end of each user's bath. The figure 5 show the device for the collection of a sample in an analyzed bathroom.

Figure 3 - Device for the collection.

Figure 4 - Device installed inside the box

Figure 5 - Device and box of analyzed bathroom.

3 Analysis and discussion of the results

The qualitative results obtained through the analyses in the laboratories, they are expressed according to table 3.

The results of the table 3 show the significant variation in most of the parameters, as Coliform fecal, BOD, COD, total phosphorus, conductivity, except for the Coliform total and pH. For instance, the variation of the Coliform fecal varies from $1{,}1.10^4$ to $3{,}6.10^5$ MNP/100ml, which should be for an effluent smaller or equal to 300 (MNP/100ml) to be thrown in rivers in accordance Ordinance 05/89-SSMA of Rio Grande do Sul. Another distinction told in the variation of the found values it is the analysis of Nitrates that varied from 1,52 to 27,5 (NO_3-N mg/l), and for the Ordinance of Ministry of Health (Brazil) 1469/2000 the allowed maximum value of water for the human consumption (VPM) it is of 10 (NO_3-N mg/l). The turbidity that varied from 297 to 372,2 NTU has like VPM for the same Ordinance, 5 NTU. The presence of the bacteria *Escherichia coli* in the three samples, indicates the recent fecal contamination, that can place in risk the users' health, because that bacteria is abundant in the human and animal feces and it can contain 95% of the present coliformes in the intestine.

Table 3 - Qualitative results of the samples of greywaters.

Parameters	**Sample 1** (wich children)	**Sample 2** (wich pets)	**Sample 3** (without children and pets)	**VPM***
Fecal Coliform (MNP/100ml)	$1,1.10^4$	$1,7.10^4$	$3,6.10^5$	≤ 300
Total Coliform (MNP/100ml)	$>1,6.10^5$	$>1,6.10^5$	$>1,6.10^5$	-
Oil and grease (mg/l)	18,2	14,8	26,7	≤ 30
PH	7,11	6,91	7,10	6,0 a 8,6
BOD (mg/l)	258	174	384	≤ 200
COD (mg/l)	470	374	723	≤ 450
Sólids (mg/l)	180	100	188	≤ 200
Alkalinity	6,7	5,0	8,2	250
Surfactantes (mg/l)	2,18	1,46	3,42	2,0
Bacteria count (CFU/ml)	$8,5.10^5$	$3,0.10^5$	$8,5.10^6$	
Chloride	26,9	14,7	29,4	250
Nitrate	27,5	1,52	4,09	10
Nitrite	<0,003	0,027	0,489	1
Total Phosphorus (mg/l)	0,43	0,31	1,79	1
Turbidity (NTU)	340,7	373,2	297,2	5
Hardnes	5,7	13,6	10,7	500
Conductivity (µs/cm)	125,9	105,8	222	2000

* **VPM** - Allowed Maximum Value of the water for human consumption and its potability pattern, in agreement with the Ordinance 1469/2000 of Ministry of Health (Brazil) and for the Ordinance 05/89-SSMA of RS.

Table 4 - Comparative Table of greywaters characterization of the according to other authors.

Parameters	**Concentrations**		
	Cristova-Boal et al. (1996) ***apud*** **Santos (2003)**	**Santos et al. (2003)**	**Fiori et al. (2004)***
Color (Hz)	60 - 100	52,30	-
Turbidity (NTU)	60 - 240	37,35	337,3
pH	6,4 – 8,1	7,2	7,04
OD (mg/l)	-	4,63	-
Total Phosphorus (mg/l)	0,11 – 1,8	6,24	0,84
BOD (mg/l)	76 - 200	96,54	273
COD (mg/l)	-	-	522,3
Total Coliform (MNP/100ml)	$500 – 2,4.10^7$	11.10^6	$1,6.10^5$
Fecal Coliform (MNP/100ml)	$170 – 3,3.10^3$	1.10^6	$1,3.10^5$
Bacteria Count (CFU/ml)	-	-	$3,2.10^6$

* According to Table 3.

Table 4 presents values of greywaters parameters found by several researchers. With relationship to the variation observed in the parameters, it is notable that the other authors also verified a significant oscillation between the results. For pH, Total phosphorus, is observed that in the analyses the medium values were reasonably seemed, however for the turbidity concentration and BOD, it is noticed that the difference is significant among the authors.

Through the questionnaires accomplished in the buildings researched in Passo Fundo city, it was found to the following quantitative results, according to the figure 6. It is observed that the washing machine is the equipment that more generates greywaters in an apartment, and in second it is the shower.

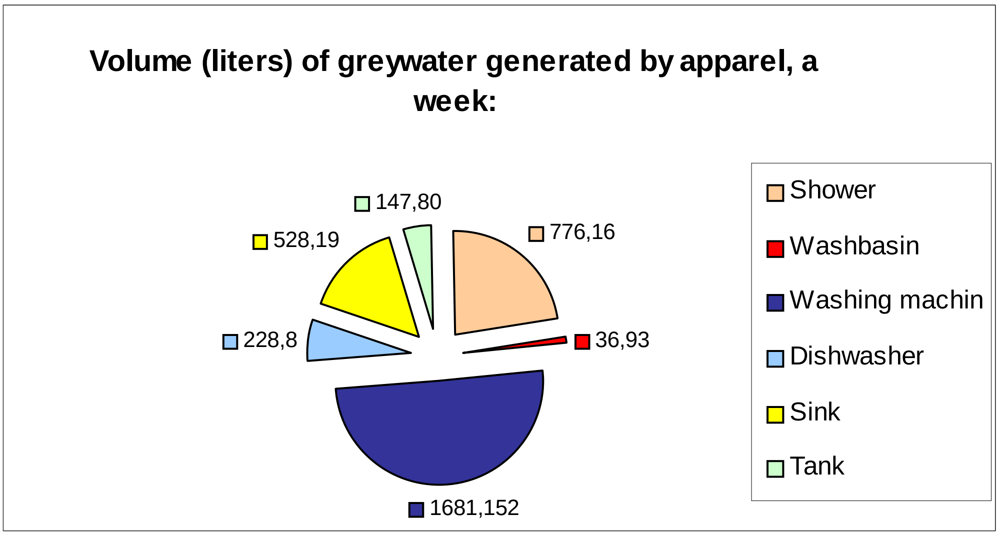

Figure 6: Volume (liters) of greywater generated by apparel, a week.

4 Conclusions

The control of the process of water reuse is phase of great importance, should begin for the compulsory of separation of the canalizations of drinking water and water of reuse. Even, those tubulações should be painted with specific coloration and with denomination to alert on the use of the same ones, mainly when it goes for cleaning of floors and irrigation of gardens.

Besides, it should be excelled by the monitoramento of the operation in matter in the acting of the disinfection accomplished in the system, mainly for the gray waters. That control should be accomplished mainly for the parameters BOD, COD, Turbidity, Coliform Nitrate and Phosphorus and the Bacteria Count. The results of these parameters should be in agreement with the demanded patterns.

The reuse of the greywaters generated in the constructions, that it decreases the consumption of drinking water for not drinking purposes, it contributes to the environmental sustainability of the cities. Also in Brazil where the basic sanitation is not for all, and most of the cities spills the domestic sewer to open sky in the rivers, the greywaters reuse contributes to minimize the amount of pollution thrown in the rivers.

The results of the table 3 show the significant variation in most of the parameters, as Coliform fecal, BOD, COD, total phosphorus, conductivity, except for the Coliform Total and pH. For instance, the variation of the Coliform fecal varies from $1,1x10^4$ to $3,6x10^5$ MNP/100ml, which should be for an effluent smaller or equal to 300 (MNP/100ml) to be thrown in rivers. Another distinction told in the variation of the found values it is the analysis of Nitrates that varied from 1,52 to 27,5 (NO_3-N mg/l), and the allowed maximum value of water for the human consumption (VPM) it is 10 (NO_3-N mg/l). The turbidity that varied from 297 to 372,2 NTU has like VPM for the same Ordinance, 5 NTU.

For the reuse of those greywaters in the discharge of toilets, there would not be need of previous treatment, it would be simply necessary a canalization system and appropriate deposit that it would take those waters for reuse in the toilets and later they be discarded as black waters. However if the greywaters go to reuse in other situations, as irrigation of green areas and fountains, washes of floors and sidewalks, combat water to fire, among other, there is the need besides the canalization system and deposit, of an appropriate previous treatment for the possible reuse of these waters that will be certain in elapsing of this master's degree research.

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5 Presentation of Author(s)

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Study on Rooftop Rainwater Harvesting System in Existing Building of Taiwan

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Abstract

This paper would focus on reuse mechanism of rainwater drainage system in existing building of Taiwan. The current design methodology of roof construction for rainwater plumbing system would be reviewed. Furthermore, we investigate circumstances and survey the conditions of typical buildings in Taiwan to find out the applicable reuse mechanism of rainwater system in existing building. In this study, some influence factors including financial and technical issues must be considered. In order to clarify the practicable performance, we would conclude some practicable models for existing buildings, which can integrate the existing roof construction for rainwater plumbing system.

Keywords
rainwater use, water conservation, guideline, design standard, evaluation system

1. Introduction

Many metropolitan areas in Taiwan have experienced water shortages in recent years, due partly to droughts, economic development and rapid urbanization. These water shortages have resulted in an anxious public consciousness to existing water supplies and created an economic barrier to development. Consequently, it is clear that alternative water resources must be investigated to alleviate the water shortage problem in urban areas. Rainwater use as a supplement to the potable water supply in Taiwan has been demonstrated a practical and promising alternative where traditional groundwater or surface water is limited.

To implement rooftop rainwater harvesting systems for domestic water-use, the Water Resources Bureau, Ministry of Economic Affair, has published the "Rainfall Catchments and Dual Water Supply System-Handbook" to provide a reference for engineers in preliminary building design. A new rainwater use guideline that had been linked to building code offers an easy approach to the evaluation of water conservation and a rainwater use system for architectural planning in Taiwan currently. However, these rainwater use system guideline mostly were conducted for new constructions and rare to mention about the large number of existing buildings.

This paper would focus on reuse mechanism of rainwater drainage system in existing building of Taiwan. The current design methodology of roof construction for rainwater plumbing system would be reviewed. Furthermore, we investigate circumstances and survey the conditions of typical buildings in Taiwan to find out the applicable reuse mechanism of rainwater system in existing building. In this study, some influence factors including financial and technical issues must be considered. In order to clarify the practicable performance, we would conclude some practicable models for existing buildings, which can integrate the existing roof construction for rainwater plumbing system. Finally, this paper would also perform a case study and simulation as the verification.

2. Calculation And Evaluation Mechanism

The calculation method and procedure of rainwater use system had been conducted in our previous research. As a new aspect, this report would focus on the rainwater utility for existing building. It is necessary to consider the integration of existing conditions and practicability. However, the calculation and evaluation mechanism are basically in similar consideration. First of all, we need to know the quantity of rainwater from collection and for usage. According to the basic balance concept of input and output, it can be concluded as four parameters to calculate the rainwater use system. Those are rainwater from collection device and replenish from tap water system in the side for input, and the others are consumption quantity for user and overflow from storage device. We can indicate this concept as the diagram shown in figure 1[10].

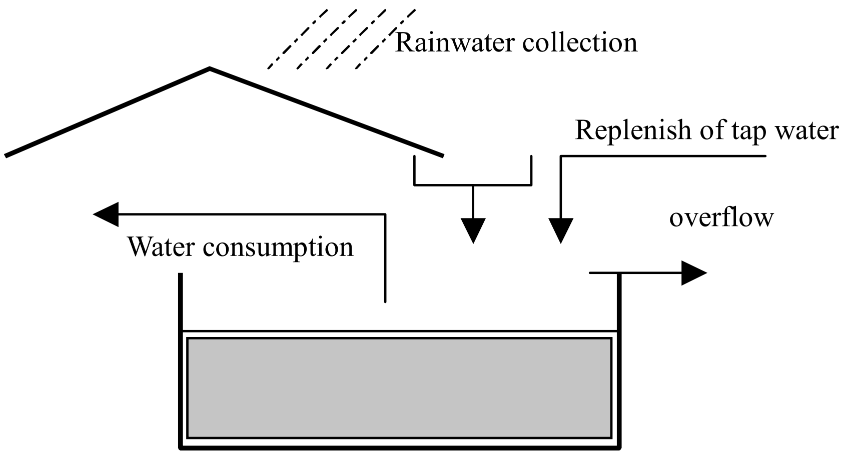


Figure 1. Balance of input and output for rainwater utilization

According to the daily precipitation database, at first, we must conform the location of design object (for example: in Taipei) and the meteorological precipitation data for simulation object or assessment as the calculation process of utilization quantity of rainwater. Then, we have to decide the area of collection device, object character of water utilization as the condition for simulation and assessment. The calculation process is as the following:

(1) The collection quantity (CRW) from daily precipitation (Rd) and collection area(CA).

$$CRW(m^3) = CA(m^2) \times Rd\ (mm/day) \times \gamma \times 10^{-3}$$

(γ is the flow out coefficient, according to the character of collection location, it is usually adopted 0.85-0.95 as general roof.)

(2) The overflow quantity (OFV) from collection quantity (CRW), volumes of storage

tank (SV) and remains quantity in storage tanks (RSV).

When $CRW + RSV > SV(m^3)$, then $OFV = CRW + RSV - SV$

When $CRW + RSV < SV(m^3)$, then $OFV = 0$

(3) The first remains quantity in storage tank (RSV') after above calculation.

When $CRW + RSV > SV$, then $RSV' = SV$

When $CRW + RSV < SV$, then $RSV' = CRW + RSV$

(4) The quantity replenish water (CW) from the remains quantity in storage tank (RSV') and consumption quantity for user (UW).

When $RSV' - UW < 0$, then $CW = -(RSV' - UW)$

When $RSV' - UW > 0$, then $CW = 0$

(5) The second remains quantity in storage tank (RSV'') after above calculation.

When $RSV' - UW < 0$, then $RSV'' = 0$

When $RSV' - UW > 0$, then $RSV'' = RSV' - UW$

(6) We adopt the second remains quantity in storage tank (RSV'') as the initial data of RSV for next day's data to add up all parameters and yearly utilization by looping calculation.

(7) According to the above add-up calculation, we can get the yearly rainwater utilization quantity (YRU), yearly rainwater collection quantity (YRC) and yearly consumption quantity (YTU).

$YRU = \Sigma(UW - CW)$, $YRC = \Sigma CRW$, $YTU = \Sigma UW$

(8) The rainwater utilization rate (PRU%) and substitution rate of tap water (PCW%) can be calculated as following:

$$PRU(\%) = YRU \div YRC \times 100, \quad PCW(\%) = YRU \div YTC \times 100$$

The above calculation procedure of rainwater assessment had been written into the computer program, and we can get the simulation results very rapidly. The program flowchart is shown in the figure 2. This calculation method offers quantity information for evaluation of rainwater utilization and help primary decision making for designer. However, we need further information about the situation of existing circumstance and conditions of existing building. Then, the practicability of rainwater use system for existing building could be arranged. Therefore, we performed an investigation and interview to verify the practical conditions and inference factors.

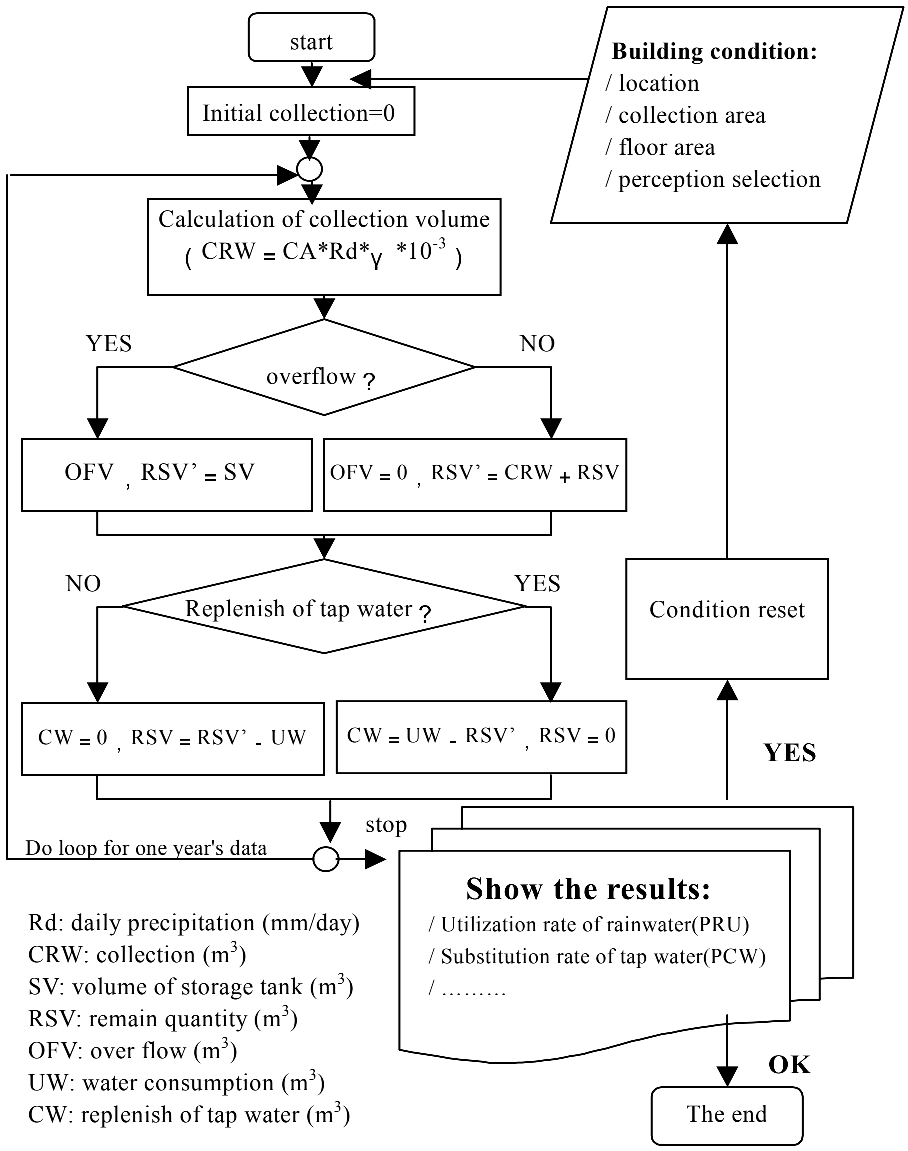


Figure 2. Flow chart of rainwater utilization simulation

3. Investigation for Existing Building

City is always constructed by infrastructure and buildings and simultaneously with high-density population. In order to figure out the existing conditions for rainwater utility, we choice the Taipei City as the study object. Figure 3 shows the urban planning map of Taipei City. Firstly, we focus on the potential rainwater utilization in Taipei City. There is about 271.8 kilometer square and about 2641000 populations in this city and its tap water availability rate is 99.49%. The precipitation is about 2400mm/year, then the total rainwater for one year is theoretically approximate 6.52 hundred million ton. On the other hand, the annual tap water supply is about 10.93 hundred million ton due to tap water authority's report. It shows the high potential of rainwater utilization for Taipei City. In fact, rainwater always becomes the burden of the city drainage or treatment device. On other words, there are high potential of rainwater utilization in Taipei City or many other place of Taiwan.

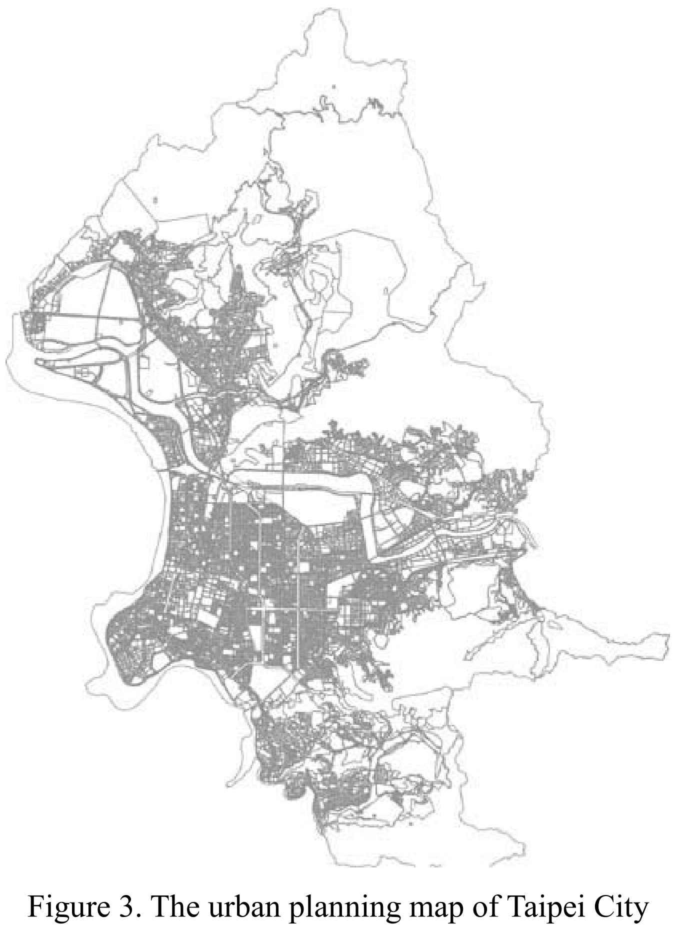


Figure 3. The urban planning map of Taipei City

As observed object, investigation take samples randomly by grid method and GIS information system. According to the city map coordinates system in 1/1000 scale, we select the intersect point building as observed object. Figure 4 is a performance example for object decision in this investigation and Figure 5 shows the whole observed objects distribution in this investigation.

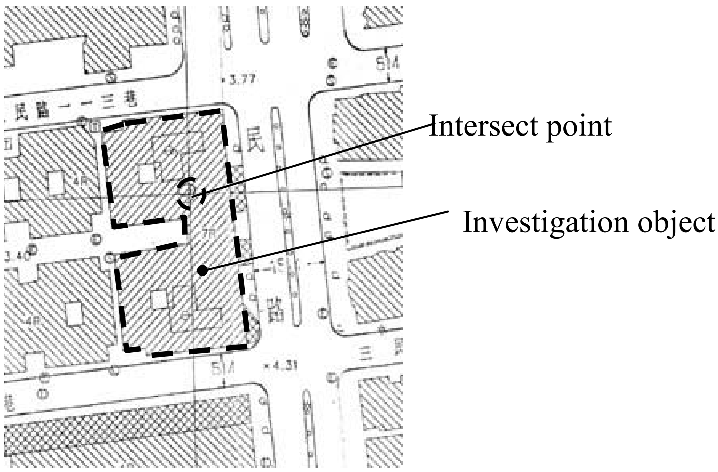


Figure 4. Performance example for object decision

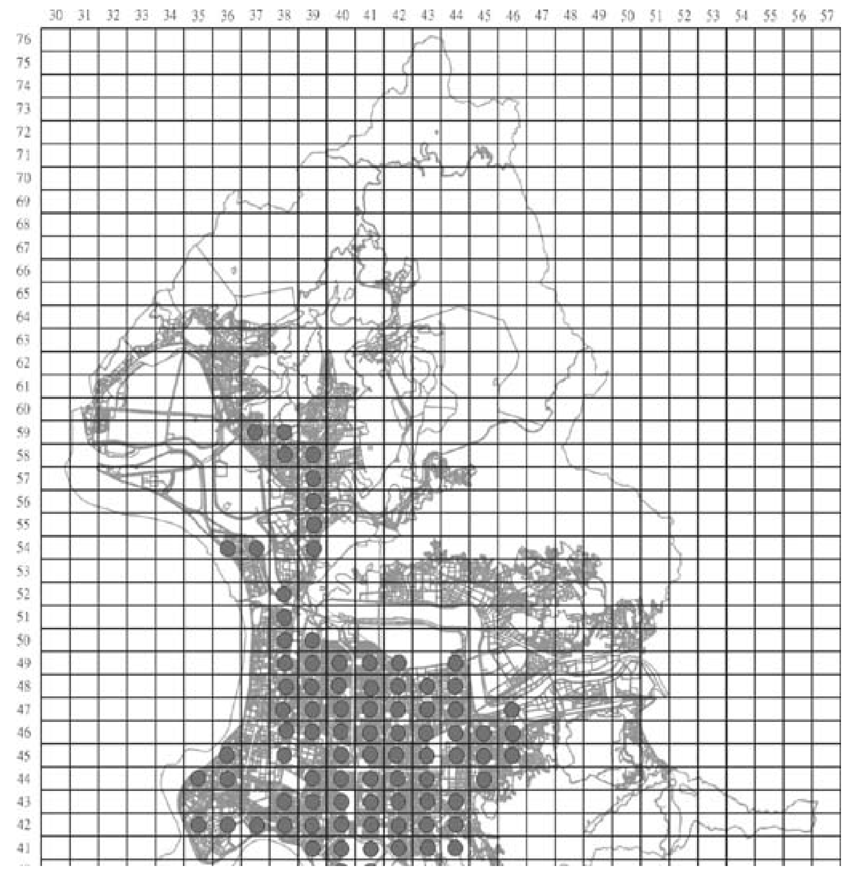


Figure 5. The whole observed objects distribution in this investigation

As the initial observation for these investigation objects, there are 97 cases were selected. Figure 6 shows that the building age is in 20~30 years at the most cases. The cases that are under 10 years or over 30 years occupy less percentage in this investigation.

Building age (year)	Case numbers	Percentage %
5~10	6	6.19%
10~15	12	12.37%
15~20	22	22.68%
20~25	24	24.74%
25~30	24	24.74%
>30	9	9.28%
Total	97	

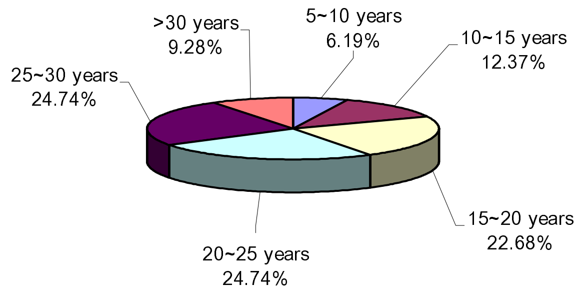


Figure 6. Building age and distribution of observed objects

Figure 7 shows that the building floors height is in 1~5 floors at the most cases with 67%. The cases above 16 floors occupy less percentage merely with 2% in this investigation.

Building floors	Case numbers	Percentage %
1-5	65	67.0
6-10	13	13.4
10-15	17	17.5
>16	2	2.1
Total	97	100

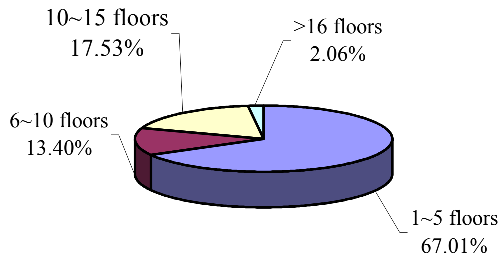


Figure 7. Building floors height and distribution of observed objects

4. Condition analyses and issues identification

As the results of investigation, this report concluded 3 issues of existing rooftop rainwater harvesting system for evaluating the practicability.

(1) Rooftop

Reinforce concrete structure buildings which are with flat rooftop occupy the most cases in this investigation. The typical building roof has two conditions, one is flat concrete roof and the other is with additional steel roof frame as shown in Figure 8 and Figure 9. The numbers of these two kinds of rooftop are very similar.

Figure 8. Reinforce concrete structure building with flat concrete roof

Figure 9. Reinforce concrete structure building with additional steel roof frame

(2) Plumbing and piping work

Drainage piping work for rainwater is also typically two types, one is conceal piping buried into structure and the other is show off piping with clear system on building envelope. Conceal piping work always has the problems of maintenance and duration. Figure 10 shows the view of existing show off piping case in this investigation.

Figure 10. View of existing show off piping case

(3) Drainage system and details

According to the observation, drainage system for rainwater generally collects from rooftop and through piping work then flows out to outside urban drainage system. Most individual cases under 5 floor height directly flow out the rainwater through simple piping work, and some building with larger scale and more complex function collect rainwater into basement structure once before driving out. Figure 11 shows the most popular driving out type and Figure 12 is some details of collection installations.

Figure 11 View of the most popular driving out type

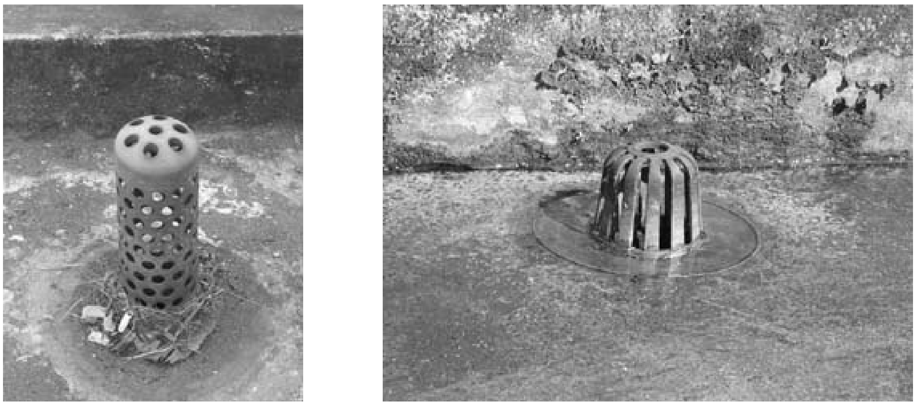
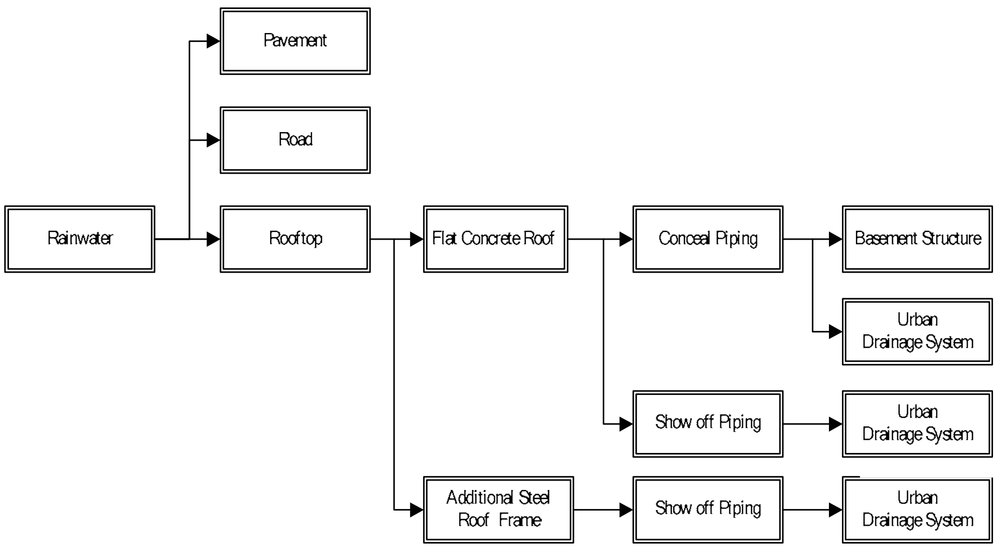


Figure 12. Details of collection installations

According to the understanding of existing building condition, the practical performance of existing rooftop rainwater harvesting system could be considered as the following diagrams as shown in Figure 13.


Pavement
Road
Rainwater
Rooftop
Flat Concrete Roof
Conceal Piping
Basement Structure
Urban Drainage System
Show off Piping
Urban Drainage System
Additional Steel Roof Frame
Show off Piping
Urban Drainage System

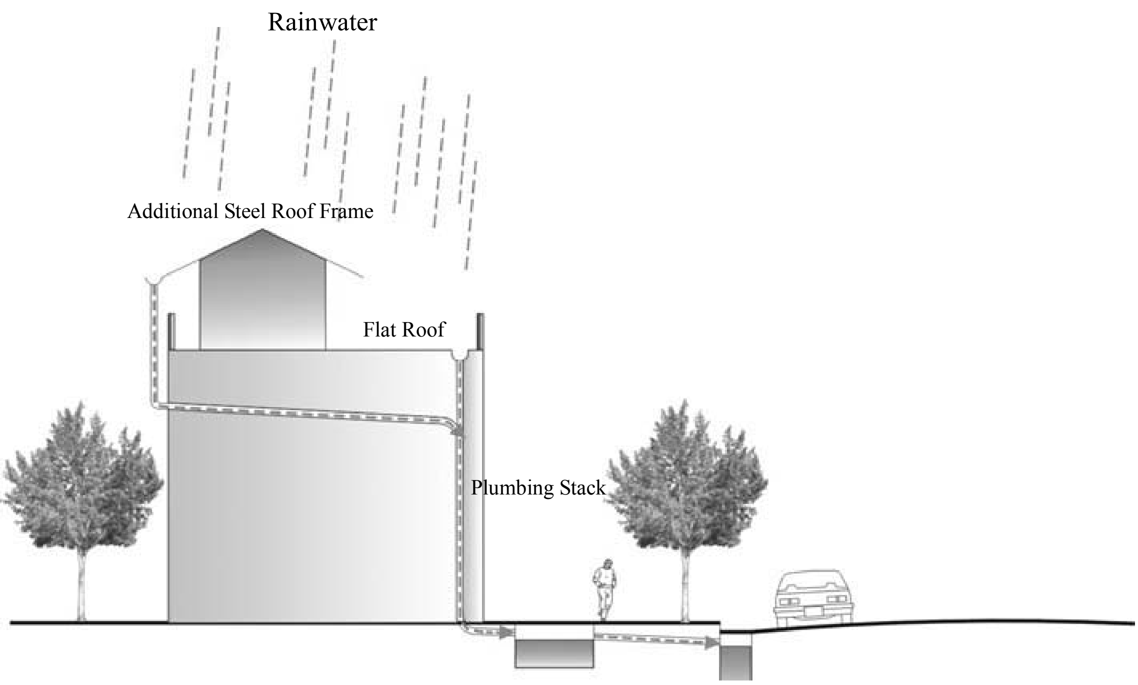

Rainwater
Additional Steel Roof Frame
Flat Roof
Plumbing Stack

Figure 13. Existing rooftop rainwater harvesting system frame

5. Evaluation Tool

Existing rooftop rainwater harvesting system is an acceptable solution for alleviating the water shortage problem in urban areas. However, practical performance need functional tool to make the real progress for the publics. Herein, we developed a practical evaluation tool in the research. By using system dynamic theory, we transfer the calculation to be dynamic simulation through commercial software STELLA. The transformation flows and the object treatment are as shown as Figure 14.

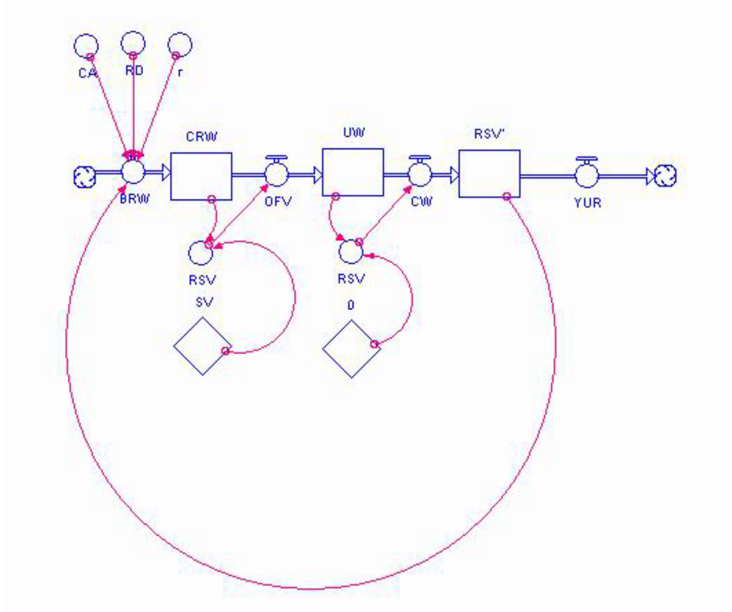


Figure 14 Transformation flows and the object treatment of dynamic simulation

The performance of this dynamic simulation is still conducting. The partial results and the application are offered in network at present. Figure 15 shows the entrance page of the dynamic simulation for practical evaluation of existing rooftop rainwater harvesting system.

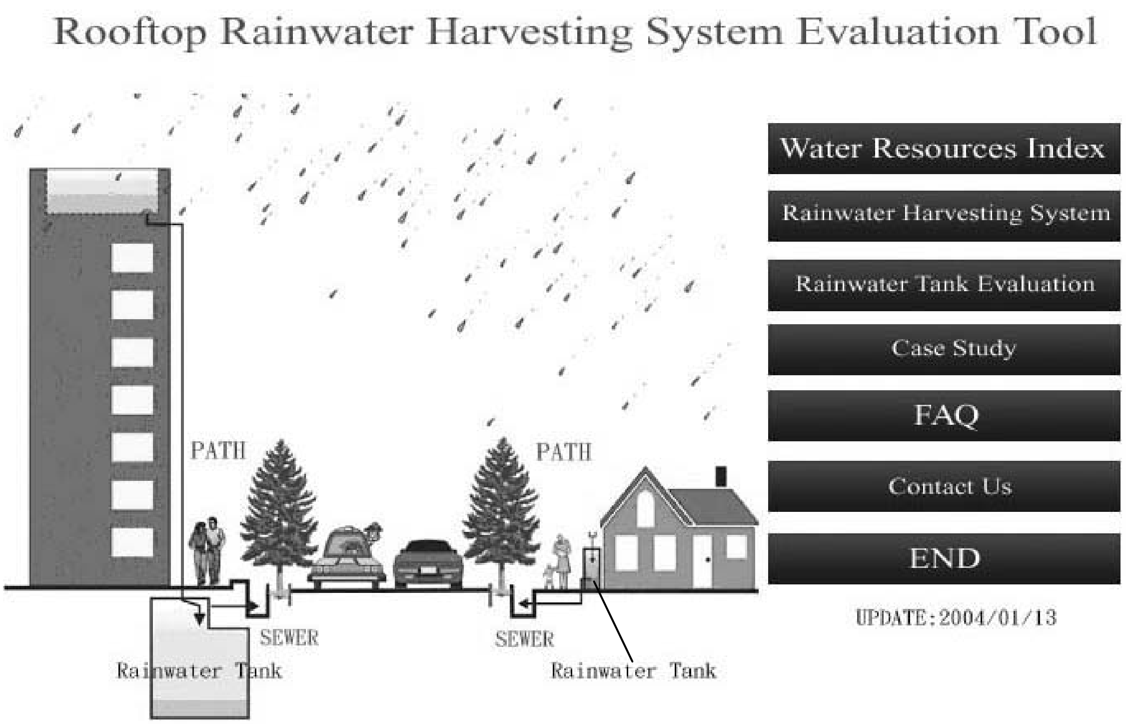


Figure 15 Entrance page of the dynamic simulation tool

6. Conclusion

This paper focuses on existing rooftop rainwater harvesting system of Taiwan. The current design methodology of roof construction for rainwater plumbing system had been reviewed. We investigated circumstances and survey the conditions of typical buildings in Taiwan to find out the applicable reuse mechanism of rainwater system in existing building. We also arrange the categories of existing building rainwater drainage conditions including rooftop, piping work and drainage system. In order to clarify the practicable performance, we concluded some practicable models for existing buildings, which can integrate the existing roof construction for rainwater plumbing system. Finally, this paper also offered dynamic simulation tool information of existing rooftop rainwater harvesting system for practical application.

ACKNOWLEDGEMENTS

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Aplication of a Vacuum Water Closet System in a Brazilian Airport

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Abstract

The conclusion of most of the researches about building's water and sewage systems around the world, always shown that the toilet is the sanitary fixture that uses more water than any other else in residential and commercial buildings. Buildings were a big number of persons circulates every day, like transportation terminals, as train and bus stations and airports are very interesting points for application of high efficiency water savings technologies, in a way to reduce water consumption, good practices as world's environment and water resources situation require. One technology that appears with the high efficiency is the vacuum toilet systems, using fixtures that consumes just 1.2 Lpf and shows an enhanced performance on collection and transportation of human waste. As a requirement of a public building, like an airport, this two primary conditions must be accomplished: use the minimum amount of natural resources, while the service is improved. The objective of this article is to show the application of a vacuum toilet system on a Brazilian airport (Santos Dumont, downtown Rio de Janeiro), identifying the benefits and features of this system.

Keywords

Vacuum system; vacuum toilet; water conservation.

1 Introduction

Over the last decades, water consumption per capita had increased by several reasons, at the same time population also increased in number. The population concentration in big metropolitan areas is today in a level never seen before. Those factors together are taking water resources to conditions of scarcity, leading for a challenge of finding better and more reasonable and efficient ways of using water.

Because of this, one of the major concerns of authorities, researches, as well of all technical community involved with water and sewage building systems is to reduce water consumption and sewage generation, keeping performance and quality in the same levels of the existing services, if not improving then.

Several studies show the toilet to be the fixture that consumes the largest quantity of water in both residential, commercial and public buildings, thus any action toward saving water in this type of fixture should be welcome [1], [2]. It's important also to notice that modifications in this type of fixture does not necessarily need to be accompanied by changes in user's behaviour, facilitating the implementation of water saving programs based on new toilet technology.

With these thoughts in mind, the authors of this article decided to collect information to show eventual benefits of a vacuum toilet system installed in an airport in Brazil.

2 Vacuum system description

2.1 Overall

Facing the problems and needs before written, an alternative technological application is the use of a vacuum toilet system. Considering two aspects of a sewage system performance, sewage transport and removal and water savings, vacuum sewage systems can show important improvements comparing to gravitational sewage systems.

Vacuum systems use difference in air pressure between the toilet environment and inside the vacuum pipe to collect and transport the sewage. During flush cycle, a vacuum toilet receives surrounding air that gets inside the pipe (permanently under pressure lower than atmospheric) through the bowl, toward the vacuum central, where vacuum is generated and therefore where is the lower pressure in the whole system. The airflow through the bowl forces the sewage to get inside the pipe and water is used only to clean the bowl (a total of 1.2 liters of water per flush), not for sewage transport. Since air that transport the sewage and water is used only for cleaning, a better understanding of the water savings potential of a vacuum toilet system is given. Many standards cover the design and installation of a vacuum toilet system [3], [4].

A Stevens Institute of Technology report shows tests made with vacuum toilets and they meet or exceed the North American Codes for sewage removal [5].

Vacuum sewage systems are not exactly new. There are indications that around 1870 in Germany and France some municipal vacuum sewage systems installations happened. Technological development of engineering at that time probably made things difficult to continue with the idea and is not until late 1950 new mentions of vacuum sewage systems appear again.

In Sweden, 1956 to 1958, a new concept of vacuum sewage systems equipped with vacuum toilet fixtures is presented in some installations in this country and others. This same basic concept have been developed over the years and this Swedish technology of late 50's is the basis of vacuum toilets systems we see today, with applications in land based projects and others fields like marine.

The idea was to generate low pressure in one centralized point (the vacuum central unit) built a vacuum pipe network with some special features and install in the extremities of this pipe network toilets operated by vacuum and that could hold the vacuum inside the pipe when not in operation.

During flush, a special design valve in the toilet opens and allows the content of the bowl to get inside the pipe in direction of the vacuum central unit. While this "flush valve" is open, another valve put some water to clean the bowl. All this operation is controlled by another pilot valve, activated by a push button. The bowl itself is made of vitreous china and because there is no siphon in the toilet, the space normally occupied by it now gives room to install all these valves.

One simplified scheme of the system can be seen in the Figure 1. This figure shows: the vacuum central unit (number 1 in the figure), responsible for vacuum generation, through vacuum pumps, and responsible also for collecting the sewage and temporarily storing it; the vacuum pipe network (simplified here with only one point of collection) (number 2); and the vacuum toilet itself (number 3).

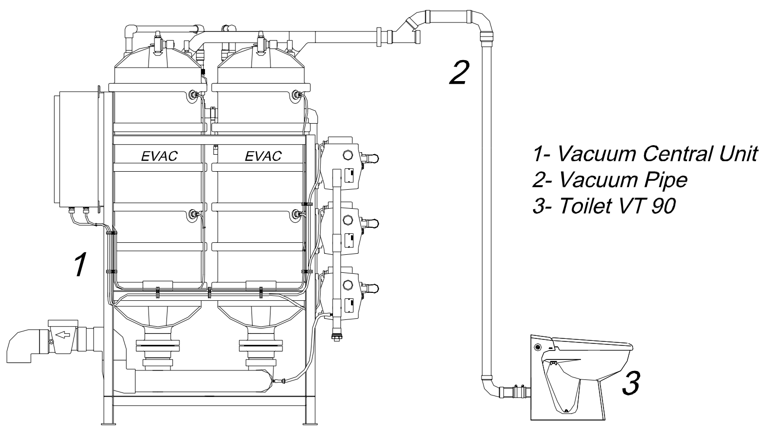

Figure 1 – Simplified scheme of a vacuum toilet system. Image: Courtesy of EVAC

2.2 Vacuum central

The vacuum central unit is built with tanks, vacuum pumps, valves, electrical control panel and other instrumentation and control devices. The vacuum pumps take out the air that exists inside the tanks and pipe until about a maximum of 1/3 of atmospheric pressure. Vacuum switches are permanently making readings of the pressure in the system and feed the Programmable Logic Controller (PLC), installed inside the electrical control panel. With this information, the PLC determines witch, when, how long and how many vacuum pumps will run. Inside the tanks float level switches are installed and they also feed the PLC with information. When one tank is partially filled and the sewage reaches one of these float level switches, a sign is given to dump the tank. This dumping is made in some cases by breaking the vacuum inside the tank (bringing the specific tank to atmospheric pressure) and leaving the sewage flowing by gravity. While one tank is dumping, the other, still under vacuum, receives the sewage generated during this period, making the availability of vacuum to the whole systems continuous. Tanks may dump to municipal sewer system or to a sewage treatment plant. Depending on the type of vacuum central unit technology and specific project needs, the tanks may dump by action of sewage pumps. The vacuum central unit is the only point where electrical energy is needed in the whole system.

2.3 Vacuum toilet (water closet)

Vacuum toilets have a special design. The vacuum toilet bowl is manufactured in vitreous china and externally they look just like a normal toilet. Inside of the fixture is different, since there is no siphon inside the bowl. In its location, a kit of valves is installed: the discharge valve, the water valve, the control valve, hoses and a metal plate that holds all these valves, all of then pneumatic operated. The discharge valve, when not in operation, holds a little amount of water inside the bowl and vacuum inside the pipe.

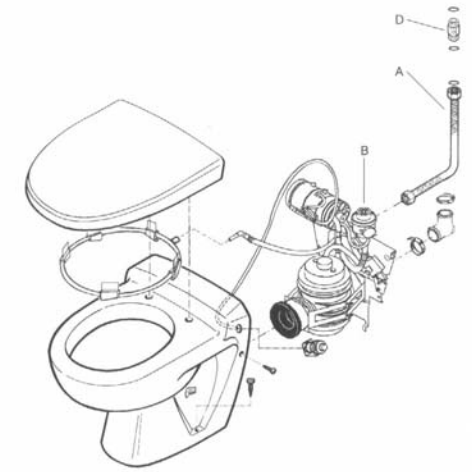

Figure 2 – Vacuum toilet fixture. Floor mounted model. Image: Courtesy of EVAC

When pressing the flush push button, witch is just an air below that forces a little bit of air inside an specific chamber of the control valve, a flush cycle is initiated. At that time, the control valve sends a pneumatic sign to both, water valve and discharge valve, and they are at that time opened.

When the discharge valve is opened, air at atmospheric pressure forces the content inside the bowl toward the vacuum pipe, at the same time the water valve rinses the bowl, cleaning it. After collecting the sewage and water that was inside the bowl, the discharge valve closes and the water valve remains open for one more instant, to re-establish the pool of water inside the bowl. The whole cycle takes a few seconds and consumes 1.2 liters of water and from 60 to 100 liters of air. The energy required for the valves to operate comes from the vacuum existing on the pipe

2.4 Pipe system

The vacuum pipe is normally built in PVC. Because of the difference in pressure, a bigger wall thickness is needed. Normally a pipe that resists to a 7,5 kgf/cm² pressure in service can resist to vacuum levels that a typical vacuum sewage system is subject to. Some particular pipe profiles and special pipe arrangements were specifically developed to improve the performance and give better functionality of vacuum sewage systems and they are shown in system's manufactures technical manuals.

Three features of vacuum pipes are especially interesting. Most of the cases the pipe diameter are much smaller the gravitational pipes would show (usually half of the size), there is no need of constant slope on the pipe and the ability of lifting the sewage. These features make, in many cases, retrofits and renovations easier with vacuum toilets systems.

3 Case of study: research development and data discussion

The Santos-Dumont Airport is located in Rio de Janeiro, the second largest Brazilian city, in down town area. First civil airport in Brazil had opened its runway in 1936, with the name "Santos-Dumont": the Brazilian who was the first person to take-off and fly a self-propulsion aircraft in 1906. It is not until 1947 that the airport's passenger terminal start it's operations, with the same basic shape it has today.

Figure 3 – Aerial view of the Santos-Dumont Airport complex, Rio de Janeiro and Internal view (lobby) of the Santos-Dumont Airport, Rio de Janeiro.

In Feb 2001 a vacuum toilet system was installed in the public restrooms of the main airport terminal, replacing regular gravity toilets with flush valves. After and before the new toilets system start-up, the toilet's use of water was measured and recorded. The collected data is the basis of this study.

The Santos-Dumont Airport had during the period of the vacuum toilet system evaluation an average of 13.000 people passing through it every day, not all of then were actually passengers, since this number includes people that works there and also because the airport's very central location, down town Rio de Janeiro, many non-passenger visitors goes there for many reasons.

The system installed in the airport consists of 21 vacuum toilets located in the main terminal lobby restrooms, 10 of then in men's restrooms and 11 in the women's one, the vacuum sewage collection unit and the vacuum pipe.

The material used to build the vacuum pipe was Brazilian class 15 (similar to American schedule 40 PVC) solvent-welded PVC in diameters varying from 1 1/2" to 2 1/2". In Brazil this type of pipe is normally used for cold-water installations. The small pipe diameter in the toilet outlet (1 1/2") and its direction (toward the wall), associated with the ability of elevation (up to 20 ft) of the sewage provided by the vacuum toilet system contributed for the system to be installed with minor disturb of the airport daily activities.

The system was installed without any interruption of the restrooms operation. The vacuum pipe was installed during the day in all areas where the installation work would not disturb the regular operation of the services of the airport.

At the same time, the vacuum central was installed and put ready to work, sharing the room space of an existing pumping lift station area. The vacuum central unit installed was equipped with 3 vacuum pumps of 1.5 kilowatts producing 48m³ of vacuum per hour each one. The pumps are started depending on the demand of use of the system and they rotate the use to equalize the usage of each one of the pumps. To collect the sewage there are 2 tanks of 60 gallons of capacity each one. These tanks drain (by gravity) their content when they are 40% full, by means of venting the tank (they are normally under vacuum). When one tank is draining, the other, still under vacuum, receives the sewage generated during the cycle. The unit contains also instrumentation and control to all the operation of the system

Figure 4 – Vacuum central unit and vacuum toilet installed

Inside the restrooms, the vacuum pipe branches had been installed in small sections that could be accomplished between 11 PM and 6 AM, when the airport was closed. There was no need of floor penetration, since the new pipe was installed on top of the floor surface, behind the toilet.

Because of the distance between the existing wall and the new toilet, created to accommodate the new vacuum pipe, Formica covered plywood and marble stone top cabinets were installed to give the job a good finish, as the airport's restrooms deserve. Underneath the cabinet, the old water flush valves that used to feed the gravitational toilets were hidden, and the same water valve connection was used to feed the new vacuum toilet of water. The cabinet was also helpful to install the new vacuum toilet flush push button.

As each one of these small sections of vacuum pipe branches were ready, the regular gravity toilet was removed, the gravity pipe connection in the floor was caped (typically gravity toilets in Brazil has their outlet toward the floor), the new vacuum toilet was installed and connected to the already existing vacuum pipe connection in that position.

Since the vacuum central unit was already in conditions to work, as well the main vacuum pipe between the braches and the vacuum central and the not ready to use vacuum pipe branches had isolation valves, the toilets could be put to work one by one, during the night.

The result was that in only two days the vacuum fixtures replaced all the gravitational toilets. This explains why the water consumption felt dramatically, as shown in the charts.

Two months before the installation of the vacuum toilet system in the airport, an authorization was given from Infraero (Brazilian airport authority, responsible for the airports operations) to install water flow meters in these specific restroom's water supply pipes.

Two 2 1/2" flow meters were installed in two lines, these pipes are exclusively used to feed the toilets, not been used to feed any other fixtures in these restrooms; sinks and urinals had a different water supply that were not object of any water consumption measurement.

These two water pipes are used, one for feeding water to the ten men's toilets and other for the eleven women's toilets. Fifty five days prior to the beginning of the operation of the vacuum toilets system in airport, daily readings in the flow meters were taken, and these readings continued for more almost fifty days, while the vacuum toilets system was already working, making a total of 100 days with flow meters daily readings. The data are shown in the Figure 5.

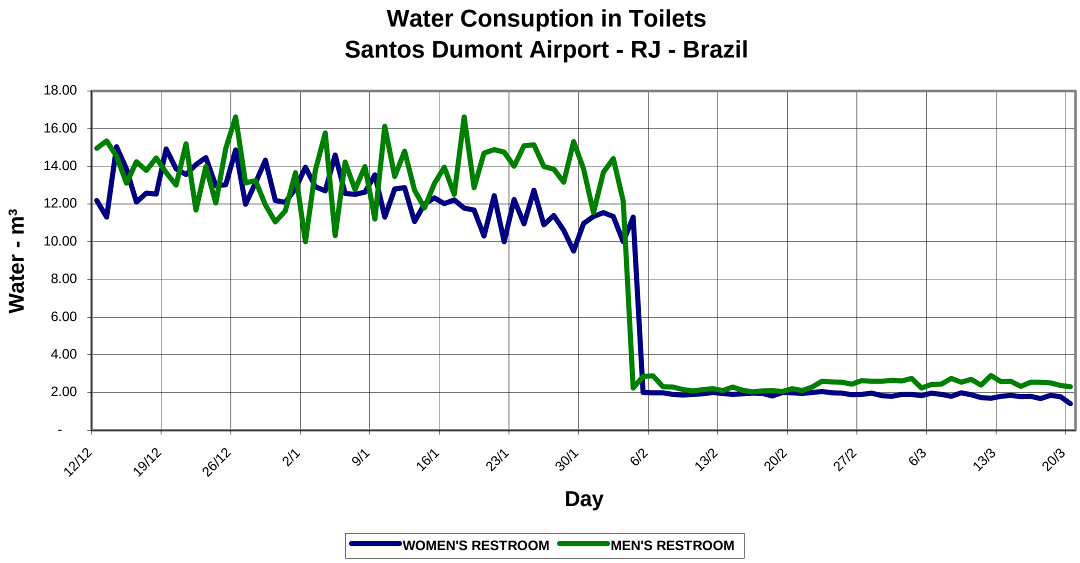

Figure 5 – Water consumption in the toilets.

During the first fifty five days of the evaluation, the average daily water consumption for the 21 toilets of the airport's terminal restrooms was 25,58 m³, achieving peaks of 16,63m³ only in the men's restroom in January 18th and 14,93m³ in the women's restroom in December 19th, but also having low consumption in some days, like January 29th, when the women's restroom consumed only 9,21m³, and January 10th when only 10m³ of water were consumed in the men's toilets.

In the other hand, after the vacuum toilets installation and begin of operation, 4,31m³ were measured, in average, of water consumption per day in the same toilets. The biggest daily consumption was 2,91m³ in March 12th and the smallest was 1,41 in the women's restroom in the last day of our measurements, the March 20th.

In average, the calculate savings in water consumption was 83% in the toilets.

Considering that the vacuum toilets nominally uses only 1.2 liters per flush, the gravitational toilets should be using about 7 liters per flush to give 83% savings. This number, 7 liters per flush for a regular gravitational toilet, is very small, since they are not the latest style 6 LPF toilets but old style toilets, designed to perform with 9 to 12 liters per flush.

This discrepancy could be explained, somehow, with most of uses of the fixtures taking place to flush liquid sewage rather than solids, as mentioned at [6]. In this situation, the siphon effect of the gravity toilets would happen easier, leading people to keep the flush valve open for less time comparing to the situation where solids would be flushed.

With vacuum toilets, it does not make difference if there is solids or liquids to be flushed: the operation of the fixture does not depend on holding or not a flush valve that will put more or less water in the bowl. Vacuum toilets are activated by pressing a flush button, and after that, an internal mechanism controls the amount of water that will be used during the cycle.

During the data period collect, the amount of water used in the vacuum toilets was measured and none of the toilets was using more then 1.2 liters per flush.

Considering also the situation of the toilet not been flushed every time it is used by someone, there is no reason to believe that vacuum toilets would be more frequently activated comparing to gravitational ones, except for curiosity of the user of seen a different type of flush. So, the tendency is to believe that if the fixtures are not flushed every time they are used, that would happen with both type of fixtures, the vacuum ones and the gravitational also, not explaining again the calculated 7 liters per flush of the gravitational toilets.

During this period other aspects of the system operation were also analyzed. Because of the type use these toilets are subject to, a big number of blockages took place everyday. It’s not unusual to find enormous amounts of paper towel, T-shirts, underwear and other strange objects clogging toilets in an open traffic facility’s public restroom like the one studied.

An average of 1 vacuum toilet blockage every 2 days has been computed. Apparently is a high number, but checking the logbook of the airport’s maintenance department, an average of 3 blockages per day of gravitational toilets was found. In both cases, the procedure was closing the toilet booth and waiting until the airport is closed to fix the problem.

This is a good indication for the vacuum toilets system, especially when comparing to other water saving toilets, like the regular 6 liters per flush gravity toilets, since a recent study showed an increase in services calls after installing this type of fixture in Denver airport [7], and the present study points to a decrease in services call after the vacuum system was installed.

Unless with 100% occupancy of the toilets, witch may be the case in some peak hours but not all the time, and, in this situation, because of big lines forming to use the toilets, people could quit waiting for using then, and then, the higher availability of the vacuum toilets would lead to higher use of the fixtures. Only in this situation, 100% occupancy, we could explain why such low volume per flush in the gravitational toilets when calculating the volume per flush based on average savings.

Another aspect of this installation is the electricity consumption. Vacuum toilets systems to operate needs electricity to run vacuum pumps or any other vacuum generation device. In any place where there is elevated water reservoir that can’t be fed by the public water system pressure, electricity is also needed to pump water into this reservoir.

When we compare the electricity consumption of vacuum toilets systems with regular gravitational ones, we have to consider these two elements: pumping water and generating vacuum. In one side vacuum systems need energy to generate vacuum, in the other needs lees water to work, gravitational systems needs more water to be pumped but is only that. Therefore, depending on the height of the water reservoir, vacuum toilets systems with vacuum pumps are more electrical efficient, because generating vacuum with vacuum pumps, in this particular situation and with the current technology, is a more efficient process than pumping water, making a positive balance to the vacuum technology.

It was not be able to precisely calculate the electrical energy consumption in this study, but preliminary considerations based on air volume consumed by the vacuum toilets during flushes, water volume consumed by both gravity toilets and vacuum ones, power and capacity of vacuum pumps, height of the water reservoir and power and capacity of water pumps showed us possible electrical energy savings of about 30% by the use of vacuum toilets. Accurate calculations in one other study were made showing electrical savings in a vacuum toilet application. [8]

4 Conclusion

The use of new technologies focusing water savings is becoming a really need. In several geographical regions and metropolitan areas in Brazil and other countries, potable water is getting very scarce. By saving water in fixtures like toilets, where potable water will become sewage in order to put away, for hygiene reasons, human excrement, a better use of this resource can be given such as drinking and cooking.

Water used by toilets, especially in public and high population non residential buildings, is one of the biggest consumer of this natural resource. Actions taken by public authorities, sanitary fixtures manufacturers, research and education institutes in order to develop better products and policies aiming lowering water consumption with better overall performance are important to face a situation, that can became dramatically bad, that is the availability of water, particularly in high densely populated urban areas.

As some studies show, the use of regular gravity 6 LPF low flush toilets in similar applications can lead to an increase number of services call because of blockages, nevertheless they can potentially decrease the water consumption.

When changing a regular gravity toilet system in an airport, putting in its place a vacuum toilet system, the saving presented was really of big amount, and having in mind the toilets are, in most of the cases, the biggest consumer of water in a public building like the one this study took place, is difficult to image any other action that could lead to better results.

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5 Presentation of Authors

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Establishing priority of water conservation actions on a building to obtain the sustainability of water resources.

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Abstract

Among possible water conservation actions in a building it is important to point out rational use of water, which includes the use of saver devices, individual measure, make users aware and alternative water sources like reuse of rain water and gray water. This work, based on this scenario presents a case study developed in a standard building in Curitiba, Paraná, Brazil; initially discuss the evaluation of actions applicability. After the evaluation this works introduce the priority of the water conservation actions from the point of view of economic viability, beneficial and risks to building appliance to promote the sustainability of water sources. The establishment of this priority is very important like an auxiliary tool for the planning of buildings water conservation actions. The aim of this work is show an application of the Decision Support System (DSS) to establishing priority of water conservation actions on a building to save water. The DSS used is multi criteria analysis, specifically ELECTRE III Method.

Keywords

Water conservation; Water reuse; Environmental Management.

1. Introduction

On this present study the term water conservation will be considered only like the actions that may be bring saving of water including sources water, public system of water distribution, and water home use. In case of water home use is important show

that the actions to save drinkable water, may be of two different types like as rational water use and alternative sources use.
Basically the rational use actions are those that reduce the waste of water in quantity by the use of saving devices, the personal motivation of the users, the programs to leak detection and lose control, and the establishment of high taxes to high consume.
On the other hand the alternative sources uses optional sources often available at residential buildings like gray water, rainwater, mineral water in bottles or distributed by water truck. It is important to point out that these sources are considered alternative sources because the main source is the public system of water supply.

2. Use of water management in Buildings

The important action to promote the sustainability of water resources in buildings is the appropriate quantitative and qualitative management of use of water. Some of the current actions that are practicing by public authority and civil society are described next.
The first example is the National Program Against Waste Water, (PNCDA) managed by Brazilian government, which promotes as a main objective the rational use of water on the public system of water supply. The specific objective of this program is to define and introduce a set of actions with a technological, economical and institutional tools, based on current standards to promote the real water safe. The program establishes some strategies against wastewater directly on watersheds, public water supply and the hydraulic and sanitary building systems.
Another good example is Rational Use of Water Program (PURA) that foresees a set of actions to promote the rational use of water for buildings systems. The PURA program is a result of a partnership of SABESP, University of São Paulo (USP) and IPT (Technological Research Institute of São Paulo State) that foresees the water conservation in residential houses. This program has begun in 1996 (GONÇALVES, OLIVEIRA, 1997), and it was created to attend the development of models to measure the use of water an efficient way, the influence of the use of saver devices and to prepare a technical report to guide the program actions.

Finally the program Use of Water Management in Buildings Program PGUAE, (SANTOS, 2001) foresees quantity and quality management water. So this program foresees actions like Conservation of Water Consumption Characterization, Characterization of Economics Actions of Water Assessment of the Economics Actions of Water and to elaborate a Management Plan of Use of Water. This program has the following structure:

2.1 Characterization of Water Consumption

The characterization of water consumption is a set of proceeds established and organized to characterize functional and transient water consumption. The transient characterization is based on historical series of consumption and the functional characterization is a function of many uses and losses in buildings.

2.2 Characterization of Economic Actions of Water

The Characterization of Economic Actions of Water is the establishment of benefits, risks and associated costs. The benefit is evaluated in function of potential economic of water in buildings and watersheds while the risk is the possible sanitary risks related with the gray water and rainwater uses measurements. And finally the associated economic costs refer to implementation, operation and maintenance of the actions.

3.3 Workability and establishment of priorities of Water Conservation Actions

Considering the conservation actions is necessary to evaluate the applicability of these functions in a quantitative, qualitative and the cost-benefit-risk relationship of these actions. The cost-benefit relationship is calculated through economic workability and the risk is evaluated through the use of alternative sources of water.
After evaluated the workability of theses actions the next step is to establish the priorities using the Decision Support System (DSS) and after that to elaborate a Management Plan of Use of Water in Buildings. This program admitted a Multi-criteria Analysis using the ELECTRE III method to establish the priorities. This method is used in optimizations studies related with water.

2.4 Use of Water Management Plan

The last phase of this program after the characterization of uses and economic actions is to propose an optimize planning that promotes the expected savings and guarantees the sanitary safety. So is necessary a set of proceeds to allow the evaluation of the applicability of the actions, the economy and the associated risk. The result of this analysis will guide the Use of Water Management Plan.

3. Decision support system (DSS)

According to KEEN (1991), the decision support systems are developed to help the decision makers and users to improve its productivity. And also said that the objective of this system is not to substitute the judgment of the decision maker, but help him to choose the best alternative for each situation. There are several decision analysis models from the classic methods like the statistical and descriptive ones to economic models and optimization ones. Currently the classic methods of analysis of multi-criteria/ multi-objective methods are denominated artificial intelligence systems and specialist systems (NETTO et al., 2001).
According to NETTO et al. (2001), the proposal criteria of the multi-criteria analyses tries to solve decision problems that have more than one objective, where the uncertainties are in different levels an types becoming a complex scenario of these objectives. There are many multi-criteria decision methods which can emphasizes ELECTRE family. The acronym ELECTRE, in the French language means ELimination Et Choix Traduisant la REalité which translation is: Representation of the Reality for Elimination and Choice.

The problems solved by the methods of the ELECTRE family (MAYSTRE, PICTET and SIMOS 2002) quotes the following: the α problem that supports the best choice actions, where the ELECTRE I and IS methods are applied. Then the βproblem, which supports the selection of the actions following a pre-establishment standard, uses ELECTRE III. And finally the γ, which its objective is to ranking the actions in a decreasing order of preference, uses ELECTRE II, III and IV.
However, as already commented, PGUAE search to establish a plan of management of water in buildings to analyze the possible actions of saving water resources and ranking it using the multi-criteria analysis method ELECTRE III, because the problem is bracket in the γ problem, previously described.

3.1. Electre III

The several versions of the ELECTRE family are based on a same concept, but differ in its handling according to the type of decision problem (BUCHANAN and SHEPPARD, 1998). The ELECTRE method compares the actions **a** and **b**, like a pair, (a, b) ε A through the following relationships: (BUCHANAN and SHEPPARD, 1998)

a**P**b where **a** is strictly preferable to **b**, if $g(a) > g(b) + p$
a**Q**b where **a** has weak preference to **b**, if $g(b) + q < g(a) \leq g(b) + p$
a**I**b where **a** is indifferent to **b**, if $g(b) - q \leq g(a) \leq g(b) + q$

Adopting that g is the general value of the action, p the preference threshold and q is the discordance threshold. Through these threshold a outranking relationship denoted by **S** is established, where an action a**S**b, that is to say, the action "**a** is at least as good as **b**" or "a is not worse than b." This relationship should be analyzed for each criteria j, in this way a$\mathbf{S_j}$b (a is at least as good as b, for the criteria j) (BUCHANAN and SHEPPARD, 1998).
Starting with this analysis, it becomes necessary to determine how much strong it is the statement a**S**b, this determination is the accomplished which is called it concordance index "C", for a pair of actions $(a,b) \in A$. The index C (a,b) (concordance index for the actions a and b) it is defined in the following way (BUCHANAN and SHEPPARD,1998):

Where:

C (a,b)–concordance index of the actions a and b;
k–sum of the weights of all the criteria;
k_j–I weigh of the criteria j, for j = 1, 2, 3,..., n;
$c_j(a,b)$–concordance index of the actions a and b, under the criteria j.

The values for the index of concordance c_j, they are given by the linear function by parts the knowledge (BUCHANAN and SHEPPARD, 1998):

$$c_j(a,b)=\begin{cases}1 \text{ if } g_j(a)+q_j \geq g_j(b)\\ 0 \text{ if } g_j(a)+p_j \leq g_j(b)\\ \dfrac{q_j+g_j(a)-g_j(b)}{p_j-q_j}, \text{for the another cases}\end{cases}$$

In the multi-criteria analysis, accomplished by the ELECTRE method, besides the concordance index we defined the discordance index, which measures the level of discordance of the statement a**S**b. In this point appears on of the innovations of the ELECTRE III method with the introduction of a new threshold, called veto threshold v. The veto threshold v is the value that starting when the statement a**S**b is refuted, in order words does not exist the possibility of **a** is at least as good as **b**, in this case it happens that $g_j(b) \geq g_j(a) + v_j$. The discordance index is determined in the following equation (BUCHANAN and SHEPPARD,1998):

$$d_j(a,b)=\begin{cases}1 \text{ if } g_j(a)+v_j \leq g_j(b)\\ 0 \text{ if } g_j(a)+p_j \geq g_j(b)\\ \dfrac{g_j(b)-g_j(a)-p_j}{v_j-p_j}, \text{ for the another cases}\end{cases}$$

Despite of the concordance, a discordance criterion is enough to discard the hierarchy of the action (BUCHANAN and SHEPPARD, 1998). With the two calculated indexes, concordance and discordance, it is possible to determine the matrix of hierarchy credibility, which measures the amount of the concordance and the discordance, it is the statement a**S**b (BUCHANAN and SHEPPARD, 1998). BUCHANAN and SHEPPARD (1998) they present the following formula for the calculation of the credibility index for each equal of actions **a,b**:

$$S(a,b)=\begin{cases}C(a,b), \text{if } d_j(a,b) \leq C(a,b) \forall j\\ C(a,b). \prod_{j \in J(a,b)} \dfrac{1-d_j(a,b)}{1-C(a,b)}, \quad \text{another cases}\end{cases}$$

Where:

J (a,b)–it is the group of criteria for which it happens $d_j(a,b)>C(a,b)$.

After the determination of the matrix of credibility it is made two pre-classifications, one being ascending and the other being descending. First of all, it has to establish a γ value which will be the maximum value of the matrix of credibility (γ =Max S (a, b). Following, it is defined an "muffled coefficient" for γ, according to the formula γ -s (γ), and them, it has to compare each of the values from the criterion with γ, forming Q (A) matrix, where there are only 0 and 1 values. The 0 value is associated with no-credibility while the 1 value is associated with high-credibility. For the Q (A) matrix, it is chosen the best-classified action, having the first step of descending distillation. The process has to be repeated for the other actions, expecting the previous classified action. At the end of distillations there will have a descending pre-classification. For the ascending classification, it has to use the same process, with the difference that it is removed the worst classified action in each stage. After the two pre-classification, it is determined the final classification, which will intersection both pre-classification (VINCKE, 1992). For the final rank, the following rules are presented (MAYSTRE, PICTET and SIMOS, 1994):

- If **a** is preferable to **b**, consedering of the two pre-classification, then **a** will be preferable to **b** in the final rank;
- If **a** is equivalent to **b**, in one of the pre-classification, but **a** is preferable in the other, then **a** is preferable to **b**;
- If **a** is preferable to **b** in one of the pre-classification, but in the other preorders **b** is preferable to **a**, then the two actions will be to each other incomparable.

4. Example of method application

For the present work were used some actions and evaluation criteria last one will have the 25% weight of evaluation each were adopted by the authors of the work. It fits to point out that the example doesn't present all the actions that will be evaluated for the research, because its objective is just to illustrate the multi-criteria analysis method ELECTRE III.

4.1 Definition of the Actions and of the Criteria

The chosen actions to exemplify the ELECTRE III method, were the following ones: use of gray waters, use of saving devices of water as air injection and pressure reducers, besides the change of sanitary vitreous china of 12 l/flux by those of 6 l./ flux. This criterion will define, how to know: economy of generated water, time of return, percentage of use of available water for the action and sanitary risk. Being the sanitary risk a qualitative criterion should be quantified, as it consists in the Table 01. This classification was defined based on the authors' experience and other consulted professionals. The action and the criterion were attributed weights to the criteria.

Table 01–Classification of the sanitary risk

RISK	VALUE
no risk	0,00
Weak risk	0,25
Medium risk	
High risk	0,75
Impossible	1,00

The Table 02 presents the values of the actions according to each criterion, as well as the weight of the chosen criteria. Related to the values of the actions, the economy is in terms of saved monthly volume of water. The return consists of the period in that the investment is muffled, while the percentile of use refers to the as of saved volume of water it is used indeed. For the present work the same values were attributed for all the criteria, that is to say, 25%. The sanitary risk was considered medium, in spite of the conceived system of use of gray water to dispose of treatment of the same.

Table 02–Values of the criteria of the actions

	Saving (L /month)	Pay back (months)	Use (%)	Sanitary risk
Use of Gray Water	**21600**	**24**	**95,7**	**0,5**
Saving Water devices	**5931**	**3**	**100**	**0**
Vitreous China change	**10800**	**5**	**100**	**0**
Weight of each Criteria	**25**	**25**	**25**	**25**

The Table 03 presents the indifference, preference and of veto thresholds, for each criterion, defined by the authors of this work.

Table 03–Values of Electre III's limits

	Saving (L)	Pay back (months)	Use (%)	Sanitary risk
Indifference (q)	**10000**	**10**	**50**	**0,50**
Preference (p)	**25000**	**20**	**70**	**0,75**
Veto (v)	**30000**	**30**	**95**	**1,00**

5. RESULTS AND DISCUSSION

The Tables 04, 05 and 06 will show, respectively, concordance, discordance matrix and of credibility of the analysis.

Table 04 – Concordance matrix

	Use of Gray Water	Saving water devices	Toilets change
Use of Gray Waters	**-**	**0,75**	**0,77**
Saving Water devices	**0,91**	**-**	**1,00**
Toilets change	**0,99**	**1,00**	**-**

Table 05 – Discordance matrix

	Use of Gray Water	Saving water devices	Toilets Change
Use of Gray Water	**-**	**0**	**0**
Saving water devices	**0**	**-**	**0**
Toilets change	**0**	**0**	**-**

Table 07 – Credibility matrix

	Use of Gray Water	Saving water devices	Toilets change
Use of Gray Water	**-**	**0,75**	**0,77**
Saving water devices	**0,91**	**-**	**1,00**
Toilets change	**0,99**	**1,00**	**-**

The result shows that for the indifference, preference and veto thresholds rates, there was not discordance as an action to be so good in relation the others, according to table 05. The one that outranked the actions were the concordance degree among them. For the Table 04, it is observed that the value of 0,99 for the concordance, that the action of toilets changing is in the minimum as good as the use of gray water, it indicates that this statement is more correct than the statement of use of gray water which concordance value is of 0,77. The pictures 01 02 and 03 below are showing the ascending, descending and final ranking respectively

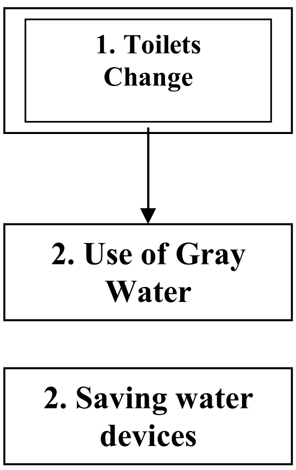

Figure 01 - Ascending classification

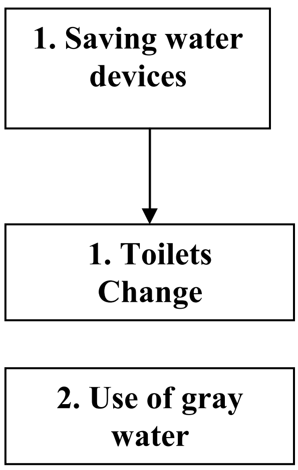

Figure 02- Descending classification

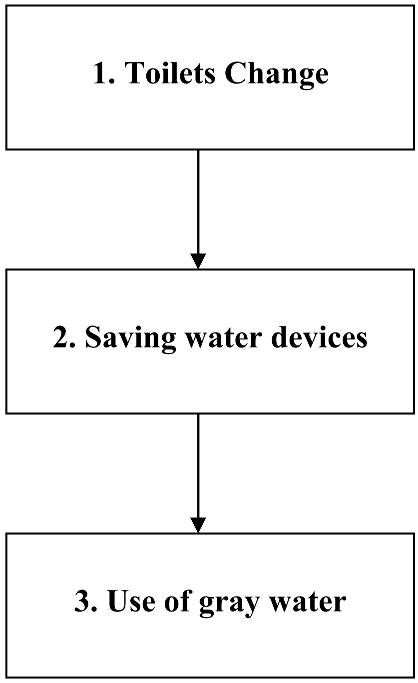

Figure 03 – Final ranking

The presented graphs of ascending and descending classification show that in the first one he use of gray water is equivalent to the use of saving water devices even so in the second classification the saving water devices are better classified than the use of gray water resulting the final classification that saving water devices are preferable to the use of gray water. Otherwise the change of saving water devices and the use of gray water in the two classifications the first one resulting in a better position on the final ranking classification to toilets change. As the change of toilets and the saving water devices the first one is better than the second in the final classification, showing that saving water devices are worst than change toilets.

6.Conclusion

Therefore, the found hierarchy is first the substitution of the conventional toilets for those of 06 l/flux followed by the use of the saving water devices like as air injectors and pressure reducers and at least the use of systems of gray waters. Such hierarchy identified by the Method ELECTRE III it can be explained when observing the Table 02. Comparing the action of use of the toilets of 06 L/flux with the action of use of the saving water devices, it is fact that while the first presents larger economy of water a month, Secondly presents smaller period return. As the use of the toilets of 06 L/flux is preferable, soon it indicates the ELECTRE III method that the economy of water is a criterion more problematic in this case, although it has the same weight that the return period. However, when comparing the use of the toilet of 06 L/flux with the system of gray water, it is noticed that that last one presents great economy, great return period and medium risk in relation to the first. Because it indicates the ELECTRE III method that the great return period and the risk presented by the use of the gray water turn that less attractive action than the use of the toilets. That verification equally is worth for the comparative between the use of economic devices and gray water system. Such verifications should base the guidelines for the management of the use of the water in buildings. In this sense, it is possible to organize a plan of implementation of the actions of conservation of the water along the time, besides a monitoring program, operation and maintenance. This, certainly, will facilitate the water economy to promote the maintainable of the use of water resources.

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Submetering as an instrument of water demand management in building systems – University of São Paulo Case Study

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Abstract

This work presents the use of submetering as an instrument of water demand management in building. In order to obtain this, the characterization of the meters and the study of the interactions of its elements with the plumbing system are based on systemic approach and performance basis. In the conservation context different systems and technologies of remote reading were studied, considering the collection of better information of water consumption. A proposal for the planning of the submetering implantation is showed, as well as the elements that should be considered for the demand management. In order to subsidize the evaluations, a case study of the submetering program in the University of São Paulo was accomplished, in which it was possible to check the importance of its application and the extremely positive results that had justified its implantation.

Keywords

Submetering; water demand management; water conservation; building systems.

1 Introduction

Water scarcity and the sewage issues have motivated the development of new practices and research concerning water conservation, in a clear change from water offer management paradigm to water demand management.

In the scope of building systems, the situation of water consumption is verified by means of the analysis of the consumption data before conservation action takes place and during subsequently stages when the efficiency of the actions is checked. Even after actions are performed, a permanent follow-up of the consumption is necessary. Mastering this data is a powerful instrument for water demand management.

In comparison to the 2001 CIB W62 paper (TAMAKI; SILVA; GONÇALVES)[6], this paper shows the deepening of some issues related to the adoption of submetering as an instrument of water demand management, such as: the interactions among the new metering system an the existing systems; the characterization of both meters besides the adopted remote reading system; and, mainly, the planning of the demand management structure, using the consumption data (TAMAKI, 2003)[5].

The Water Conservation Program of the University of São Paulo – PURA-USP (SILVA; TAMAKI; GONÇALVES, 2002)[4], stands in the case study of submetering application.

2 Interaction among the submetering and the existent systems

A systemic approach which included the different aspects of the building and its relation with the building systems was required in order to provide suitable conditions for the correspondence between the consumption and the system besides enabling the utilization of the consumption data as an instrument of management, concerning the comprehension of several aspects of the buildings and its relationships with the involved building systems, using the performance concept (GRAÇA; GONÇALVES, 1997)[1].

The water supply system can be characterized by the following subsystems (ILHA; GONÇALVES, 1994)[2]:

- Supply subsystem;
- Metering and Storage subsystems;
- Distribution subsystem; and the
- Equipment subsystem – fixtures attending accessibility, flexibility, water control, etc.

According to the Water Conservation Plan Guidelines (USEPA, 1998)[8], submetering is the metering for units of a larger service connection (used to measure individual consumption). Then, to implant submetering as an instrument of water demand management two conditions are required:

- Compatible work between the cold water supply subsystem and the equipment systems, attending the user needs;
- The installed meters must give adequate information to allow an effective water demand management.

3 Water meters and remote reading system

3.1 Water meters

The most employed meters in submetering in Brazil are the mechanical ones (velocity type) due to: 1) ability to integrate metering functions, 2) totaling and data storage; 3) easy application; 4) resistance under weather exposition and use; 5) reduced costs.

The influence of the water supply type must also be considered. When the meter is installed in a pipe which is connected directly to the storage tank, the operation regime of the meter suffers little influence from the consumption. When the meter is installed in a pipe attending fixtures directly, a great fluctuation of the flow rates occurs and the choice of the meter must take into consideration broader ranges of flow rates.

3.2 Remote reading systems

Besides submetering, remote reading is another instrument of water demand management. It collects fast and reliable data, as well as the creation of new control parameters. The remote reading is a new management tool.

The benefits of remote reading provide information for different users such as utility company, the facilities managers or the end users. These users get from the remote reading system different information that enable to create and develop routines in order to save water and reduce expenses.

The adopted remote reading system can be based on communication technologies such as radio-frequency, power line carrier, fixed and mobile telephone, cable TV, satellite, field-bus or even hybrid systems (ROZAS, 2002)[3].

4 Submetering and water demand management

4.1 Submetering

The introduction of the submetering in a building or group of buildings of an organization has to be directly related to the importance given to water conservation and to the water sustainability.

Adopt submetering provides:
- Mastering Consumption data of specific systems, allowing its follow-up and control;
- Saving resources: cost reduction and water and energy savings;
- Possibility of billing different types of water users.

In order to implement the submetering it is necessary to define the submetering level to according to the established planning and the available resources.

4.1.1 Submetering level

The introduction of submetering levels has as objective to make easier the determination of submetering application in a building in order to mastering consumption data where the water demand occurs.

In order to register common points to many submetering possibilities six submetering levels of a system are presented:

- organization: all the infrastructure located in one area (industry, university, etc.;
- group of buildings: according to functional and administrative aspects, etc.;
- Building/Block;
- Floor/Sector;
- Local area: room, restroom, laboratory, kitchen, pool, etc.;
- Fixture or equipment.

4.1.2 Planning and implantation of the submetering

Planning must be accomplished by means of collecting information about the existing systems (area of the building, pipelines and storage tanks drawings, existing equipment), occupation (population), the developed activities in the buildings and the available consumption data. With the obtained information, the water consumption of each area can be estimated and therefore the water meter dimensioned. According to the needs, the adoption and the choice of a remote reading system must be considered at this moment. The next step is to estimate the costs and the periods for the submetering implantation must be done.

The tasks and responsibility attribution phase must precede the implantation phase. The responsible staff in charge of the design, execution, and management of the activities and coordination of the hired companies must be defined then.

4.2 Water demand management – Utilization of the consumption data

The demand management implies action on the water demand, with the objective of efficient use and saving. The demand management exceeds the concept of consumption management (to organize consumption data and to make graphics): it demands the accomplishment of data studies and to do the system feedback in the sequence (correction of leakage or revision of a procedure that consumes water).

The water consumption data acquire fundamental importance for the management, because they allow the establishment of consumption patterns for determined conditions of the use of water in building systems, being obtained through the utilization of single or combined instruments such as the utility bills, readings *in loco*, remote reading and submetering.

These consumption data and the complementary ones allow to define control parameters (as the consumption indicators) and to characterize the water utilization. Considering the usual consumption patterns for a specific system, these control parameters can signalize any abnormal occurrence. For these situations, it can be defined intervention procedures that look for the recovery of the efficiency of the systems, concluding the demand management cycle.

4.2.1 Instruments of demand management

The utility bills constitute the simplest tool of demand management. For each meter they provide the current and the previous readings, the consumption values of the last month. The demand management, based on this instrument, implies monthly procedures: comparison of this new data with the previous ones and the action on the systems if necessary.

As the bills give data only once a month, the readings *in loco* done by the staff are suggested. Daily readings allow the follow-up of mean consumption values in week days, weekend days and holidays. With this information, control parameters can be created and used in order to detect, in few days, any abnormal consumption and then to give start to a correction action in a shorter time:

- Readings done by a remote reading system joined with a data management system are the most complete and versatile way of acquiring data. The main advantages of using automation systems are: On line readings with high acquisition rates (few minutes between readings) in order to provide consumption profiles;
- survey of flow rate curves that allow identification of flow rate peaks and minimum values, daily consumption, etc.;
- Use of these curves to create control parameters enables both fast leakage detection and the start of correction actions.

Finally, submetering allows the acquisition of more qualified information by the straight correspondence between the metered consumption and its respective area.

In this way, submetering adoption combined with a remote reading system allows:

- Better follow-up of the consumption of a large number of points simultaneously (survey of daily profile and minimum weekly flow rates);
- Faster detection of abnormal consumption as leakages (by remote reading) and more accurate localization of it (by submetering);
- Possibility of billing the water users.

4.2.2 Data survey

Beyond the water consumption data, there is the complementary data survey (constructed area, population, existing equipments and developed activities) which is used to define the consumption indicators.

4.2.3 Control parameters

Consumption data (such as monthly consumption readings and flow rate profile) can be considered as control parameters directly obtained.

Graphics obtained by remote reading systems give some useful information, such as:

- Flow rate peaks: determination of the highest flow rate peaks under normal conditions, abnormal peaks due to mains pressure fluctuation or leakages;
- Minimum flow rates: show the existence of leakages or nightly consumption (equipment of continuous use), the growth of the minimum flow rate curve indicates the possibility of leakage;
- No flow: lack of water or system not used in the period.

It can be also used the control parameters indirectly obtained– the ones that use the complementary data together. They constitute the consumption indicators. The most employed are the monthly consumption *per capita* and the monthly consumption per area. Among their benefits are:

- Comparison among situations where the variable varies. For example: the consumption *per capita* considers the fluctuation of both consumption and population;
- Definition of the more efficient systems and the ones that need more attention;
- Possibility to extend the indicator values to similar cases.

4.2.4 Intervention procedures

To conclude the demand management cycle, it must also be included the establishment of procedures and responsibilities when abnormal occurrences happen. For the ordinary case of leakages, procedures of advice for the responsible ones for the correction should be made as well as the recording of the information about the correction. The indication of the necessity of retrofits in critical pipelines, or revision of equipment, should be accomplished too. The recordings of the occurrences allow the identification of the systems that need more maintenance or retrofitting.

Regular contacts with the users, maintenance staff, and utility company must be kept, in order to verify high consumption occurrences or possible data recording mistakes. The continuous improvement of the knowledge concerning the building systems, accomplished by surveys and users opinion polls, can also be adopted as intervention procedures.

5 Submetering implantation – PURA-USP Case Study

Some aspects of the characterization of the University of São Paulo and the PURA-USP are showed in the below, as well as the planning and the implantation of the submetering.

The actions of the submetering implantation occurred in the main *campus* of the USP – *Cidade Universitária Armando de Salles Oliveira* (CUASO) – situated at the city of *São Paulo*, since 1998. The adoption of submetering in CUASO was motivated by the need of best information about the water consumption. Some adopted actions as the PURA-USP implantation, the first submetering experience at the *campus* (in 1992) and the deepening of conservation ideas contributed for this decision.

5.1 The University of São Paulo and the PURA-USP

In 2002 the population of the USP was composed by 73,000 students (college and graduate school levels) and 20,000 professors/employees, totaling 93,000 persons. About 60,000 of them have their activities developed in the main *campus* (USP, 2003)[7]. The CUASO, created in 1944, suffered many alterations and enlargements during these years, having nowadays 760,000 m² of constructed area on a 3,600,000 m² land area (USP, 2003)[7]. It is noticed the existence of buildings with different ages, built according to the needs, building and technical cultures, knowledge and availability of resources of each time. Since the conclusion of the majority of its buildings the building systems did not suffer significant modernization. Recent technologies were adopted only when new extensions were added to the buildings or in the case of retrofitting.

The water supply to the *campus* is provided by the public utility company mains (*Companhia de Saneamento Básico do Estado de São Paulo* - SABESP). There is one large water inlet for the whole *campus*, for buildings and installations of the university and for other external users placed in it. In 1992, 122 water meters were installed, being then, all these water service connections metered by the SABESP.

The PURA-USP was established in the *campus* in 1998, having as objectives: to reduce water consumption (without quality decreasing) and to keep the reduced consumption profile all along; to implant a structured system of water demand management; and to developed a methodology that could be applied in other places in the future.

It had as stages: General diagnosis; Physical losses reduction; Reduction of consumption in points of use; Characterization of habits and rationalization of activities that consume water; and Program spreading, awareness campaigns and training.

Simultaneously to the physical intervention stages of the Program, it was noticed the need of a system able to make consumption readings (considering all the actual connections and the future ones), to establish the permanent character of water demand management in order to keep the consumption level reduced. Therefore, a remote reading system was adopted to allow the follow-up of water demand, the treatment and the evaluation of data just in time.

The remarkable results of the Program are:

- Expressive reduction of the consumption: 36% in the whole *campus* – 48% in the Units of Phase 1 and 19% in the Units of Phase 2 (1998 to 2003), as showed in Figure 1;
- Reduction in expenses with the utility company: from USD 6.1 million to USD 4.6 million per year (comprising water supply and collection of sewers), despite the price has raised 69% in this period (1997 to 2003).

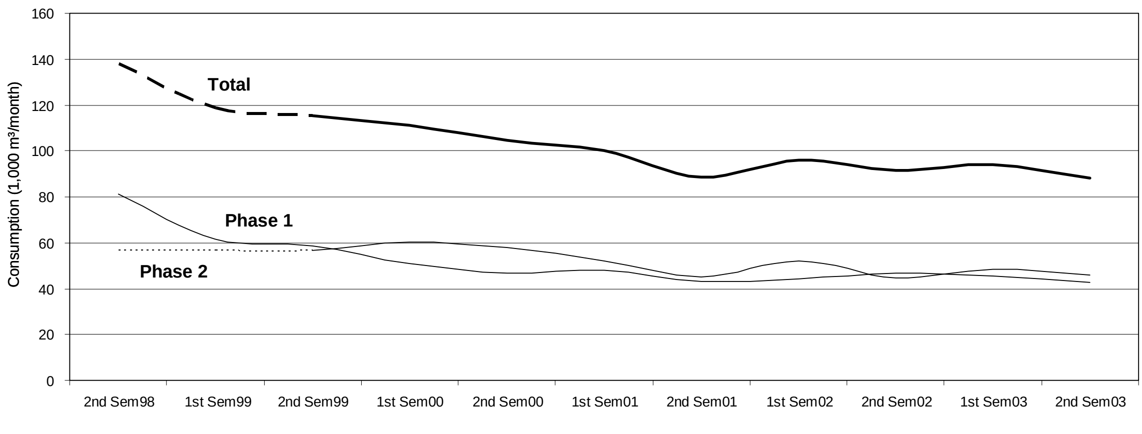

Figure 1 – Water consumption variation Units of Phases 1 and 2

5.2 Submetering planning

The process for the submetering implantation was developed in several stages:

- Definition of the objectives of the submetering;
- Definition of the submetering level;
- Definition of the sequence of implantation;
- Preliminary data survey and the choice of the metering points;
- Meters dimensioning;
- Definition of logistic of the tasks, staff responsibilities attribution;
- Hiring services.

The determination of the number of points and their localization was considered:
- The objectives of the submetering: to lower the water consumption and to keep the reduced level, through the individual follow-up of the consumption; to create demand profiles and so the possibility of actives control and action over anomalies;
- Determination of the water consumed by private companies located inside the *campus* such as restaurants, bank agencies, shops, etc.;
- Number and distribution of buildings;
- Water consumption: mean consumption and utilization peaks, as well as their use typology;
- Characteristics of the cold water supply system and equipment system: storage system, pipelines cadastre, existence of high consumption fixtures, among others;
- Infrastructure of the wired telephone network.

5.3 Submetering implantation

The choice of meter was done according to the submetering areas. After the definition of the submetering level as of the Building/Block, it was considered for the selection of the meters: the aspects of the involved cold water supply system (existence of storage tanks) and the equipment system (existence of flush valves, special equipment), data about the water utilization (distribution of use in the blocks, occupation, distribution of activities, etc.), and data about the consumption.

Finally, it must be noticed that the adoption of a remote reading system had as objectives the necessity of a better information about the water demand and the systematization of this collection, the evaluation of the impacts of the actions of the PURA-USP, the detection of consumption anomalies as leakages, and the possibility of on-line monitoring of a great number of consumers simultaneously.

Then, it was adopted the field-bus (M-BUS) as the remote reading system as presented below (Figure 2):
- *Electronic water meters:* velocity type, DN 15 to DN 100, with nominal flow rate from 1.5 m^3/h to 60 m^3/h. The electronic register has microprocessors that give information such as total consumption and instantaneous flow rate. These data can be collected locally or by a wired field-bus network (M-BUS protocol);
- *Communication network:* constituted by a wired network, equipment responsible for communication interface (level converter installed between meter and the microcomputer), equipment responsible for the signal regeneration and/or amplification (repeater), and grounding system (with the installation of protection devices against atmospheric discharges). The infrastructure of the wired telephonic network of the *campus* was used.

- *Remote reading management center:* composed by a microcomputer with the M-BUS management and monitoring software and a level converter. The current software, adopted in 2002, is based on *SQL* database software (more reliable for continuous operation of large databases) with automated backup routines.

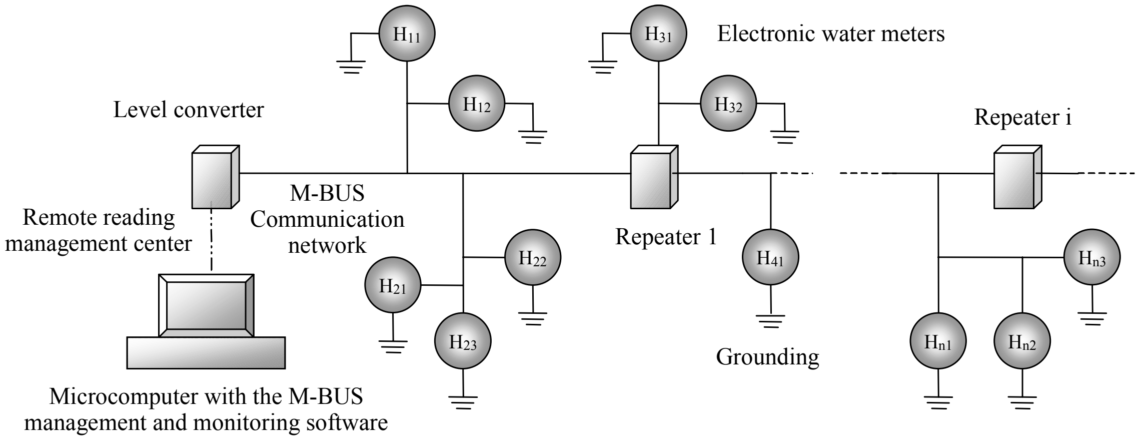

Figure 2 – Remote reading system

6 Water demand management – PURA-USP Case Study

6.1 Demand management and its instruments

After the creation of the PURA-USP a new structure was adopted, being the PURA-USP Technical Staff responsible for the water demand management:

- Water service connections: cadastre of the actual connections of CUASO;
- Conditions of the connections: the meter box and water meter;
- Bills: checking the amounts, data recording mistakes, etc.;
- Building systems: water supply system files (components and conservation state of both the cold water supply system and the equipment system, operation conditions, maintenance routines, etc.);
- Water consumption.

Other data, such as constructed area, population and existing systems were adopted for the creation of control parameters. The control parameters directly obtained (consumption) and the indirectly obtained ones (indicators) allowed the knowledge about the water use in different systems installed in the *campus*.

With the suitable information for the water demand management, the intervention procedures were defined: ways of disposition of the information to the maintenance staff and to the administrative personnel of the Units and of the CUASO.

6.2 Example – EPUSP - *Electrical Engineering Department Building*

This example illustrates one of the results of the submetering and remote reading in water demand management: the identification of an abnormal consumption in the Electric Engineering building of the *Escola Politécnica* of USP (EPUSP).

The building is composed by four linked blocks (A, B, C and D), all of them supplied by the same service connection (Fig. 3, point 0301), with no underground storage tank.

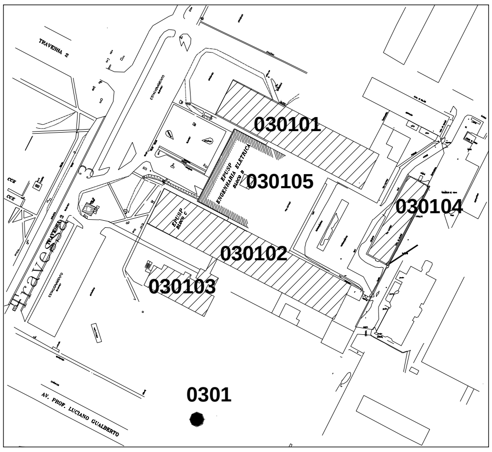

Figure 3 –*Electrical Engineering Department Building view*

Blocks A, C and D (according to the hatched areas 030101 to 030103) have upper storage tanks. Block B has only few consumption points, and is directly supplied by the water service pipe (as the cafeteria point, 030105) as well as of the post graduation building (030104) and some laboratory equipment. The mean water consumption of the four blocks is 1,500 m³ per month.

Block was the submetering level adopted. The metering points were: 1) blocks A, C and D – next to their storage tanks; 2) post graduation building – directly supplied by the water service pipe; 3) block B – in the cafeteria branch.

In June 09, 2002, 10:30 p.m., there was a sudden increase of the consumption registered in the main meter (Figure 4). The expected flow rate for the period (Sunday night) was less than 1 m³/h (due to the operation of some laboratory equipment) and the registered was of 15 m³/h. The flow rate curve showed a typical sudden fracture of a pipe. The reading data of the submetering meters indicated the occurrence of leakage in the stretch between the main meter and the submetering meters.

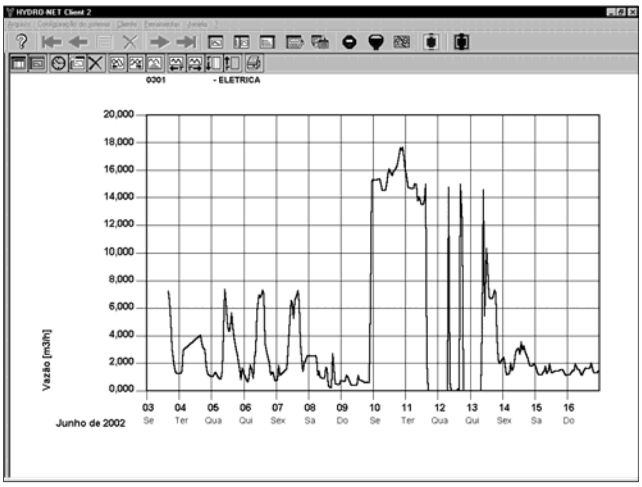

Figure 4 – Flow rate curve of the *Electric Engineering Dept.* meter

The communication of the leakage occurrence to the maintenance staff was done in order to identify the exact leakage spot (underground leakage) and to carry out its immediate correction.

The leakage correction required special equipment for deep excavation and for asphalt demolition therefore special service was hired. Moreover, at that time the water supply could not be interrupted due to the activities on course.
The graphic shows the leakage starts, its lasting time, the flow rate value, the period of no water supply (and tests) and the return of the water supply.

The water loss and its impacts on the expenses can be compared with the monthly consumption, the costs of the leakage correction and the estimated losses in the case of the remote reading and the submetering were not available. In this example, it was verified:

- water loss during leakage period: 622.5 m^3 (in 41.5 hours at 15 m^3/h);
- Water Leakage cost per hour: USD 49.20 /h (15 m^3/h at USD 3.28 /m^3);
- Total leakage cost: USD 2,041.97 (622.5 m^3 at USD 3.28 /m^3);
- Impact on the monthly consumption: increase of 41.5 % (622.5 m^3 in 1,500 m^3);
- Estimated correction costs: USD 2,422.15.

Considering the hypothesis that submetering and the structured water demand management were not implemented and the leakage duration would last for a longer period of time (a month for instance), the cost of this water loss would be approximately US$35,000 without correction. So, it can be observed that the pay back was about two days.

7 Final considerations

This work allowed verifying the usefulness of the submetering as an instrument of water demand management for the CUASO, mainly in the permanent context of the Water Conservation Program that has been developed since 1998. The adopted system for the remote reading of the meters (main meters and submetering meters) also allowed a better follow-up of the consumption of the Units in order to improve the benefits of submetering.

The information obtained with these instruments and the new management structure changed the necessities for the water supply systems perform accordingly to the water conservation proposal. It should be noticed that water conservation actions, as adopted by the PURA-USP, have short paybacks, justifying all the efforts.

Regarding water demand management, the benefits of the University of São Paulo case study can be extended to similar situations of submetering implantation, taking into consideration the specific conditions of each organization.

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Experiences with a collective domestic water system in Leidsche Rijn

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Abstract

This paper focuses on a collective domestic water system. The development of sustainable water systems was supported by the Dutch government with a pilot project. 30.000 houses should have been fed with domestic water. A lot of precautions were taken during the design and construction to ensure there would be no threat to public health. Despite all these precautionary measures, some mistakes were made during the construction, which lead to situations where domestic water entered the drinking water system.

Keywords

Sustainable development; collective domestic water system; grey water.

Introduction

In the Netherlands the target of achieving healthy and sustainable water systems has a short history. The issue of pollution of surface water lead, at the end of the sixties, to a structural approach to the main sources this pollution. The poor quality of the surface water not only threatening public health but also the natural environment. In the eighties there was growing awareness of the necessity of integral water management. Integral water management and water system approach became household words in the nineties. The government policy with respect to water, environment and nature has greatly developed in the last decade. This was the reason for the government to support a pilot project for a collective domestic water system.

1 The source is easy found

Leidsche Rijn is located near Utrecht in the centre of Holland. Figure 1 shows the district.

In the early ninety's the Dutch government researched the possibilities of using drinking water in a sustainable way. Research showed that 45% of the drinking water was used for secondary applications such as flushing toilets, for washing clothes or for watering the garden. So, the idea was born to use "domestic water" for lower quality applications. Application of domestic water requires a separate piping system parallel with the normal piping system for drinking water.

The Ministry of Housing, Spatial Planning and the Environment chose at the end of the ninety's the location Leidsche Rijn for the application of a domestic water system as a pilot project. The location Leidsche Rijn was attractive because it concerned a yet to be built (completion in 2015) residential development with about 30.000 houses. Figure 1 shows the district. The separate piping system for domestic water was also relative easy to install parallel with the construction of the houses and the drinking water system.

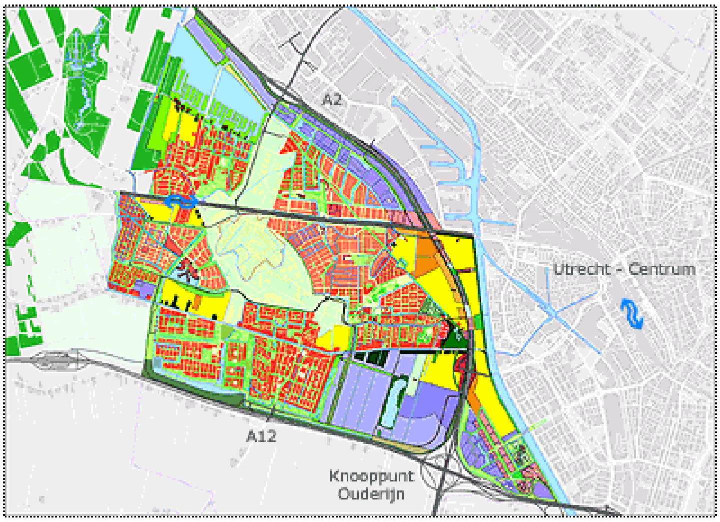

Figure 1: The district "Leidsche Rijn" near Utrecht with 30,000 houses

An attractive local source of domestic water is available. The Water transport company Rijn Kennemerland produces this product for the Dune water industry on the Dutch coast, which is used as a basic product for drinking water production. This basic product for drinking water is a suitable source for domestic water and taken from the Lekcanal.
This water is pre-purified and the quality is better then normal surface water but not suitable for consumption.

2 Construction

From 1997 parallel to the construction of the houses in Leidsche Rijn a domestic water system was designed and constructed. January 2002 about 3,000 houses in Leidsche Rijn were provided with a domestic water system.

The water systems in the houses consist of two different systems: drinking water system and a domestic water system. To avoid mistakes during the construction several technical and organizational precautions were taken.

A few technical precautions:

- In the houses the domestic water system is constructed with piping of different material and colour. This also prevented that the residents of the houses or a plumber from making mistakes when making changes to the water system.
- The connection for the washing machine was provided with a special device.
- The pressure in the domestic water system was higher than that of the drinking water system.

A few organizational precautions:

- Every house was inspected before the inhabitants entered the house.
- Instructions how to construct the two different water systems were given to the installers.

So every risk was defined and precautions were taken.

3 Mistakes in the collective water supply

On the 3rd of December 2001 the water company received complains about the taste of the water. The laboratory sampled the water and found the coli bacteria in the drinking water. The inhabitants were advised to boil the water before consumption.

On the 6th of December 2001 the water company carried out pressure tests. It seems that there was a direct connection between the drinking water distribution system and the domestic water distribution system. It was caused by a temporary connection, which was used to fill the domestic water distribution system with drinking water. About 1,000 houses were supplied for a few days with polluted drinking water. The temporary connection was removed and on the 17th of December 2001 the advice to boil the water was withdrawn. The figures 2, 3a and 3b show the process.

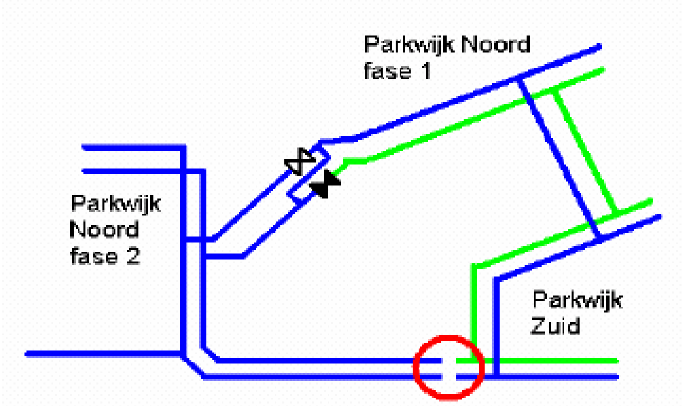

Figure 2: Situation on September 2001, drinking water system (blue) and domestic water system (green) both are filled with drinking water by the temporary connection. There is no connection between the quarters "Parkwijk Noord fase 2" and "Parkwijk Zuid". See the red circle.

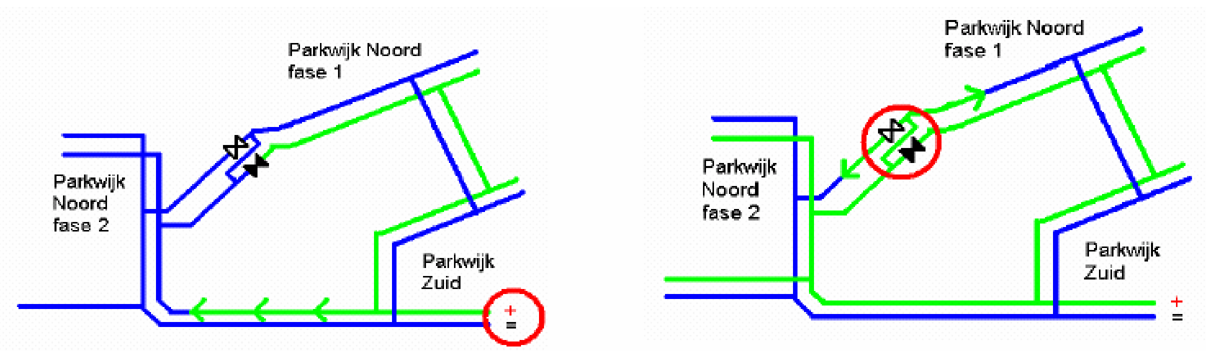

Figure 3a and 3b: Situation on 20 November 2001, an installer construct a connection between the quarters "Parkwijk Noord fase 2" and "Parkwijk Zuid". There is still a temporary connection between "Parkwijk Noord fase 2" and "Parkwijk Noord fase 1". Domestic water enters the drinking water system.

Also on the 3rd of January 2002 inhabitants complained about the taste of the water in their house. Analyse in the laboratory showed that there must be a mixing between domestic water and drinking water. The pollution appeared only in one specific house. Research lead to the conclusion that the connections just before entering the house where changed. The inhabitants of the house had use domestic water for drinking water for some 17 months.

4 What was learned

After studying the problem investigators concluded that the most important factor was: the public.

The water company suggested improving the attention on different fields:
- Avoiding wrong connections in the distribution network.
- How the connections to the houses were constructed.
- The temporary connections during construction and commissioning.
- How to use the valves in the in the main system distribution network.
- Inspection during the construction.

The suggestions mentioned above were given to the inspectors of The Ministry of Housing, Spatial Planning and the Environment.

5 Solution

The Ministry of Housing, Spatial Planning choose for safe drinking water systems. To avoid the risks with domestic water in combination with drinking water it was decided to fill the domestic water distribution system with drinking water. Thus pollution is no longer possible.

6 Domestic water systems in the future

Pilot projects for domestic water systems on a large scale as Leidsche Rijn have in the mean time been abandoned. The Ministry has chosen the guarantee for public health as being more important than saving drinking water.

To save drinking water the Ministry have other preferences such as the reduction of the volume for flushing toilets.

Domestic water systems are still allowed on a small scale, for instance in one house, but not for a collective water supply system.

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8 Presentation of Author

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A Study on the Proper Number of the Fixtures in Toilets of Schools

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Abstract

Primary school children and junior school students are restricted to the class schedules in their schools. When they wish to use the toilet during break times, the queues generated may obstruct the smooth running of these class schedules. It is necessary to set up the optimum number of the fixtures in the toilets. In this investigation, the authors measured how often the students visit the toilets, and brought together the basic materials to design a proper number of fixtures in the toilets of a primary school and a junior high school.
This investigation scheme had been made possible under the cooperation of two schools attached to Shinshu University. Investigations of all schools toilets were practiced on each 2 days in November/2001 and November/2003. The numbers of users were measured using a hand counter in the vicinity of the toilet entrance. Micro switches were set up in all WC cubicles, and photoelectric sensors were set up on all urinals, washbasins and sinks. The usage signals were recorded with the personal computer. The frequency of use and occupancy periods of all fixtures was analyzed. This data could be used as the valuable material from which a proper number of toilet fixtures, in both the primary school and the junior school, could be planned.

Keywords

Toilets, occupied period, simultaneous use, number of fixture, school

1 Introduction

When the students accumulate around the schools toilets at break time and at lunch time, a queue might be generated that becomes an obstruction to school life. Having the proper number of the fixtures in the toilets is important, and designing the toilets using the data from an actual investigation should be promoted. School children in Japan attend primary school for six years from 6 to 12 years old, and students attend junior high school from 12 to 15 years old for three years. These nine years are compulsory education. In this research, the authors investigated fixture usage in the above mentioned elementary and the junior high schools toilets, and analyzed the resulting characteristics.

2. The schedules in the schools

The schedule of the primary school is shown in Table-1. The school was opened for the children to come in to school at 7.30 am. 3rd year children and below study for 5 periods a day, and those who are older study for 6 periods a day. There is an exception on the 14th November where 1st years study for only 4 periods. After school, all children should leave at 16.30 pm.

The schedule of the junior high school is shown in Table-2. The weather on 19th and 20th November was cloudy, and it was warm in daytime. The break time was 15 minutes between the 2nd period and the 3rd period, and the other break times were 10 minutes between periods. The lunch time was 55 minutes. All students should leave the school at 16.25 pm.

3. Outline of investigations

3.1 Contents of the investigations

The investigations were executed in Nagano primary school of Shinshu University from 8 am to 4.20 pm on the 14th and 15th November, 2001. It was cloudy on both days, and the highest temperature was 12 degrees (C). The number of users in each toilet was measured with the hand counter at the entrance. All fixtures were equipped with sensors. Micro switches were set up on the top of the doors of the cubicles, and photoelectric sensors were set up in the urinals, washbasins and sinks, and the signals of the on-off situations were recorded with the personal computer in every second. The frequency of use and the occupancy period of the various fixtures were calculated from these data.

The next investigations were executed in Nagano junior high school of Shinshu University from 7.30 am to 4.30 pm on the 19th and 20th November, 2003.

3.2 Toilets in the primary school

The plan of Nagano primary school is shown in Figure-1. The classrooms building is three stories high, and two school years of children study on each floor. For example, the 1st year and the 2nd year children study in their classrooms situated on the 1st floor. There were 3 classes in each school year, and the all school children were targeted for investigation.

The male and female toilets were located on each floor and the gym, and all toilets were investigated. The detailed chart of the toilets in the classroom building on each floor and the gym are shown in Figure-2 and Figure-3 and the numbers of fixtures of each toilet are shown in Table-3. No.4 washbasin in the male toilet on the 2nd floor, and the No.2 washbasin and No.1 WC in the male toilet on the 3rd floor were out of investigation, since they were broken. The total number of children was 703, and the ratio between male and female was almost same. The attendance number was 689 in each investigated day, and the details of the number of toilet users are shown in Table-4 and Table-5.

3.3 Toilets in the junior high school

The plan of Nagano junior high school is shown in Figure-4. The total number of students was 701, with 351 boys and 350 girls. There are 6 classes in each year, with 229 students in the 1st year, 237 students in the 2nd year and 235 students in the 3rd year. Each classroom building is three stories high, and there are special classrooms, a staff room, a kitchen for all students to have lunch and a service room on the first floor. There are six 1st year classrooms and three 2nd year classrooms on the second floor. There are three 2nd year classrooms and six 3rd year classrooms on the 3rd floor. The toilets are installed alternating male and female on each floor. Detailed charts of the toilets are shown in Figure-5 and the numbers of fixtures in the toilets are shown in Table-6. Student attendance figures and the number of toilets users on the investigated days are shown in Table-7 and Table-8.

4. Male toilets in the primary school

4.1 The number of the toilet users

The variations of the number of toilet users and urinal users are shown in Figure-6 and Figure-7. The numbers of users of each type of fixture are shown in Table-9. The 1st floor toilet was used more frequently than any other, because it was near both the entrance and to a passage to the gym. The toilet in the gym was hardly used even though children were taught physical education. On average a child used the toilets 2-3 times a day. About 5% of the children used the WCs.
Many children used the 1st floor toilet as soon as arriving at the school in the morning and after the final meeting. In the case of the long interval break, that was 30minutes, a concentration around the toilets had occurred by the end of the break, because the children used the toilet when they had come back to the classroom from the gym or schoolyard. The maximum number of urinal users over ten minutes was 41 persons at 10.50 am, and next value was 39 persons at 12.30 pm.
All fixtures were used simultaneously, but usage periods were less than a minute. When two boys used the urinals together, they selected those next to each other.

4.2 Review of the fixtures usage

(1)Review of the occupied periods
The averaged occupied periods of the various fixtures are shown in Table-10. There was no difference between the averaged occupied periods of the urinals and the washbasins in the 1st floor toilet and the 2nd floor toilet. However, the figures for the 3rd floor toilet were longer, because the upper year children were close to adults.

(2)Review of the usage frequency
The urinal nearest to the entrance of the toilet was used the most frequently, and in the case of the 3rd floor toilet the nearest and the farthest urinals were frequently used. The upper years children did not select the urinal near the entrance. Also, they liked WCs which were of the ordinary type, not the Japanese traditional type. They preferred to use the middle washbasins out of the row of four, and tended to avoid the washbasins near

the wall.

5. Male toilets in the junior high school

5.1 The number of the toilets users

The variations of the number of toilet users and urinal users are shown in Figure-8 and Figure-9. The numbers of users in each type of fixture are shown in Table-11. The data for the 2nd floor and the 3rd toilets from 7.30 am to 2.00 pm in 19 November was lost. Hence, the other data was analyzed. The students used the toilets at the break time and the lunch time. There were more users in the 3rd floor toilet because the upper year students often used the washbasins. The average frequency of toilet use was about twice a day per person.
The washbasin users were more than the urinal users in every toilet, and many students used the sinks out of toilets. The number of inside washbasin users in the 3rd floor toilet was more than any other floor, because upper year students often used the mirrors above the washbasins. Only 2% of all students in the school used the WCs. The average times of the urinal use was 1.2 times a day per person. The number of toilet users was 87 and the peak number of urinal users was 44 persons over a 10 minute period.
The simultaneous use of the four or more urinals was extremely rare, and all urinals were seldom simultaneously used. It was also extremely rare that all washbasins and sinks were simultaneously used at lunch time.

5.2 Review of the fixtures usage

(1)Review of the occupied periods
The average occupied periods of the various fixtures are shown in Table-10 and the distribution profile of the occupied periods is shown in Figure-11. There was no difference between the average occupied periods of the urinals of all toilets, but the average occupied period of the washbasins in the 3rd floor toilet was longer than for the 1st and the 2nd floor toilets, because many upper-year students used the mirrors attached with the washbasins. The outside sinks were often used for brushing teeth after lunch and such usage made the occupied period longer. The number of WC users was small so the occupied period characteristics of WC usage were not remarkable.

(2)Review of the usage frequency
No.1 and No.5 urinals, which were located at the ends of the row of urinals, were used more frequently than the others. No.1 urinal was most frequently used in the 3rd floor toilet. No.2 urinal in the 2nd floor toilet was out of order, but the other urinals were used evenly.
No.2 washbasin was used most frequently in all toilets, because it was easier to approach. The outside sinks were used frequently for many purposes in the school life.

6. Female toilets in the primary school

6.1 The number of toilets users

The variations of the number of toilets users and WCs users are shown in Figure-11 and

Figure-12. The numbers of users in each type of fixture are shown in Table-13. Children in the lower years often used the toilets during lessons. Therefore, the change of users profile was gentle. Children often used the toilets together with their friends. The 1st floor toilet was used more frequently than the others as with the case for male toilets, because it was near to the entrance and to a passage to the gym. After 3pm the 1st and 2nd year students had gone home so the 1st floor toilets were used just by the older students.

The toilet in the gym was hardly used. Some girls said that this toilet was scary because it was dark. Actually, there was no sunlight in this toilet, and the lights automatically turned on via a sensor when someone entered. Thus, most children used the toilets near the classrooms before or after the physical education instead. The ratio of the number of WC users versus the toilet users at the peak 10 minutes was 83.7% (41 persons/49 persons). The number of maximum WC users within ten minutes was 41 persons at 10.50 am, and next highest value was 40 persons at 12.30 pm.

Simultaneous use of WCs, washbasins and sinks was significant when the children arrived at school, just before leaving school and at lunch time. The simultaneous use of five or more WCs was seldom, but it occurred more with the lower year children.

6.2 Review of the fixtures usage

(1)Review of the occupied periods

The average occupied periods of the various fixtures is shown in Table-14. The occupied periods are longer in the case of the upper year children. The average occupied period of the washbasins and sinks was longer than for boys.

(2)Review of usage frequency

No.2 and No.3 washbasins were used more frequently than No.4 and No.1. No.1 was hardly used because it was set nearest to the doorway in all toilets. No.1, No3, No4, No.6 and No.7 WCs were used more frequently in the 1st floor toilet, while No.3, No.5 and No.7 WCs were used more frequently in the 3rd floor toilet. Summarizing the results, the frequency of use of No.1 WC near the doorway was high, and No.2 was extremely low.

7. Female toilets in the junior high school

7. 1 The number of toilet users

The variation of the number of toilet users and WCs users are shown in Figure-13 and Figure-14. The numbers of users in each type of fixture are shown in Table-15. The data for the 2nd toilets and the 3rd toilets from 7.30 am to 2.00 pm in 19 November were lost. Hence, the other data was analyzed. It was remarkable on 20th November that many students used the toilets from morning to noon besides the break time. This was because course consultations for high school were held during those times (rather than the usual school schedule), so they were able to use the toilets freely.

The average toilet use was 2 times a day per person, and the average WC use was 0.96 times a day per person. Average washbasin use was 2 times a day per person. WC users used the washbasins set in the toilets whereas many students used the sinks set outside of the toilet area. The purposes of use included hand washing at lunch time, brushing

teeth, checking themselves in the mirrors by the washbasins, etc. The number of toilet users was 108 persons, and the number of WC users was 39 persons during the peak 10 minutes. Many schoolgirls used the toilets for the purposes other than using the WCs, and it was quite remarkable in comparison with the schoolboys.
There was remarkable WC, washbasin (outside the toilet area) and sink (inside the toilet area) usage, simultaneously, at break time and at lunch time, however it seldom occurred that every one of fixtures were use at any one time. Many schoolgirls simultaneously used the washbasins and sinks for hand washing and brushing teeth at the lunch time. The maximum number of WCs in use at any one time was 4, and the maximum number washbasins in use simultaneously were 3.

7.2 Review of the fixtures usage

(1)Review of the occupied periods
The average occupied periods of the various fixtures are shown in Table-16 and the distribution profile of the occupied periods is shown in Figure-15. The sinks were used more frequently, but their occupancy periods were shorter. The average occupied period of the washbasins was longer than the sinks. The occupied period of the WCs was almost same as an adult woman, and the purposes of the use of washbasins and the sinks by the girls were similar to an adult woman.

(2)Review of the use frequency
No.2 and No.5 washbasins and sinks were used frequently. They are set near the doorway making the walking distance to them shorter. For the same reason No.3 and No.5 WCs were used frequently. On the morning of 20th November, a water leakage was found in No.2 and No.4 WCs in the 3rd floor toilets, therefore their use was prohibited in the afternoon.

8. Conclusion

In this report the characteristics of toilet usage in a primary school and a junior high school were investigated. The results are summarized as follows.
(1)The average times of toilet use was about twice per person per day for both boys and girls of the primary school and the junior high school. The average frequency of urinal use by boys was about once per person per day. WC usage by girls was about once per person per day. For junior high school boys WC usage increased a little when compared to primary school boys.
(2)Accumulation around toilets occurred at lunch time. The simultaneous use of the washbasins was significant.
(3)In the investigated schools there were adequate fixtures and so queues did not form in the toilets.
Such investigation needed to take into consideration the psychological environment, as it was not desirable to detract students from using the toilets by the presence of test equipment. The problems that should be considered for school toilets in the future are cleanness, brightness, the necessary area and the layout of the fixtures and so on.

9 References

1. BS 6465 Sanitary installation – Part1: Code of practice for scale of provision, selection and installation of sanitary appliances.,1994

10 Presentation of Author

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Table-1 Time schedule for school Children, PS

7:30	School gates open
8:30-9:00	Registration
9:00-10:30	1st and 2nd periods
10:30-11:00	30 minute break
11:00-12:30	3rd and 4th periods
12:30-13:30	School lunch time
13:30-13:50	Cleaning time
13:50-14:00	Change over time
14:00-14:45	5th period
14:45-15:00	Meeting before going home
15:00-15:45	6th period

Table-4 Time schedule for students, JHS

	19th (Wed)	20th (Thu)
7：40～7：50	Cleaning duty	
7：50～8：00	10 minute break	
8：00～8：10	Reading time	
8：10～8：20	Registration	
8：20～8：30	10 minute break	
8：30～9：20	1 period	
9：20～9：30	10 minute break	
9：30～10：20	2 period	
10：20～10：35	15 minute break	
10：35～11：25	Achievement test	Meeting of representative committee
11：25～11：35	10 minute break	
11：35～12：25	Achievement test	4 period
12：25～13：15	School lunch time	
13：15～13：20	5 minute break	
13：20～14：10	5 period	
14：10～14：20	10 minute break	
14：20～15：10	6 period	
15：10～15：20	10 minute break	
15：20～15：35	Asahino-time	Cleaning time
15：35～15：45	(45 minute	10 minute break
15：45～16：05	playtime)	Registration
～16：25	General time for leaving school	
～16：55	Time for leaving school of students that have done club activities before event	

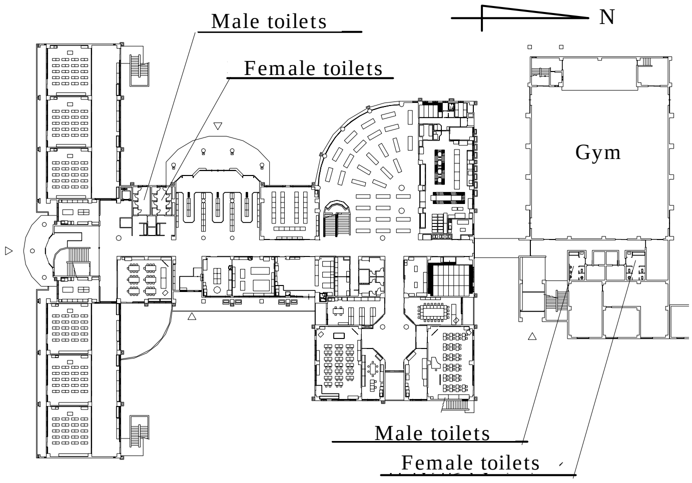
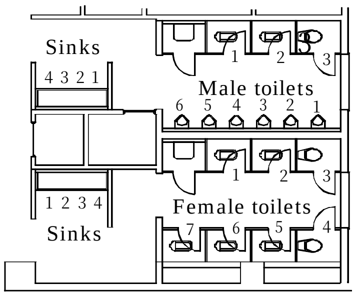


Figure-1 Plan of 1st floor of the primary school



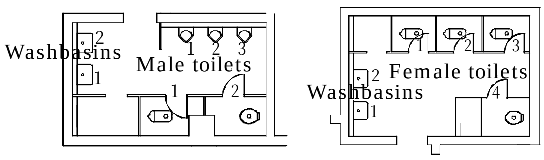


Figure-3 Detailed plan of the toilets in the school gym

Figure-2 Detailed plan of the toilets in the school building

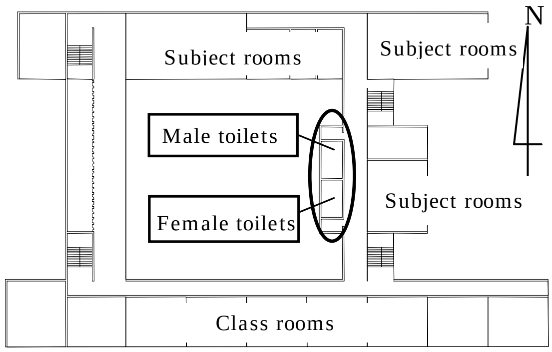


Figure-4 Plan of 2nd or 3rd floor of the junior high school

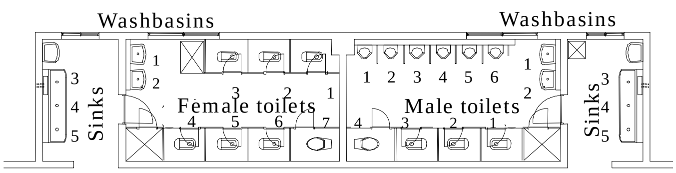


Figure-5 Detailed plan of the toilets in the school building

Table-3 The number of the sanitary fixture in the toilet (Unit: pieces), PS

	Male toilets			Female toilets	
	Urinals	Washbasins	Cubicles	Washbasin	Cubicles
1F	6	4	3	4	7
2F	6	3	3	4	7
3F	6	3	2	4	7
Gym	3	2	2	2	4

Table-4 The total number of school children and the number that attended school (Unit: people), PS

		1st grade	2nd grade	3rd grade	4th grade	5th grade	6th grade	Total
Total number of school children		113	119	119	118	117	117	703
Number of that attended school	14th	111	117	114	115	116	116	689
	15th	111	116	116	113	117	116	689

Table-5 The number of toilets users (Unit: people), PS

	Man					Woman					Total
	1F	2F	3F	Gym	Total	1F	2F	3F	Gym	Total	
14th	291	233	152	11	687	199	226	131	0	556	1243
15th	320	208	118	14	660	215	142	108	5	470	1130

Table-6 The number of the sanitary fixture in the toilet (Unit: pieces), JHS

	Male toilets				Female toilets		
	Urinals	Sinks	Washbasins	Cubicles	Sinks	Washbasins	Cubicles
1F	6	3	2	4	3	2	7
2F	5	3	2	4	3	2	7
3F	6	3	2	4	3	2	7
Total	17	9	6	12	9	6	21

Table-7 The number of students that attended school (Unit: people), JHS

Grade	19th			20th		
	Man	Woman	Total	Man	Woman	Total
1	119	116	235	117	114	233
2	114	108	222	115	108	223
3	113	114	227	115	113	229
Total	346	338	684	347	335	685

Table-8 The number of toilets users (Unit: people), JHS

	Man				Woman				Total
	1f	2f	3f	Total	1f	2f	3f	Total	
19th	211	262	311	784	236	336	323	895	1679
20th	180	254	275	709	235	262	274	771	1480

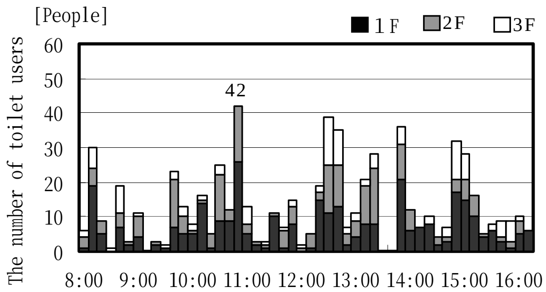


Figure-6 Changes of the number of male toilet users with intervals of 10 minutes,

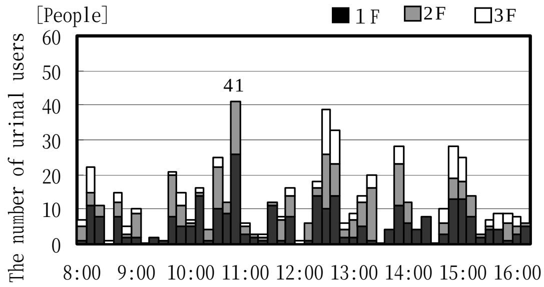


Figure-7 Changes of the number of urinal users with intervals of 10 minutes,

Table-9 The number of the sanitary fixtures in the male toilets (Unit: people)

	Urinals			Washbasins			Cubicles		
	1F	2F	3F	1F	2F	3F	1F	2F	3F
14th	284	204	124	120	156	102	6	6	2
15th	277	202	105	133	150	87	12	11	0

Table-10 Occupied period of the sanitary fixtures in the male toilets (Unit: seconds)

	Urinals			Washbasins			Cubicles		
	1F	2F	3F	1F	2F	3F	1F	2F	3F
14th	21.5	21.8	21.0	4.7	4.7	6.7	85.6	119.6	62.0
15th	20.3	19.5	23.6	5.1	5.2	6.2	90.6	136.2	—
平均	20.9	20.7	22.3	4.9	5.0	6.5	88.1	127.9	62.0

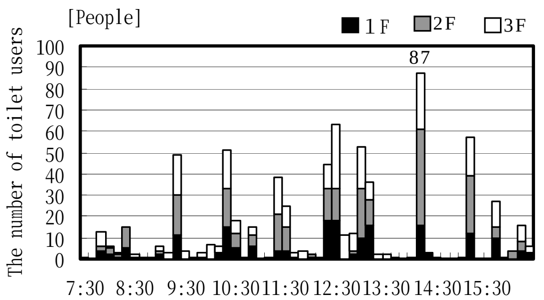


Figure-8 Changes of the number of male toilet users with intervals of 10 minutes

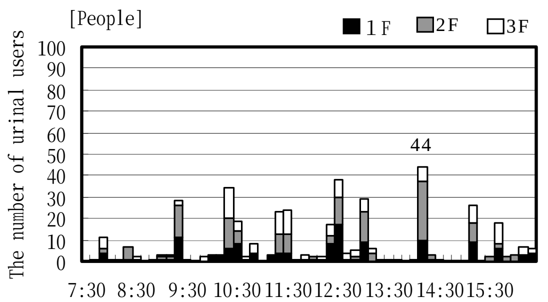


Figure-9 Changes of the number of urinal users with intervals of 10 minutes

Table-11 The number of the sanitary fixtures in the male toilets (Unit: people)

	Urinals			Washbasins			Sinks			Cubicles		
	1F	2F	3F	1F	2F	3F	1F	2F	3F	1F	2F	3F
19th	148	34*	45*	56	8*	29*	150	47*	45*	1	0*	0*
20th	123	153	127	40	47	109	134	189	176	1	1	5

Table-12 Occupied period of the sanitary fixtures in the male toilets (Unit: seconds)

	Urinals			Washbasins			Sinks			Cubicles		
	1F	2F	3F	1F	2F	3F	1F	2F	3F	1F	2F	3F
19th	25.0	26.3	30.4	5.7	7.0	14.8	7.5	13.4	12.3	50.0	—	—
20th	27.9	29.4	28.8	7.5	6.2	12.3	10.1	9.8	17.5	134.0	87.0	175.6
Average	26.5	27.9	29.6	6.6	6.6	13.6	8.8	11.6	14.9	92.0	87.0	175.6

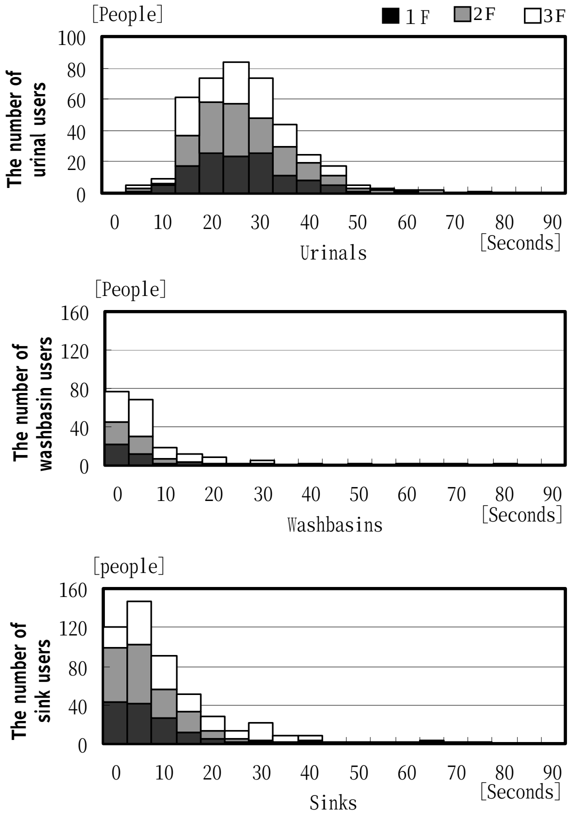


Figure-10 Occupied period of urinals and washbasins in the male toilets

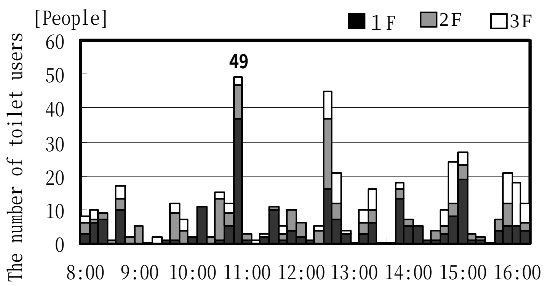


Figure-11 Changes of the number of female toilet users with intervals of 10 minutes

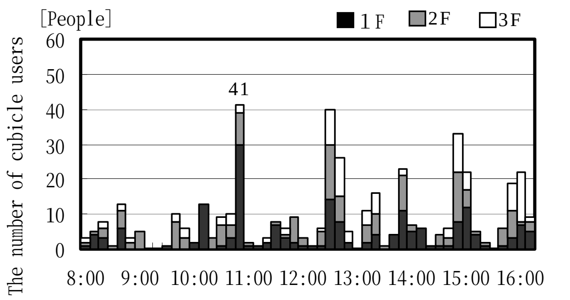


Figure-12 Changes of the number of female cubicle users with intervals of 10 minutes

Table-13 The number of the sanitary fixtures in the female toilets (Unit: people)

	Washbasins			Cubicles		
	1F	2F	3F	1F	2F	3F
14th	180	175	106	138	168	142
15th	183	157	100	142	106	150

Table-14 Occupied period of the fixtures in the female toilets (Unit: seconds)

	Washbasins			Cubicles		
	1F	2F	3F	1F	2F	3F
14th	9.5	8.2	9.0	46.5	42.1	51.3
15th	9.4	8.3	9.4	50.0	41.3	48.3
Average	9.5	8.3	9.2	48.3	41.7	49.8

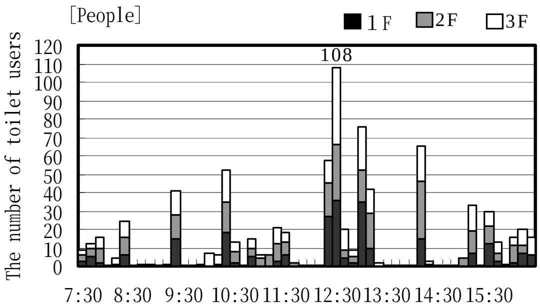


Figure-13 Changes of the number of female toilet users with intervals of 10 minutes

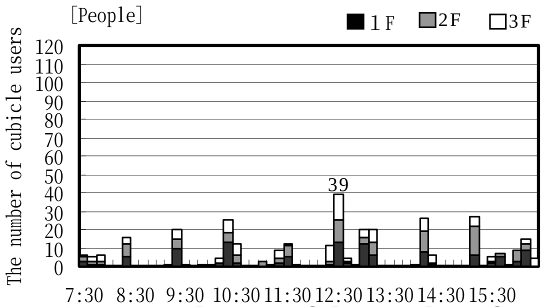


Figure-14 Changes of the number of cubicle users with intervals of 10 minutes

Table-15 The number of the sanitary fixtures in the female toilets (Unit: people)

	Washbasins			Sinks			Cubicles		
	1F	2F	3F	1F	2F	3F	1F	2F	3F
19th	40	54*	43*	187	52*	68*	102	32*	42*
20th	107	220	164	185	233	274	115	106	99

Table-16 Occupied period of the fixtures in the female toilets (Unit: seconds)

	Washbasins			Sinks			Cubicles		
	1F	2F	3F	1F	2F	3F	1F	2F	3F
19th	11.4	14.4	13.0	11.4	10.7	11.0	63.9	67.8	56.5
20th	7.7	18.6	13.5	11.3	12.6	13.6	67.9	67.4	75.9
Average	9.6	16.5	13.3	11.4	11.7	12.3	65.9	67.6	66.2

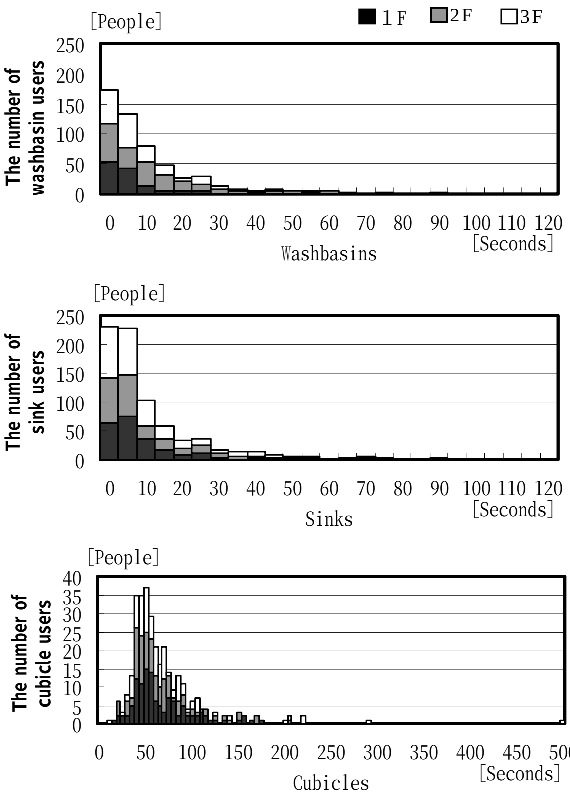


Figure-15 Occupied period of cubicles and washbasins in the female toilets

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Current Design of High-Rise Building Drainage System in Taiwan

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Abstract

The main purpose of the research is to find the solution of drainage issues in high-rise building through the observation and basic study of stack fluid mechanism. Firstly, we will investigate the existing high-rise buildings and summarize the design methodology from our previous researches. Through the observations and reviews, this paper would conclude the solutions for existing drainage problems and the theory of air pressure distribution in stack of high-rise building may be applied.

Keywords
high-rise buildings, drainage, stack, air-pressure, methodology

1. Introduction

Since 1985, Tai-power office building that is the first domestic building above 100 meters was constructed, high-rise building evidently appeared to the metropolis area of Taiwan from north to south. Moreover, Taipei 101 is seen as the milestone of high-rise building. The design of high-rise building is complex and high integration work and the success reveals the technical achievement of a country. Nonetheless, the importance of building drainage, which is a humble but very substantial issue, might not be ignored.

The gravity drainage system without any energy supply is commonly used in building all over the world, and the trap with simple structure is also preferred to set as a critical part for most of sanitary facilities because of its easy elimination of stench and vermin. Owing to the increasing of potential energy of height, inappropriate design of drainage system is facile to cause the sanitary problems in high-rise building and inconvenient utility. Particularly, people recognize the importance of healthy environment through the impact of SARS disease. The community infections of Hong Kong give us a great lesson that the problems of drainage system including the infectious disease caused from loss of seal water in trap, and we should not ignore the hidden troubles of building drainage.

In order to improve the drainage performance of existing high-rise building, investigation is necessary and appropriate design technology of domestic application must be conducted. The main purpose of the research is to find the solution of drainage issues in high-rise building through the observation and basic study of stack fluid mechanism. Firstly, we will investigate the existing high-rise buildings and summarize the design methodology from our previous researches. Through the observations and reviews, this paper would conclude the solutions for existing drainage problems and the theory of air pressure distribution in stack of high-rise building may be applied.

2. Mechanism and Theoretical Reviews

Appliance discharges to a vertical stack of drain may be described as unsteady or time dependent flow, and the form of the appliance discharge flow contributes to this flow condition. An actual discharge of vertical drainage stack has a complex phenomenon and may consist of triple phase flow feature with incorporated solid, liquid and air. Airflow in the drainage stack is promoted by through-flow mixing as well as the interaction of friction with the falling water and air. This mechanism causes the negative pressure on the upper floors and the positive pressure on the lower floors in the building vertical drainage system.

According to the previous researches, the airflow rate (Q_a) was identified as a critical parameter for a prediction model which can express the mechanism of vertical drainage flow. Therefore, the airflow performance in vertical drainage stack is the dominated issue and it needs to be solved. Hence while air flow rate is dominant in the vertical drainage stack it plays a critical role in the subsequent operation of vertical drainage stack where the mechanism may be assumed to be a quasi-fan machine, thus the laws of fan can be introduced to link with the vertical drainage flow. The laws of fan can be expressed by the hydraulic parameters such as air density, pressure, velocity, gravity, resistance coefficient, lift, and et al. Practically, the operation energy for airflow within fan is mainly from electric power, thus potential energy of height is the dominating power for conducting the airflow in vertical drainage stack. This antithesis mechanism can be expressed as quasi-fan theory, namely the initial model of vertical drainage flow was conducted from the lows of fan machine alike.

The mechanism of flow within vertical drainage is now schematically understood. Air pressure in vertical drainage stack is caused by series interactions between downstream water and through-flow air in vertical pipe. Fig.1 illustrates the image of flow state and the modified interaction, thus it conducts the main parameters with air pressure, airflow rate, and resistance coefficients, and they are the essential factors for prediction model of air pressure distribution in vertical drainage stack.

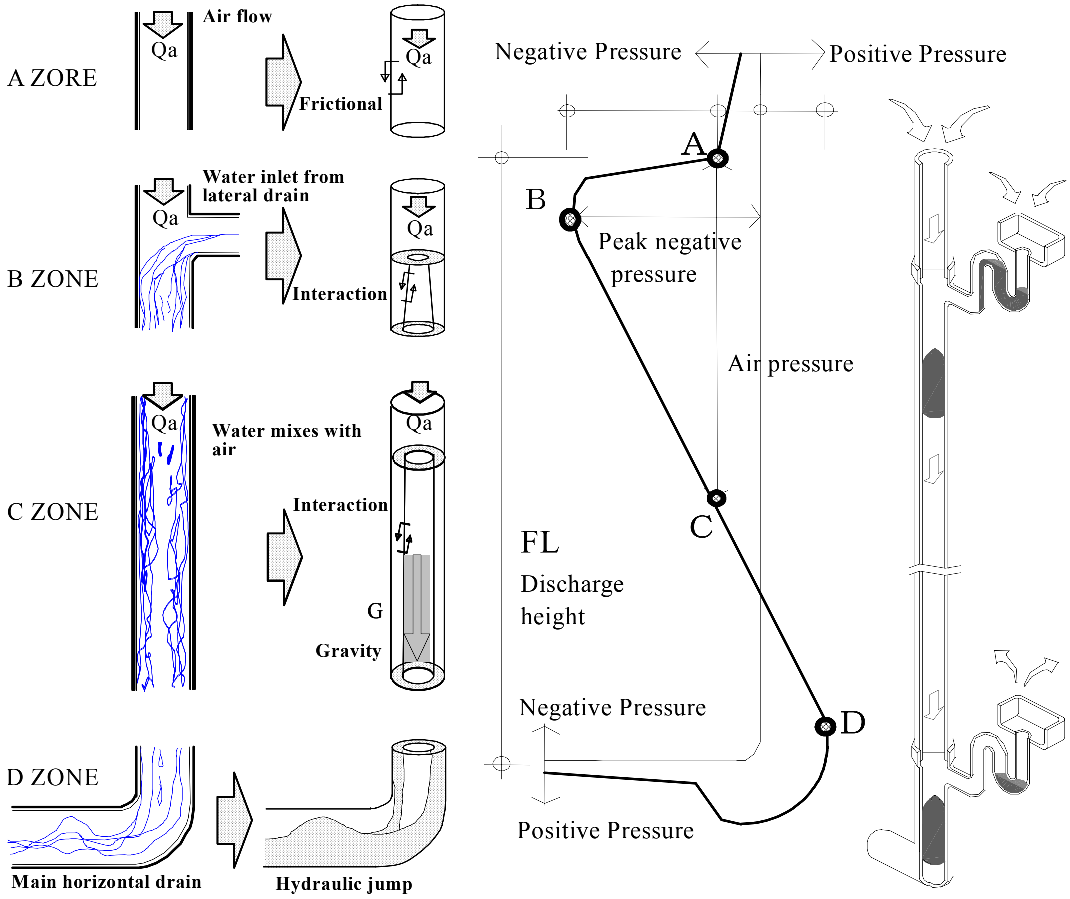


Fig.1 Mechanism of vertical drainage feature and inverted model

The guideline of National Plumbing Code (NPC) of US was used to set the permit flow rate as the regulation of drainage system [3]. Following initial work of the HASS 203 of Japan in 1970s, the method of steady flow condition was merged as the provision reference and evaluation technique, hence it conducted a series researches of steady flow method with reference to building drainage network. Consequently, a prediction model about the air pressure distribution, which occurred in the drainage stack by high-rise experiment tower (108m) and middle-high experiment tower (30m), was developed in Japan from 1990, then considerable progress has been made in predicting the air pressure distribution within vertical drainage stack [4][5].

According to the mechanism and feature of vertical drainage flow from the theoretical reviews, the profile of drainage stack was divided into four zones, and each zone is individually modeled due to the corresponding characteristics. Meanwhile, the air pressure distribution, which reveals the time average air pressure data with steady flow condition, does not involve the instantaneous air pressure fluctuation in vertical drainage flow.

3. High-rise Building Issues

The competition of construction up to the sky is never stop in the human history. People always notice and like to talking about the building of top height in the world. Figure 2 shows the holistic views of top ten high-rise building all over the world. Figure 3 is the situation of high-rise buildings in Taiwan. As mentioned above, Taipei 101 is seen as the milestone of high-rise building in Taiwan's develop as shown as Figure 3 and Figure 4. The design of high-rise building is complex and high integration work. People see the success reveals the technical achievement of a country.

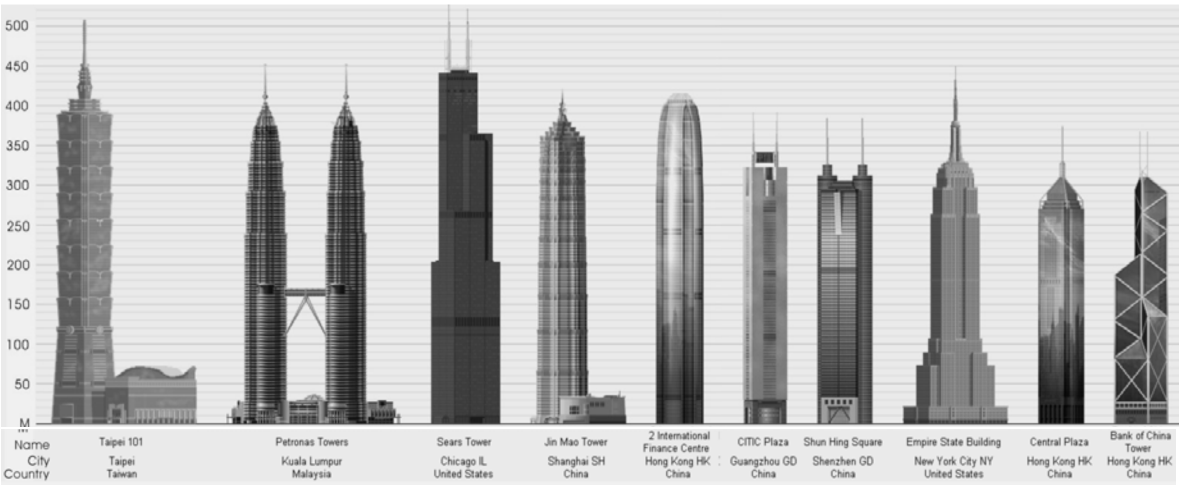


Figure 2 World top ten high-rise buildings

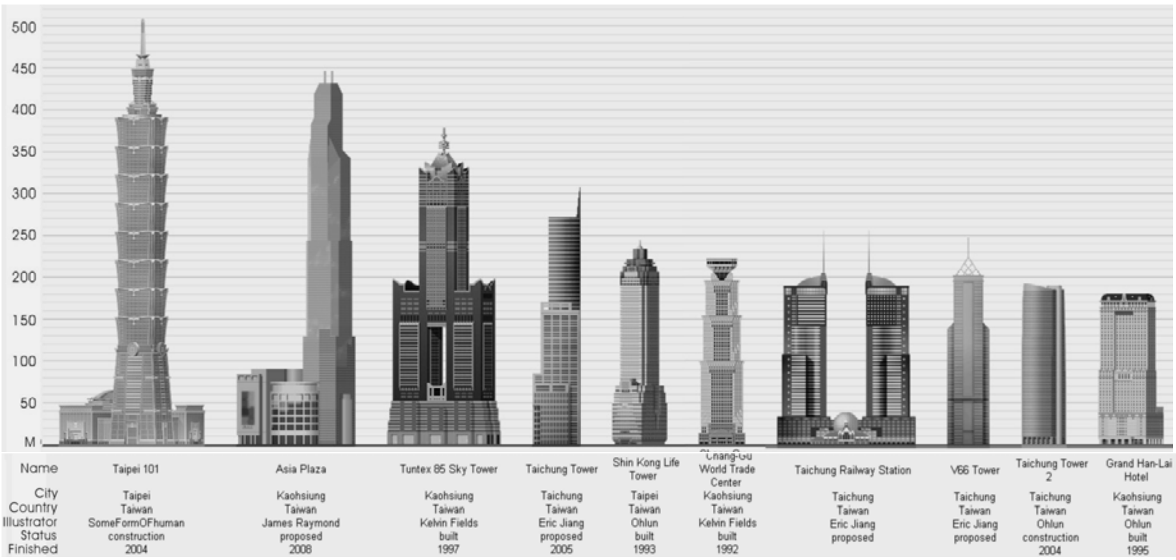
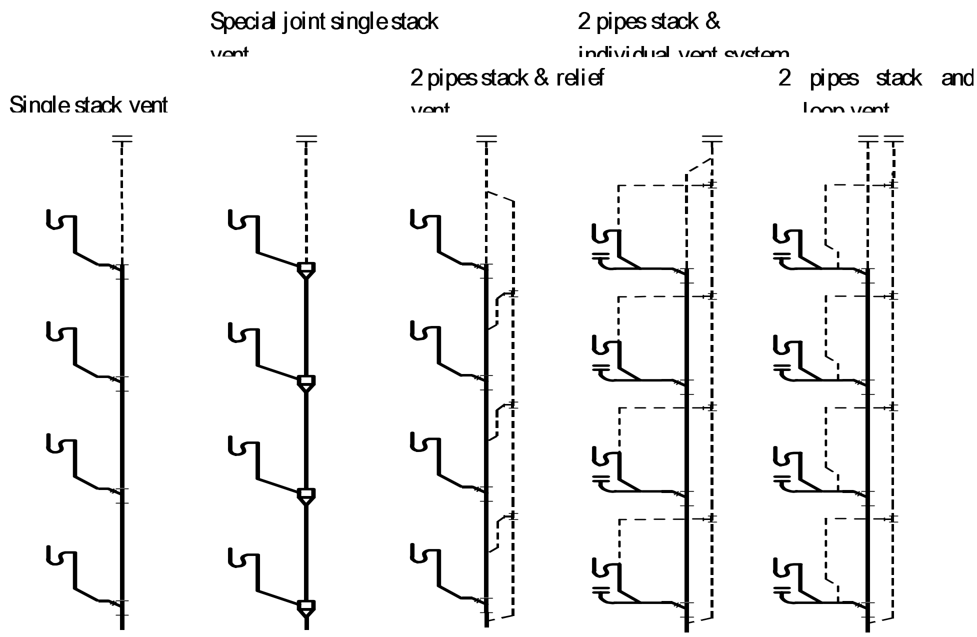


Figure 3 Taiwan top ten high-rise buildings

Primary investigation reveals that design methodology of high-rise building drainage system is still unclear in Taiwan. Building drainage problems such as destroy of trap seal, chaotic or block plumbing, sanitary performance and ill infection … are very possible existing in current buildings. Technical solutions and suitable design methodology need to be conducted for local issues at present.

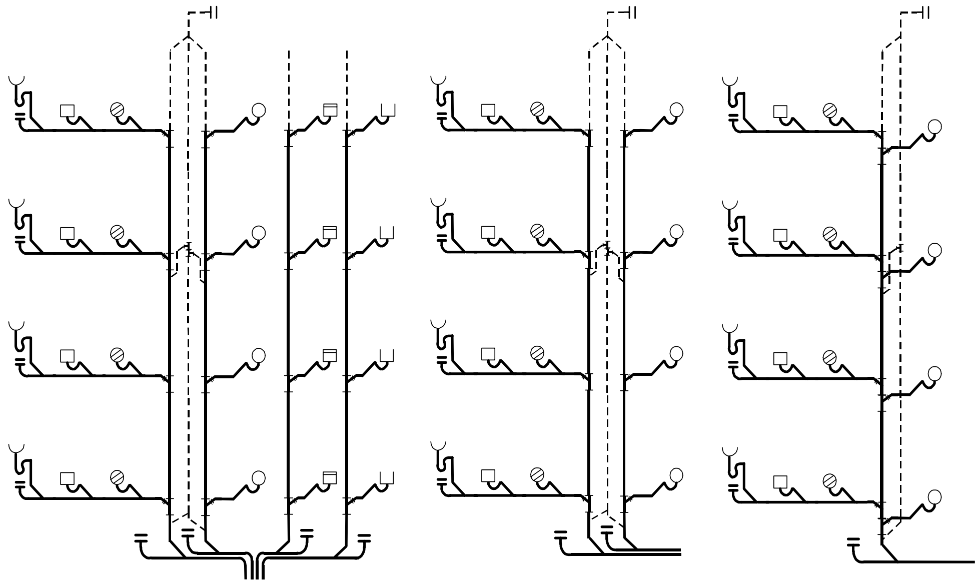
4. Investigation of Building Drainage and Vent Systems

Past research and design codes show that apartment houses can have single-pipe or dual-pipe drainage vent systems (see **Figure 4**). Vertical drainage stack pipe can be single or multiple pipe due to the several types of discharge—sewerage, bath, kitchen, abstergent from the washing machine, rain water (see **Figure 5**)—and to prevent the drainage pipe from being choked by waste water with oil and cleanser. The vent pipe system includes four types: Loop vent, individual vent, stack vent, and relief vent and vent stack (see **Figure 6**).



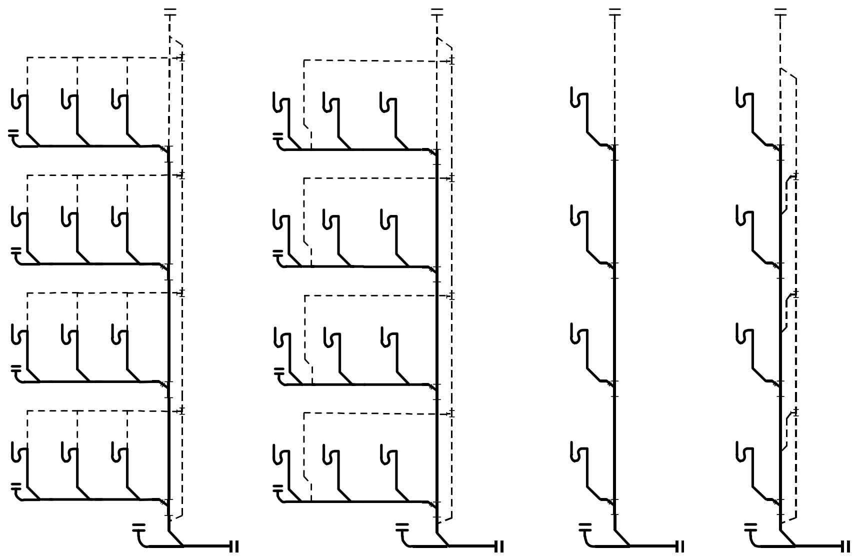
a. Single-pipe drainage & vent system   b. Two-pipe drainage & vent system

Figure 4. Types of Building Drainage Systems



a. more than 2 drainage pipes b.2 drainage pipes c. single drainage pipe

Figure 5. Types of building drainage pipe for building drainage system



a. individual vent system c. stack vent system

b. loop vent system d. relief vent & vent stack

Figure 6. Types of the vent pipe for building drainage system

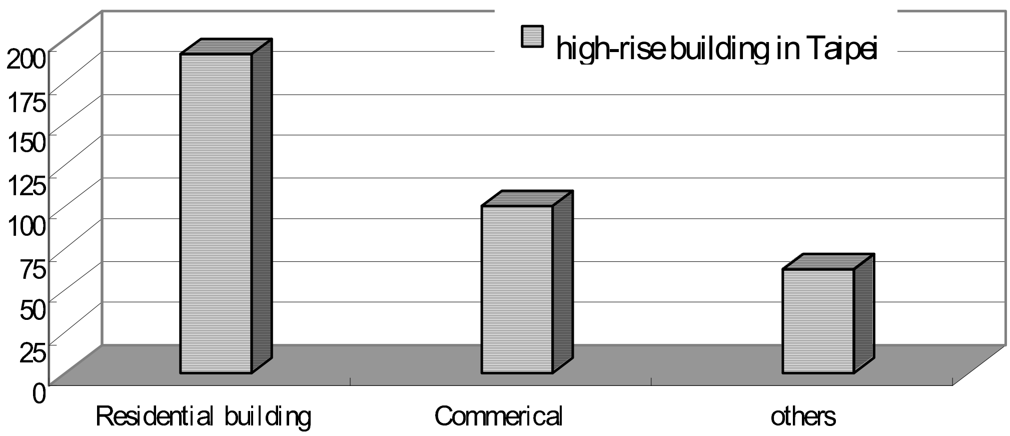
5. Investigation

This report focuses on the high-rise buildings, which are according to building code definition with over sixteen floors or fifty meters height. The further information concerning building drainage system was collected by investigation and interviews with plumbing engineers. Meanwhile, technical reviews and previous researches also offer the reference and understanding of current design methodology. This information would lead to the solutions for building drainage problems of high-rise buildings.

According to authority records, there are 354 cases of high-rise buildings, which are over sixteen floors or 50 meters height in Taipei city. Table 1 shows the Taipei authority's records about these cases of high-rise buildings with utility categories before 2003. It reveals that residential buildings are the most occupation with 191 cases and 54.1%. The following is commercial buildings with 100 cases and 28.3%. The others are of 62 cases and 17.6%.

Table 1 High-rise building with utility categories in Taipei

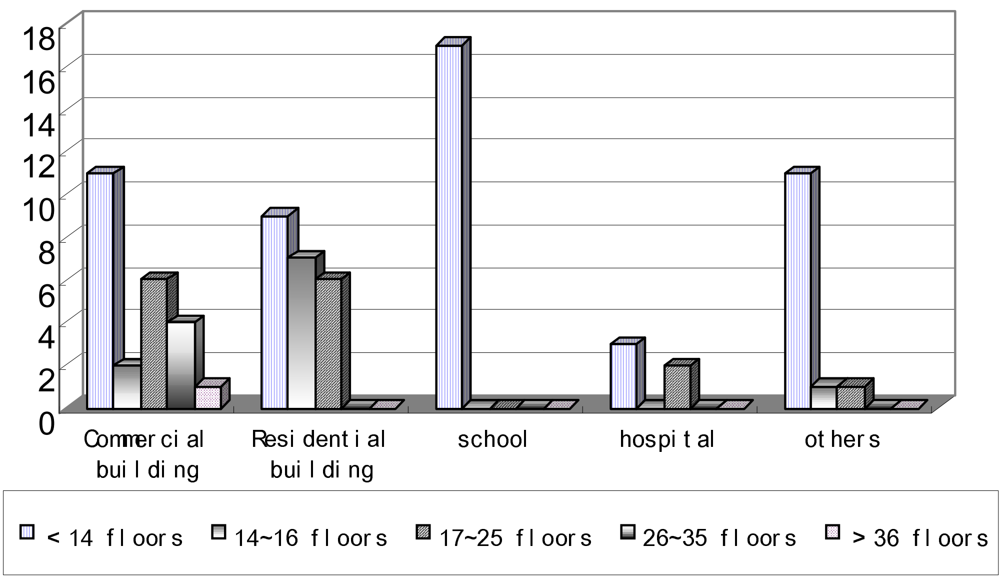
Utility category	Case numbers	Percentage
Residential building	191	54.10%
Commercial building	100	28.30%
Others	62	17.60%



As the detail study objects, 51 cases were arranged due to interviews of professional companies and plumbing engineers. The floor height and utility categories are shown in Table 2.

Table 2 Interview cases with floor height and utility categories

Floor height	Commercial building	Residential building	School	Hospital	Others
< 14 floors	11	9	17	3	11
14~16 floors	2	7	0	0	2
17~25 floors	6	6	0	2	1
26~35 floors	4	0	0	0	0
> 36 floors	1	0	0	0	0



6. Analyses and Discussion

According to the previous categorization of building drainage system, the system design including four types, which are combined single and double-barreled stack, separated double-barreled and individual stack as shown as Figure 7.

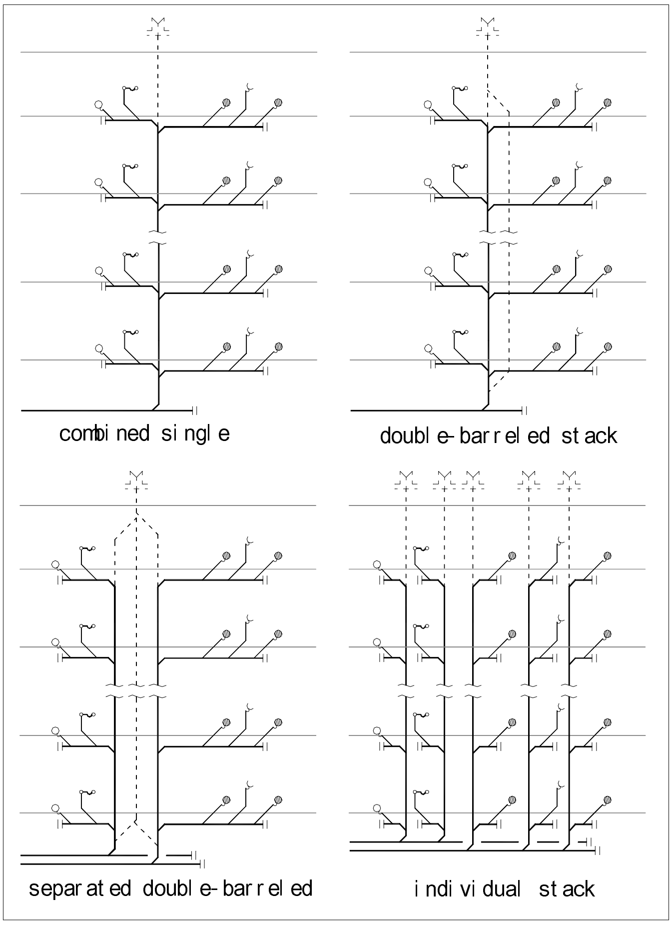


Figure 7 Building drainage categories

Due to above categories, the observed cases are arranged as shown in Table 3. The results shows that combined single stack system were rare adapted in high-rise buildings for avoiding the instant peak discharge. Although the combined single stack system is good for less fitting space. The most occupations of these cases are consternated on separated double-barreled individual stack. It means that current engineers have higher confidence in this system.

Table 3 Drainage categories for the observed cases

Drainage categories	combined single	double-barreled stack	separated double-barreled	individual stack	total
< 16 floors	8	5	38	0	51
> 16 floors	0	4	27	0	31

On the other hand, vent stack for air way is corresponding to the drainage stack. The categories for vent stack are shown in Figure 8. We also arranged the categories for the observed cases as shown in Table 4. It is obvious that double stack with connection type is the most popular in these cases.

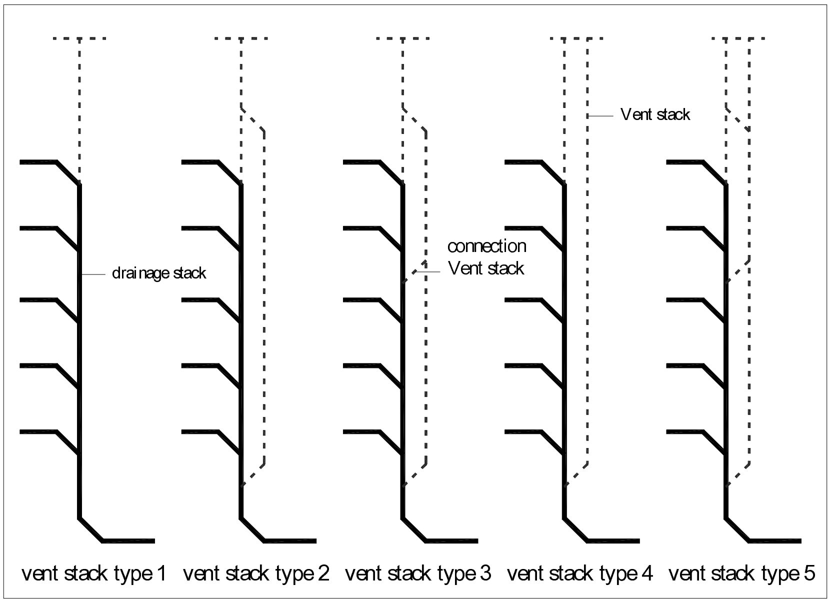
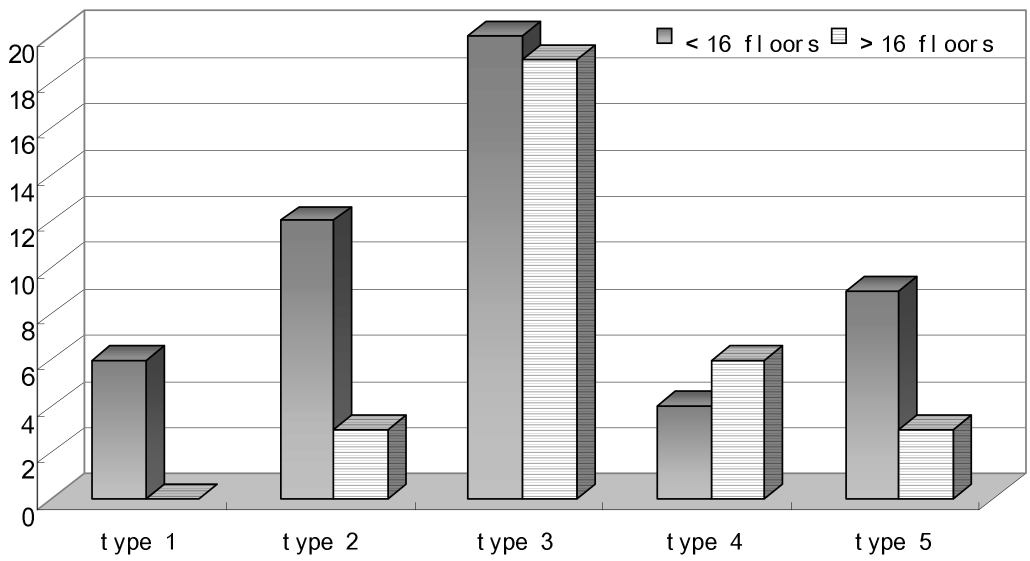


Figure 8 Categories for vent stack

Table 4 Categories for observed cases

vent stack	type 1	type 2	type 3	type 4	type 5
< 16 floors	6	12	20	4	9
> 16 floors	0	3	19	6	3



According to the partial detail observation, we concentrated on the loop vent design and concluded the current construction categories as shown in Figure 9. Owing to insufficient guideline for building drainage vent construction, the current design is not under regulation. This situation might cause problems in building drainage system especially for high-rise building.

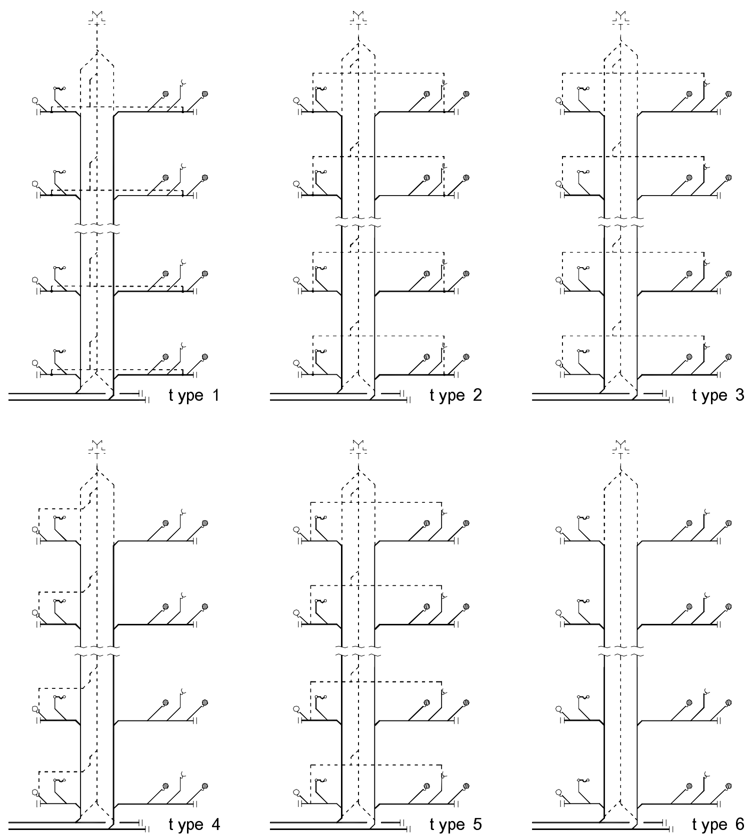


Figure 9 Categories of partial detail drainage loop vent construction

In Taiwan, building with reinforce concrete is the most popular construction. Figure 10 and Figure 11 show a typical partial detail of drainage plumbing construction. The most piping works are under the floor construction and involve into another authority space. Although it is habitually accepted in Taiwan, maintenance problems always happened in this unreasonable custom. It is obvious that stricter regulation needs to be conducted for refine this situation especially for high-rise building.

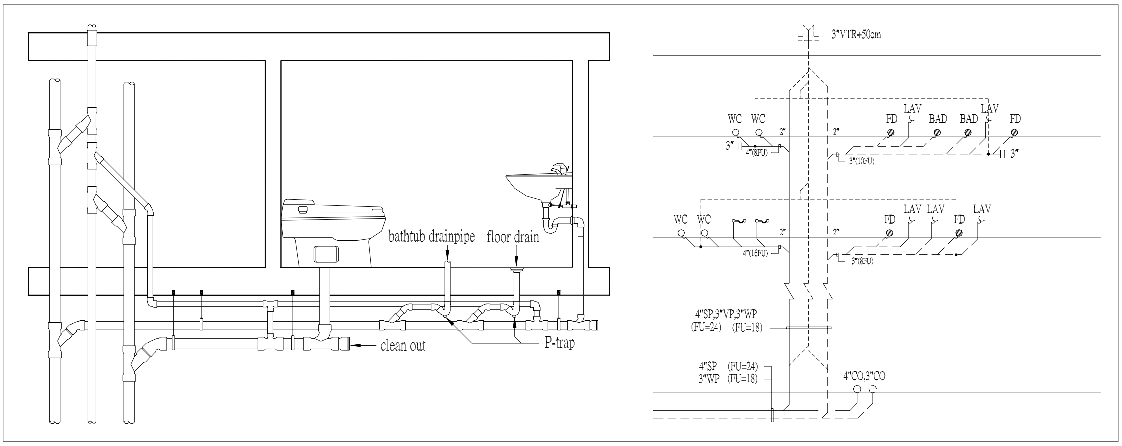


Figure 10 a typical partial detail of drainage plumbing construction

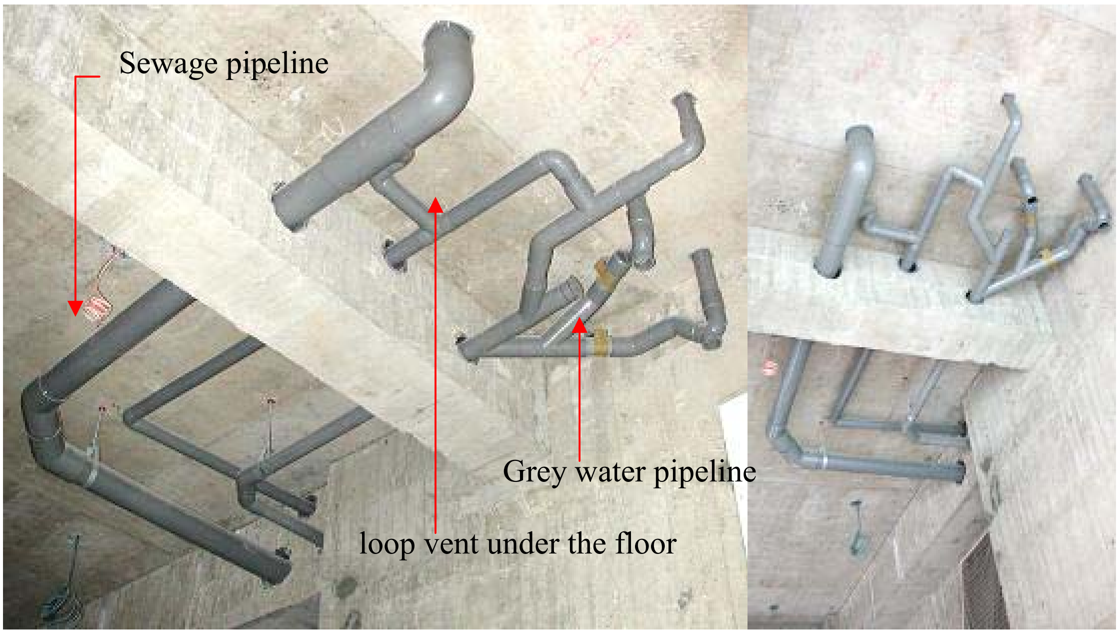


Figure 11 Picture of partial drainage piping work under floor

In order to avoid the air pressure variation and high impact of drainage owing to the height, engineers developed some construction of building drainage system for high-rise building. We categorized the current design cases and concluded them as six types as shown as Figure 12.

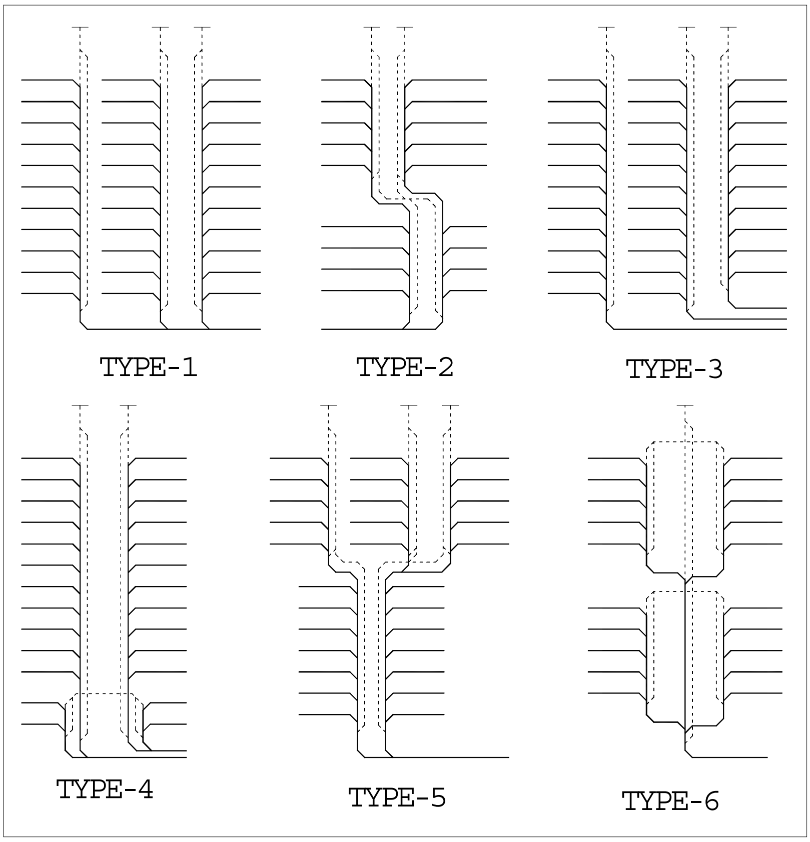


Figure 12 Drainage construction categories for current high-rise buildings

7. Conclusion

Pressure fluctuation control in vertical drainage stacks has been identified as important to insure sanitary drainage performance in early empirical studies. Chaotic plumbing and over-design are common in utility services within building envelopes from domestic investigations in Taiwan. The main purpose of the research is to find the solution of drainage issues in high-rise building through the observation and basic study of stack fluid mechanism. We investigated the existing high-rise buildings and summarize the design methodology from our previous researches. Through the observations and reviews, this paper concludes the current design of building drainage system from existing drainage constructions. Owing to insufficient guideline for building drainage vent construction, the current design is mostly not under regulation. This situation might cause problems in building drainage system. It is obvious that stricter regulation needs to be conducted for refine this situation especially for high-rise building.

ACKNOWLEDGEMENTS

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Main author presentation

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Study of the limit conditions for Single stack and fully-vented systems in Brazilian residential building drainage systems

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Abstract

This work studies the behavior of the pressures existing in the drainage system under Brazilian conditions, in order to determine not only the conditions of use of single stack piping system but also, after verifying the inviability of its use, to determine the necessary conditions in order to use a fully-vented system by means of branch vents and vented stacks or of air-admittance valves.

In order to obtain the ultimate intention, two prototypes of Brazilian drainage systems were tested where not only the pressures in different points of the piping system but also the performance of the water traps of the system were studied.

The tests of the prototypes took into consideration the single stack system and included several arrangements of discharge of fixtures as well as different types of vent system.

Thus, the intention of this study is to subsidy building systems designers with data to better conceive and dimension the vent subsystem as well as to use the air admittance valves instead of the fully vented system.

Keywords:

Drainage system; vent system; fully vented systems; air admission valves;

1 Introduction

The principles used today in Brazil for design of drainage systems have shown in the last years their usefulness, doing the job of efficiently draining the wastes.

At the same time, they disagree with the present reality, as they do not follow the need to rationalize costs of materials, labor and ease of maintenance.

This work is done, comprising a study of a system with only single stack venting in two configurations of Brazilian building usage, in order to define its application limits.

Based on these limits, full venting shall be recommended, first with vent piping (pipes and ventilation stacks), and later with air admittance valves.

Air admittance valves are devices that, under certain circumstances, can not only replace the fully vented (piping) system maintaining its performance level but also reduce the costs of material and labor, as all the piping used on branches and stacks is not needed.

So it is necessary the development of studies in order to obtain parameters related to the behavior of the single stack together with the vent piping system and the air admittance devices, when they are employed in drainage stacks and branches of the building drainage system.

The determination of these parameters will be carried out by means of analysis and comparison of the results obtained by means of tests performed in two sanitary rooms: a residential kitchen and laundry area, with different types of vent system and discharge flow rate of sanitary appliances.

The determination of these parameters will be based upon the needed venting capacity required for the drainage systems, in order that the balance of the pressure inside the piping enables the flushing at atmospheric pressure and consequently to protect the integrity of the trap seals.

2 Experimental studies

According to the intended goal of this work, we shall study the performance of the venting within the drainage system under three different types of venting systems: single stack, fully vented and air admittance devices.

Measurements were made in a drainage system prototype, where the variation of pressures inside the piping was analyzed and consequently the behavior of the trap seals, due to these variations.

The tests were run in full-scale prototypes of drainage systems as used in Brazil, assembled in the Building Systems Laboratory of the Escola Politécnica of the University of São Paulo.

2.1 Assembly of the Experimental Apparatus

The prototypes were installed in the Building Systems Laboratory (eight-story tower each story = 12 m^2)) of the Escola Politécnica of the University of São Paulo.

A typical local assembly was reproduced in the prototype, comprising a kitchen adjoining a laundry room, including the following equipment: kitchen sink, clothes basin, and clothes washing machine.

2.1.1 Characterization of the sanitary fixtures and of the water supply system

Although the basic configuration assembled in the prototype is not the one recommended by the Brazilian Standards, it is the most usual configuration found in buildings in São Paulo.

This basic configuration comprises a stainless steel sink in the kitchen and a chinaware clothes basin in the laundry room, each one connected to its bottle-type trap. To simulate the washing machine, a continuous feeding system, with the characteristic flow of this equipment, was installed.

The three equipments were supplied with running water during a defined time period. Figure 1 shows partially the assembly of the prototype.

Fig. 1 – Detail of water supply system of Prototype 2 – home kitchen and laundry room.

Figure 2 shows the drainage system of the prototype, the piping diameters are presented in the figure.

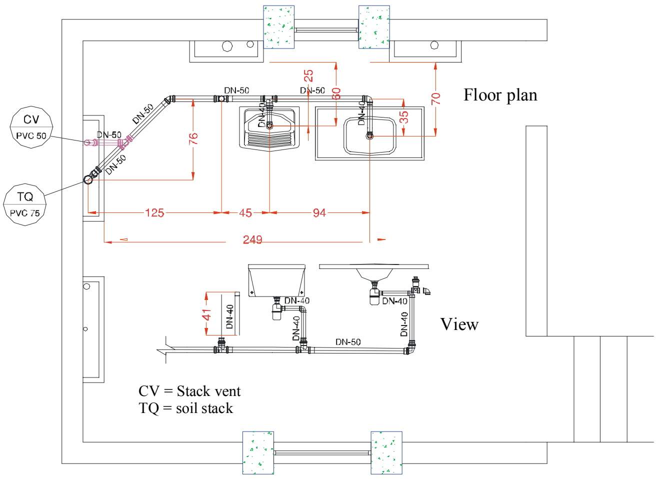

Fig. 2 – Detail of the drainage system of the prototype –kitchen and laundry room.

2.1.2 Description of the measurement points in the prototypes

In order to study the ventilation conditions in the drainage systems, it's necessary to know the behavior of the pressures developed inside the piping. This paper evaluates the pressures at critical points of the drainage system. We also made the measurement of the water seal of the traps to verify the magnitude of the phenomena of self-syphonage, induced syphonage and the occurrence of "back" pressure.

In order to study the behavior of the pressures along the soil stack, the measurement points were placed in the drainage branches, close to the soil stack, according to (MONTENEGRO, (1987), CHENG (1996), and SANTOS (1998)).

Besides the measurement of the pressures near the stack, we also made measurements in each of the horizontal branches which comprise the five standard floors, in order to allow the knowledge of the pressures that occur inside these pipes due to the flow passing through the stack, and those originated from the flow of the fixtures installed in the same floor.

For the prototype, residential kitchen and laundry room the pressure measurement points and the heights of water seals are shown in Tables 1 and 2.

Table 1- Measurement points of trap seal heights

Measurement points of trap seals height	Floor				
	7º	**6º**	**5º**	**4º**	**3º**
kitchen sink trap	FE7	FE6	FE5	FE4	FE3
clothes basin trap	FF7	FF6	FF5	FF4	FF3

Table 2- Pressure measurement points

Pressure measurement points	Floor						
	8º	**7º**	**6º**	**5º**	**4º**	**3º**	**2º**
Stack vent pipe	PH8	-	-	-	-	-	-
Kitchen sink drain	-	PA7		PA5	PA4	PA3	-
Clothes basin drain	-	-	PD6	-	-	-	-
Kitchen sink branch drain	-	-	PB6	PB5		PB3	-
Branch drain near soil stack	-	PC7	PC6	PC5	PC4	PC3	-
Building drain	-	-	-	-	-	-	PF2/PG2

Note: TQ – soil stack.

Figure 3 shows the location of the pressure and trap seal measurement points.

(a) Soil stack entrance (b) laundry basin water seal (c) kitchen sink water seal

Fig. 3 – Trap seals and pressure measurement points

2.4 Description of the fixture discharges arrangements

In order to know the flow rate in the studied drainage system one has to determine number of fixtures discharging simultaneously. This flow, called design flow, is a function of the simultaneity of use and types of fixtures.

2.4.1 Unit flow rate of the fixtures:

- kitchen sink = 0.25 l/s
- clothes basin = 0.25 l/s

- washing machine = 0.30 l/s

2.4.2 Discharge arrangements for the configurations;

Table 3 Discharge arrangements

Sanitary fixtures	Discharge combination			
	Da	Dc	Df	Continuous
Continuous discharge at the eighth floor				
WC at seventh floor				
WC at sixth floor				
WC at fifth floor				
Floor drain trap at seventh floor				
Floor drain trap at sixth floor				
Floor drain trap at fifth floor				

Based on table 3 and with the unit flow rates of the fixtures, the design flows used were the following:

- Da – 1.90 L/s;
- Dc – 1.35 L/s;
- Df – 0.80 L/s e
- Continuous – 6 L/s /s

The continuous flow of 6 l/s was discharged directly in the eighth floor soil stack, measured with a rotameter.

2.5. Characterization of the prototype ventilation system

With the basic configuration, three types of ventilation systems were analyzed, in order to enable a comparison between using traditional ventilation by means of branches and stacks and ventilation by means of air admission valves, which were:

Type 1a (T1a)

The drainage system is a fully vented system, with vent pipe (stack and branches). The branch vent was placed in the branch drain after the washing machine, as shown in Fig. 4

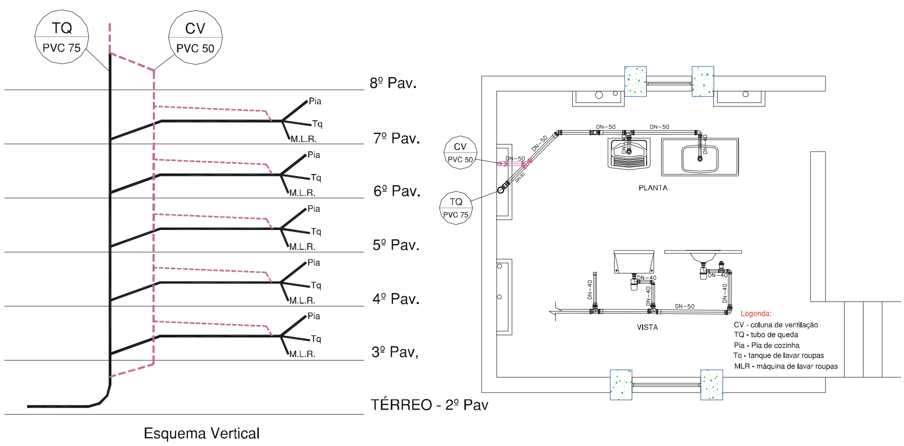

Fig. 4 – Vertical and floor plan of prototype Type 1a

Type 3 (T3)

The drainage system is a single stack system, as shown in Fig. 5.

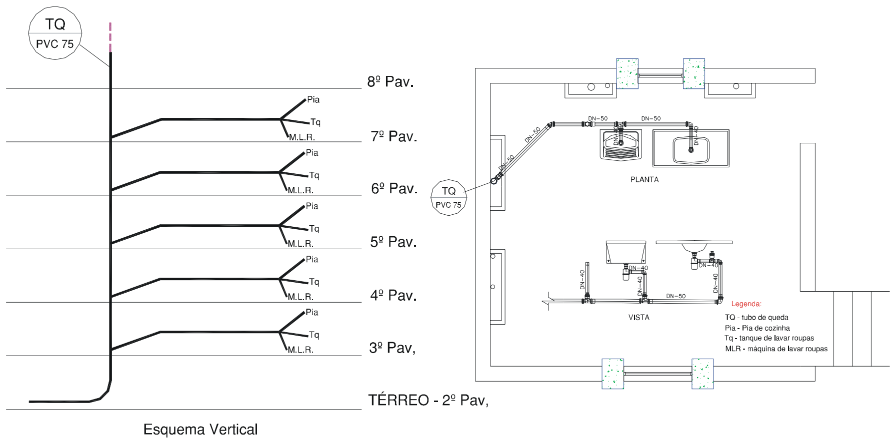

Fig. 5 – Vertical view and floor plan of prototype Type 3

Type 5 (T5)

Air admission valves are used in the ventilation subsystem. The air admittance valve was placed in the fixture drain, after the washing machine, as shown in Fig.6.

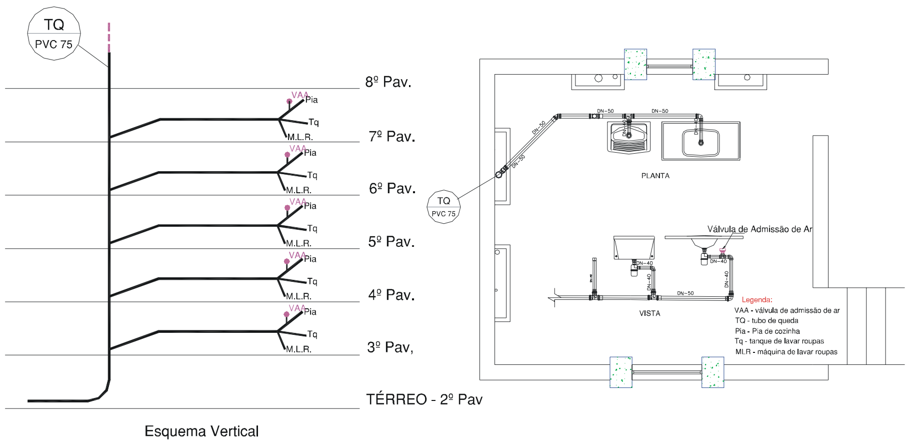

Fig. 6 – Vertical view and floor plan of prototype Type 5.

4. Final Considerations

This section organizes and shows the utilization limits of the single stack and fully vented systems, based on the results obtained in this study.

A comparison table between the values of maximum negative pressures of the soil stack calculated and measured for single stack.

In the model proposed by GRAÇA (1985) it is the determination of maximum negative pressure in the soil stack that evaluates the eventual need of secondary ventilation (vent pipes or air admittance valves).

The maximum negative pressure values which depend upon the air flow inside the soil stack were obtained using the formulae proposed by GRAÇA, LILLYWHITE, WISE and CHAKRABARTI, all detailed in SANTOS (1998).

The negative pressure values measured in the prototypes tests, and those "adjusted" values resulting from the use of uncertainty analysis (SANTOS (1998)), (correction of ± 1.66 m.c.a.) are presented in Table 4.

Table 4 shows the values of maximum negative pressure in the stack, calculated and measured, using only primary ventilation.

Table 4 – Maximum values of measured and calculated negative pressure (Dmax) in the 75 mm stack, for the residential kitchen and laundry prototype.

Discharge flow rates (L/s)	**Dmax Calculated -1 (mm.c.a)**	**Dmax Calculated – 2 (mm.c.a)**	**Dmax Calculated – 3 (mm.c.a)**	**Dmax measured (mm.c.a)**	**Dmax adjusted (mm.c.a)**
0,80	-7,23	-4,12	-3,22	-3,16	-4,82
1,35	-18,51	-10,30	-8,27	-3,86	-5,52
1,90	-33,72	-18,36	-15,11	-4,16	-5,82
6,00	-31,59	-14,84	-14,71	-31,98	-30,32

Note: Dmax Calculated 1 – values calculated with the formulation proposed by GRAÇA;
Dmax Calculated 2 – values calculated with the formulation proposed by LILLYWHITE, WISE;
Dmax Calculated 3 – values calculated with the formulation proposed by CHAKRABARTI;
Dmax measured – values measured in the tests;
Dmax adj – values measured in the tests, corrected with the use of uncertainty analysis.

Table 5 shows the limits to use each type of vent systems in the home kitchen and laundry prototype, for a soil stack of 75mm of diameter.

This table was organized using the method proposed by CHAKRABARTI apud SANTOS (1998) for the calculation of maximum negative pressures of the soil stack. The maximum number of floors was obtained by means of the use of the method proposed by GRAÇA (1985).to determine the simultaneous use of sanitary fixtures.

Table 5 – Limits to use each type of vent systems in residential kitchen and laundry rooms.

D_{max} (mm.c.a.)	Recommended vent system			Nº of floors
				31
				30
				29
-115,06				28
				27
				26
-99,29			T1a	25
				24
				23
-84,38				22
		T5		21
				20
				19
-70,37				18
				17
				16
-57,32				15
				14
				13
-45,31				12
-28,44				11
				...
-14,55	T3			5
				4
-8,05				3
				2
-2,24				1

D_{max}	Maximum negative pressure
T5	Air admission valve
T1a	Fully vented system
T3	Single stack system

Based on the table shown above, it is possible to determine the utilization limits of single stack systems and also choose the type of vent system, where single stack system does not fulfill the needs for the maximum negative pressures in the stack.

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The interaction of solids in above ground near horizontal drainage pipes

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Abstract

Waste solids in building drainage systems may still be considered as discrete, subject to a system of forces including hydrostatic, mass, buoyancy and frictional components. Recent water conservation proposals, including legislation, have led to the reduction in the quantities of water available to transport waste into the sewer, and have had a major impact on the hydraulics associated with the transportation of discrete solids in near horizontal drains in buildings. The need for predictive techniques in this area has never been greater.

Previous research on solid transport in building drainage systems has allowed the development of time dependent numerical analysis models capable of describing the unsteady flow conditions when solids are present within a network, using the method of characteristics in a finite difference scheme. This research builds upon a model included in the computer program 'Drainet' which predicts the transport of single, or multiple non-interacting solids, based on boundary conditions relating the velocity of a discrete solid to the velocity of the surrounding water had a solid not been present.

The development of a novel technique to include the effects of the presence of solids within a method of characteristics model is introduced and validated to show solid to solid interaction and the transportation of solids in the deposition region. Overall the paper confirms the application of the St.Venant equations of continuity and momentum to the simulation of solid transport in building drainage.

Keywords

Building Drainage, Solid transport, mathematical modelling, method of characteristics.

Notation

c_n	Wave speed of flow at normal depth	h_{ds}	Water depth immediately downstream of solid
c_{ds}	Wave speed of water immediately downstream of solid	h_{us}	Water depth immediately upstream of solid
		h_i	Flow depth at node i
c_{us}	Wave speed of water immediately upstream of solid	M_S	Mach Number of solid
		Q_W	Flow rate of water
		S	Friction slope
dH_S	Lengthwise water depth difference across a solid	S_o	Pipe slope
		t	Time in free surface flow equations
g	Acceleration due to gravity	V, V_f	Mean flow velocity
		Vs	Solid velocity

1. Introduction

The deposition of solids in a near horizontal drainage pipe network is a measure of the effectiveness of its design and a strong indicator of its ultimate aim; to move waste material away from habitable spaces to a place of treatment. Due to the close proximity to the point of entry to the system, models dealing with above ground drainage systems must consider solids as discrete, as opposed to models of sewer systems where initial breakdown of the organic matter has occurred leading to consideration of suspended, rather than discrete solids.

This proximity to the point of entry to the system and the means by which this entry takes place has been the subject of much research over the past 30 years. [1],[2],[3] . Discharge of waste solids into a drainage system is due to discharge from a wc which produces a surge wave, discharging the solid into the drainline. The inclusion of the surge in this scenario requires a modelling technique capable of predicting the attenuation of a surge wave along a pipe. The method most suited to this, and described in this paper, is the solution of the St.Venant equations of momentum and continuity in a finite difference scheme through the method of characteristics. Physical attributes of the system, such as entry and exit conditions, pipe junctions, slope defects and obstructions [4] are easily catered for by the inclusion of empirical boundary equations which describe their effect on the water. The method of characteristics is very effective at predicting the attenuation of waves along a pipe, but it has not been shown to easily include a moving boundary condition suitable for the description of solid objects moving through the system at a velocity differing from that of the water.

This paper proposes a technique for including a boundary equation for a moving solid object through a single pipe utilising the method of characteristics.

2 Method of characteristics applied to free surface partially filled pipes

The water flows within building drainage systems have been defined as belonging to a class of unsteady flow conditions fully described by the St Venant equations of continuity and momentum [1]. It has been shown by Lister [5] that this family of equations can be solved by the method of characteristics in a finite difference scheme.

The St Venant equations may be represented by two first order finite difference equations, known respectively as C^+ and C^- characteristics linking known conditions at time t to conditions at P at one time step in the future.

With reference to Figure 1 it may be seen that;

$$\frac{dV}{dt} \pm \frac{g}{c}\frac{dh}{dt} + g(S - S_o) = 0 \qquad 1$$

provided that the calculation time step conforms to the Courant criterion, defined as

$$\frac{dx}{dt} = V \pm c \qquad 2$$

where the wave propagation speed c is defined as $c=(gA/T)^{0.5}$, S and S_o are the friction and pipe slopes respectively, and A and T are the flow cross sectional area and the surface width. The form of equation 1 requires a small base flow in the pipe in order that the calculations can commence.

From Figure 1 it can also be seen that only one characteristic is available at system entry or exit. Thus it is necessary to define boundary equations that may be solved with the appropriate C^+ and C^- characteristic at these nodes. Previous research in this area [2] has yielded boundary equations for many conditions including;

- W.c. discharge
- Pipe junctions
- Displaced upstream hydraulic jumps
- Flow at the base of a vertical stack.

The grid used to represent the progress of a calculation in the method of characteristics scheme of the type most relevant to the partially filled pipe, unsteady flow regimes experienced in building drainage systems is also shown in Figure 1. This is a specified grid system in that the nodal distances along the x axis are pre-defined while the time step may vary depending on the flow conditions and subject to the courant criterion outlined above.

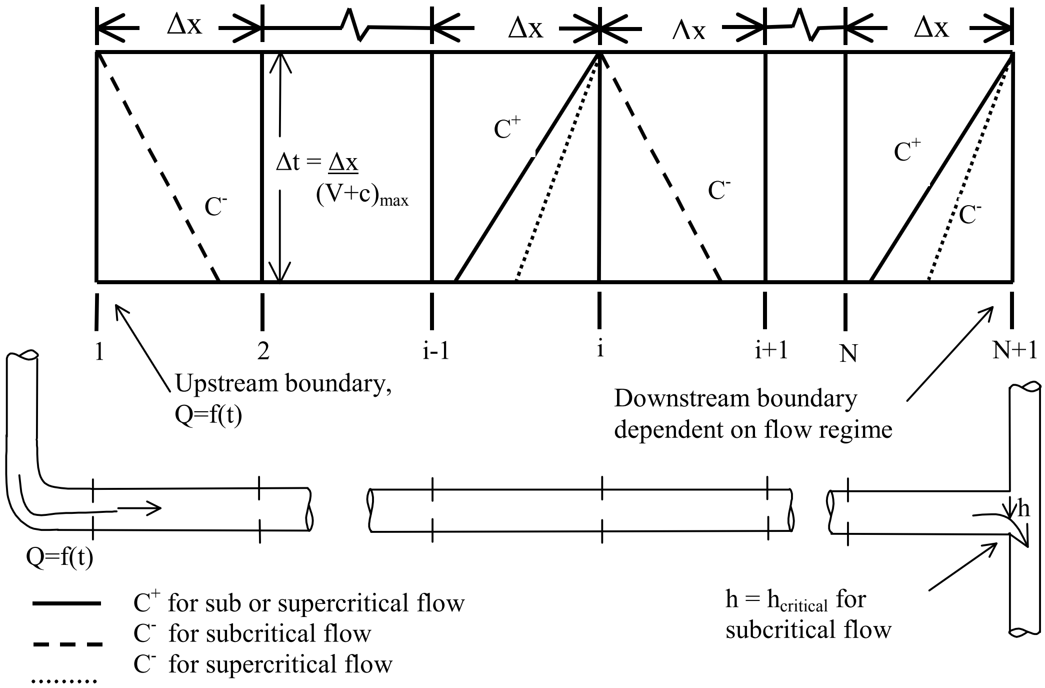

Figure 1 **Application of specified time interval grid to partially filled pipe flow with known entry and exit boundary equations**

3 Solid boundary condition

3.1 Characteristics of a moving solid in water.

The transport of a solid in a near horizontal drainage pipe under steady flow conditions is characterised by a number of significant changes in the flow depth profile along the pipe, as shown in Figure 4.1. The water height behind the solid reduces gradually to a point where the water depth is normal for the particular flow regime due to the inflow and the water immediately in front of the solid is below normal water depth and increases downstream. This bow wave is due to the effects of water tumbling over the solid at a higher than normal velocity, as shown in Figure 2.

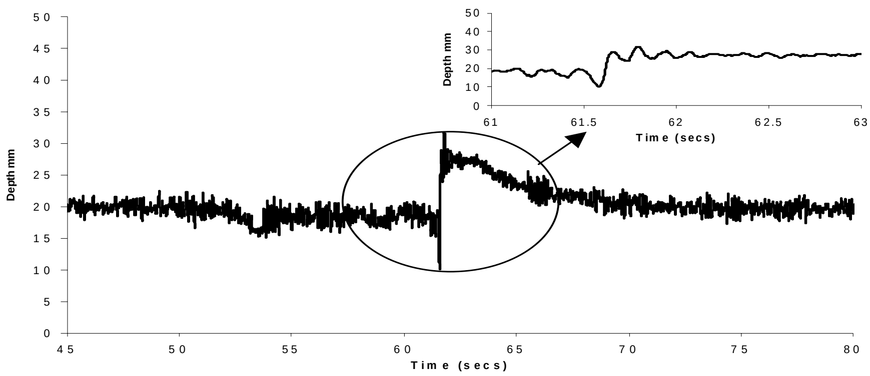

Figure 2 Water depth difference across a solid

3.2 Solid velocity measurement

Velocity measurement of a solid is not straightforward. At the outset of this project the available technology was found lacking. Velocity measurement techniques used in industrial applications rely on the uniform movement of the object to be measured, and small distances between the object and the pickup device. For solids travelling in partially filled pipes under unsteady flow conditions the situation could not be more different.

Systems used in the past by the Drainage Research Group at Heriot-Watt University and others earlier [4] relied on the solid breaking a visible light beam. When the beam is broken a signal is registered and a time logged. There are several problems with this approach;

- The system uses visible light so it is prone to false triggering from surrounding light sources (sunlight, artificial light)
- The movement of a solid through the water creates waves which cause reflections and can 'confuse' the system [7]
- Because solids in motion are subject to movement anomalies (see below) it is possible for the system to completely miss a solid.
- The system is not capable of detecting solids at the extremes of the flow rate range – i.e flow rates less than 0.8l/s and flow rates above 4l/s (in some cases less)

Previous data gathered on solid velocities [4],[6] have been shown to be accurate, however the limitation of the range of flow rates, particularly at the lower flows, and the time taken to achieve the results suggested that an improvement was required. The low flow rate data is of particular interest in this research as it is in this region that interaction is likely to occur.

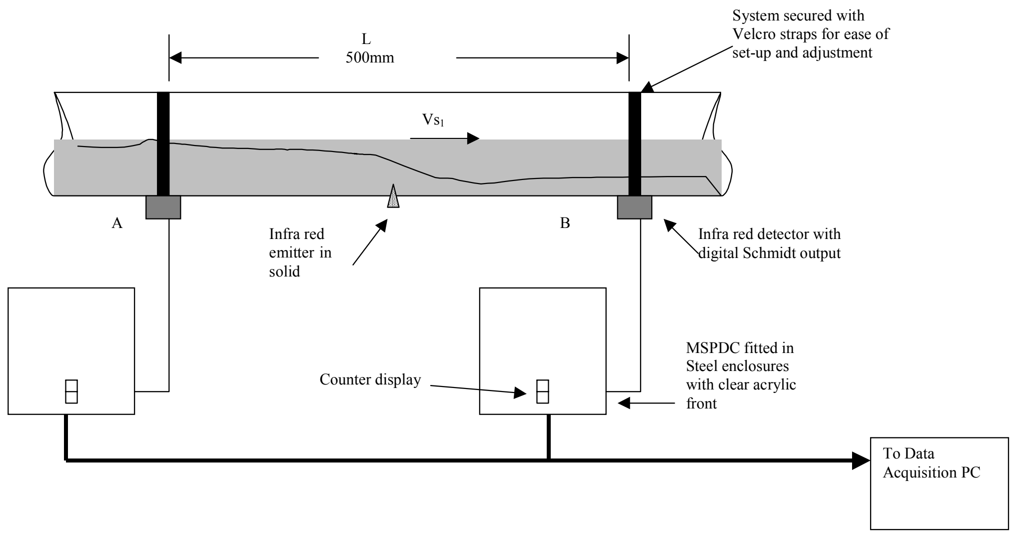

Figure 3 Solid velocity measurement

3.3 Solid movement anomalies.

Assuming the solid in question to be a rectangular cylinder in plan, the object is subject to three main movement anomalies as it travels in a flow;

- Pitch: The solid pitches from front to back
- Roll: The solid rolls
- Yaw: The solid swings from side to side

The difficulty arises in how to ensure that the method of pickup used can cope with these differing distances between object and pickup and angle of approach.

3.4 The multiple solid position detection system

In response to the problems encountered with repeatability of solid velocity measurements in the past, the Multiple Solid Position Detection System (MSPDS) was developed. The system uses an active solid fitted with an infra-red emitter. As a solid passes a pre-defined location along a pipe length an infra-red detector is activated and produces a digital pulse. This pulse advances a counter giving an indication that detection has occurred, it also shows how many solids have passed that location in the case of multiple solids. The detection card then channels the output pulses from the detector so that all outputs for the first solid are input to the computer via channel 1 and all for the second solid are input to solid two….and so on. The output of data onto different channels effectively identifies each solid and makes future processing in a spread sheet easier. The system has the added advantage of requiring only the same number of channels as solids (typically 1 to 4), rather than the number of detectors (typically 28 to 40). The arrangement is shown in Figure 3.

The enhanced resolution of the system provides the opportunity to look at solid transport in general and the interaction of solids in particular. Figure 4 shows a trace of the interaction of solids in a 100mm pipe. Solid 1 is allowed to enter the pipe on a small baseflow of 0.4l/s, enough to sustain movement. When solid 1 has passed 2m, solid 2 is entered. When solid 2 reaches 1m a surge is initiated up to 1.8l/s. Solid 2 accelerates until it enters the backwater of solid 1 where it decelerates until both solids are swept away by the surge. It can be seen from Figure 4 that the developed measuring system is capable of recording this interaction, which occurs over a relatively short time and distance.

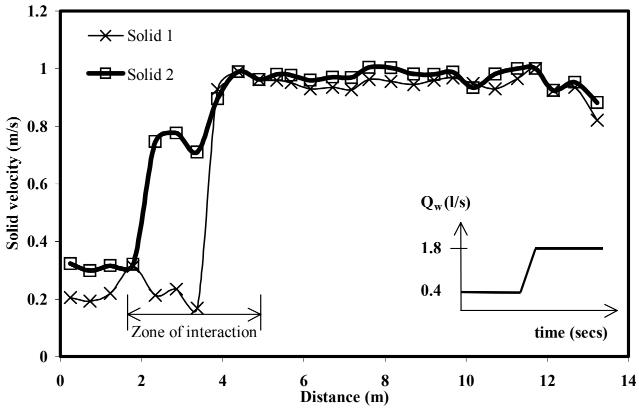

Figure 4 Interacting solids

3.5 Solid boundary condition

The presence of the solid in a flow requires a simple modification to the water depth profile at the solid's location along the pipe at a given time. The water depth is therefore given by

$$h_i = h_i + dH_S \qquad 3$$

Where h_i is the water depth at node i if no solid is present and the flow can be either supercritical or subcritical, and dH_S is the water depth difference across the solid which is a function of the velocity of the solid, V_S such that;

$$dH_S = f(V_S) \qquad 4$$

A gradually varied profile can then be fitted between the solid boundary and the upstream location where the flow depth returns to h_i . It should be noted that the boundary condition given by equation 3 is valid for a solid at one location only or for the special case where a solid has deposited.

4 Mathematical modelling of solid transport

4.1 Existing model

The most significant existing model in terms of its usability and accuracy is due to McDougall [2]. This model was initially developed to describe the effects of pipe slope defects on solid transport, however some inconsistencies were highlighted in existing models leading to the development of a more robust model [4]. McDougall's model is based on the relationship between the flow velocity (V_f) and the velocity of the solid (V_s) . This relationship between (V_f) and (V_s) is capable of tracking the velocity of a solid under many flow conditions, the velocity of the solid decreasing with decreasing flow velocity and *vice versa* . This method works well, however it has deficiencies, the presence of the solid does not modify the surrounding water conditions, the solid does not exist within the flow represented in the model, it is in effect a virtual solid. The consequences of this in terms of describing the interaction of solids is quite significant. If the water conditions are not modified to account for the presence of a solid then the modification of the velocities of approaching solids would need to be described in a way that covers a very wide range of interaction scenarios. However McDougall's model exists and fills a gap in simulation capability.

4.2 A mathematical model based on dH_S

The classification of the movement of a solid in a flow based on the water depth difference across the solid presents a simple means of defining solid velocity in steady supercritical flows. The model however needs to be able to cope with solid transport in a variety of flow regimes. The following describes a general mathematical model for the transport of solids in all flow regimes where a water depth difference exists. While the classification is for water depth difference across the solid it was found that a more robust model was obtained when the water depth was classified in terms of the wave speed of the flow at that depth. This leads to the general classification of solid transport in terms of the Mach Number of the solid thus;

$$M_s = \frac{V_s}{c_n} \qquad 5$$

The water depth difference dH_S is related to V_s in that dH_S is at its maximum when $V_s = 0$, and dH_S is at its minimum when $Vs \rightarrow V_{s(max)} \rightarrow V_f$. In keeping with the general classification of water depth in terms of wave speed then the following can also be said of the solid ;

when $Vs \rightarrow 0$

$$\frac{c_{us}}{c_{ds}} \rightarrow \frac{c_{us}}{c_{ds}}\max$$

and when $Vs \rightarrow V_{s(max))} \rightarrow V_f$

$$\frac{c_{us}}{c_{ds}} \rightarrow 1$$

where c_{us} is the wave speed at the upstream face of the solid
and c_{ds} is the wave speed at the downstream face of the solid

The 'positive' curve shown in Figure 5 shows the relationship between c_{us}/c_{ds} for a single solid of diameter 36mm, specific gravity 1.05 in a 100mm pipe set to a slope of 1 in 100. The trendline shown represents the possible acceleration or deceleration of a solid when $c_{us}/c_{ds} \geq 1$, that is when there is a water depth difference across the solid and the solid is not fully buoyant. The data for this curve was obtained under normal supercritical conditions, therefore $c_{ds} \approx c_n$, in practice there is likely to be a depth depression downstream of the solid so it is usual for the following expression to be true;

$$c_{ds} \leq c_n \qquad 6$$

where c_n is the wave speed of the flow at normal depth.

So the positive curve in Figure 5 is applicable when the condition in equation 6 is met. In the case where a solid is travelling in a flow where the flow is not supercritical then the inverse curve can be used. In this case the following condition applies;

$$c_{ds} \le c_n \qquad 7$$

This equation will cause a solid to decelerate as it enters deeper slow moving water such as the backwater of another solid.

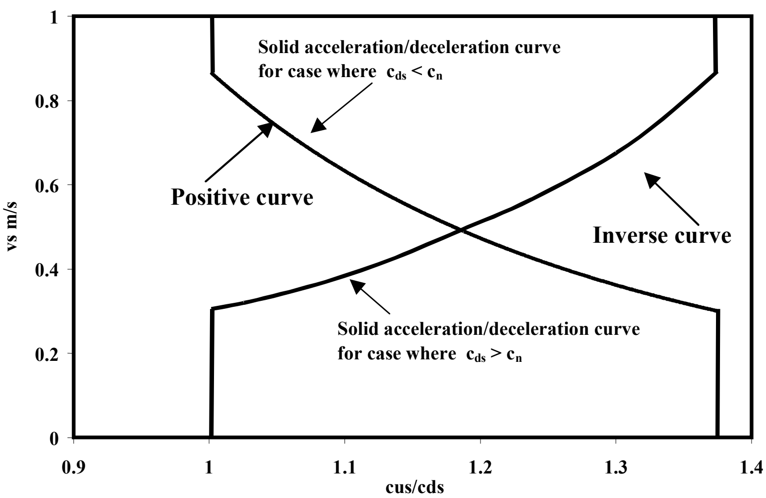

Figure 5 General form of the model

5 Results

The measure of success for this method of modelling solid transport in drain pipes can be described as follows;

i. A water depth difference across a solid can be made to move along a pipe at a velocity dependent upon the characteristics of the solid.
ii. The velocity of a solid is modified as it enters the backwater of another solid
iii. The water depth difference of a solid varies as its velocity varies
iv. A single solid will deposit when the water conditions dictate in the pipe however the stationary solid will allow a water buildup behind it instigating movement again, this process can repeat, nudging the solid further than predicted by velocity decrement models.
v. The distance between solids varies as they travel along a pipe subject to an attenuating wave in a push pull fashion until deposition finally occurs.

Figure 6 shows a water depth history along a pipe when a solid is present. The flow is steady and the water depth associated with the presence of the solid is seen to move across the nodes.

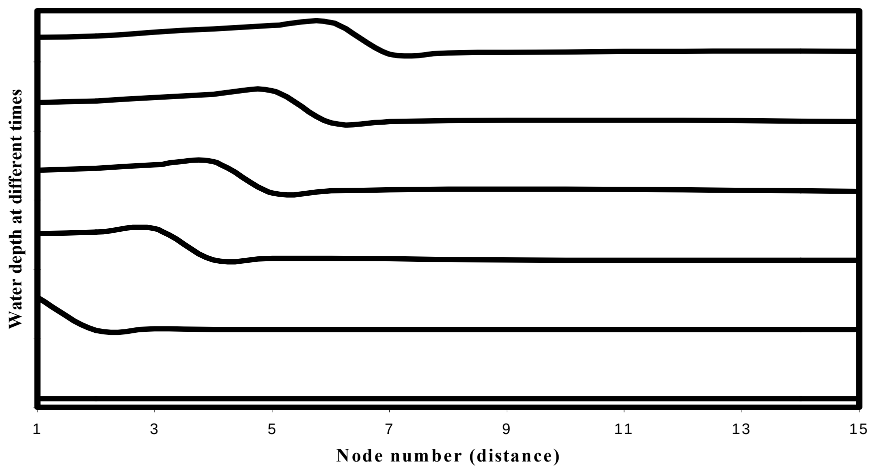

Figure 6 Water depth history along pipe showing dH_S

Figure 7 shows the modification of solid velocity as a solid moves into the backwater of another solid. Figure 7 also shows the model's ability to modify the water depth difference across the solid as the solid velocity varies.At the start of the test run when the solids are travelling in a steady flow both solids have a steady dH_S . The acceleration of solid 2 due to the arrival of the surge causes dH_S for solid 2 to decrease. Solid 2 decelerates as it moves into the backwater of solid 1 and as a consequence, dH_S increases again until the two solids have moved close together. At this point both solids follow a similar solid velocity down the pipe and the value of dH_S settles down to a common level. It is interesting to note though that even in this relatively steady flow there is still a push pull element to the travel, particularly for solid 2 as it travels in and out of the backwater of solid 1.

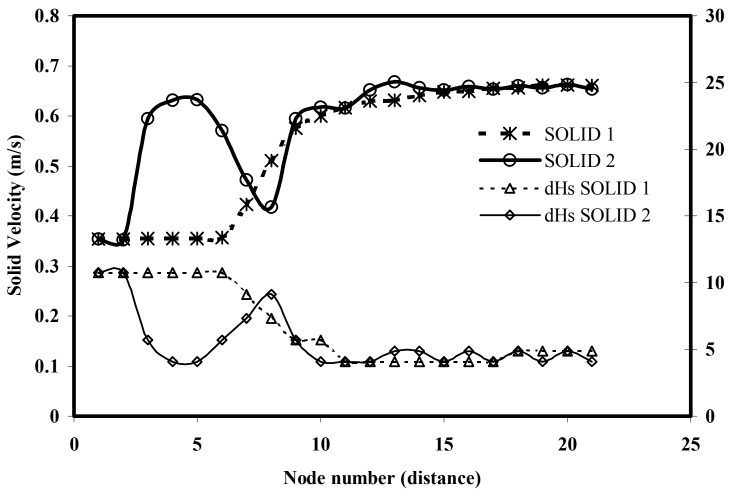

Figure 7 Variation in dH_S with V_S when solids interact

Figure 8 shows a predicted velocity profile for a solid subject to the inflow profile that is also shown. The solid velocity decreases with the attenuating wave as it travels along the pipe. When the velocity of the solid falls below 0.2m/s, there is a levelling off and an eventual deposition. This levelling off represents transport in zone 3 as defined by Wakelin [7] and is the velocity measured between nodes. The solid is seen to deposit and start moving again due to the water build up behind it. This process repeats until a final deposition occurs.

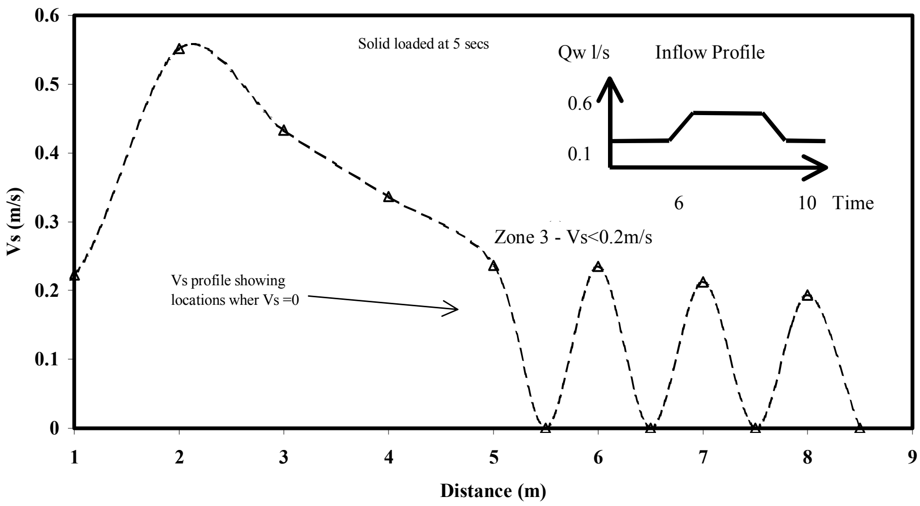

Figure 8 Solid deposition showing stop/start motion

The case for the deposition of multiple solids is similar however the effects of their interactions are also significant. Figure 9 shows the variation in the distance between solids as they move along a pipe. Solid 1 is input at 1 second and solid 2 is input at 5 seconds. The solids are subjected to a surge wave as shown on the inflow profile on Figure 9. Solid 2 is affected by the wave first, moving it closer to solid 1. The effects of the proximity to solid 2 and the arrival of the surge wave pushes solid 1 forward, moving the solids further apart. As the wave abates both solids approach each other again interacting in a push - pull fashion until the wave and the effects of interaction abate and the solids deposit.

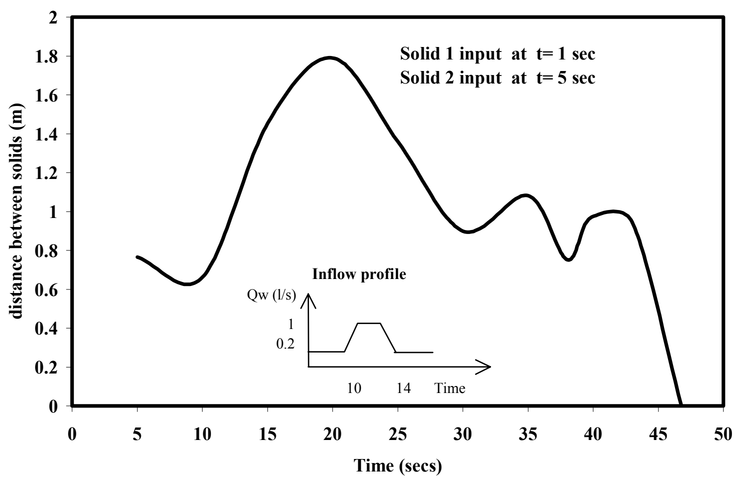

Figure 9 Variation in distance between solids as they travel along pipe.

6. Conclusions

The model developed has been shown to accurately predict the motion of multiple solids in near horizontal building drainage systems. Existing models deal well with the calculation of solid velocities based on the surrounding water conditions but do not modify them, this seriously limits the flexibility of the system in that equation are required for every scenario the solid encounters. The method described in this paper provides a more robust deterministic approach, where depth profiles are modified from which other variables can be calculated. The model has been shown to effectively predict the interaction between the velocity of the solid and the upstream water depth in a variety of scenarios, including interaction between solids.

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Investigation of water installation system in a group of Ottoman Baths

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Abstract

Ottoman baths (hamams) were social institutions that provided the population with communal bathing facilities. Apart from their creative architectural characteristics they included ingenious water installation systems which provided bathing facilities with running water in accordance to Islamic cleanliness rules. It is thought that the technical aspects of these social institutions might be determined through the remaining traces emerging from surveys that will be conducted. The documentation and identification of water installation systems which represent the historical sanitary installation are important as they are in danger of disappearing. The aim of this study is the documentation of the characteristics of water installation systems in a group of baths which represent the Ottoman period cultural inheritance in small settlements of Western Turkey. The water installation system was arranged with a supply of water being brought to the reservoir (water tank) which is a spatial component of the bath, distribution of water to various spaces of the bath and carrying waste water outside.

Keywords

Ottoman baths; water installation; cultural heritage.

1 Introduction

Turkish baths (hamams) are one of the significant building types of the Seljuk and Ottoman periods in Anatolia. During the Ottoman period, except for the main cities baths, a large number were constructed in smaller settlements. Traditional Turkish baths have separate sections for women and men, or have different visiting times or days for women and men. Against the plain and unpretentious appearance of their exterior walls, the Ottoman baths have a dynamic expression with their superstructure consisting of vaults and domes in different numbers and sizes for the general composition of the mass (Figure 1).

Figure 1 - General view of the Düzce Bath

They have plan schemas consisting of row of spaces which are disrobing area (soyunmalik), the warm area (iliklik) and hot area (sicaklik) besides the furnace (külhan) and the water reservoir. Transition elements to the superstructure and their domes and vaults which are pierced by oculi create plastic effects in their spatial perception. Apart from these architectural characteristics, they have cleverly planned water installation systems for their functional requirements. The aim of this study is the documentation and identification of authentic water installation systems in a group of Ottoman baths which have historical and cultural values from the point of the history of building technology in Urla, Seferihisar and their villages near İzmir in Western Anatolia. The studied baths are Double Bath (Çifte Hamam or Hersekzade Ahmet Pasha Hamamı) and Rüstem Pasha Bath in the center of Urla, Kamanlı Bath (Yahsi Bey Bath) in Kamanlı neighborhood of Urla, Özbek Bath in Özbek village of Urla, Great Bath (Büyük Hamam) and Small Bath (Küçük Hamam) in the center of Seferihisar, Citadel Bath (Kaleici Hamamı) in Sigacik neighborhood of Seferihisar, Ulamıs Bath in Ulamıs village of Seferihisar and Düzce (Hereke) Bath in Hereke village of Seferihisar. They are out of use and abandoned because of changes in the life style. According to their architectural features they can be dated to the 15th and 16th centuries. The method of the study is the documentation of the water installation systems in the baths through field surveys and the evaluation of the obtained information. Field studies are based on sketches, measured surveys and photographic documentation.

2 Analysis of water installation system

In the studied baths, the water installation system can be divided into three sections which are supply of water from a water source to reservoir, distribution of water to various spaces from the reservoir and carrying waste water outside. Supply of water, brought into the reservoir and distribution of water to various spaces of the bath constitute the clean water system while discharge of waste water constitutes the waste water system. Reservoir, pipes, basins, waste water channels and toilet are the essential elements which compose the water system (Figure 2).

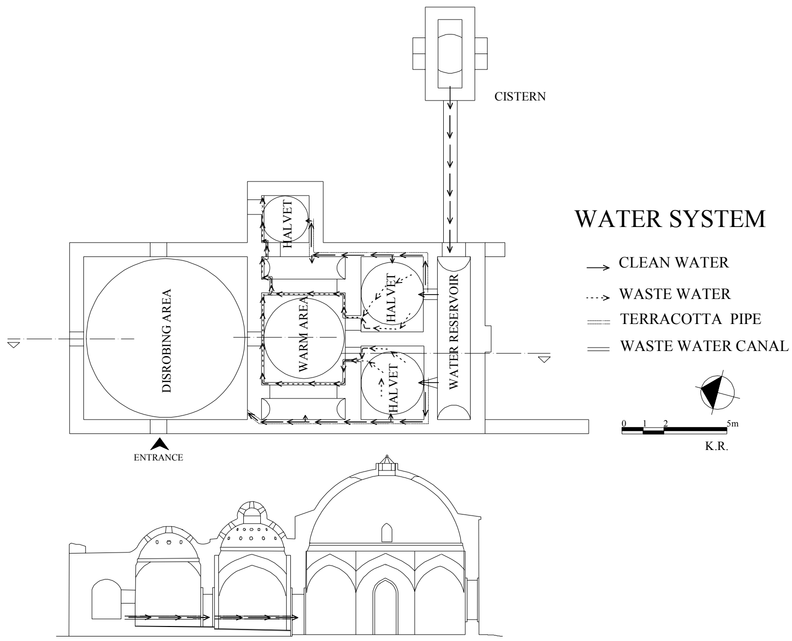

Figure 2 - Düzce (Hereke) Bath, analysis of the water system

2.1 Clean water system

In the studied baths, the needed clean water is supplied from natural water sources like stream, brook, river or well and cistern (Figure 3). In the water system of Turkish baths, it is known that the clean water brought to the bath spaces passing through a distribution section was a stone trough called “maslak” or “maksem”. “Maslak” was usually in the form of a perforated stone coffer which was placed in a niche in the height of a person in the wall of the reservoir. The water which was supplied to the “maslak” has been transmitted to the reservoir through one of the holes at the bottom of the “maslak” and through another hole to the fountain in the disrobing area and warm area [1, 2]. However, this type of arrangement has not been determined in the studied baths. If the reservoir was arranged as two sections for cold and hot water; the cold water was collected in the reservoir, then it was distributed by terracotta pipes to the appropriate spaces (Figure 4). However, if the reservoir was arranged as one section the distribution of cold water was provided directly by terracotta pipes to the spaces. The clean water system which was arranged for hot and cold water exhibits differences. When terracotta pipes which have been placed along the walls are in one line, only the hot water system, if there are two lines, the cold and hot water systems were arranged. In Urla Double Bath, Kamanlı Bath, Düzce Bath and Ulamış Bath, terracotta pipes are placed in two lines for cold and hot water, while in Seferihisar Great and Small Baths, Sıgacık Kaleiçi Bath and Özbek Bath; pipes are placed in one line for only hot water. In Rüstem Pasha Bath, the original water system has not been determined due to the floor level filled with earth.

Figure 3 - Düzce Bath, the cistern and water channel

Figure 4 - Urla Kamanlı Bath, the terracotta water pipes

2.1.1 Cold Water System

This system was analyzed under two headings as distribution of cold water to the bathing spaces collecting in a separate section of the reservoir or distribution of it by terracotta pipes placed along the walls without collecting in the reservoir.

Distribution of cold water collecting in the separate section in the reservoir: After collection of clean water, which is brought to the bath, in the separate section arranged for cold water in the reservoir, sufficient quantity is transmitted to the hot water section, and a quantity is distributed to the bathing spaces by terracotta pipes. This arrangement was illustrated in Urla Double Bath.

Distribution of cold water, which is drawn from the well or cistern at the outside, directly to the bathing spaces without collecting in the reservoir: Clean water was brought to the reservoir from the cistern or well either by stone channels or terracotta pipes at the upper level of the reservoir. In this arrangement, cold water supplies of both the reservoir and is directly transmitted to the taps running in the basins at the bathing spaces and to the fountain in the disrobing area. Ulamış, Düzce, Kamanlı Baths illustrate this arrangement. The traces of terracotta pipes in the southwest corner of the disrobing area in Düzce Bath, and in the east part of the floor level in Kamanlı Bath point out the fountain which supplied water. In the east wall of the warm area in Kamanlı Bath, there is an opening in a rectangular profile which is in the dimensions of 20 cm. in width and 60 cm. in height and the traces of terracotta pipes are seen inside. It may be thought that this opening was arranged for a distribution element which was in the form of perforated stone trough that is generally arranged on the wall of the reservoir.

2.1.2 Hot Water System

Distribution of hot water is done directly from the hot water section of the reservoir. It is sent to the taps running in the basins through terracotta pipes in the walls. When terracotta pipes are placed in one line, the clean water is distributed as hot water.

Hot water section of the reservoir is right above the furnace (külhan) which is located below the regular floor level. The fire in the furnace, which is the heat generating space, heats the water with a concave copper boiler.

2.2 Waste water system

The open channels arranged on the floors of the hot and warm areas for waste water, taking it outside from the warm area or toilet constitute the waste water system. The discharge of waste water from the private rooms of the hot area is provided by inclined floors towards their entrances, from the main space of the hot area and warm area is provided by open waste water channels arranged on their floors (Figure 5). Open waste water channels are arranged along the walls and the bottom edges of stone seats by placing cut stone floor coverings above masonry walls which constitute hypocaust (cehennemlik) to form a stepped channel. Waste water channels are approximately 10-12 cm. in width, 7-8 cm. in depth (Figure 6). Waste water coming from private rooms, pass into the open channels arranged along the bottom edges of the stone seats in the main space of the hot area. They become a single channel in the entrance of the warm area and then either in the toilet in the warm area or from the corner of the one wall outside. In Ulamış Bath, Seferihisar Small Bath, Sıgacık Kaleiçi Bath and Özbek Bath, waste water coming from private rooms was separately transmitted to the channels lying along the bottom edges of the stone seats in the main space of the hot area and sent outside from the corner of one wall. In Düzce Bath, waste water coming from the southern private rooms was transmitted to the channels in the main space of the hot area and discharged from the northeast corner of the third private room outside. In Seferihisar Great Bath, waste water coming from private rooms transmitted to the channels arranged along the bottom edges of the stone seats and then it was conducted to the single channel in the warm area and in the end the toilet (Figure 7). In Double

Bath and Kamanlı Bath, waste water coming from private rooms was channeled through the channels in the main space of the hot area and was carried from the corner of one wall of the warm area outside.

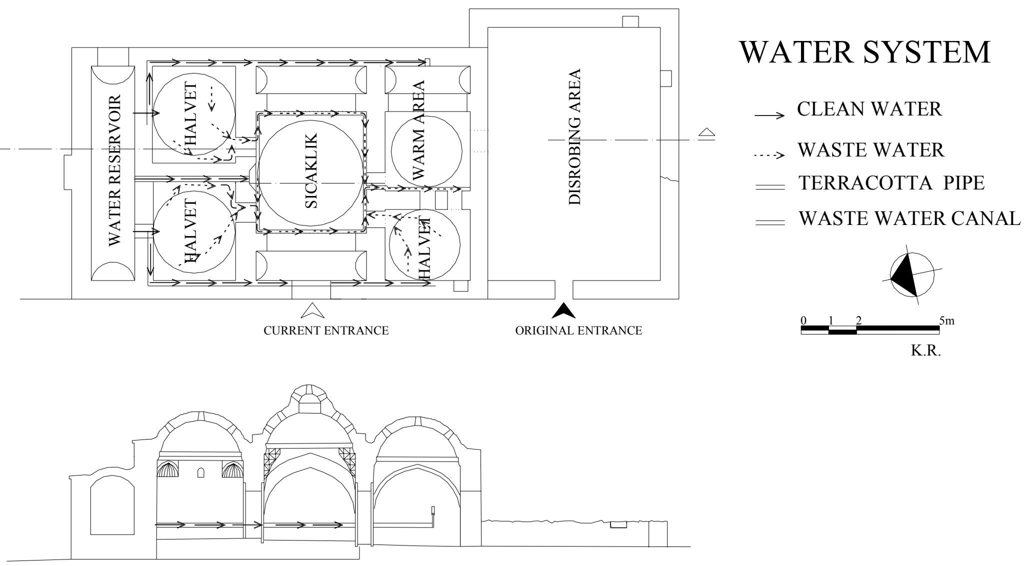

Figure 5 - Urla Kamanlı Bath, analysis of the water system

Figure 6 - Urla Özbek Bath, waste water channel in the warm area

Figure 7 - Seferihisar Great Bath, the toilet in the warm area

2.3 The elements constitute the water system

The water reservoir, terracotta pipes and basins are the elements of the clean water system, waste water channels and toilet outlets are elements of the waste water system. The clean water system is the distribution of the water through terracotta pipes placed in the walls, from the reservoir to the bathing spaces and sending it to the taps running in the basins (kurna). The reservoir was located adjacent to the hot area after the sequence of bath spaces which are the disrobing area, warm area and hot area. It was arranged as two sections for cold and hot water or one section for only hot water. The rectangular planned reservoir is covered with a barrel vault. It is in similar construction technique and material of the walls and superstructure of the bath. The floor and interior walls of the reservoir are covered with horasan plaster and the thickness of it is 3 - 4 cm. to the water level.

Beneath the reservoir, there is a furnace (külhan) that heats the water and bath. In this part, there is an arched opening in the form of a fireplace which opens outside for lighting the fire. Just over the fireplace, in the middle there is a concave copper boiler for heating the water in the reservoir by the fire in the furnace. It is known that copper boilers were continuously maintained due to their poor material durability. Copper boilers have the diameter varying between 90-240 cm. according to the size of the water reservoir. In the studied baths, Özbek Bath is the only one in which the entire copper boiler that has survived up to today (Figure 8). Taps running in the basins of the hot area spaces were connected to the reservoir by terracotta pipes placed along the walls. When they are left open, heated water had been running in the basins without pressure. Amount of water in the reservoir was regularly controlled via the observation window on the wall between the reservoir and the private rooms and water was added when the necessity arose. An arched opening was arranged on the short side of the reservoir where the water entered.

Figure 8 - Urla Özbek Bath, the copper boiler in the water reservoir

Terracotta pipes, which were also called “merbah” or “pöhrenk” [2], were made of baked clay and were placed along the walls to provide distribution of cold and hot water from the reservoir to the hot area. They are in the cylindrical form and one end is larger than the other to be connected to each other. One end is approximately 10.5 cm. the other is 12.5 cm. in diameter, 1.5 cm. in thickness and 37.5 cm. in length (Figure 9). They were embedded with a waterproof mortar called “lökün” along the walls [2]. These pipes in the walls are arranged in one or two lines for cold and hot water according to the necessity or the size of the bath. They were divided into two lines from the wall of the reservoir and placed along the internal surfaces of the walls.

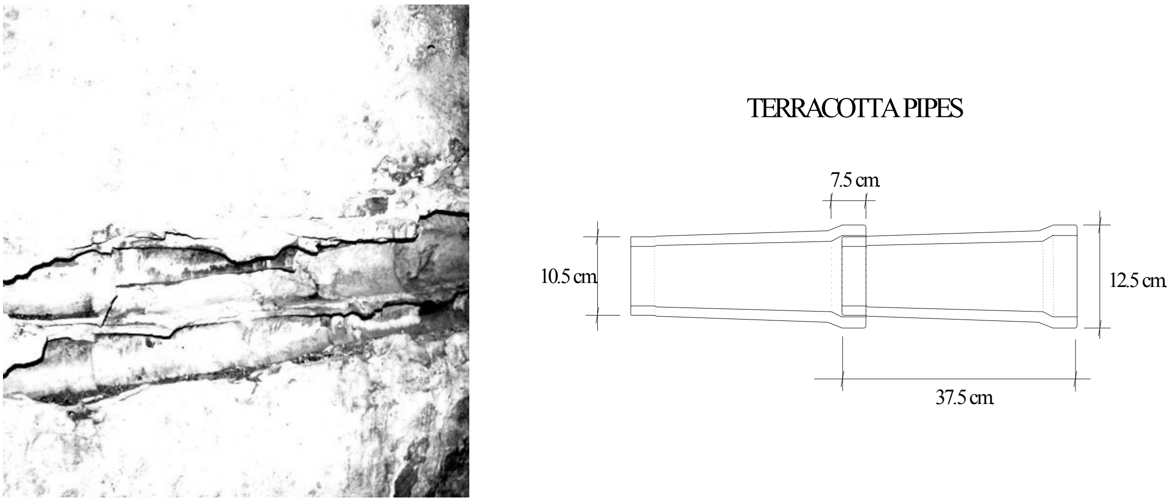

Figure 9 - Urla Kamanlı Bath, terracotta pipes in two rows in the northwest halvet

Most of the basins belonging to the clean water system, which were placed on the floors of the spaces of hot water, were made of stone. However, in the women's section of Urla Double Bath and Seferihisar Small Bath, some basins were made of reused material (Figure 10). Basins are in the circular, semicircular, semi octagonal or semi decagonal form. In the west private room of Seferihisar Small Bath and in the women's section of Urla Double Bath, the basins have geometrical or muqarnas decorations. Stone seats on each side of the basins were arranged rising approximately 20 cm. from the floor level using brick material and covered with cut stone. Muqarnas decorations were arranged along the upper edge of the stone seat in front of the east wall of the west private room in Seferihisar Küçük Bath. On the walls above the basins tap panels were placed and outlets for taps were fitted on the panels (Figure 11).

Figure 10 - Urla Double Bath, reused marble basin in the main hot area of women's section

Figure 11 - Urla Double Bath, tap panel in the main hot area of men's section

One can either bath himself by sitting on the stone seat near the basin and filling it with hot water, then dipping the “tas” which is a bowl, traditionally of copper or brass having grooves and ornamentation, and pouring it over himself, or he may request the attendant to scrub him with a “kese” which is normally a coarse mitt made of natural fibers. This process results in deep skin cleaning and a feeling of refreshment after the bath.

3 Conclusions

In the Ottoman period, every neighborhood contained a bath. The bath was a part of community life. In contrast to the Roman and Byzantine baths where bathing was in the pools, in Ottoman baths bathing was performed by sitting on the stone seat near the basin and pouring water. In this study, the water installation system in a group of Ottoman baths in small settlements of Western Turkey was investigated from the point of planning and construction techniques. The studied bath buildings were built near a water source like a stream or a well that was built near the baths. Water was drawn to reservoirs through cisterns or channels. The reservoir was generally a rectangular vaulted space which had a window opening to the hot area of the bath to control the level of water. The clean water system was the distribution of the water through terracotta pipes placed in the walls, from the reservoir to the bathing spaces and sending it to the taps running in the basins. Terracotta pipes are in the cylindrical form and one end is larger than the other to be connected to each other. The waste water system is the discharge of waste water from bathing spaces through the channels arranged on the floors. Waste water channels coming from each bathing space, lying along the bottom edges of the stone seats, become a single channel in the entrance of the warm area and then end in the toilet in the warm area or from the corner of one wall outside.

The importance of this study is clarifying the water installation system of Ottoman baths which depend on the tradition of bathing with running water even in the baths in small settlements that were ingeniously solved.

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5 Presentations of Authors

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Identification of potential contamination routes and associated prediction of cross flows in building drainage and ventilation systems

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Abstract

The main role of the sanitary appliance trap seal is one of provision of physical separation between the habitable space and the foul odour present within the drainage network, and system design has traditionally focussed on the protection of this seal from pressure excursions generated as a result of appliance discharge. Ventilation is typically provided via a roof level stack termination and can be supplemented by either a connected vent stack or by mechanical devices capable of providing local relief for both negative and positive transients. However once installed, the maintenance of individual components, particularly appliance trap seals, can often be overlooked, thereby changing the dynamic response of the system, and jeopardising network integrity.

Using the Method of Characteristics approach to modelling the propagation of low amplitude air pressure transients generated as a result of appliance discharge, this paper will show how system operation can be simulated, thereby providing information on entrained airflow, pressure and trap seal retention. The paper will also demonstrate how changes in the dynamic response of the system that arise either as a function of normal operation or due to an external driver, may result in the introduction of routes for transferral of network gases between spaces, thereby highlighting the link between system design and the provision of and adherence to general maintenance programmes. Furthermore, the paper will show that the research underpinning this work can be used to corroborate the suspected cross contamination route for SARS identified at the Amoy Gardens apartments in Hong Kong.

KEYWORDS

Pressure transient, vent system, modelling, cross contamination

1. Introduction

The earliest formal piped drainage systems were developed around the 1880s and had the aim of removing waste from the building whilst protecting the habitable space from the ingress of foul odour. Although this fundamental objective remains unchanged today, drainage networks have, since the beginning of the 20th century, been progressively simplified where the driver for change has tended to be cost reduction through pipe and/or space economy. A brief examination of the historical development of building drainage clearly demonstrates a significant reduction in the use of pipework as the design of networks progressed from the heavily ventilated two-pipe system of the late 19th century through to the introduction of the single stack system – a design developed following extensive research undertaken at the BRE[1] and now commonly used in the UK and Europe up to heights of around 60m.

Globally, there are a wide range of network and system designs implemented in accordance with local regulations, guidelines, knowledge and experience. Despite the many differences exhibited however, failure of these systems may be commonly characterised, in terms of trap seal retention, as the ingress of foul odour from the drain or sewer to the habitable space – an incident that despite being unpleasant has, generally, not been associated with any real risk to health. However, the SARS epidemic of 2003 that resulted in over 800 fatalities, 42 of which occurred following a 'community' outbreak in Amoy Gardens, Kowloon, Hong Kong where transmission was facilitated by the building drainage system, has resulted in a re-examination of design, specification and installation practices, particularly when analysed within the context of associated maintenance programmes.

It should not be forgotten however that the issues of water conservation and sustainability remain. In addition, as buildings become progressively more complex whilst in many cases the physical space available for ventilation provision is reduced, the requirement for a means of analysing the performance of systems under changing design, operation and maintenance scenarios becomes clear. This approach however, requires a fundamental understanding of the way in which pressure levels within a network vary as a result of appliance discharge and normal system operation, and how resultant pressure transients interact with system boundaries to provide local time-dependent information that ultimately determines the degree of protection offered by retention of the trap seal. Inherent within this is the requirement for recognition of the conceptual difference between sustained pressure levels and transient events. In addition, there is often an assumption that the provision, or 'overprovision' of ventilation will negate any detrimental pressure effects, whereas, in many cases, ventilation pipework can be of limited benefit, particularly when the point of pressure relief – normally the pipe termination at roof level – is distinctly remote from the point of generation of the transient.

This paper will present the basic principles supporting the operation of building drainage and ventilation systems, and will show how the appropriate descriptive equations are amenable to numerical solution via the finite difference Method of Characteristics technique. The fundamental research underpinning the simulation model AIRNET will be discussed, as will recent findings related to the generation and impact of positive air pressure transients – this will include simulation model output that corroborates the postulated route of transmission in the Amoy Gardens case.

2. Building Drainage Ventilation

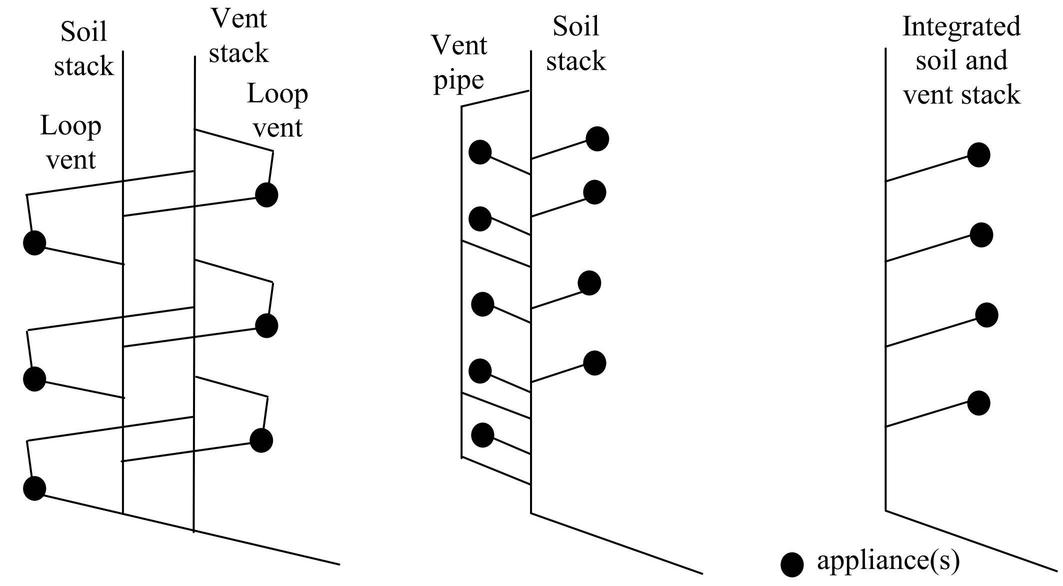
2.1 Basic Principles

As appliances discharge into the vertical stack, an annular column of water is formed that due to the condition of no-slip entrains an airflow from the upper stack termination that, in turn, induces system pressure changes dependent upon height and local flow conditions. These changes may be represented by the well-established pressure response for drainage systems that comprises dry stack frictional losses, local losses across active ie discharging junctions, and pressure regain to atmospheric in the 'wet' section as air moves through the water curtain formed at the base of the stack.

Depending on the building occupancy, the number of connected appliances, and the associated discharge flow profile and probability of use of each fixture, it can be seen that the overall system will continuously be subject to changing flow conditions. As the flow rate in the vertical stack increases there will be a corresponding increase in the entrained air flow rate that generates the transmission of negative air pressure transients. Conversely, any stoppage of this entrained airflow, typically intermittent and of short duration, will result in the generation of positive transients. These pressure transients - that seldom exceed 100mm water gauge and are therefore described as 'low amplitude' - propagate throughout the building drainage system at the appropriate acoustic velocity (ie wave speed) and are subject to attenuation, amplification and reflection as determined by the particular and unique design of each network.

2.2 Ventilation Solutions

Internationally, there is good recognition within building standards and regulations of the potential impact of air pressure transients - positive and negative, and in conjunction with efficient removal of waste, the main aim of recommended design solutions is to negate any potentially detrimental pressure excursions. A brief resume of ventilation solutions yields three current fundamental designs, shown in Figure 1. Figure 1a shows the 'one-pipe' system where appliances are each connected via a 'loop vent pipe' to a dedicated ventilation stack – a design used extensively in the USA. Figure 1b shows the 'modified one pipe system', where a dedicated ventilation stack is provided however this has no direct link to appliances and instead cross-connects to the main soil stack – a design approach that is common in the UK and Europe for buildings greater than around 60m in height. Figure 1c shows the single stack system, suitable for buildings of height less than 60m and where one downpipe provides a fully integrated soil and ventilation stack.



(1a) One Pipe System **(1b) Modified One Pipe System** **(1c) Single Stack System**

The single stack system, having been used successfully for more than 40 years, clearly presents an economical and efficient design solution. However, the positioning and/or grouping of appliances can nonetheless result in the generation of air pressure transients with the potential to threaten the integrity of the appliance trap seal. Use of the single stack system therefore requires careful specification of pipe dimensions. Occasionally however, the physical constraints imposed by the building structure make such specification difficult and it is this that has prompted the introduction of devices specifically designed to alleviate local pressure differentials, for example, Air Admittance Valves (designed to relive negative pressure) and Positive Air Pressure Attenuators, as shown in Figure 2[2].

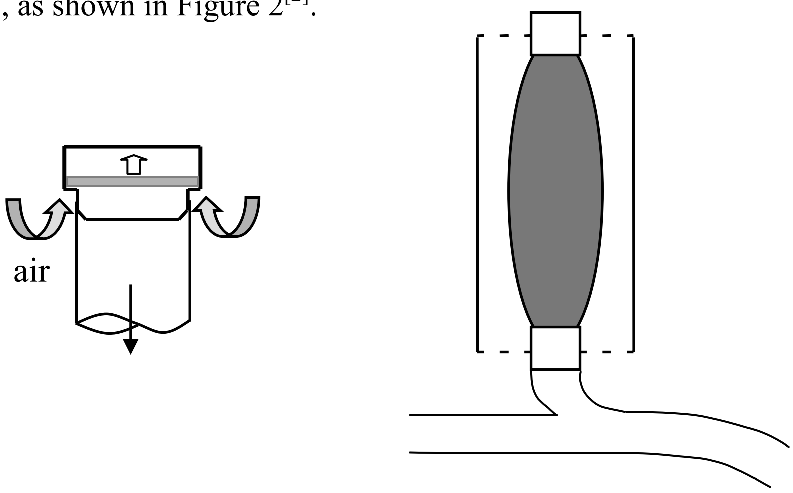


Figure 2 Air Admittance Valve and Positive Air Pressure Attenuator

Bearing in mind the fluid flow conditions prevalent within the network, and the interaction of air pressure transients with the system boundaries as determined by the pipework arrangement, careful positioning of such devices is hence required to ensure that the provision of pressure relief is introduced between the point of generation and the specific appliance location that requires protection.

3. System Design and Operation

3.1 Network Pressure Regime & Potential for Cross Contamination

The well-established pressure response for drainage systems, referred to in section 2.1, that comprises dry stack frictional losses, local losses across active, and pressure regain to atmospheric in the 'wet' section is based upon the fundamental assumption that air enters the system via the upper stack termination and exits to the main sewer pipework via the water curtain formed at the base of the stack as the flow detaches from the upper pipe invert. It should be recognised however that the resultant prevailing negative pressure generated within the network means that air may be drawn from a range of locations, as illustrated by Figure 3a. This shows that although much of the air entrainment will be facilitated by the upper stack termination, air (in the form of bubbles) may also be drawn through the discharging appliance or through a remote trap seal.

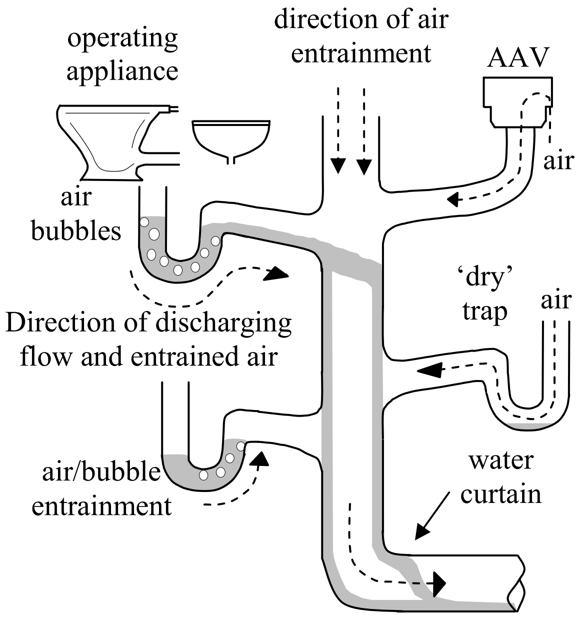


Figure 3 Airflow direction under negative pressure

Additionally, air may be drawn through an inwards pressure relief device, such as an air admittance valve or waterless trap, or through a trap that has dried out due to lack of use and/or high temperatures within the space served, or poor maintenance.

However, it is know that the flow conditions within the system give rise to positive transients that are typically generated at the base of the stack and that then propagate throughout the network. The intermittent nature of the formation

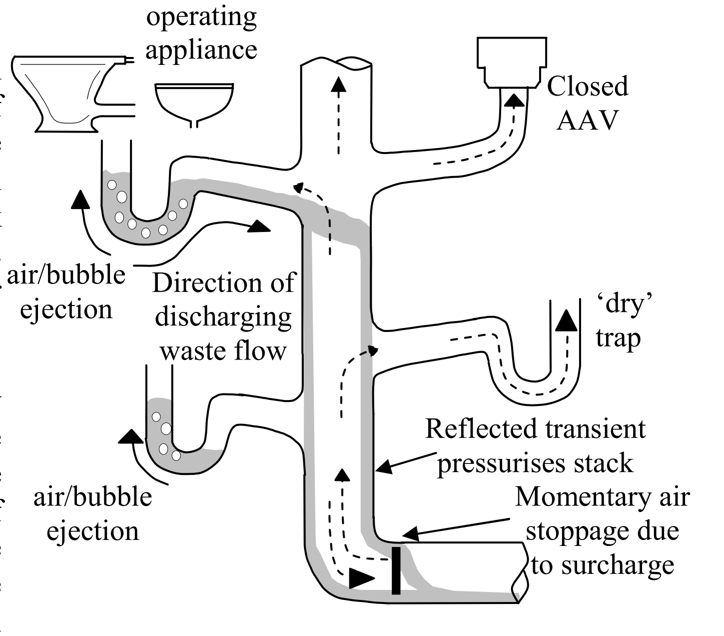


Figure 3b Airflow movement during surcharge event

of this curtain means that the duration of airflow cessation will be short however, the magnitude of the resultant transient, as determined primarily by the velocity of air stopped, may still be sufficient to compromise the integrity of the connected trap seals. This is particularly true if the water level is already depleted.

Additionally, it has been shown through laboratory experimentation that air movement from the network to the habitable space may be facilitated by bubble ejection – an effect that, post event, may not be detectable. Figure 3b illustrates these routes, as well as that facilitated by the 'dry' trap.

3.2 Conditions for Cross Contamination

Network flow conditions required to introduce the potential for cross contamination are dependent upon several factors, the most important of which is the generation of positive pressure. As discussed above, this pressure may arise due to the formation of the water curtain at the base of the stack that temporarily halts the flow of entrained air thereby creating a positive air pressure *transient*. Alternatively, conditions downstream ie in the sewer connection pipe may be such that waste and water flows combine to give a surcharge condition that can vary significantly in terms of duration, and hence may result in the generation of either a *transient* or a *sustained positive pressure*. Evidence from site investigations undertaken by the authors indicates that, as a result of normal operation, positive air pressure transients reaching a magnitude of around 110mm water gauge may be generated – clearly sufficient to jeopardise trap seal integrity. Additionally, anecdotal evidence also suggests, in some systems, a not infrequent occurrence of sustained positive pressures that affect, generally, appliances connected nearer the lower section of the vertical stack.

It is important to note that the prevention of cross contamination will not necessarily be facilitated by the introduction of additional ventilation pipework. Because of the way in which transient waveforms propagate, systems demonstrating a higher level of ventilation provision will inevitably result, generally, in lower line pressures. In each design discussed in section 2 however, the point of pressure relief is the upper stack termination. This means that dependent upon the point of generation of the transient, the subsequent time delay for pressure relief will be determined by the distance between the source location and this above roof line pipe termination. In addition, the natural propagation of the transient means that all branch connections encountered en route will be subject to corresponding pressure variations.

Depletion of a trap seal such that free air movement is facilitated clearly introduces a location of vulnerability, and thus highlights the importance of a rigorous maintenance programme. However, it should also be remembered that traps can facilitate bubble ejection and hence post event, may provide no evidence of cross contamination.

It is generally assumed that ingress of foul odour to the habitable space may be, at worst, described as unpleasant. However, following the SARS outbreak in 2003, and the subsequent link made between transmission of the virus and failure of the building drainage system, serious concerns have now arisen regarding the possibility of transmission of airborne viruses or indeed any contaminant that may demonstrate a potential risk to health. Clearly the only requirements of transmission in this regard are that the contaminant must be able to be aerosolised and that a route is presented by the drainage system.

4. Simulation of Air Pressure Transients

It has previously been shown that the unsteady flow conditions present within the drainage network may be modelled using the Method of Characteristics technique applied to the solution of the relevant equations of continuity and momentum[3]. For the case of low amplitude air pressure transient propagation, these equations are cast in terms of wave speed and fluid velocity and yield a pair of quasi-linear hyperbolic differential equations amenable to finite difference solution via equations that link conditions at a node one time step in the future to current conditions at adjacent upstream and downstream nodes[4].

With only one characteristic equation defined at each boundary, this technique therefore requires the definition of a further equation linking airflow conditions to applied water flow or other system parameters. These may be either passive or active, where examples of passive boundary conditions are pipe junctions or closed pipe ends, and examples of active boundary conditions include operating air admittance valves or water curtains formed at branch junctions. Once these equations have been defined, the mathematical simulation is enabled provided that the relationships linking applied water flow rate and entrained air flowrate have been specified. These must also encompass the definition of any changes induced within this relationship due to differing pipe diameter, roughness or length. Previous and ongoing research at Heriot-Watt has facilitated the development of the AIRNET model that allows the simulation of the propagation of air pressure transients within the building drainage ventilation system, and that is based upon the methods and techniques outlined above.

5. Developments in Modelling Positive Air pressure Transients

A review of literature on the study of the generation and propagation of air pressure transients in building drainage ventilation systems reveals a focus, up until around 2001, on negative transients[5,6]. Around this time, a general recognition of the lack of understanding in the area of positive transients resulted in subsequent research activity that has helped identify the mode of generation of positive pressure transients[6,7]. Inherent within the modelling approach adopted forthwith are the relationships developed by Jack[6] that facilitates use of a pseudo friction factor term, operable across the water-to-air boundary, and that readily allows the simulation of combined discharge flows and associated pressure regain within the system where appropriate.

In assessing the contribution of the water curtain formed at the base of the stack to the generation of positive air pressure transients, previous work has demonstrated how the shape of this curtain varies significantly, despite the imposition of steady downflow in the vertical stack[7]. A change in shape results in a change in the representative loss coefficient that in turn determines the impediment to the movement of entrained air.

Clearly when this coverage reaches a maximum, positive transients will be generated that propagate throughout the system and interact with other fluid flows and network junctions. Initial research[7] indicated that this 'shape categorisation' would be determined by water downflow and stack configuration ie pipe diameter, roughness and radius of curvature, and highlighted the requirement for a closer examination of digital images of the water curtain. This was achieved using a high speed digital camera, yielding images at 250Hz. Subsequent electronic analysis of these images then permitted the generation of statistical data demonstrating, for example, area coverage (absolute, maximum and minimum), percentage coverage and frequency of 'complete coverage'. Figure 4 shows a comparison between the 'pre' and 'post processing' image captured using the high speed digital camera, where processing involves the disaggregation of a jpeg camera image into pixels that are then individually allocated a binary logic unit dependent upon whether the pixel comprises either 'water' or 'air'. Incorporated within this approach is object recognition to aid edge detection, and hence enhance the accuracy of shape allocation.

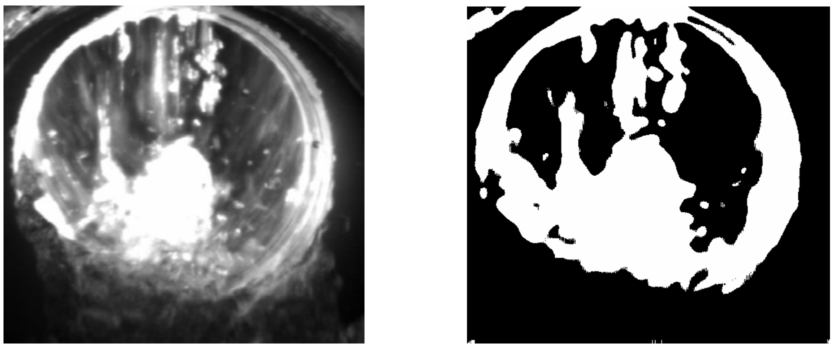


Figure 4 Comparison of Digital Camera Image – Pre and Post Processing

The simultaneous trigger of pressure monitoring equipment connected to the laboratory pipework has also allowed a comparison of post processing images with pressure data.

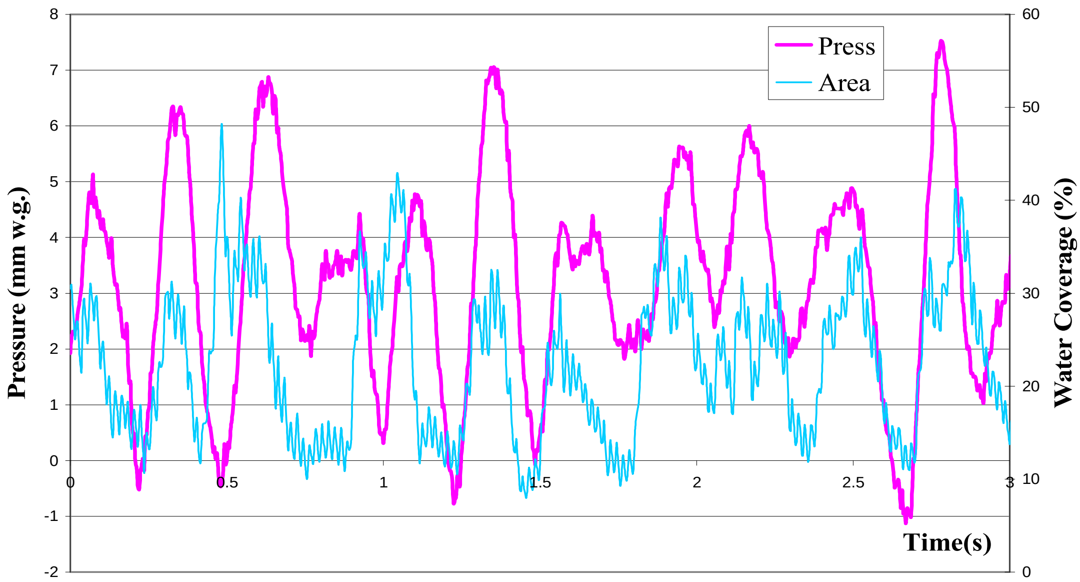


Figure 5 Comparison of stack pressure and % water curtain coverage

Figure 5 demonstrates some early results that present data representing percentage water curtain coverage and pressure recorded approximately 130mm above the pipe invert. This shows a degree of ‘oscillation’ of the water curtain, where the corresponding frequency is approximately 4Hz. Noteworthy, this frequency appears relatively constant regardless of water downflow in the stack. Since a change in water downflow was previously considered to be the main driver for change of any frequency of ‘closure’ of the water curtain, it is envisaged that alterations in, for example, radius of curvature of the bend at the base of the stack, pipe material or pipe diameter will therefore have little effect - suggesting that the frequency of closure, or oscillation, of the water curtain is 4Hz, regardless of flow conditions. This phenomenon arises due to the prevalent flow conditions within the vertical stack and is assumed to be analogous to the development of roll waves in narrow channels and spillways.

6. Case Study – Amoy Gardens, Hong Kong

Early 2003 saw the outbreak of SARS – a viral disease whose transmission was facilitated, in the case of the Amoy Gardens Hong Kong, to a degree by the building drainage and ventilation system. The Amoy Gardens complex comprises 19 housing blocks, each 33 storeys high and with eight ‘units’ (ie residences) per storey. Of the 19 blocks, one in particular (Block E) accounted for 41% of (the 329) Amoy Gardens SARS cases and displayed a prominent vertical distribution – particularly where adjacent ‘units’ were separated by a narrow lightwell. Hong Kong Government investigations attributed this spread to faecal virus shedding resulting in droplet transmission through the drainage system. Re-entry to residents’ apartments was facilitated by dry U-traps where this route was aided by shower cubicle extract fans that discharged to the outdoors lightwell. Virus spread was then enhanced by the natural buoyancy effect in the lightwell and re-entry to apartments facilitated by open windows.

Through development of the AIRNET model, the authors have been able to corroborate the route of transmission discussed above. An abbreviated schematic version of the network is shown in Figure 6, and illustrates the typical bathroom connection pipework serving a w.c., a sink, a shower and facilitating discharge from a floor drain. Both the soil and vent stacks have been specified as 100m diameter, and the ventilation cross connection serving the w.c. only as 50mm. To permit an approximated simulation, detailed specification of pipework has been limited to floors 1, 16 and 33, with the assumption that any recirculation effect on duplicated floors 2 to 15 and 17 to 32 is negligible. Investigations by the Hong Kong Health Department postulated that changes in the typical method of cleansing the bathroom area had resulted in a lack of sufficient replenishment to the floor drain traps, and in each of the three cases shown in figure 6 and for the purposes of simulation, the floor drains have therefore been assumed as fully depleted. To provide a driver for the simulation, two w.c. discharges have been introduced on Floor 16, and based on the assumption that the bathroom fan is activated automatically, a negative pressure introduced on the same level. Both the soil and vent stack pipes terminate at atmospheric conditions, and no cross connection venting was introduced, other than that provided by the w.c. vents. Finally, a sewer surcharge was simulated during the second w.c. discharge in order to provide comparative data on the potential for airflow from the sewer connection pipework.

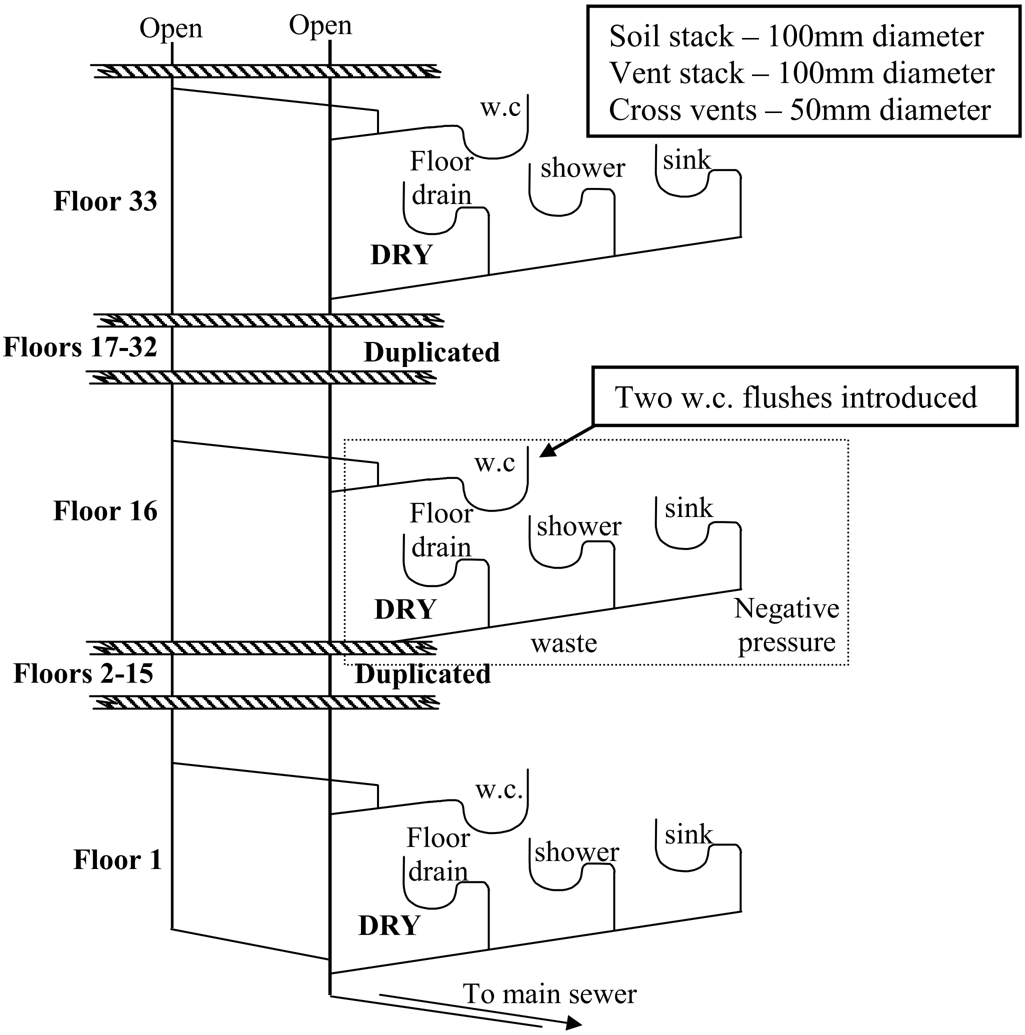


Figure 6 Schematic stack and vent connections, Amoy Gardens, HK

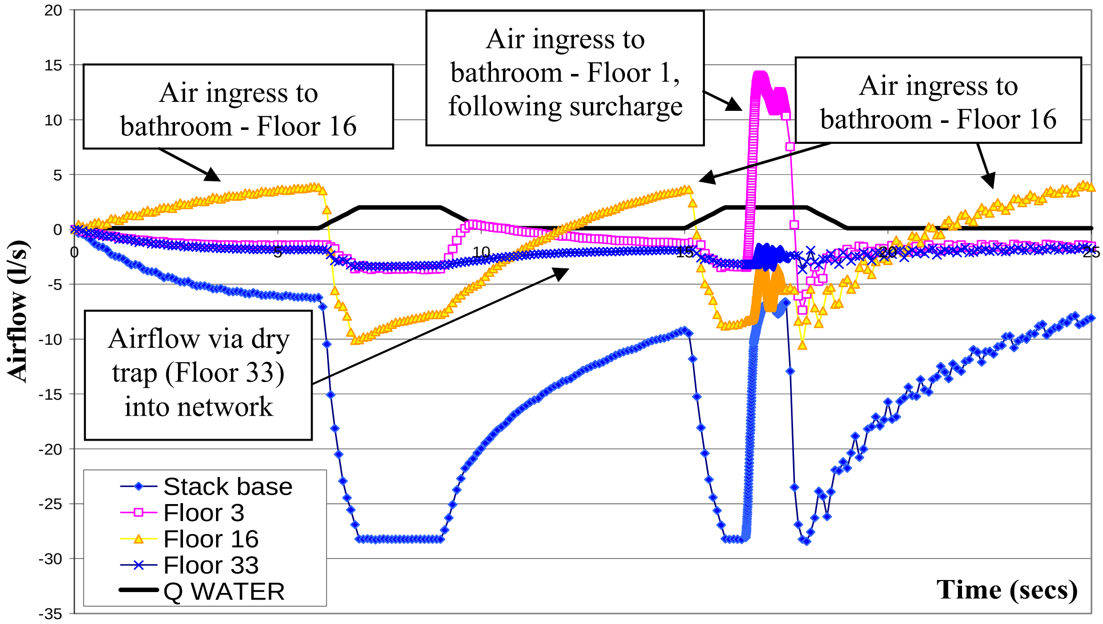


Figure 7 Airflow results for (schematic) Amoy Gardens system

Figure 7 (where positive airflow represents an upwards direction and vice versa) illustrates the mode of ingress of air from the network to the bathroom on Floor 16 during the initial phase of the simulation, during the period between w.c. flushes and subsequent to both discharge flows. This is caused by the negative room pressure generated by the operation of the extract fan, and clearly demonstrates the potential for cross contamination, where aerosolised virus laden faecal matter is transmitted by air movement. This ingress into the habitable space however, is overridden during each w.c. flush when the no-slip condition introduced by the annular column of falling water induces a prevailing negative pressure within the system. The presence of the dry traps on Floors 1 and 33 effectively provide ventilation to the network, thereby rendering much of the intended ventilation provision redundant.

The sewer surcharge event introduced into the simulation at around 17 seconds clearly demonstrates the reversal of airflow within the system and highlights the vulnerability of the dry trap on Floor 1. Figure 7 also demonstrates that the pressure distribution throughout the stack protects Floor 16 from further ingress of contaminated air during the surcharge event, despite the presence of the extract fan. This is further illustrated by Figure 8 that shows cumulative airflows into Floors 1, 16 and 33.

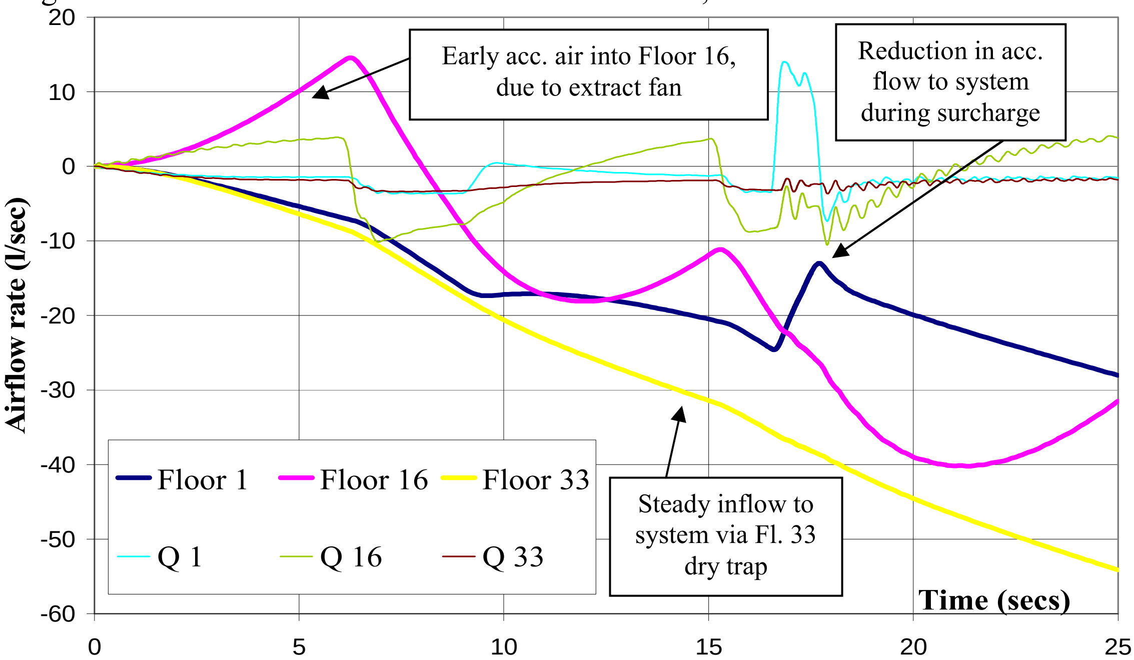


Figure 8 Airflow and accumulated airflow into rooms on Floors 1, 16 and 33

7. Conclusions

This paper has outlined the fundamental principles underpinning the generation, propagation and associated modelling of low amplitude air pressure transients – in particular positive transients. It has presented recent research findings that progress knowledge in this area, where preliminary data indicate that generation of positive transients as a direct result of water curtain formation at the base of the stack may demonstrate a frequency of oscillation that is independent of driving flow conditions. Furthermore, using the simulation techniques developed as a direct result of this ongoing research, this paper has also corroborated the transmission route of SARS in the Amoy Gardens outbreak, and demonstrated the role played by poor maintenance that results in trap seal depletion, thereby altering the dynamic response of the system.

8. References

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Presentation of Authors

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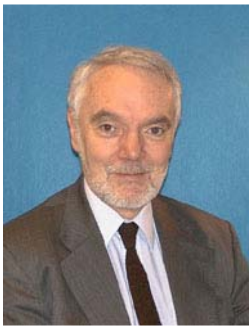

Professor John Swaffield is Head of the School of the Built Environment and leads the Drainage Research Group at Heriot-Watt University. His research interests include water conservation and the development of mathematical simulations for drainage and vent system flows. He has been involved in drainage and water conservation research for 30 years and has contributed regularly to CIBW62 meetings since 1975.

Mr Steven Filsell is a full time research student based in the School of the Built Environment at Heriot-Watt University working on a project entitled 'Investigations of Positive Air Pressure Transients in Building Drainage Vent Systems'. Steven's research is funded by the UK EPSRC (Engineering and Physical Sciences Research Council).

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An Empirical Approach to Peak Air Pressure on 2-Pipes Vertical Drainage Stack

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Abstract

In Taiwan, vertical drainage stack pipe for the medium-height apartment houses is almost designed as 2 or more vertical pipes systems. A prediction method of air pressure distribution on vertical drainage system with single discharge for apartment houses had been conducted in our previous researches. Accordingly, this paper focuses on the issue of 2-pipes vertical drainage and vent system, which is widely used in Taiwan. We focus on the air pressure prediction in 2-pipes drainage and vent stacks from the predicted results of single drainage stack. Comparison between the measured data and calculated values reveals that the prediction method can reproduce the negative and positive peak air pressure values within 2-pipes vertical drainage stacks given single point discharge and steady flow condition. This prediction method can be easily applied for design work.

Keywords

2-pipes drainage and vent system, apartment houses, trap

1. INTRODUCTION

Pressure fluctuation control in vertical drainage stacks has been identified as an important issue to insure sanitary drainage performance. In our previous presentation in 2002, a comprehensive domestic investigation was conducted that showed the vertical drainage stack pipes are mostly designed as 2 or more pipe systems. Relief and stack vent types have been widely used as drainage systems for medium-height apartment houses [1].

Considerable progress has been made in predicting the air pressure distribution within drainage systems. And we had also established a prediction model for air pressure distribution in a single drainage stack system. Following these previous researches, this paper focuses on an empirical approach to the prediction of peak air pressure values of 2-pipes drainage and vent system, using an experimental device that can simulate a medium-height apartment to provide empirical parameters and model verification. The vertical drainage flow mechanism and prediction model methodology had been schematically described and illustrated [2]. Device of the existing experiment tower was modified to multi-vent-loop types of 2-pipes drainage and vent system by relief vent pipes connection. Experimental results and verification also have been stressed for hypothetical appliance discharges to drain under single point discharge and steady flow conditions.

Following the previous researches, this study focuses on 2-pipes drainage and vent stack type building drainage system with single-point discharge through the single stack type prediction method. This method focuses on peak negative and positive air pressure of 5 vent-loop types of the discharge and vent system.

2. THEORETICAL REVIEWS

The National Plumbing Code (NPC) guidelines from the US were used to set the permitted flow rate for drainage system regulations [3]. Following initial HASS 203 work from Japan in the 1970s, the steady flow condition method was merged as the reference provision and evaluation technique. Hence, a series of researches on the steady flow method with reference to building drainage networks were conducted. An air pressure distribution prediction model for drainage stacks in high-rise (108m) [4], and medium-height (30m) experiment towers [5] was developed in Japan in 1985. Considerable progress has been made in predicting the air pressure distribution within a vertical drainage stack.

According to the vertical drainage flow stack feature from the theoretical reviews, the drainage stack profile was divided into four zones, shown in the following diagram,

Figure 1 Each zone is individually modeled due to the corresponding characteristics. The air pressure distribution, which reveals the time average air pressure data with steady flow condition, does not involve instantaneous air pressure fluctuations in vertical drainage flow. The features of each zone were described in the previous reports [6].

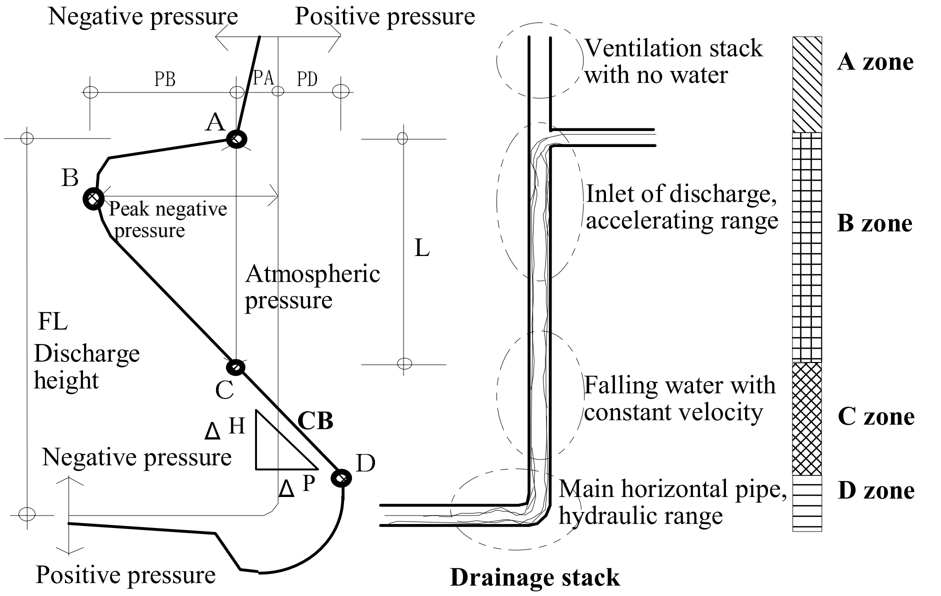


Figure 1 - Air pressure distribution zone profile in a drainage stack [6]

3. EXPERIMENT DEVICE

A full-scale drainage experimental tower in Taipei was reported in previous presentation of CIB-W62 symposium [7]. This experimental tower adhered to the parameters of a real building 40 m I height to simulate a drainage system within medium-height apartment houses 12 floors. Following the results of previous investigation and single drainage stack experiment, the device of experiment tower has modified to a 2-pipes drainage and vent system for conducting the empirical parameter and evaluation method of air pressure distribution in vertical drainage stack. The experimental device details are shown in Figure 2. The diameter of the stack pipe was φ100mm, the building drain pipe was φ125mm, the horizontal fixture drain branch (branch pipe) wasφ75mm, the vent stack pipe was φ75mm, and the relief vent pipe was φ50mm. For vent loop control, we inserted ball valve on each relief vent pipe, shown in Figure 3. Hence, we can dominate vent loops in 2-pipes drainage system.

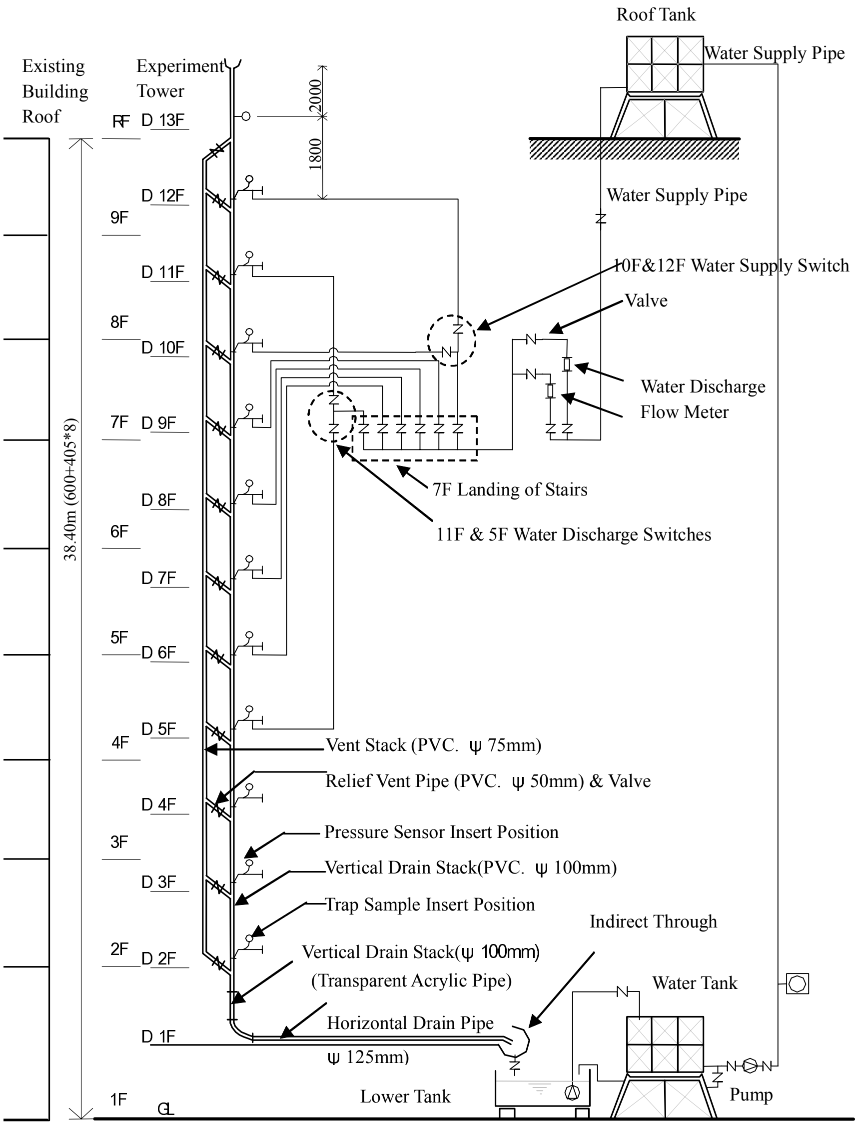


Figure 2 - Device of 2-Pipes drainage and vent stack system of the experiment tower

By the control of 2-pipes drainage system, we developed 5 types of vent loop, including: (1) Simplified drainage and vent stack system (Type 1), (2) Designed vent loop drainage stack system (Type 2), (3) Designed single relief vent drainage stack system (Type 3), (4) Storied-relief-vent drainage system (Type 4), (5) 3-stories-relief vent stack drainage system (Type 5). When all the ball valves closed, the system can simulate as a single drainage stack system (Type O). All the drainage and vent loop types are shown as Figure 4. Concerning the recording data format, the mean air pressure value was surveyed for 40 seconds in each measurement with 10ms sampling time.

The central 20-second samples with 2000 data were adopted for the mean air pressure performance value [8]. These experiments depended on discharging from 6F to 12F with water flow rate ranging from 1.0 l/s to 4.0 l/s under single-point and steady discharge flow conditions. [2]

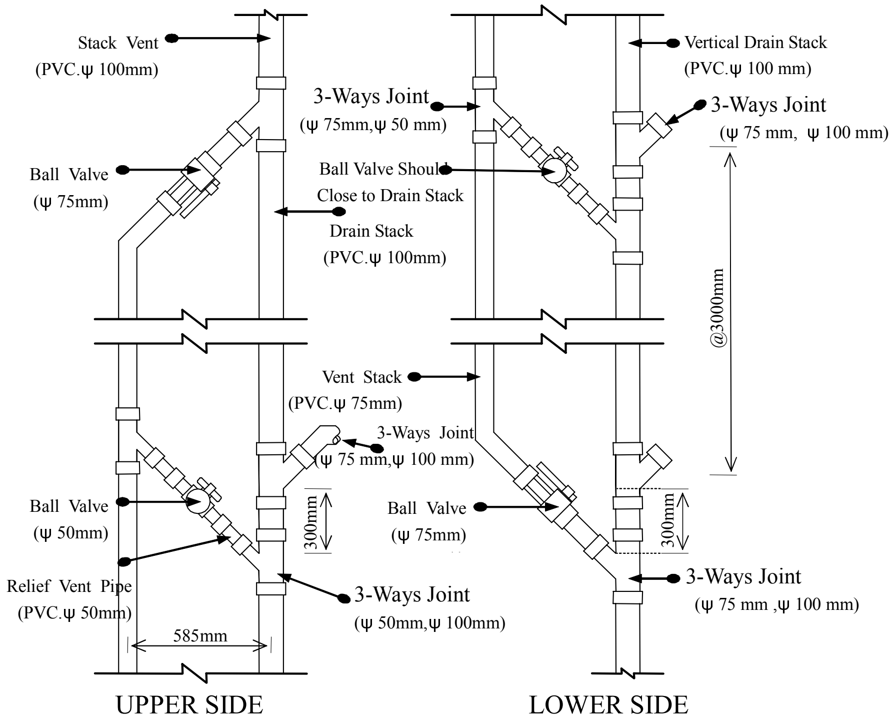


Figure 3 - Details of the joint between drainage and vent stack

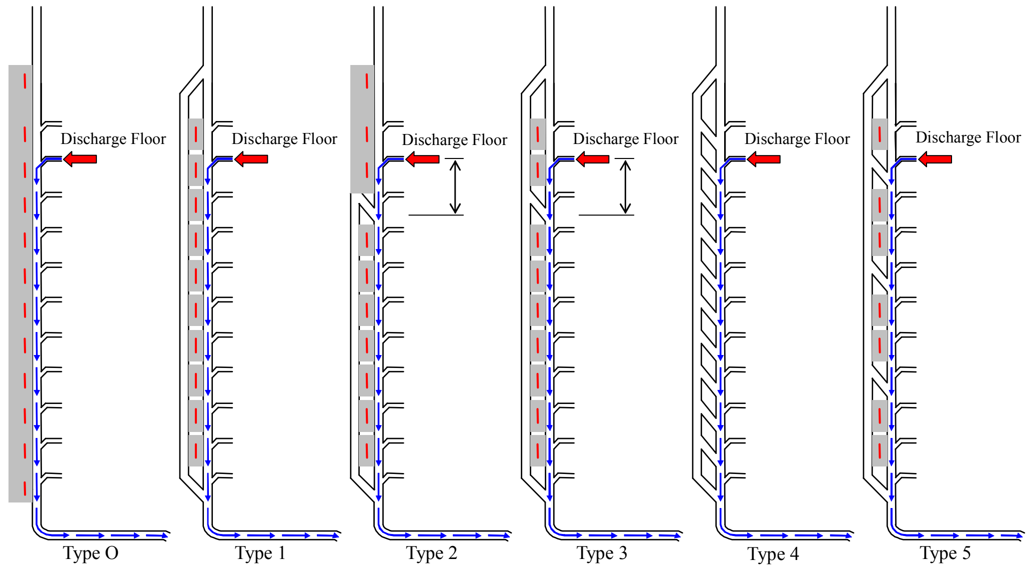


Figure 4 - Profile of the vent loop types within drainage and vent stack system

4. METHODOLOGY: DETERMINATION OF PEAK AIR PRESSURE REDUCTION RATIO OF 2-PIPES DRAINAGE SYSTEM

The air pressure balance performance is different from the vent loops of 2-pipes drainage and vent system. On the lower part of drainage stack to drain, we set a vent pipe to connect with vent stack. And on the vent pipe of it, we also linked these 2 stacks. There are both a impulse force and suction existing in the bottom and top of the vent pip when water discharged into the drainage stack to form a difference of air pressure. As the reference air pressure distribution of single drainage stack shown in Figure 5(a), the air pressure balance depended on the connection position between drainage and vent stacks. Figure 5(b) showed the results of air pressure reduction in the drainage stack. The peak negative values of experimental data didn't change obviously, but the positive air pressure was nearly going back to the atmosphere affected by the vent stack. The other vent loops showed in Figure 6 to Figure 9 illustrated that the connection of relief vent pipes between drainage and vent stacks formed different way of air pressure balance. When the relief vent pipe inserted in the peak negative air pressure position, the performance of air pressure reduction was the best, as shown in Figure 2(a) and Figure 2(b).

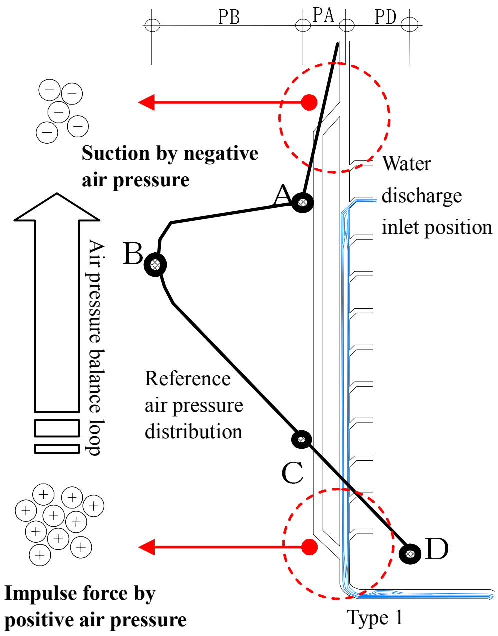
According to the experimental results, peak air pressure prediction depends on the air pressure reduction ratio from single drainage stack system. The reduction ratio can be conducted to a regression function related with flow rate Qw and discharge floor height FL. By the predicting procedure, it is clear that the reduction ratio based on its vent loop type. In order to predict the air pressure of 2-pipes drainage system, we compared their peak air pressure values between each type and Type O. The results were shown in Figure 5(c) to Figure 9(d). For example, we predict the negative air pressure of Type 5 which is widely used in Taiwan by Eq. (1).

$$TO_{(PA+PB)} \times (0.000395 \times FL^2 - 0.00382 \times Qw^2 - 0.0348 \times FL - 0.04104 \times Qw + 1.284758)$$

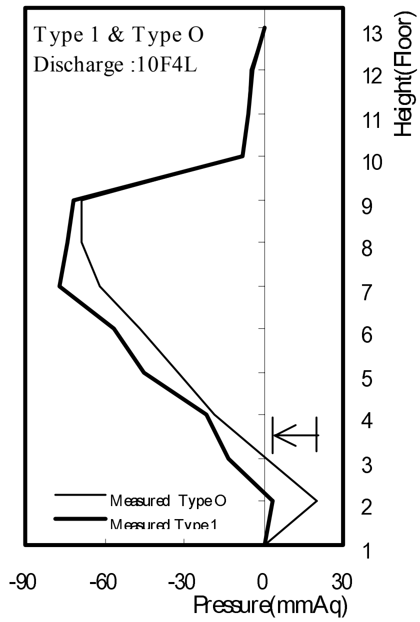
$$= T5_{(PA+PB)} \ldots (1)$$

On the other hand, Figure 5(d) to Figure 9(d) revealed that fine variation to atmosphere caused the reduction ratio of positive air pressure to be scattered. As the results shown, the prediction method will be corrected to the proportion of maximum difference between peak negative and positive air pressure in drainage stack, as in Figure 10. Figure 11 shows the relationships between maximum air pressure difference, flow rate, and discharge floor height. Following the methodology of this prediction model, the reduction ratio method was confirmed in this experimental range.

(1) TYPE 1

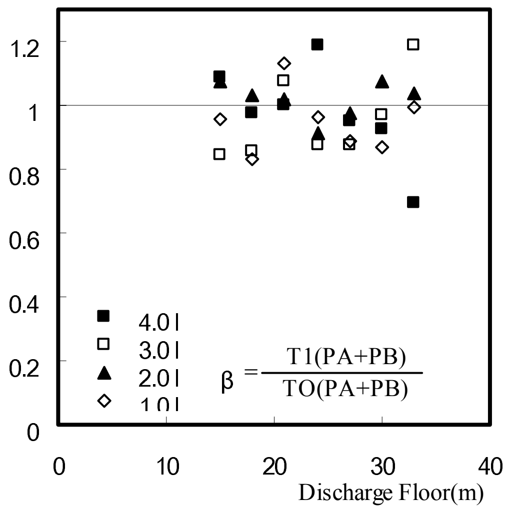


(a) - Profile of the air pressure balance loop of Type 1

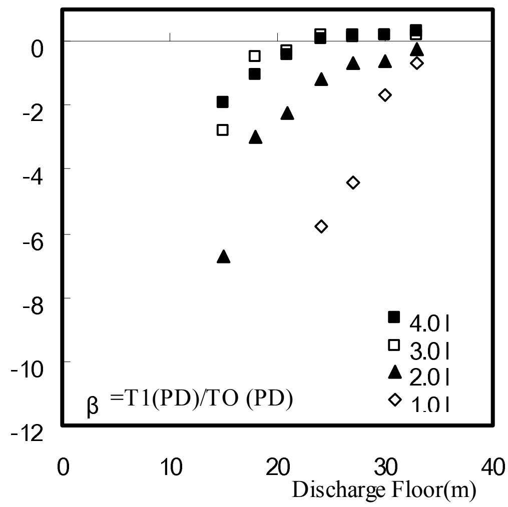


(b) – Reduction ratio of negative air pressure between Type 1 and Type O

(discharge floor: 10F, flow rate:4.0 l/s)



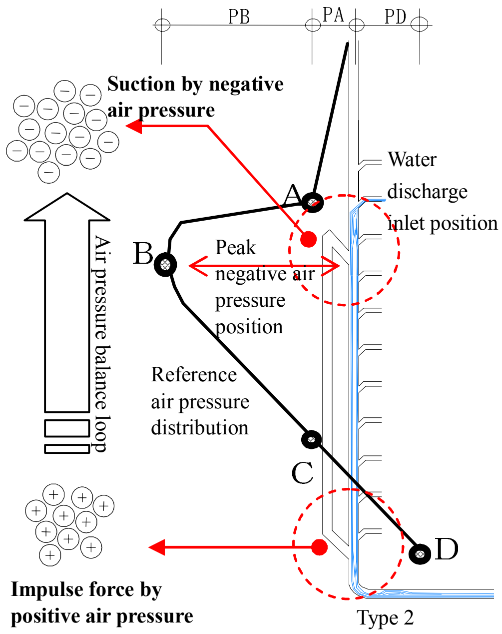
(c) - Ratio of negative air pressure between Type 1 and Type O



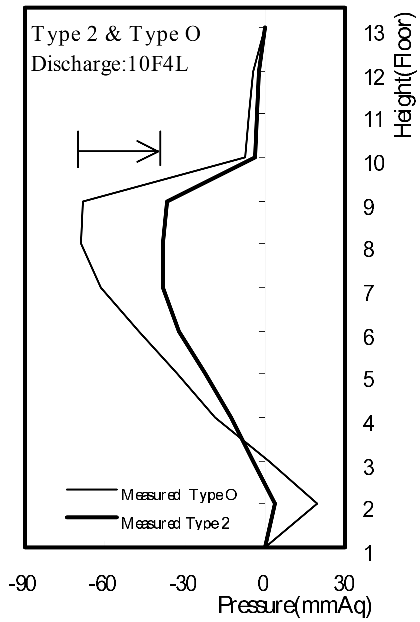
(d) - Ratio of positive air pressure between Type 1 and Type O

Figure 5 –Peak air pressure prediction method of Type 1 by reduction ratio

(2) TYPE 2

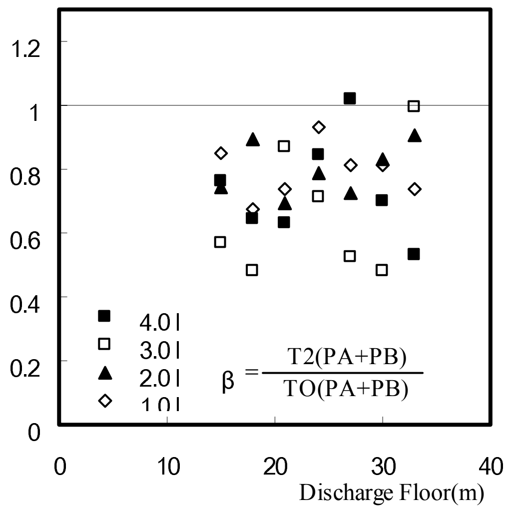


(a) - Profile of the air pressure balance loop of Type 2

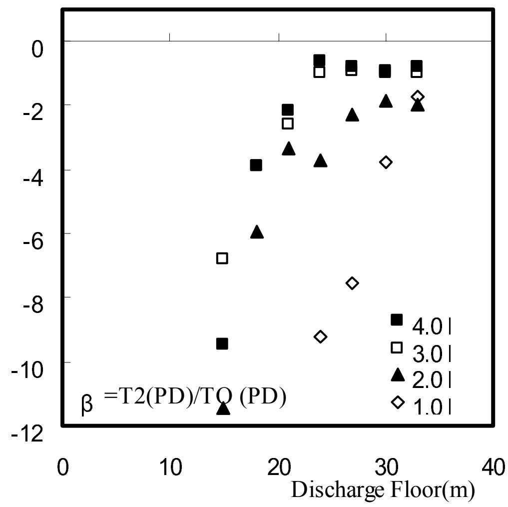


(b) - Reduction ratio of negative air pressure between Type 2 and Type O

(discharge floor: 10F, flow rate:4.0 l/s)



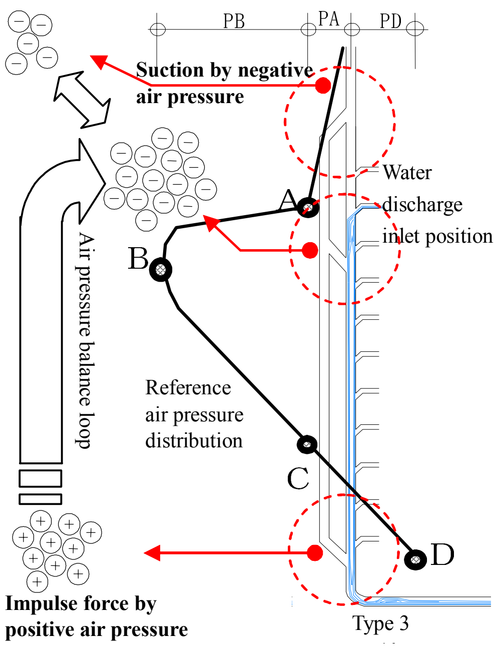
(c) - Ratio of negative air pressure between Type 2 and Type O



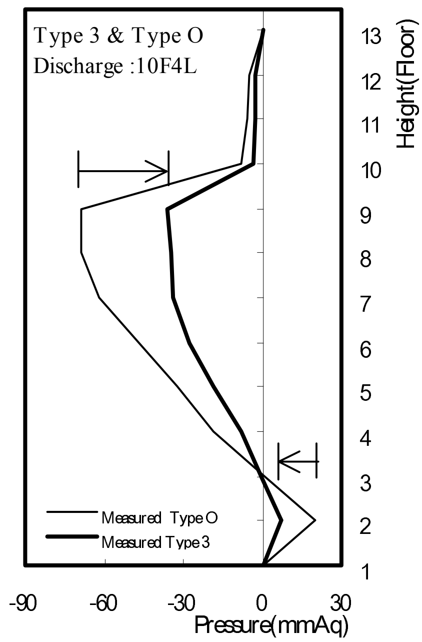
(d) - Ratio of positive air pressure between Type 2 and Type O

Figure 6 –Peak air pressure prediction method of Type 2 by reduction ratio

(3) TYPE 3

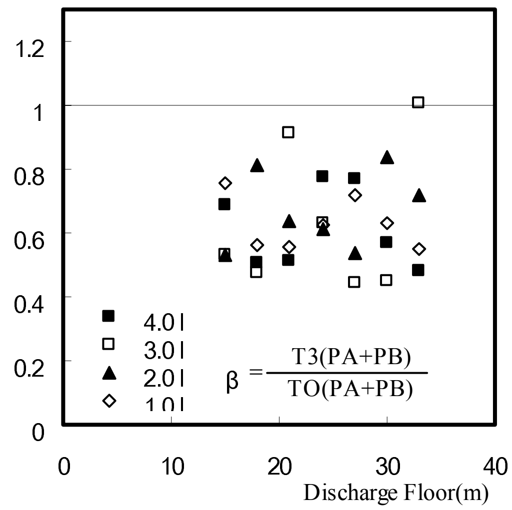


(a) - Profile of the air pressure balance loop of Type 3

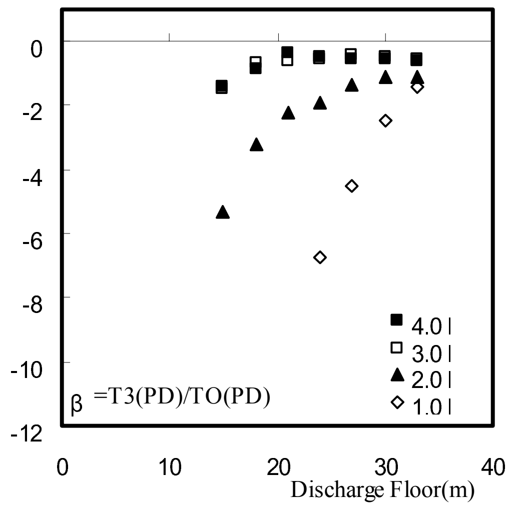


(b) - Reduction ratio of negative air pressure between Type 3 and Type O

(discharge floor: 10F, flow rate:4.0 l/s)



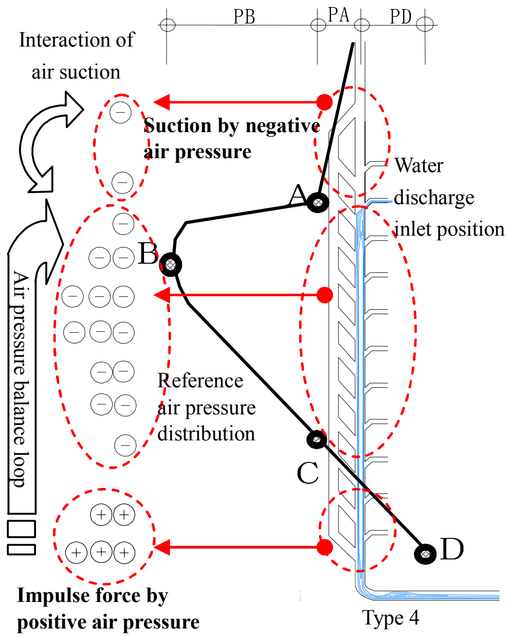
(c) - Ratio of negative air pressure between Type 3 and Type O



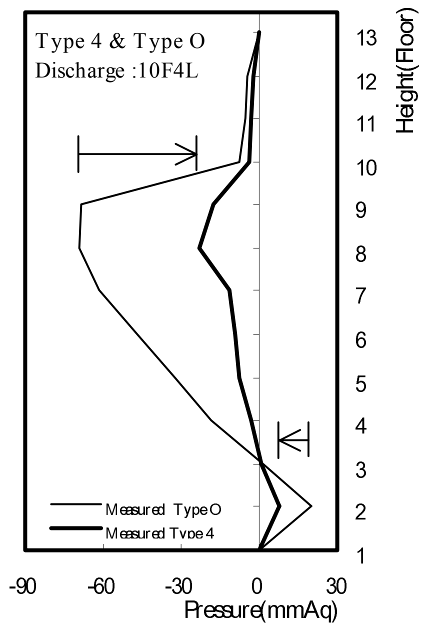
(d) - Ratio of positive air pressure between Type 3 and Type O

Figure 7 –Peak air pressure prediction method of Type 3 by reduction ratio

(4) TYPE 4

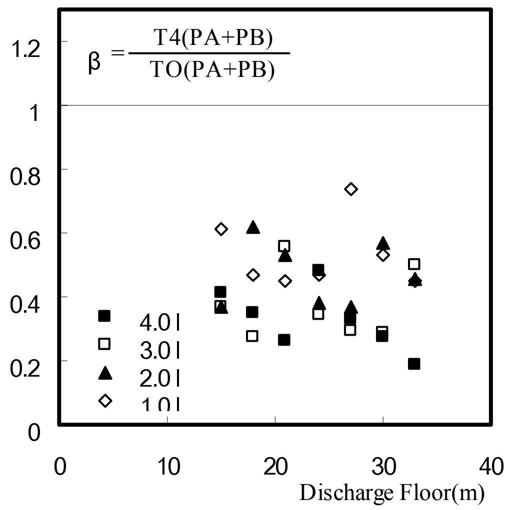


(a) - Profile of the air pressure balance loop of Type 4

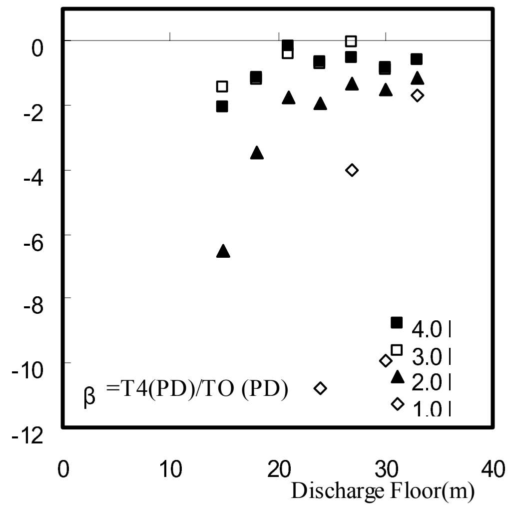


(b) - Reduction ratio of negative air pressure between Type 4 and Type O

(discharge floor: 10F, flow rate:4.0 l/s)



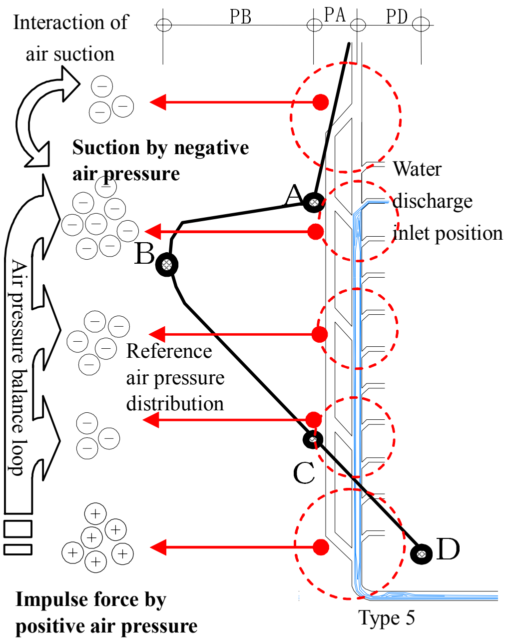
(c) - Ratio of negative air pressure between Type 4 and Type O



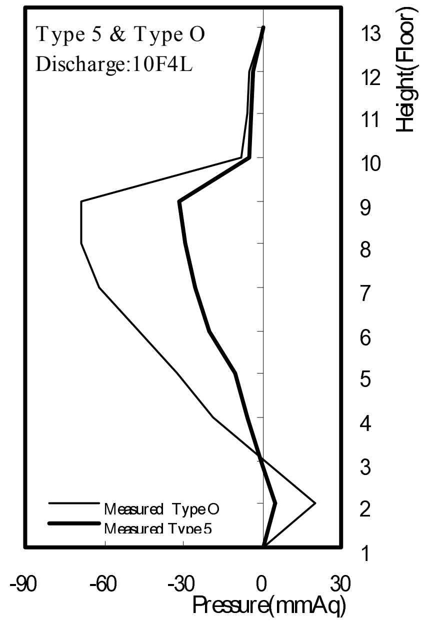
(d) - Ratio of positive air pressure between Type 4 and Type O

Figure 8 –Peak air pressure prediction method of Type 4 by reduction ratio

(5) Type 5

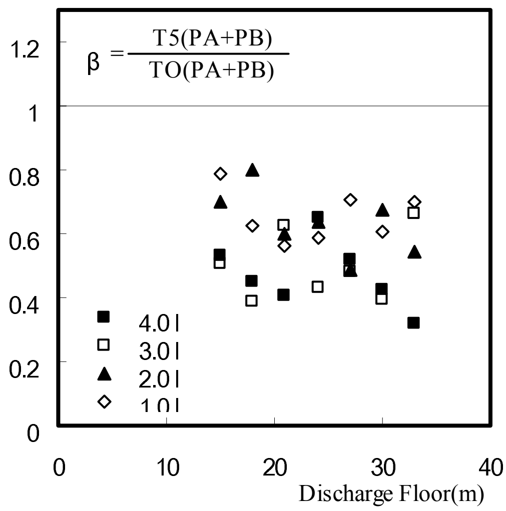


(b) - Profile of the air pressure balance loop of Type 5

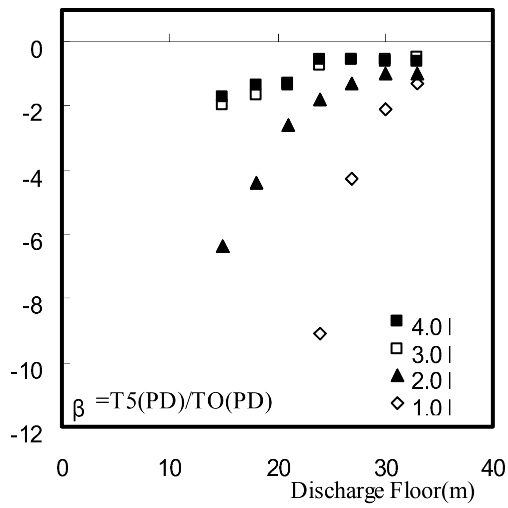


(a) - Reduction ratio of negative air pressure between Type 5 and Type O

(discharge floor: 10F, flow rate:4.0 l/s)

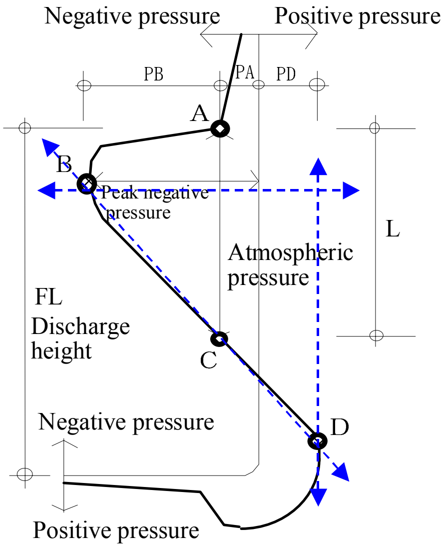


(c) - Ratio of negative air pressure between Type 5 and Type O



(d) - Ratio of positive air pressure between Type 5 and Type O

Figure 9 – Peak air pressure prediction method of Type 5 by reduction ratio



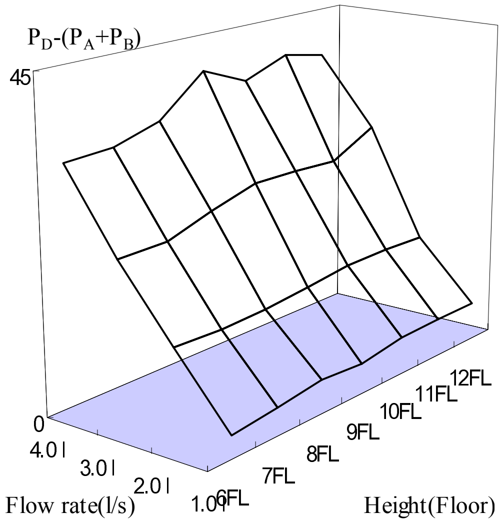


Figure 10 - Profile of maximum air pressure difference in vertical drainage stack

Figure 11 - Relationship between maximum air pressure difference, flow rate and discharge height

The peak positive air pressure is related to maximum air pressure difference and peak negative air pressure which is directly related to flow rate and discharge floor height. Thus it can be determined using a regression function shown in Eq. (2).

$$T5_{(PA+PB)} \times (\ 0.046767 \times Qw^2 - 0.002078 \times FL \times Qw - 0.013351 \times FL - 0.337502 \times Qw + 1\ )$$

$$= T5_{(PD)} \ldots \quad (2)$$

Following the air pressure prediction procedure, this paper determines the ratio between peak negative and positive air pressure of single and 2-pipes drainage systems. The comparison was divided into 2 parts which include peak negative and positive air pressure, and the peak negative air pressure values of 2-pipes drainage system are determined. The peak negative air pressure in 2-pipes drainage system can be identified as P_B values in B zone of single drainage system. The predicting procedure shows as Figure 12.

To clarify this prediction methodology for each vent loop type of 2-pipes drainage system, a calculation procedure was undertaken to determine the air pressure reduction ratio and the proportion of maximum air pressure difference within the vertical drainage stack under steady and sequential discharge conditions. The air pressure distribution of single drainage stack system should be predicted in the beginning. By the prediction procedure, the prediction method of peak negative and positive air pressure for 2-pipes drainage and vent system is summarized as Table 1 listed.

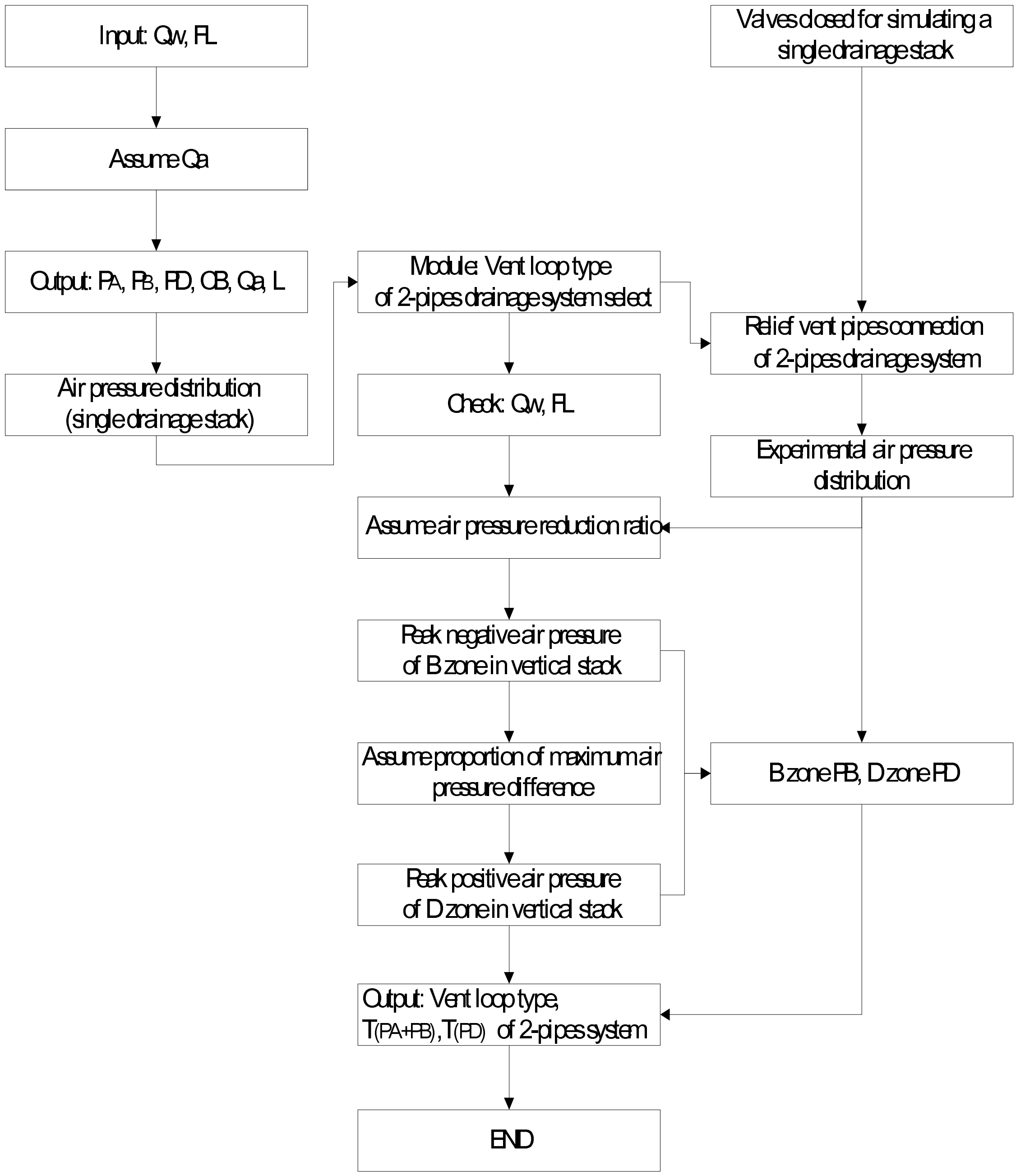
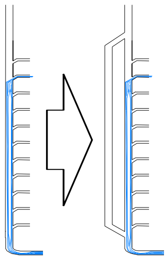
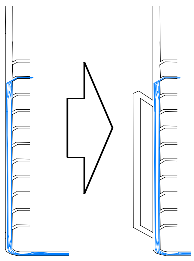
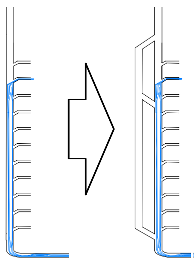
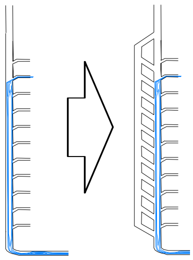
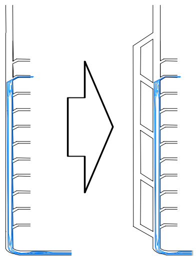


Figure 12 – Procedure of peak air pressure prediction of 2-pipes drainage system

Table 1 - Prediction method of peak negative and positive air pressure for 2-pipes drainage and vent system

Profile	Prediction method of peak negative and positive air pressure
	$\text{Type } 1_{(PA+PB)} = TO_{(PA+PB)} \times \beta 1_{(-)}$ $= TO_{(PA+PB)} \times (- 0.00058 \times FL^2 + 0.01451 \times Qw^2 + 0.02 \times FL - 0.12 \times Qw + 1.058)$
	$\text{Type } 1_{(PD)} = T1_{(PA+PB)} \times \beta 1_{(+)}$ $= T1_{(PA+PB)} \times (0.04932 \times Qw^2 + 0.002 \times FL \times Qw - 0.02 \times FL - 0.39 \times Qw + 1)$
	$\text{Type } 2_{(PA+PB)} = TO_{(PA+PB)} \times \beta 2_{(-)}$ $= TO_{(PA+PB)} \times (0.00203FL^2 + 0.02576 \times Qw^2 - 0.11 \times FL - 0.24 \times Qw + 2.621)$
	$\text{Type } 2_{(PD)} = T2_{(PA+PB)} \times \beta 2_{(+)}$ $= T2_{(PA+PB)} \times (0.06487Qw^2 - 0.005FL \times Qw - 0.008 \times FL - 0.32 \times Qw + 1)$
	$\text{Type } 3_{(PA+PB)} = TO_{(PA+PB)} \times \beta 3_{(-)}$ $= TO_{(PA+PB)} \times (0.00071 \times FL^2 + 0.04386 \times Qw^2 - 0.04 \times FL - 0.34 \times Qw + 1.671)$

	$\text{Type } 3_{(PD)} = T3_{(PA+PB)} \times \beta 3_{(+)}$ $= T3_{(PA+PB)} \times (0.04844 \times Qw^2 + 0.00079 \times FL \times Qw - 0.02 \times FL$ $- 0.4 \times Qw + 1)$
	$\text{Type } 4_{(PA+PB)} = TO_{(PA+PB)} \times \beta 4_{(-)}$ $= TO_{(PA+PB)} \times (0.00014 \times FL^2 + 0.01513 \times Qw^2 - 0.02 \times FL$ $- 0.16 \times Qw + 1.076)$
	$\text{Type } 4_{(PD)} = T4_{(PA+PB)} \times \beta 4_{(+)}$ $= T4_{(PA+PB)} \times (0.08897 \times Qw^2 - 0.009 \times FL \times Qw + 0.004 \times FL -$ $0.47 \times Qw + 1)$
	$\text{Type } 5(P_A+P_B) = TO_{(PA+PB)} \times \beta 5_{(-)}$ $= TO_{(PA+PB)} \times (0.0004 \times FL^2 - 0.00382 \times Qw^2 - 0.03 \times FL$ $- 0.04 \times Qw + 1.285)$
	$\text{Type } 5(P_D) = T5_{(PA+PB)} \times \beta 5_{(+)}$ $= T5_{(PA+PB)} \times (0.04677 \times Qw^2 - 0.00208 \times FL \times Qw - 0.01 \times FL$ $- 0.33 \times Qw + 1)$

*** $TO_{(PA+PB)}$: Negative air pressure of Type O.**

5. VERIFICATION: REPRODUCTION OF EXPERIMENTAL DATA

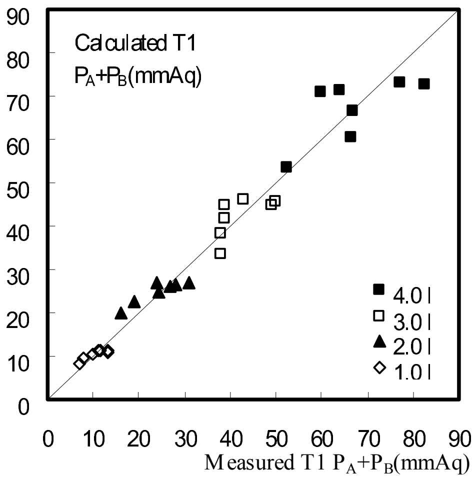
Following the previous research, the single-stack experiment tower was modified to a 2-pipes drainage and vent system to simulate a middle-height apartment house with 12 floors, which is widely used in Taiwan. By the prediction method of air pressure distribution in single-stack drainage system, peak air pressure of 2-pipes drainage system could be predicted through pressure reduction ratio between single and 2-pipes drainage system. Comparison of air pressure distribution of single stack and 2-pipes drainage system by experimental data reveals that negative air pressure reduction depends on different types of vent loops. Reduction ratio could be conjectured from flow rate Qw and discharge floor height FL. Hence, effective design of drainage and vent loop would reduce the peak air pressure in drainage stack and prevent the destruction of water trap seal.

Herein, we focus on the verification of this prediction model using experiment data.

Reproduction of the performance of the boundary conditions for these experiment device types were 28 water discharge test patterns for each vent loop type, which is totally contains 168 patterns, including discharge height variations from 6F to 12F and water flow rates from 1.0 to 4.0 l/s. The most important factor in the prediction model, air pressure distribution of single drainage stack must be confirmed first. Next, reduction ratio, which is conjectured from flow rate and discharge floor height, has to be confirmed by its vent loop type.

We reproduce the peak negative and positive air pressure to verify the reliability of this prediction model. These results revealed that the calculation procedure can approximately reproduce the experimental data for peak negative and positive air pressure for each type of vent loop of 2-pipes drainage and vent system, and the deviations were acceptable under the designed experimental conditions, shown as Figure 13 to 22.

According to the prediction method, a series of reproduction of experimental data were conducted to verify the reliability of this prediction model. Comparisons between measured data and calculation results showed the good performance of prediction results of peak negative and positive air pressure for 2-pipes drainage and vent system. These figures indicate that the prediction model is reliable for those water discharge patterns and vent loops of 2-pipes drainage and vent system under the controlled boundary conditions.



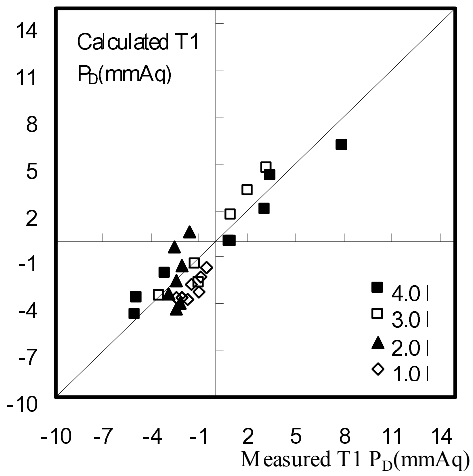
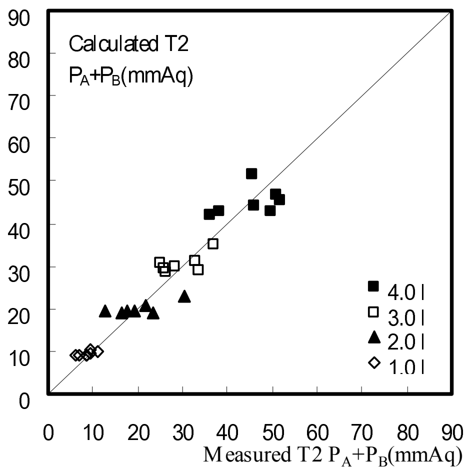


Figure 13 - Verification of Type 1's peak negative air pressure P_B

Figure 14 - Verification of Type 1's peak positive air pressure P_A



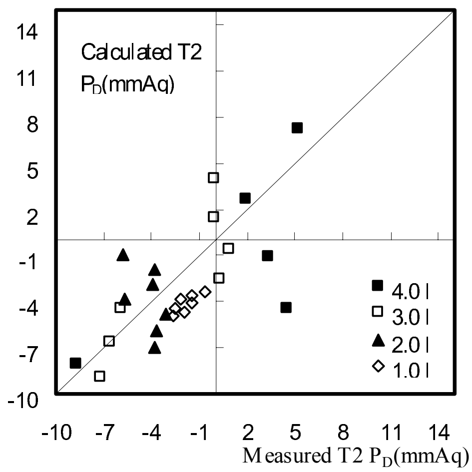
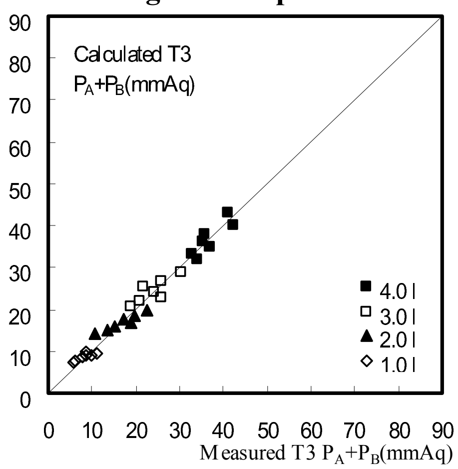


Figure 15 - Verification of Type 2's peak negative air pressure PB

Figure 16 - Verification of Type 2's peak positive air pressure PA



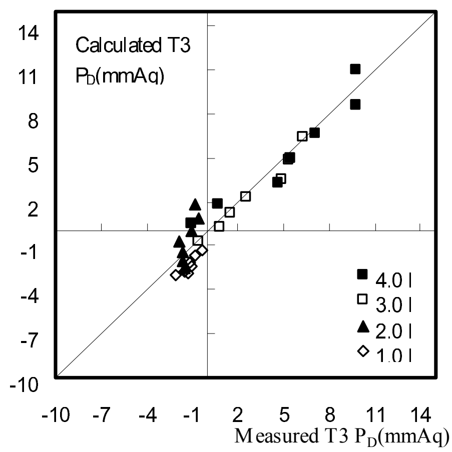
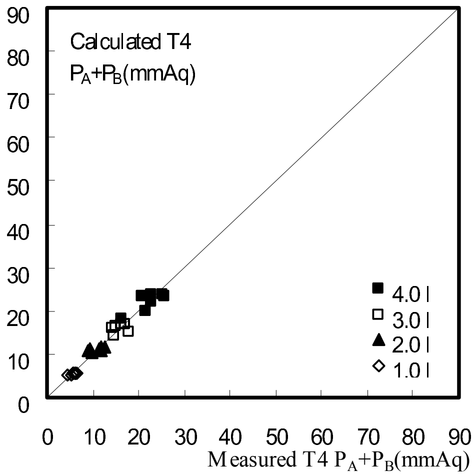


Figure 17 - Verification of Type 3's peak negative air pressure PB

Figure 18 - Verification of Type 3's peak positive air pressure PA



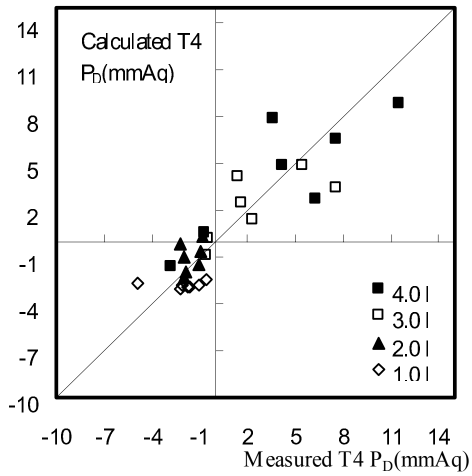
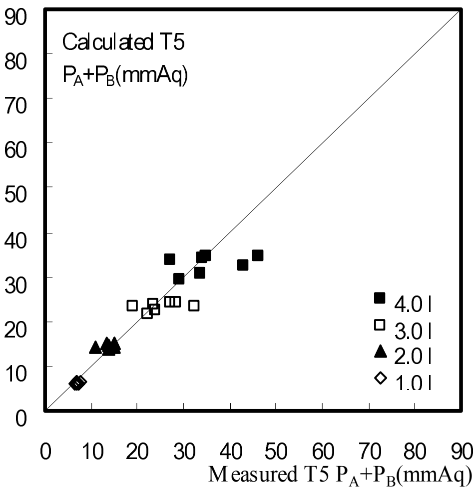


Figure 19 - Verification of Type 4's peak negative air pressure PB

Figure 20 - Verification of Type 4's peak positive air pressure PA



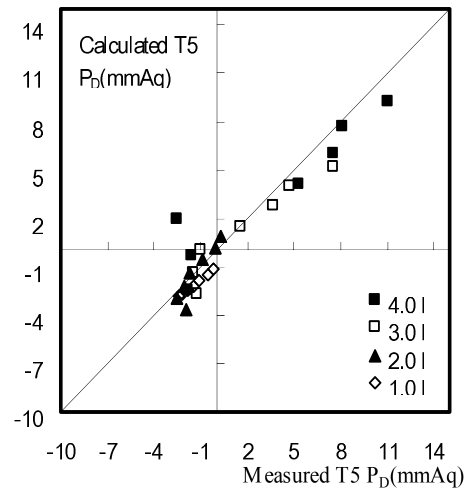


Figure 21 - Verification of Type 5's peak negative air pressure PB

Figure 22 - Verification of Type 1's peak positive air pressure PA

6. CONCLUSIONS

This paper focused on peak air pressure prediction in 2-pipes drainage and vent stack system, which is widely used in Taiwan to take care of the topics of healthiness and comfort for living environment. Prediction results of air pressure distribution in a single vertical drainage stack are used for peak air pressure prediction for 2-pipes drainage system as well. Reduction ratio between each vent loop type of 2-pipes drainage system and single drainage stack system is promoted by flow rate and discharge floor height for peak negative air pressure prediction. And the peak positive air pressure can be conjectured through the results of negative air pressure prediction. Path of vent loop in 2-pipes drainage and vent system is the important parameter for negative air pressure reduction. Depending on the designed loop path in 2-pipes system, the performance of air pressure balance has been confirmed. An appropriate relief vent pipes connection will conduct a good air pressure balance loop to control air pressure fluctuation in the drainage stack.

A prediction model based on the empirical parameters offers a reference to drainage system designers for designing and maintaining water trap functions in the building. Verifications from the comparisons between the measured data and calculated values reveal that the prediction model can approximately reproduce the negative and positive peak air pressure values within 2-pipes vertical drainage stacks in a building vertical drainage stack for single point discharge and steady flow conditions. This prediction method can easily apply for design work. The importance of the trap function within a building drainage system has been confirmed during early researches. More related studies include appliance discharges with unsteady flow and multiple water discharge points must be conducted to provide additional building regulation references.

Nomenclature

Ah length from the top of stack vent pipe to the discharge height (m)

P_A pressure of A zone

P_B pressure of B zone

P_D pressure of D zone

P_O pressure of outside interaction ($=P_A + P_D$)

P_I initial total pressure of drainage stack ($=P_A + P_B + P_D$)

γ specific weight of air(kgf/m3)

V_a velocity of air flow at stack vent (m/s)

Q_a air flow rate in stack vent (m^3/s)

$\beta_{(+)}$ proportion of maximum air pressure difference

Q_w water flow rate (V/s)

ξ_A drag coefficient of A zone

ξ_B drag coefficient of B zone

ξ_D drag coefficient of D Zone

CB constant pressure gradient (mmAq/m)

$\alpha\beta$ empirical constant of constant pressure gradient in C zone

g acceleration of gravity (m/s^2)

FL Discharge floor height (m)

L Length scale of the B zone (m)

C_L Constant of L

$\beta_{(-)}$ reduction ratio of peak air pressure values

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Main author presentation

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THEORETICAL AND EXPERIMENTAL RESEARCHES ABOUT THE FLOW IN INTERIOR SEWERAGE INSTALLATIONS

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Abstract

Random and nonpermanent character of the flows in interior sewerage installations represents the principal difficulty for the realization of a rigorous mathematical model.
As following, the dimensioning and the verification of these installations are made with experimental calculus relations, which precision is dependent by the type and the number of the considerate parameters.
The paper present the results of some theoretical and experimental studies effectuated in scope of the elaboration and the validation a model for characterization the flow in column of evacuation, in different functional hypothesis.
The principals parameters considered has been simultaneity and volume of evacuated flow, air pressure in column and geometrical and hydraulic characteristics of the pipe.
Simulation of different functional conditions have been effectuated both on a physical model, at natural scale, and through utilization of the virtual simulation medium SIMULINK/MATLAB or SIMSCI/TACITE, SIMSCI/PIPEPHASE.

Keywords

Nonpermanent flow; hydraulic characteristics; model.

1. Theoretical considerations about the film flow.

There are a lot of studies about flow phenomenon inside the sewage columns. The reason of these studies was to establish the maximum evacuation capacity and to point out the qualitative and/or quantitative evolution of the main geometric or hydrodynamics parameters.

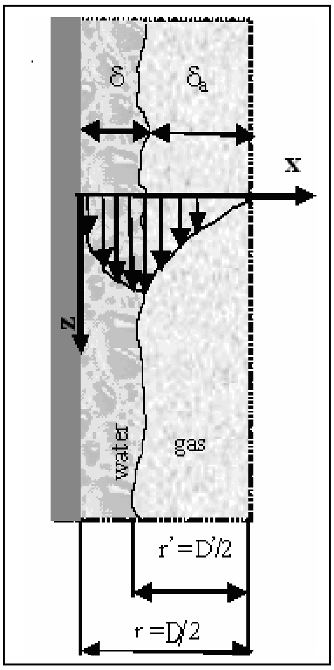


Figure number 1: The scheme of the flow.

The random nature of the receiver usage and associates phenomenon's complexity represent the main difficulty for elaborating of mathematics models.

Considering that in normal conditions, inside the column we have a film flow, we can obtain an approximate analytical solution for the evacuated flow.

Considering a uniform and laminar flow and neglecting the energy forces, the equilibrium of forces differential equation will be:

$$\frac{d\tau}{dx} + \gamma = 0 \qquad [1]$$

where:

-τ-tangential stress depends of dynamic viscosity

-γ-specific weight of water

If we consider that the tangential stress depends of dynamic viscosity -μ and local velocity of water -v,

$$\tau = \mu \frac{dv}{dx} \qquad [2]$$

the formula number 1 will become:

$$\frac{d^2 v}{dx^2} = -\frac{\gamma}{\mu} \qquad [3]$$

The value of velocity in local area will vary from 0 near to the wall to v_{max} at the contact surface with gaseous fluid inside the column and the tangential stress from σ to 0.

If we integrate the equation with the extremes conditions

$$\begin{aligned} &x = 0;\ v = 0 \\ &x = \delta;\tau = 0 \qquad [4] \end{aligned}$$

we will obtain the general velocity formula:

$$v = \frac{\gamma}{\mu}(\delta x - \frac{x^2}{2}) \qquad [5]$$

In this formula, for x = δ we will obtain the value for maximum velocity at the external surface of film

$$v_{\max} \frac{\gamma}{2\mu}\delta^2 \qquad [6]$$

and the average velocity value

$$v_{med} = \frac{1}{\delta}\int_0^{\delta} \frac{\gamma}{\mu}(\delta_x - \frac{x}{2})dx = \frac{\gamma}{3\mu}\delta^2 \qquad [7]$$

If we express the volumic flow (when we have a film flow) using the continuity equation depends of the average velocity

$$Q = \pi D \delta v_{med} = \pi \mathrm{D} \frac{\gamma \delta^3}{3\mu} \qquad [8]$$

we can find the relations between the parameters δ, v_{med}, Q [9] and [10]

$$\delta = \sqrt[3]{3\frac{Q\mu}{\pi D\gamma}} \quad [9]$$

$$v_{med} = \sqrt[3]{\frac{1}{3}\cdot(\frac{Q}{\pi D\gamma})^2\cdot\frac{\gamma}{\mu}} \qquad [10]$$

The equations number 9 and 10, valid in that simplified assumptions, can offer us theoretical signs about the film flow inside the sewage columns.

2. Dimensional analyses theory application for establish the functional parameters.

On the other hand the complex phenomenon can be expressed with an implicit function depends on physical parameters that we consider it determinative.

If we consider as well as determinative sizes the flow - Q, the height - H, inside pressure - p, average velocity - v, film thickness - δ, specific weight of water - γ, dynamic viscosity - μ and gravity acceleration - g, the implicit function will became:

$$F(Q,H,p,\delta,v,\rho,\mu,g) = 0\,[11]$$

According with dimensional analyses theory, 11 can be expressed in short way depends on 5 dimensionless parameters Πi with equation [12]

$$F(1,1,1,\pi_1,\pi_2,\pi_3,\pi_4,\pi_5) = 0\,[12]$$

where the complex's and a dimensionless sizes, are defined as a ratio of unfundamentals physicals sizes and as a multiplied power of a considered fundamentals basic sizes.

Having the experimental results we can find relations between parameters Πi and after this we can determinate the functional parameters, film thickness, inside pressure, velocity etc.

The value of the searched parameters is close to the real value if the number of physical parameters is bigger.

To simplify, we consider that the effect of δ, v, μ is less important for the determination of inside pressure we suggest an implicit formula [13]

$$F(Q,H,p,g,\rho) = 0 \quad [13]$$

with an simple function [14] where [15]:

$$\varphi = (\pi_1,\pi_2) = 0 \qquad [14]$$

Where:

$$\left.\begin{aligned}\pi_1 &= \frac{Q}{\rho^{x_1}\cdot g^{y_1}\cdot H^{z_1}}\\ \pi_2 &= \frac{p}{\rho^{x_2}\cdot g^{y_2}\cdot H^{z_2}}\end{aligned}\right\} \qquad [15]$$

Observing that in dimensionless parameters structure Πi, 2 we have variable parameters (Q, H, p) it is possible to explain the relations between parameters on the experimental way.

According with 14, 15, the inside pressure is:

$$\left.\begin{aligned}\pi_2 &= k\varphi'(\pi_1)\\ p &= k\varphi'(\pi_1)\end{aligned}\right\} \qquad [16]$$

where:

$$\left.\begin{aligned}\pi_1 &= Q\sqrt[3]{\frac{H}{g}}\\ \pi_2 &= \frac{p}{\gamma\cdot H}\end{aligned}\right\} \qquad [17]$$

Making measurements when we flush an known quantity of water (4,5; 6,0; 7,5 liters) in a 90 mm diameter PE pipe we can determine the grapho-analitiqual correlations between dimensionless parameters and the pressure relation witch depends of the flow and the heights as below (figure number 1, and 2, a, b, c):

Table number 1

The relative position of the point en rapport a coupling H [m]	**Volume discharged [l]**					
	4,5		**6,0**		**7,5**	
	Values of the complexes size $10^3\Pi_i$					
	Π_1	Π_2	Π_1	Π_2	Π_1	Π_2
0,5	19,6	0,508	27,8	0,667	39,8	0,840
1,0	11,4	1,436	15,7	1,915	20,4	2,390
1,5	5,8	2,639	9,07	3,519	12,1	4,399

2,0	5,2	4,063	7,30	5,418	9,10	6,770
2,5	5,4	5,679	7,32	7,572	5,40	9,465
3,0	3,33	7,465	5,00	9,950	6,76	12,440

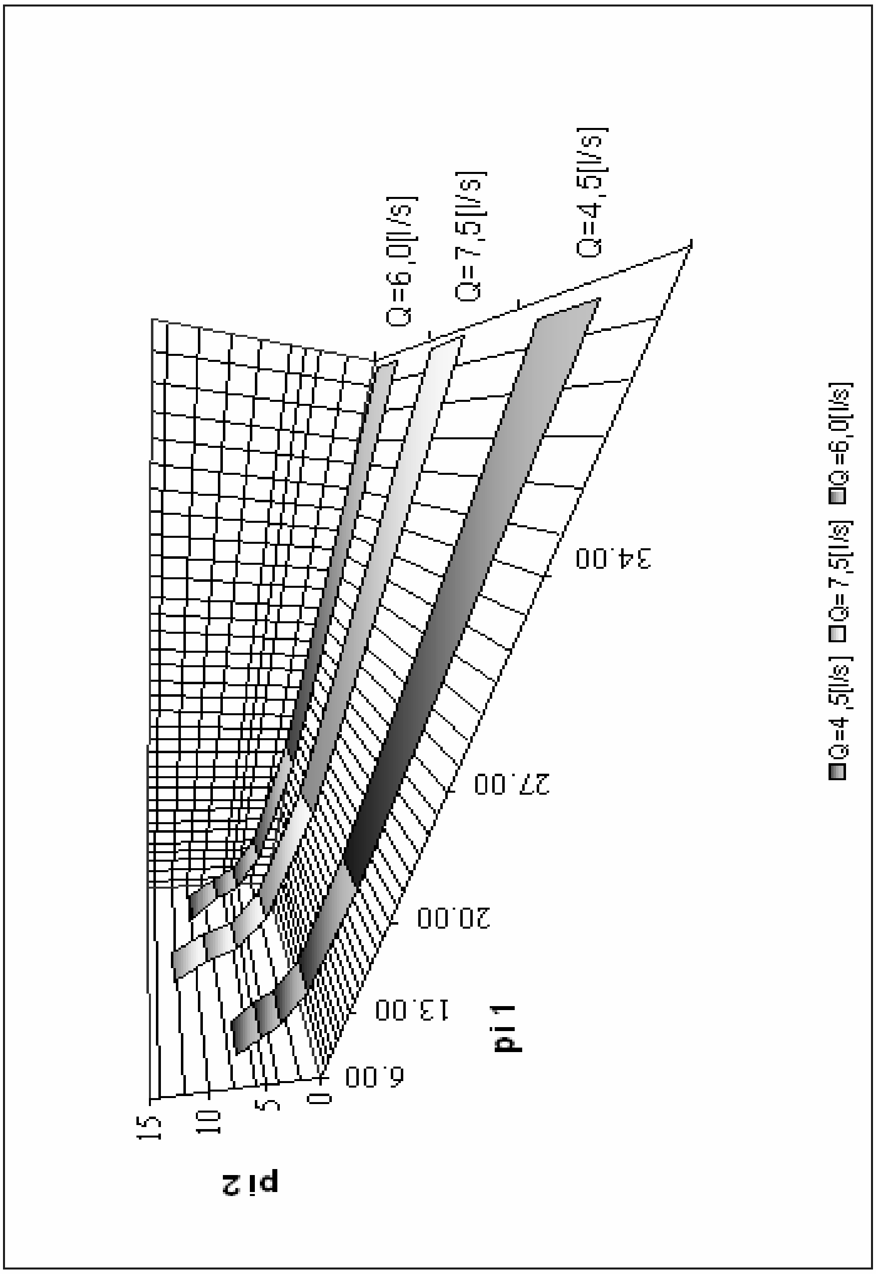


Figure number 1 : Pressure values estimation in pipes

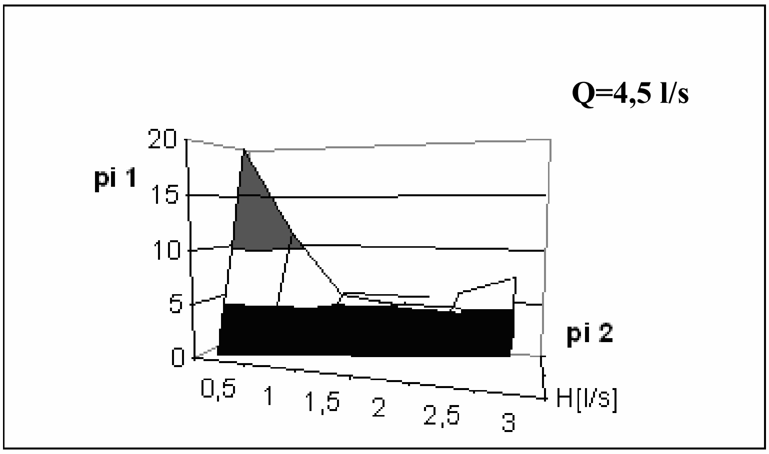


Figure number 2a

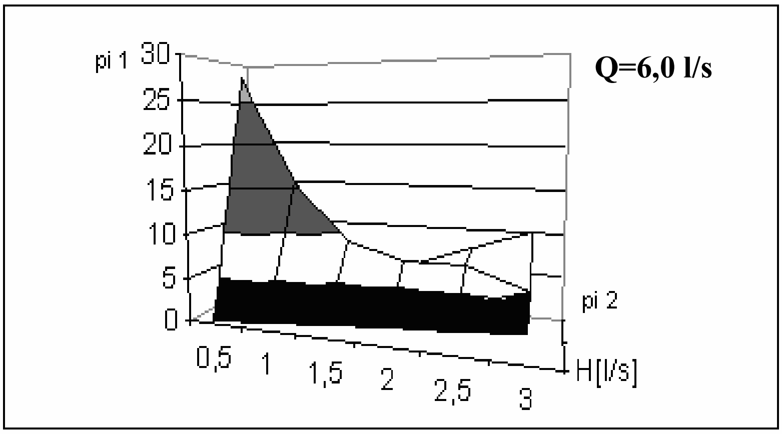


Figure number 2b

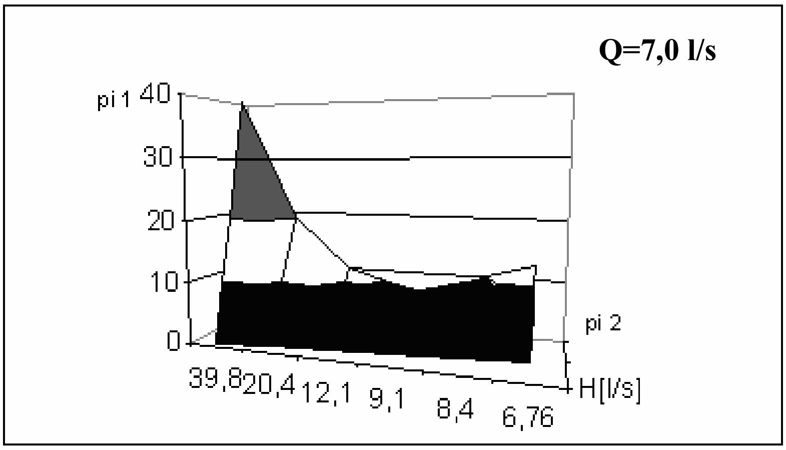


Figure number 2c

The final form of the pressure relation is determinate with optimization function's of the MATLAB soft, module OPTIM, with usual optimization algorithm.
The principe of the function evaluations is "fitting a nonlinear function to a set of data. It is the different methods (Broyden-Fletcher-Golfarb-Shanno, Davidon-Fletcher-Powell, Steepest Descent, Simplex Search, Gauss-Newton, Levenberg-Marquardt, Seq. Quadratic Progr.GAUSS) which can be used in the OPTIMIZATION TOOLBOX. It to fit the function

y = c(1)*exp(-lam(1)*t) + c(2)*exp(-lam(2)*t)

to the data. This function has 2 linear parameters c and 2 nonlinear parameters lam.

Since the function has a combination of linear and nonlinear parameters, we will separate the solving into two steps. We will use one of the optimization routines such as LSQNONLIN to solve for the nonlinear parameters, and inside our function we will use "\" to solve for the linear parameters. We write a function, called FITFUN2 that, given the nonlinear parameters lam and the data, solves for the current estimate of the linear parameters and then returns the error in the fit. Next, we provide a guess for initial estimates of the nonlinear parameters and invoke an optimization routine.

It is tested the methods presented and it is selected the method with the minima error. In the figure number 3 it present the principia the work and in figure number 4, 5, 6, it is present the function $\Pi_2=f(\Pi_2)$, for the discharged flow Q=4,5 l/s (fig. no. 4), Q=6,0 l/s (fig. no. 5), and Q=7,5 l/s (fig. no. 6).

For the height precision, this problems can extended for the function and multivariable (for multiplies complexes sizes) and we can determined the dependence relation of the principals parameter's of the flow in sewerage pipe.

In present recherché is presented the principle of the method.

The final form of the pressure relation is determinate with a limited number of experimenter's resulted. It is resulted the form

$$p = -\gamma \cdot h \cdot 9{,}6739 \cdot 10^{-3}\left(e^{\lambda_1} + e^{\lambda_2}\right) \qquad [18]$$

where:

-λ_1, $\lambda_2=f(Q)$

For 4 values of Q, we obtain λ_1 and λ_2. It follows the generalization, based on a extended program of measurements.

This forms you be enriched bye base the experiments dates in situ what were obtained in the framework of the recherché en deroulated. The recherché of the comportment of the different ipotesis we be realized with the soft specialized of the simulation the poliphases flow in pipes- SIMSCI-TACIDE and PIPEPHASE.

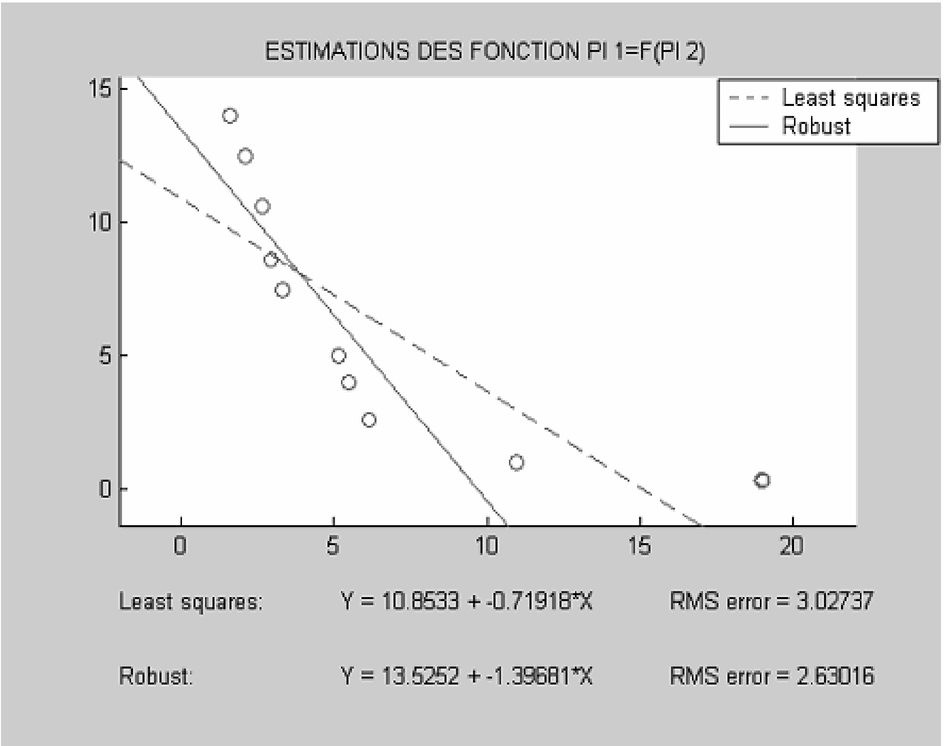
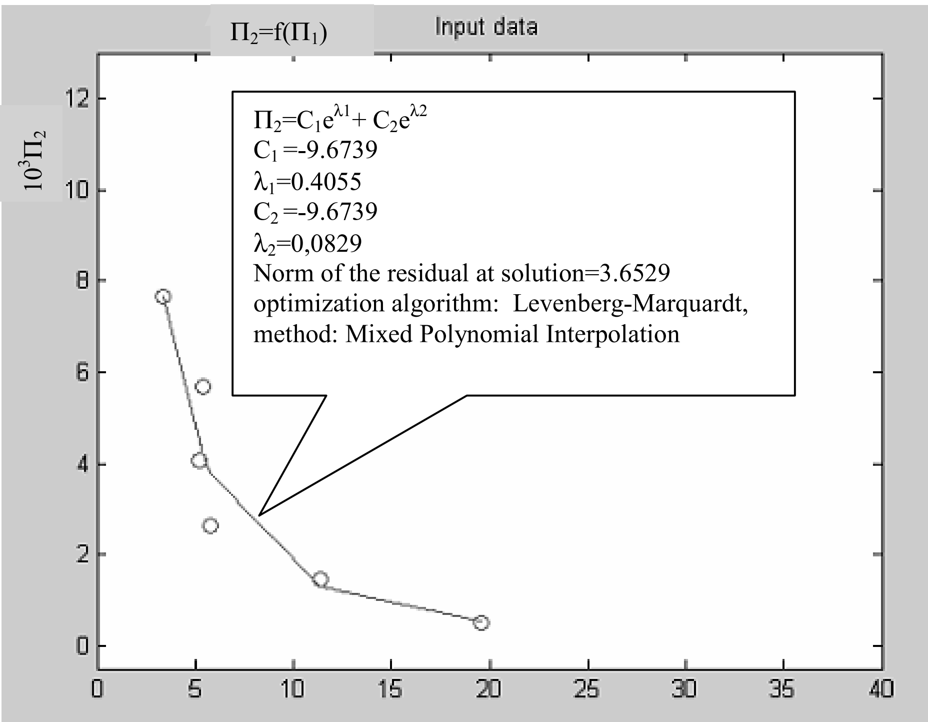


Figure number 3



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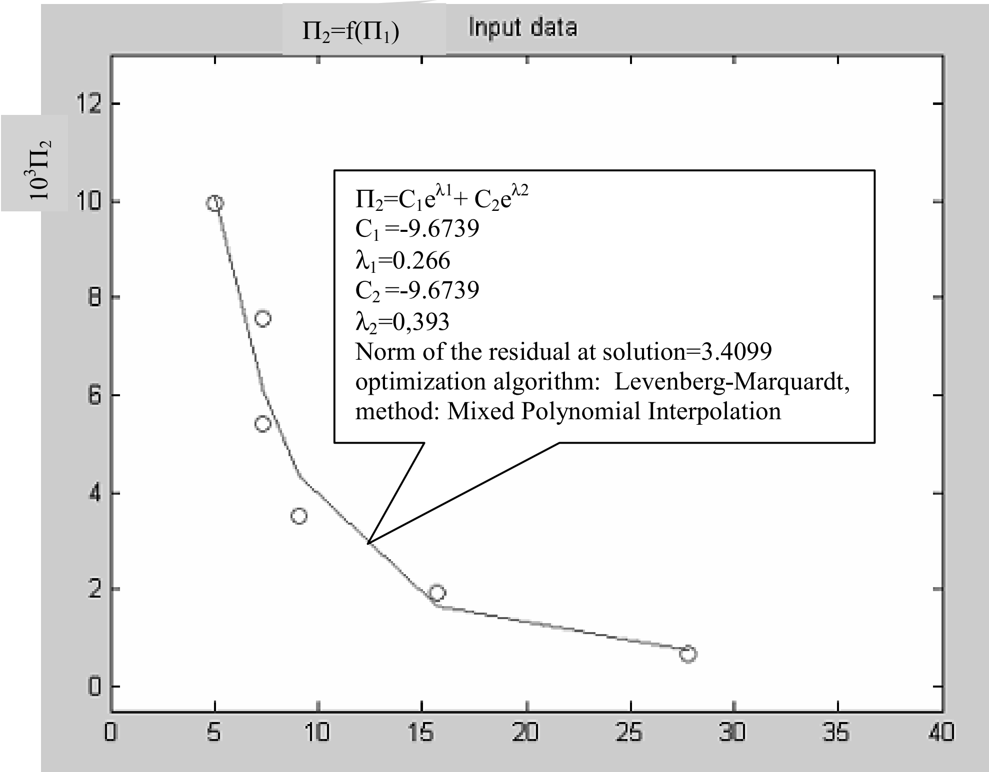

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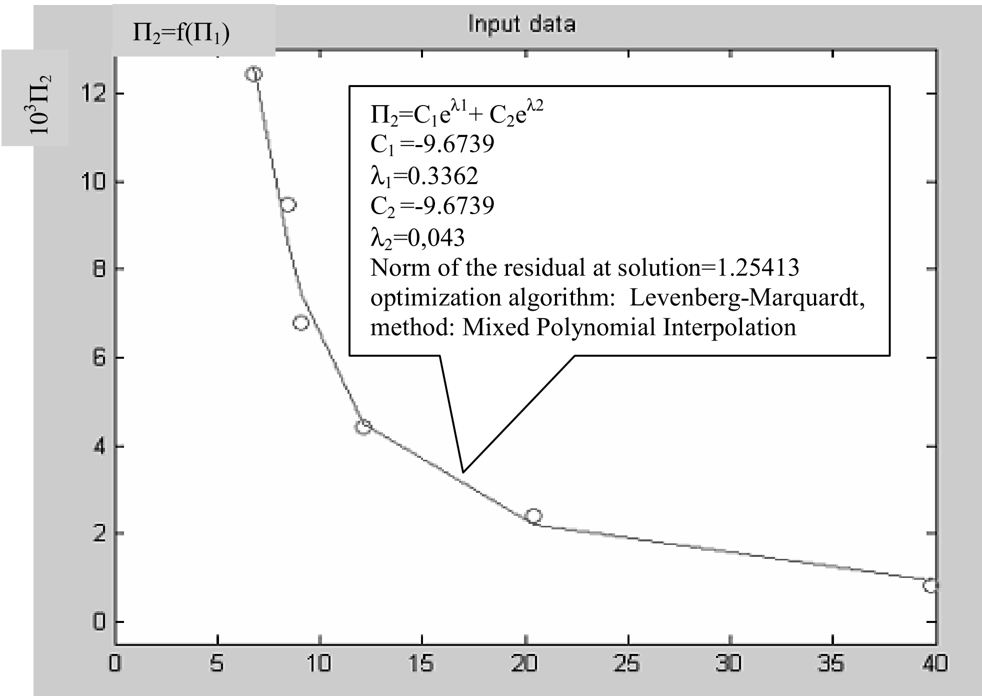

Figure number 6

3. Conclusions:

Dimensional analyses theory application for describing the complex phenomenon, offer the possibility to find some good precision relations for determinative parameters calculation in same condition of repeating.

4. References

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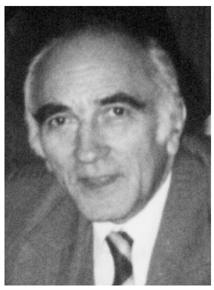

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Study of the Flow Pattern of Ground Food Waste in the Drainage Stack

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Abstract

There has been a significant increase in the number of high-rise apartments centring on metropolitan areas. One of the latest equipment systems installed into these apartments is the disposer system.

This paper describes the drainage performance of the disposer drainage system. The following are the two objectives of this study. The first concern is to clarify the flow pattern of wastewater containing food waste from a food disposer (grinder), when it runs through the stack. The second issue is to recognise the fluctuation in positive pressure caused by the collision of ground waste and wastewater, which are drained through the stack.

Keywords

drainage system with food waste grinder, drainage stack,
flow pattern, positive pressure

1. Introduction

Many high-rise and super-high-rise apartments have been built in metropolitan areas in recent years. Equally, the adoption of disposer drainage systems for these apartments has been on a rapid increase. Records show that disposer drainage systems were adopted for more than 50,000 newly-built apartments in 2003. A typical disposer drainage system comprises a disposer, a drainage pipe system and a treatment tank. The study is intended to evaluate drainage performance in relation to the disposer and the pipe system and to discuss designing methods. The fundamental review of the flow performance of the horizontal fixture drain branch system was carried out in the previous paper. The next step is to identify the influence of wastewater on the drainage performance when it flows down the drainage stack system. Drainage through the disposer contains ground food waste, wastewater and air. Ground food waste is likely to accumulate at the basal part of the drainage stack system and it collides with wastewater. The collision generates instantaneous positive pressure at a high level, which may exceed the drainage performance criteria. This is rather problematic behaviour. Nevertheless, until now, very few studies have quantitatively identified factors that contribute to the aforesaid behaviour, including consideration for drainage load conditions and pipework conditions, plus the relationship with the flow performance of ground food waste.

Taking into account the abovementioned background information, this study evaluates quantitatively, with the experiment subject restricted to the drainage stack system for high-rise apartments, the flow performance of ground food waste in the drainage stack, the formation of sediment accumulated at the basal part of the drainage stack and the level of positive pressure generated as a result. The study is also intended to identify the characteristics of wastewater through the disposer, based on the flow pattern recorded at each measuring point. The characteristics are then presented as basic data that may be useful for further studies of performance evaluation methods and designing methods of disposer drainage systems.

2. Experimentation method

2.1 Experimentation overview

The experimentation was conducted with the emphasis on the following two points:

(1) Flow pattern of wastewater in the drainage stack

The behaviour, where wastewater and ground food waste are separated while running through the drainage stack, was examined. A basic pipework model comprising only a drainage stack was used to identify different flow patterns by various water volumes in the drainage tank, which was installed to one end of the model.

(2) Characteristics of wastewater through the disposer and the formation of ground food waste accumulated at the basal part of the drainage stack

The drainage stack system was used for the basic examination of instantaneous pipe pressure, which impedes the drainage performance, and the possible influence, by the seal water performance of the trap, based on each flow pattern measured. The formation of ground food waste accumulated at the basal part of the drainage stack was observed and classified by load condition.

2.2 Experimental system

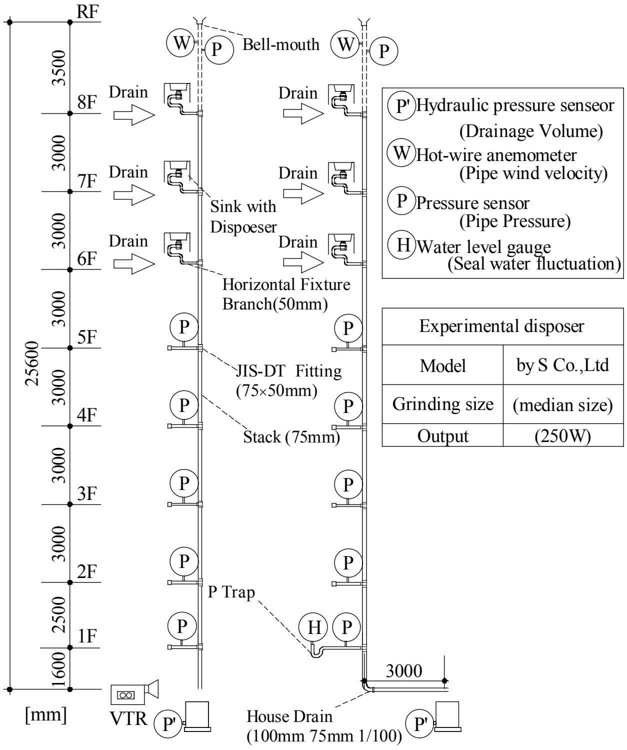
The environmental experimental construction simulation tower (25.6m high, nine storeys) at Kanto Gakuin University was used for the experimentation. The experimental system is shown in Photo 1 and Fig. 1.

The house drain was removed from the drainage stack system (shown in Fig. 1 (1)) and only the stack was used for examination 2.1 (1).

The drainage stack system (shown in Fig. 1 (2)) was used for examination 2.1 (2).

The end of the vent pipe was left open to the air. A 75A-diameter pipe was used for the drainage stack. As for the fittings, JIS-DT (50×75) was used for identifying basic characteristics of wastewater. The length of the horizontal fixture drain branch, which was connected to each floor, was specified to be 500[mm]. For the house drain, a standard pipe with a 100[mm] diameter and a 75[mm] diameter pipe to provide more severe conditions for the experimentation. More details are shown in Fig.2

Photo 1 KGU tower



(1) Drainage stack (2) Drainage stack system [mm]

Fig.1 Experimental drainage system

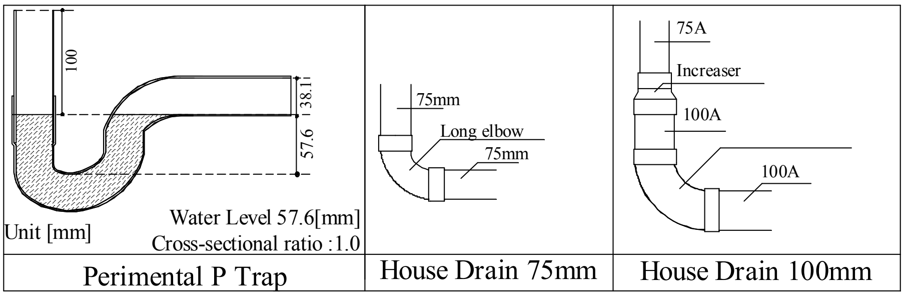


Fig.2 Experimental trap and house drain

2.3 Drainage load conditions

The disposer, its operating method and the type of kitchen waste for the previous experimentation were also used for this experimental system. Shown in Photo 2 is kitchen waste typically produced in Japan. Water was drained constantly for a period of 40 seconds. The disposer was activated 5 seconds after the start of water draining and was in operation constantly for 30 seconds. The flow rate of the water drained was increased from 4 to 6 and to 8[L/min]. Two different drainage load conditions were applied; clean water only and water combined with kitchen waste, as shown on Table 1.

As shown on Table 2, a drainage load was applied from each floor, one at a time (single drainage). It was also applied from three floors simultaneously (simultaneous drainage) in the order of an upper floor to a lower floor.

Table 1 Drainage load conditions

Draining method	Condition
1. Clean water	Apply 4, 6 and 8[L/min] of clean water each at a fixed flow rate for 40 seconds.
2. With kitchen waste	Combine the above clean water with 250g or 500g of typical kitchen waste. Operate the disposer.

Photo1 Typical kitchen waste produced in Japan (250g)

Table 2 Test pattern

Test No.		Floor No. 2	3	4	5	6	7	8
Single	1	●						
	2		●					
	3			●				
	4				●			
	5					●		
	6						●	
	7							●
Simultaneou	8	●	●	●				
	9			●	●	●		
	10					●	●	●

2.4 Items to measure

The following five items were measured at the measuring points shown in Fig.1.

(1) Pipe velocity: velocity fluctuation V_b [m/s] measured within the vent pipe

(2) Pipe pressure: measured using the small pressure sensor installed onto the horizontal fixture drain branch

(3) Trap seal water fluctuation: of the P trap located 1600[mm] from the centre of the house drain.

(4) VTR recording: of the formation of ground food waste accumulated at the bottom end of the drain stack and the flow pattern of wastewater.

(5) Wastewater volume: the water head pressure measured using the hydraulic-pressure sensor installed to the tank at the bottom end of the drainage stack, plus the end flow rate of wastewater with ground food waste, when drained from the top floor, calculated based on the water volume fluctuation.

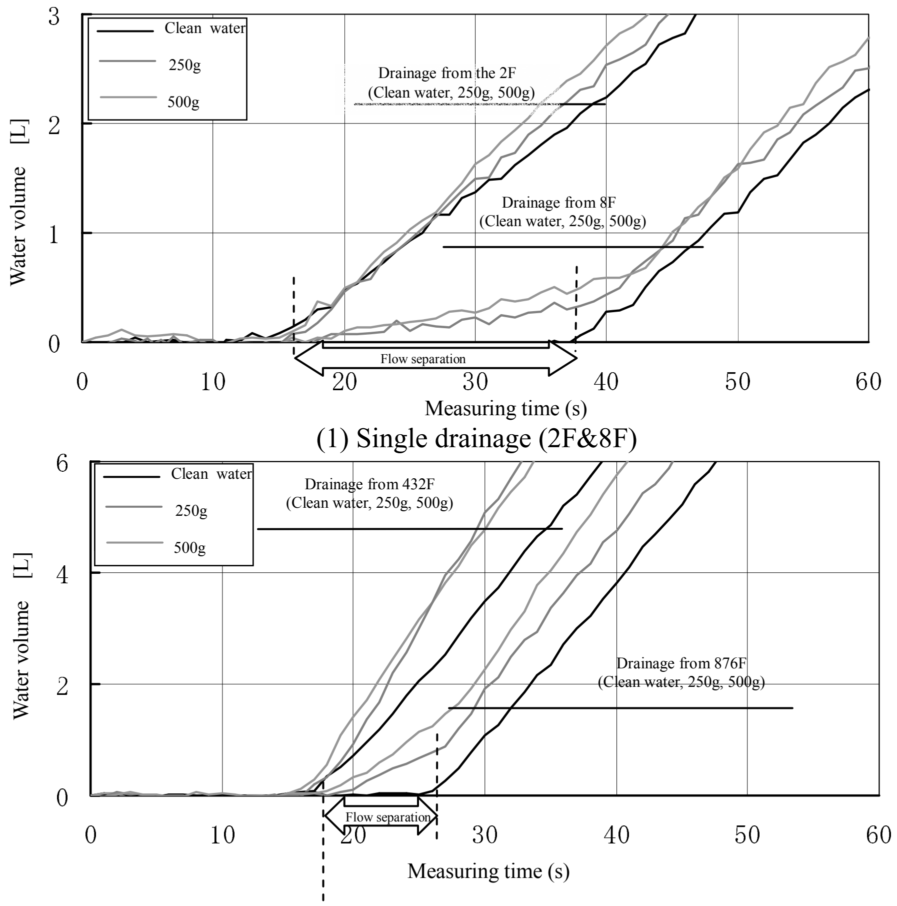
Amongst the above measurements, the data of pipe pressure measurements (2) and trap seal water fluctuation (3) were processed in accordance with SHASE-S-218 “Testing Methods of Flow Capacity for Drainage System in Apartment Houses” stipulated by the standards of the Society of Heating, Air-conditioning and Sanitary Engineering of Japan. Criteria were also set to identify obstacles to the wastewater; pipe pressure (2) must not exceed ±400Pa, trap seal water fluctuation (3) must remain at half or below of the loss value of seal water and there should be no bubbles existing in the wastewater.

3. Results and consideration

3.1 Identification of the flow pattern in the drainage stack

1) Water volume fluctuation

Illustrated in Fig.3 are different volumes of wastewater, which were measured at the end of the drainage stack (see Fig.1 (1)) when drainage loads were applied from lower floors and upper floors. Fig.3 (1) shows the results with single drainage and Fig.3 (2) with simultaneous drainage applied from three floors. As shown in Fig.3 (1), both clean water drainage and combined drainage with kitchen waste from the second floor created more or less identical wave patterns with a steady volume increase. In contrast, when the drainage loads were applied from the upper floor, the wave pattern of the wastewater with kitchen waste started off more quickly than that of the clean water drainage, although indicating a smaller increase, and both patterns later became identical but creating a significant separation between the two. This suggests that when the draining distance is approx. 4.1m from a floor, wastewater and ground food waste flow down well together whereas wastewater and ground food waste flow down separately as the draining distance becomes greater, i.e. ground food waste flows down preceding wastewater, as indicated by the wave patterns. This behaviour was confirmed by VTR verification as well as with reference to the water volume fluctuation.

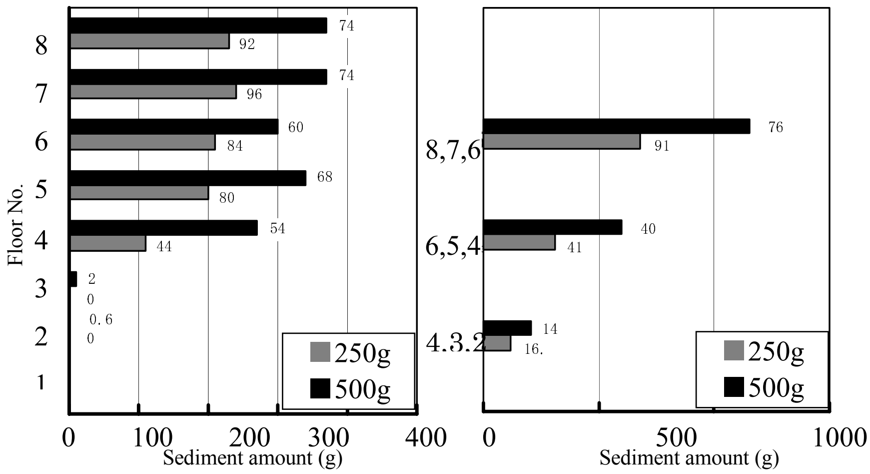


(2) Simultaneous drainage (432F, 875F)

Fig.3 Floor levels and water volume fluctuation

2) Sediment accumulation

Fig.4 exemplifies different sediment amounts that were measured at the bottom end of the drainage stack. Each sediment amount was regarded as remaining ground food waste contributing to the fluctuation of water volume, which was accumulated from the start-up time of combined drainage with kitchen waste until the start-up time of clean water as shown in Fig.2. Various accumulation ratios of kitchen waste are also stated in Fig.4. Equally to the above conclusion reached regarding the water volume fluctuation, the increase of sediment accumulation and the level of separation of ground food waste from wastewater correspond to the increase in floor level. Especially kitchen waste drained with water together from upper floors was almost completely separated from the water while flowing down the drainage stack. When a single drainage was applied from the eighth floor with 250g of kitchen waste, approx. 92% of the kitchen waste remained at the bottom end of the stack. The collision of the accumulated sediment with wastewater raises the concern that a significant air-flow resistance may be created in the house drain.



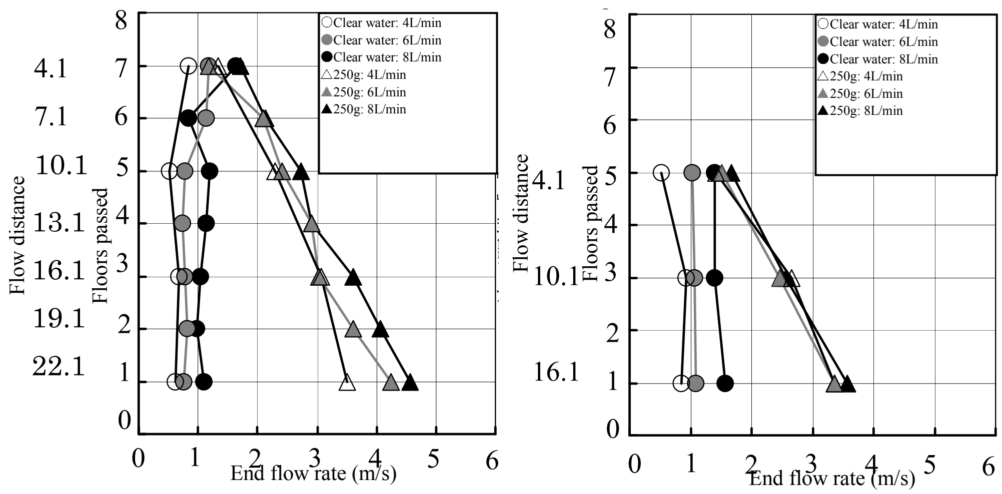
(1) Single Draina (2) Simultaneous drainage

(Figures indicate sediment accumulation ratios (%) against drainage loads applied)

Fig.4 Floor levels and sediment accumulation

3) End flow rate

Flow rates were measured at the time when ground food waste and wastewater, which were applied from different floor levels, reached the drainage tank. These flow rates are end flow rates and are translated into flow pipe lengths in Fig.5. As shown in (1), when single drainage loads were applied with different volumes of clean water, end flow rates measured 0.60[m/s] at 4[L/min] of water and approx.1.10 [m/s] at 8[L/min] of water. Wastewater through the disposer flows down the drainage stack in annular formation with less water to facilitate a smooth flow and the end flow rate corresponds to this condition. For reference, the ultimate rates Vts were calculated by applying Wily Eaton's empirical formula (1), which indicated the annular flow formation and they were 0.60[m/s] at 4[L/min] and 0.79[m/s] at 8[L/min]. The association between the ultimate flow rates and the actually measured end flow rates confirms the formation of annular flow. Meanwhile, the flow rate of wastewater with kitchen waste rocketed after it was drained down the stack and with a single drain it measured approx. 4.5[m/s] when the flow distance was 22.1[m]. This value overwhelms the flow rate of clean water drainage by nearly four times, which implies that wastewater and kitchen waste flows separately down the stack.



(1) Single drainage (2) Simultaneous drainage

Fig.5 Floor levels and end flow rates

3.2 Sediment accumulation at the basal part of the drainage stack

So far, the experimentation was conducted upon and speculations were made about the test results using a drainage stack pipe alone without a house drain. During the next experimentation, the formation of sediment accumulated around the fitting at the basal part of the drainage stack was examined and classified, as shown in Fig.6, when a house drain was installed to the experimental system. Class I shows a considerable amount of sediment accumulated close to the fitting at the bottom of the stack. Class II shows sediment remaining in the house drain section. Class III indicates very little amount of sediment, which suggests a smooth flow of drained water and ground food waste together.

Shown in Fig.7 are the results after the formation of sediment accumulation around the fitting at the basal part of the drainage stack was classified when a 75[mm]-diameter house drain was used. (1) Refers to single drainage and (2) signifies simultaneous drainage from three floors. Comparing the results in the light of water flow rates, both (1) and (2) indicate that lower water flow rates encourage sediment accumulation. In terms of floor levels, drainage from upper floors also encourages sediment accumulation. It is speculated therefore that drainage from a high-level floor at a low water flow rate causes flow separation in the drainage stack, increasing the risk of hindrance to drainage system performance. This behaviour is discussed in more detail later in this paper.

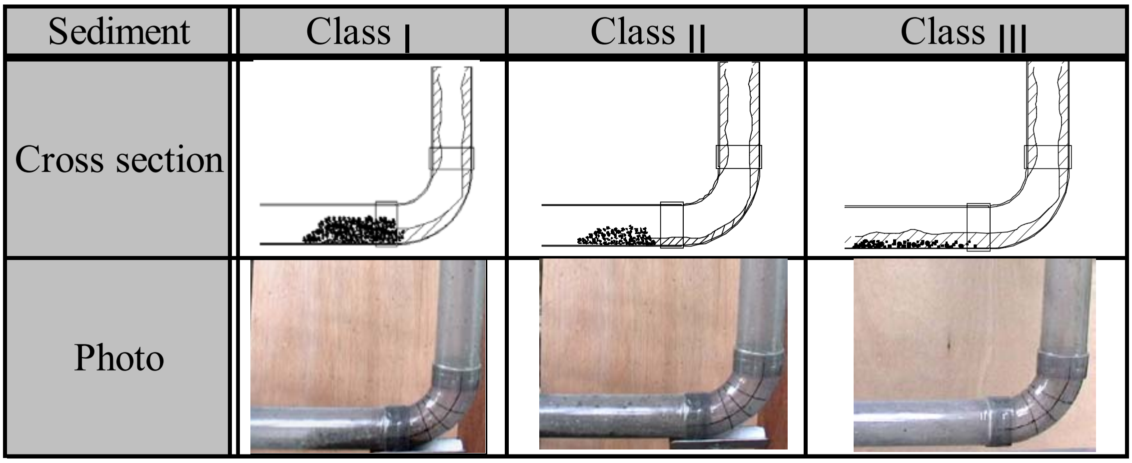


Fig.6 Classification of sediment accumulation

	Kitchen waste 250[g]			Kitchen waste 500[g]		
	Water flow rate[L/min]			Water flow rate[L/min]		
Floor No.[F]	8	6	4	8	6	4
8	II	I	I	I	I	I
6	II	II	II	II	II	II
4	II	II	II	II	II	II
2	III	III	III	III	III	II

(1) Single drainage

876	II	I	I	II	I	I
654	II	II	II	II	II	I
432	III	III	II	III	III	II

(2) Simultaneous drainage

Fig.7 Sediment accumulation by drainage load condition

3.3 Characteristics of air-flow rate and pipe pressure fluctuations

Exemplified in Fig.8 are different fluctuation patterns recorded at each floor level when 250g of kitchen waste was drained from floors 8, 7 and 6 respectively. The following speculations about the items, which were measured, were made in association with the characteristics of the disposer drainage system.

1) Air flow rate fluctuation

Fig.8 exemplifies air-flow wave patterns that were recorded when clean water and wastewater with kitchen waste were drained. The fluctuation of air-flow rates shows a steady wave pattern with the clean water drainage. In contrast, it is characteristic that the wave pattern of the combined drainage with kitchen waste indicates the maximum air-flow rate $Q_{a(max)}$. This is because ground food waste becomes separated from wastewater and flows down the stack, preceding the wastewater, as explained previously, thus absorbing a significant amount of air.

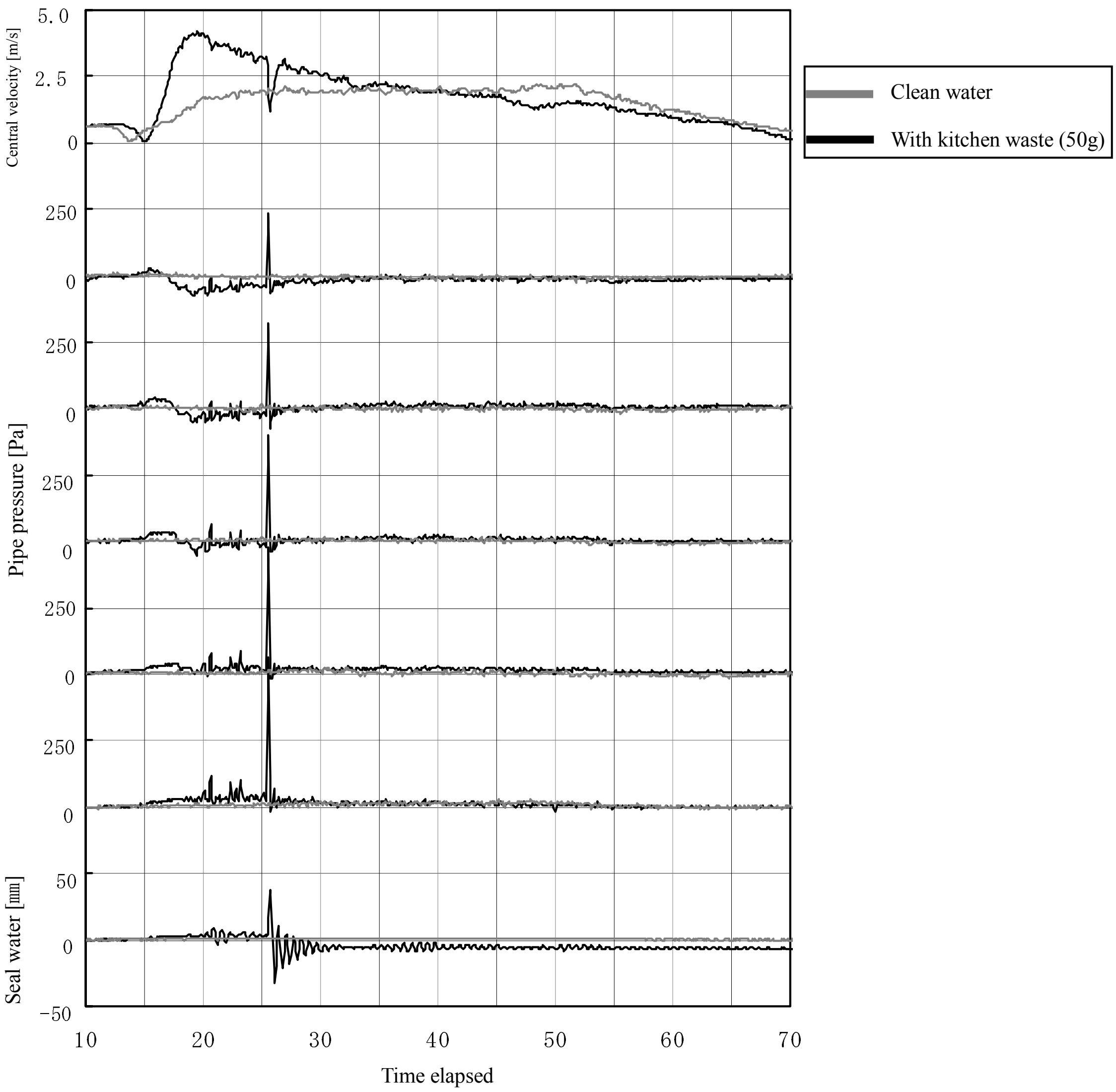


Fig.8 Examples of fluctuations

Illustrated in Fig.9 is the relationship between the water flow and the maximum air-flow rate $Q_{a(max)}$. The clean water drainage does not seem to relate to the floor level, nor does it greatly affect the water flow rate. The combined drainage with kitchen waste, however, decreases the water flow rate and increases corresponding to the floor level. $Q_{a(max)}$ also increases by 3.4 times with single drainage load and by 2.3 times with a simultaneous load, creating more loads to the vent pipe.

2) Pipe pressure fluctuation

The pressure fluctuation shown in Fig.10 was recorded when wastewater with kitchen waste was drained down the stack. Instantaneous positive pressure P_{max} was generated when the air-flow rate dropped temporarily. This suggests that a considerable amount of air absorbed temporarily, as the kitchen waste flew down the stack, was suddenly blocked by the collision between the accumulated sediment and the wastewater, which generated instantaneous positive pressure. Fig.11 shows the relationship between the water flow and instantaneous positive pressure. It is evident that the clean water drainage did not generate any pressure impeding the drainage performance. It is also apparent that the combined drainage with kitchen waste raised pressure especially when it was drained from a higher floor level with a smaller water volume.

3) Trap seal water fluctuation

Shown in Fig.12 are the fluctuations of trap seal water. In line with the generation of instantaneous positive pressure triggered by pressure fluctuation, which was explained previously, the trap seal water also indicated instantaneous changes. When the maximum positive pressure was 635.9[Pa] at a flow rate of 4[L/min], the maximum seal water fluctuation was 42.1[mm] and the minimum was 38.9[mm], caused by instantaneous positive pressure. This evokes concern about a risk of instantaneous seal breakage caused by bubbles in the flow produced by instantaneous positive pressure. However, the ultimate seal water loss was 9.0[mm], which satisfied the criteria stipulated by SHASE-S218. This demonstrates that although the seal water increases temporarily by positive pressure under severe conditions, the ultimate loss is retained within the criteria.

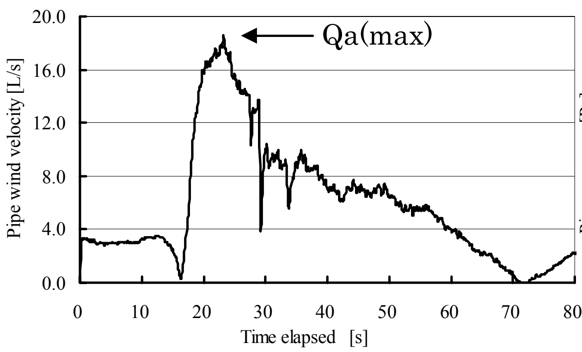


Fig.9 Pipe velocity
(8,7,6F, kitchen waste 250[g])

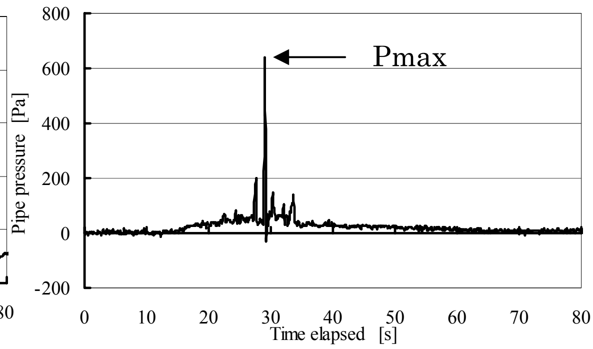


Fig.10 Pipe Pressure fluctuation
(8,7,6F, kitchen waste 250[g])

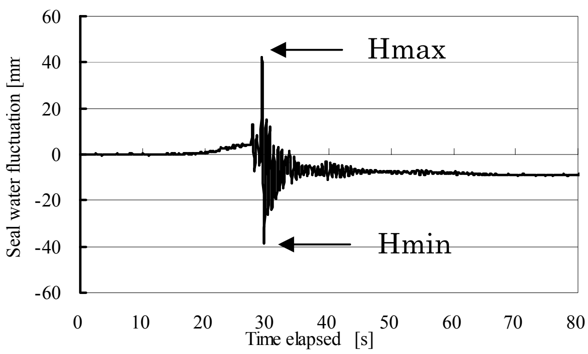
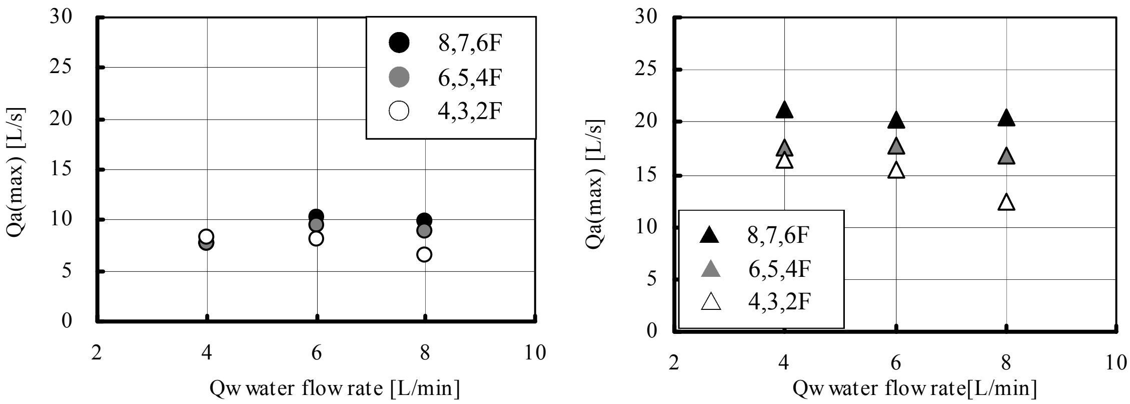
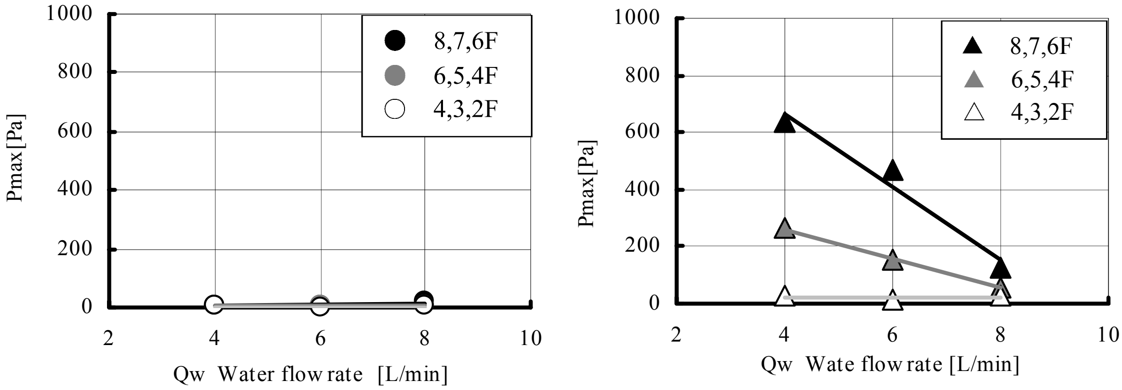


Fig.13 Seal water fluctuations
(8,7,6F, kitchen waste 250[g])



(1) Clean water (2) Kitchen waste (250[g])

Fig.10 Water flow rates and pipe air-flow rates $Q_{a\ (max)}$



(1) Clean water (2) Kitchen waste (250[g])

Fig.12 Water flow rates and Presser max (house drain 75A)

4. Summary

The experimentation using the experimental drainage stack system for high-rise apartments under controlled conditions was concluded with findings as described below:

1. The flow pattern of wastewater through the disposer in the drainage stack was examined and the flow separation between ground food waste and wastewater was identified with reference to water volume wave patterns.
2. Equally, the formation of sediment accumulation at the basal part of the drainage stack was examined and flow rates in the stack were identified.
3. Sediment accumulation was classified into three different formations in association with different drainage loads.
4. The characteristics of drainage through the disposer were recognised. The velocity fluctuation with combined drainage with kitchen waste is 2.3 to 3.4 times greater than that with clean water drainage, which contributes useful data to the designing of the end section of a vent pipe.
5. There is a risk of temporary seal breakage upon the generation of instantaneous positive pressure to a high degree, yet it has been confirmed that the ultimate loss of trap seal water still remains acceptable by the criteria.

In order to prevent the generation of instantaneous positive pressure, a sufficient size should be retained for the house drain. For the prevention of sediment accumulation at the basal part of the drainage stack, it is considered that a water flow rate of 8[L/min] is required and water and ground food waste should be mixed well so as to facilitate a smooth flow.

Reference

Listed below are the styles for referencing

1. SHASE-S-218-1999 (Heating, Air Conditioning and Sanitary Standard), The Society of Heating and Air conditioning and Sanitary Engineering of Japan (2000.3)
2. Keeping maintenance of disposer drainage system, Public Health Research of Ibaraki Pharmaceutical Association (2004.3)
3. SHASE-HASS206-2000 ; The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan
4. The Building Center of Japan; Development of Raw Garbage Recycling System Using a Food Waste Grinder (1999)

Personal date of authors

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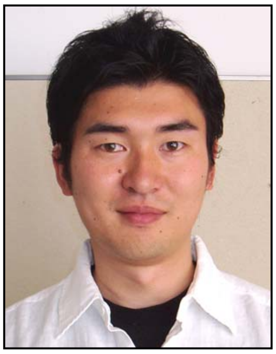

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Proposal of the Flow Capacity Prediction Method for Drainage Systems
Considering the Influence of Combined Drainage Loads inside House Drains

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Synopsis

SHASE-S218 is a "Testing Method of Flow Capacity for Drainage Systems in Apartment Houses.", which is stipulated by the standards of the Society of Heating, Air-conditioning and Sanitary Engineering of Japan. This testing method has been developed using drainage system models with very basic pipe structures whereas in actual buildings, drainage systems each comprise rather complex pipe structures with multiple stack systems connected to one large-diameter house drain. SHASE-S218 intends to identify the flow capacity of a standard drainage system model, often on the basis of negative pressure generated at upper levels of the system model as wastewater is drained through its pipe structure. In actual buildings, it is more likely that wastewater is drained simultaneously through several stack systems that are all connected to one house drain. Drainage flows therefore become combined and generate instantaneous positive pressure to an excessive degree, which affects the performances of each stack system and the house drain (allowable flow rates). Global-scale research studies centring on CIBW62 have gradually shifted their attention from the identification of negative pressure generated at upper levels of drainage systems to the understanding of the mechanism of instantaneous positive pressure generated at lower levels. They have made important steps in developing preventative measures against such pressure. This research study aims to discuss and establish a preventative measure against instantaneous positive pressure by predicting its degree when generated by drainage flows through stacks and combined in the house drain. Stated below are the focal points of the research study.

(1) Proposition of an experimental apparatus that creates combined drainage loads in the house drain in order to highlight the importance of understanding positive pressure.

(2) Further exploration of the proposed prediction method in order to stabilise its reliability using combined drainage loads, based on which the maximum value of instantaneous positive pressure generated at lower floor levels is identified.
(3) Proposal of a relaxation technique of drainage load in the house drain and the demonstration of its effectiveness through experimentation.

Keywords:
Drainage stack system, combined drainage loads, house drain, instantaneous positive pressure, flow capacity.

1. Introduction

As previously mentioned, SHASE-S218 is used for testing the flow capacity of drainage systems in Japan and as illustrated in **Fig.1,** the configuration of a typical drainage system (drainage stack system) comprises a vent pipe, a drainage stack and a 5-meter-long straight house drain pipe (primary house drain). In contrast, **Fig.2** exemplifies the structure of a drainage system actually used in real buildings. It comprises several drainage stack systems connected to a house drain (secondary house drain), the diameter of which is larger than that of the primary house drain.

Hence, SHASE-S218 is considered to be a testing method to determine the flow capacity essentially required for drainage systems (reference flow capacity). There is very little resistance identified in the house drain and therefore positive pressure generated at lower floor levels is of a very low degree. The flow capacity of a drainage system is conventionally determined by the degree of negative pressure (maximum value) generated at higher floor levels. In actual buildings, however, combined drainage flows have a rather large influence on the secondary house drain, increasing a risk of burst seal water at lower floor levels due to a sudden generation of positive pressure to an excessive degree. It is therefore vital to understand such influence over the flow capacity by predicting the maximum value of positive pressure generated by combined drainage loads. Furthermore, damage caused by burst seal water due to the generation of positive pressure rather than negative pressure is severe, creating an awful stench and a back flow. From this point of view, the authors of this paper have always stressed the importance of predicting positive pressure values.

Firstly, the research study suggests that the use of the building environment simulation tower at Kanto Gakuin University, to which the authors are attached, and an adjacent building as an experimental apparatus of combined drainage loads is suitable to execute the proposed prediction method. The apparatus combines drainage flows from multiple stack systems in the secondary house drain section.

Secondly, the research study explores further development on the stack pressure prediction method, proposed by the authors, so as to estimate the maximum value of positive pressure of combined drainage loads in the secondary house drain. Prediction results produced by using the above are compared with actual measurements in order to seek the effectiveness of the new prediction method.

Finally, the research study proposes a relaxation technique of maximum positive pressure, which makes a key point in the evaluation of combined drainage loads, as well as identifying the effect of the technique.

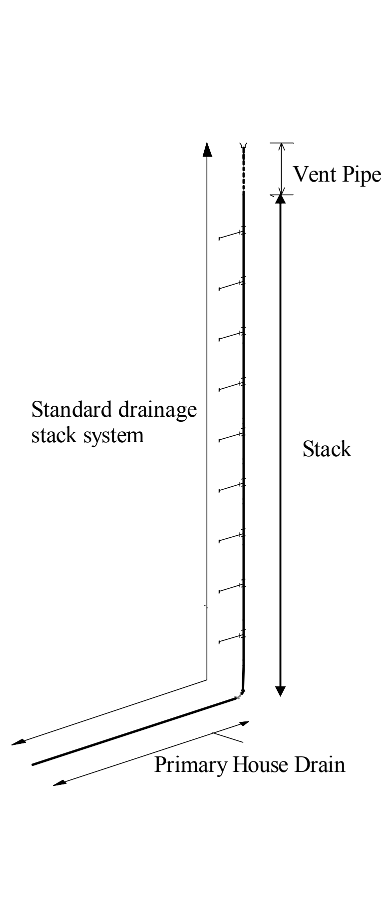


Fig.1 Drainage Stack System
(SHASE-S218)

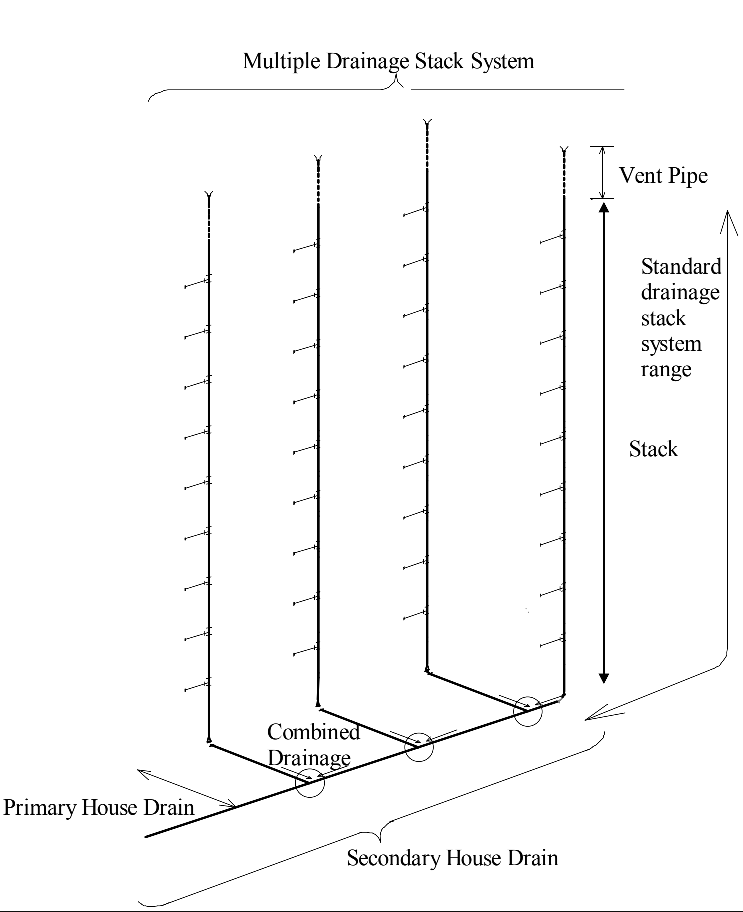
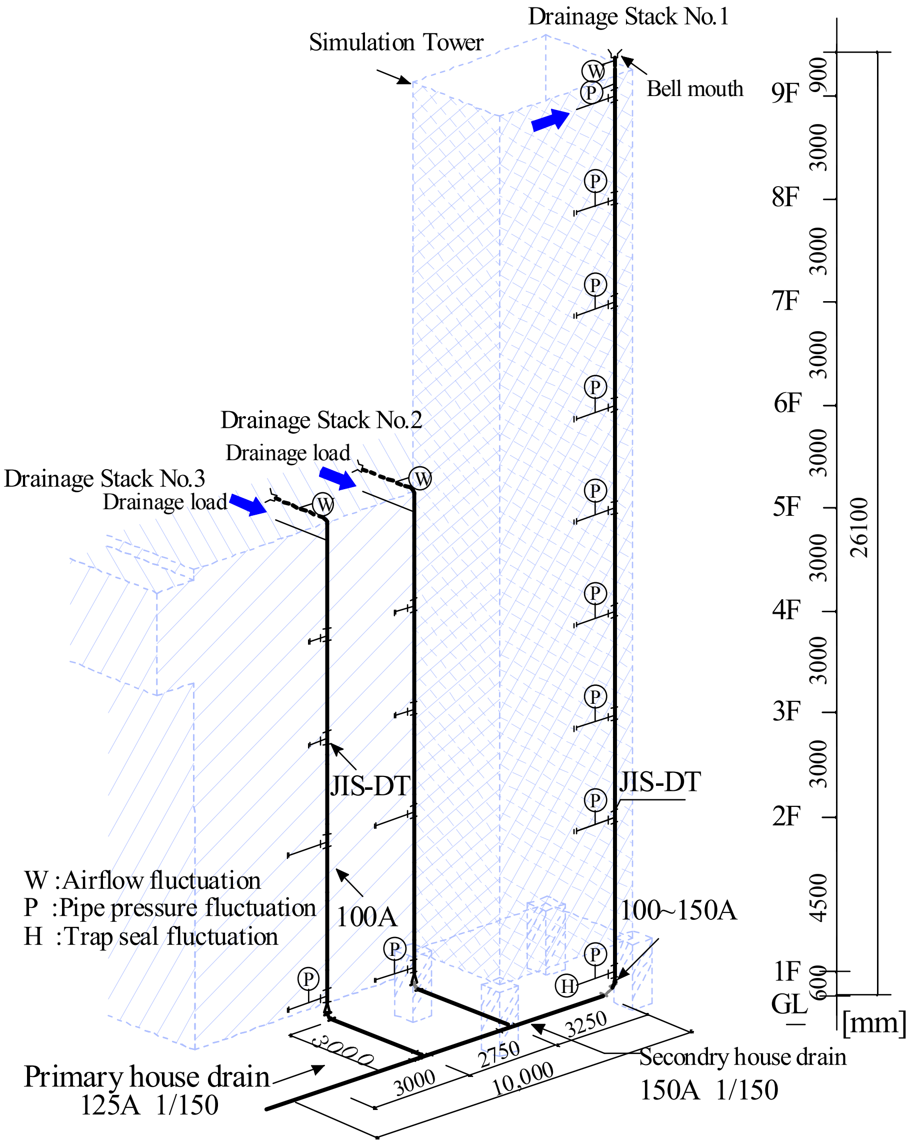


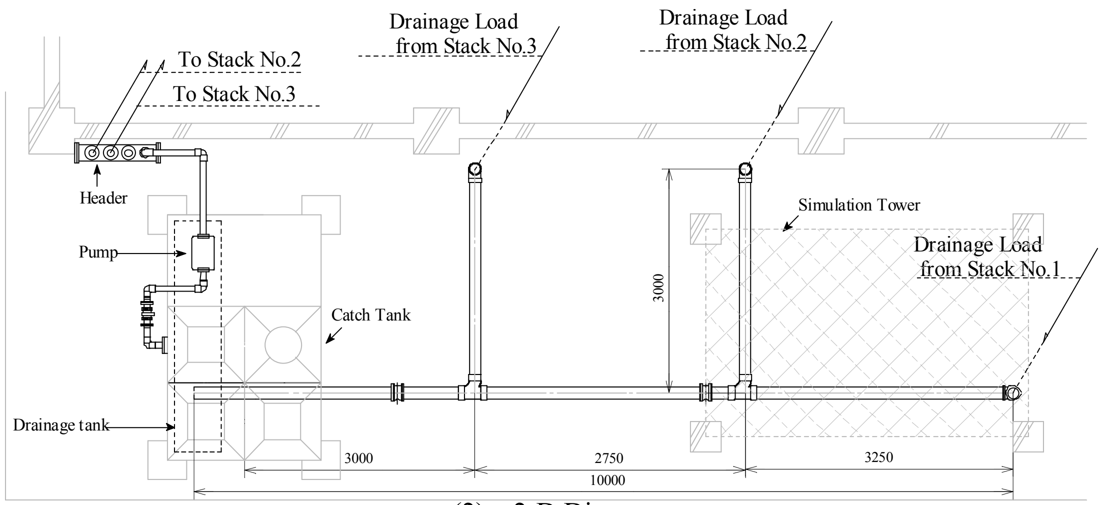
Fig.2 Drainage system used in actual buildings
(of housing complex)

2. Outline of the combined drainage loads experimentation

Illustrated in **Fig.3** is the schematic diagram of an apparatus and the 2-D diagram of a house drain used for the combined drainage loads experimentation. The experimental apparatus comprises a drainage stack system (No.1), which is the main unit, the secondary house drain, which is connected to the stack system and stacks (No.2 and No.3), which are installed 3.25m and 6.0m respectively above the secondary house drain. For the experimentation, drainage loads were combined according to the rated flows and load combinations specified on **Table 1**. They were drained through the stacks from the top floor level. Measurements were recorded on airflow rate fluctuation W in the vent pipe, pipe pressure fluctuation P at each floor level and trap seal water fluctuation H at the 1st floor (see **Fig.3**). The specifics of the test drainage system and trap are shown on **Table 2**.



(1) Schematic Diagram



(2) 2-D Diagram

Fig.3 Combined Drainage Loads Experimental Apparatus

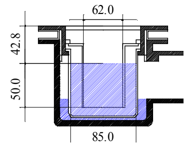
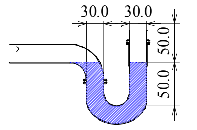
Table 1 Drainage Load Flow Pattern

	Rated Flow Load [L/s]							
Drainage Stack No.1	1.0		1.5		2.0		2.5	
Drainage Stack No.2	1.0～2.5	-	1.0～2.5	-	1.0～2.5	-	1.0～2.5	-
Drainage Stack No.3	-	1.0～2.5	-	1.0～2.5	-	1.0～2.5	-	1.0～2.5

Note: at 0.5[L/s] intervals

Table 2 Test Pipe and Trap

Drainage Stack	Diameter 100[mm](VP),JIS-DT Fitting
Primary House Draine	Diameter125[mm](VP)
Secondary House Drain	Diameter150[mm],125[mm](VP),JIS-LT Fitting
Standard Floor Level	3000[mm]
1F– 2F Level	4500[mm]
Draining Floor 9F	9F

	Installed to the house drain at 1F (se the diagram)	
Test Trap		
	Water machine floor drain trap	Lavatory P Trap
	Ratio of cross-sectional area=0.82	Ratio of cross-sectional area=1.0

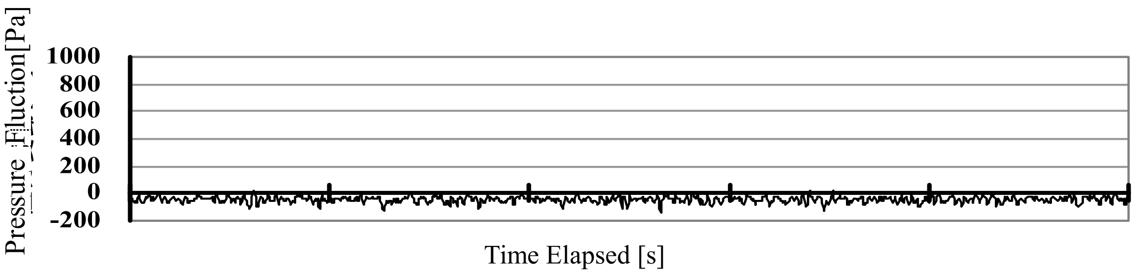
3. Pressure prediction model and pressure prediction

3.1 Prediction method of Pave(max) and Pave(min) of mean pressure

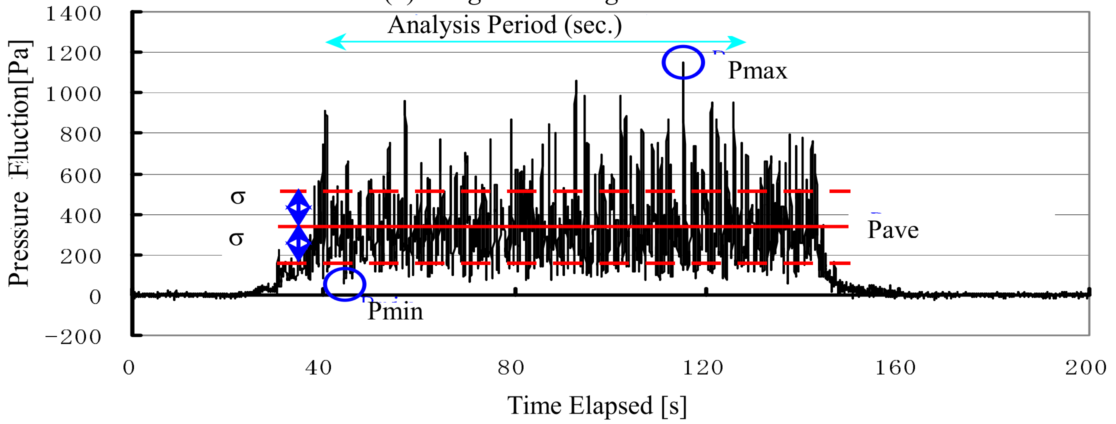
Fig.4 exemplifies wave patterns of pipe pressure fluctuations, with or without combined drainage loads, recorded at the bottom floor. With combined drainage loads, the wave pattern indicates clearly the sudden generation of positive pressure, implying a high risk of burst seal water.

Fig.5 describes pressure distributions including maximum pressure values Pmax, minimum pressure values Pmin and mean pressure values Pave according to pressure fluctuations measured at each floor level. The pressure distributions are divided further into certain regions, as referred to the previous paper (sections (3) and (5)), which are regions 1, 2, 3 and 5 (resistance regions) and section 4 (suction region). A balance equation is developed when pressure distributions in all the regions are assumed to be even. The definition of each region refers to the previous paper. **Fig.6** shows pipe network models to combine drainage loads using two drainage stack systems No.1 and No.2. Calculation formulae are listed on **Table 3**.

The distinctiveness of the proposed pressure prediction method is that a balance equation is calculated from simultaneous equations between two drainage stack systems whereas a conventional prediction method uses a balance equation applied to the simultaneous equation of each individual drainage stack system. Moreover, the proposed prediction method enables the calculation of a balance equation involving simultaneous equations of three drainage stack systems. The method is explained by applying drainage loads from drainage stack systems No.1 and No.2. This means that region 5 (resistance region) of the house drain becomes affected by the combined drainage loads from the above stack systems. Airflow-resistance coefficients of region 5 of the stack systems are defined as $\zeta_{5\text{-}1}$ and $\zeta_{5\text{-}2}$. Air-flow rates measured in the stack systems at the time of applying combined drainage loads are Qa1 and Qa2 and a total air-flow rate between the two systems is defined as Qa. Simultaneous equations of stack system No.1, (5) (f (Qa1, Qa2)), and stack system No.2, (6) (g (Qa1, Qa2)) are calculated and Qa1 and Qa2 are predicted in order to acquire Pave(max) and Pave(min).

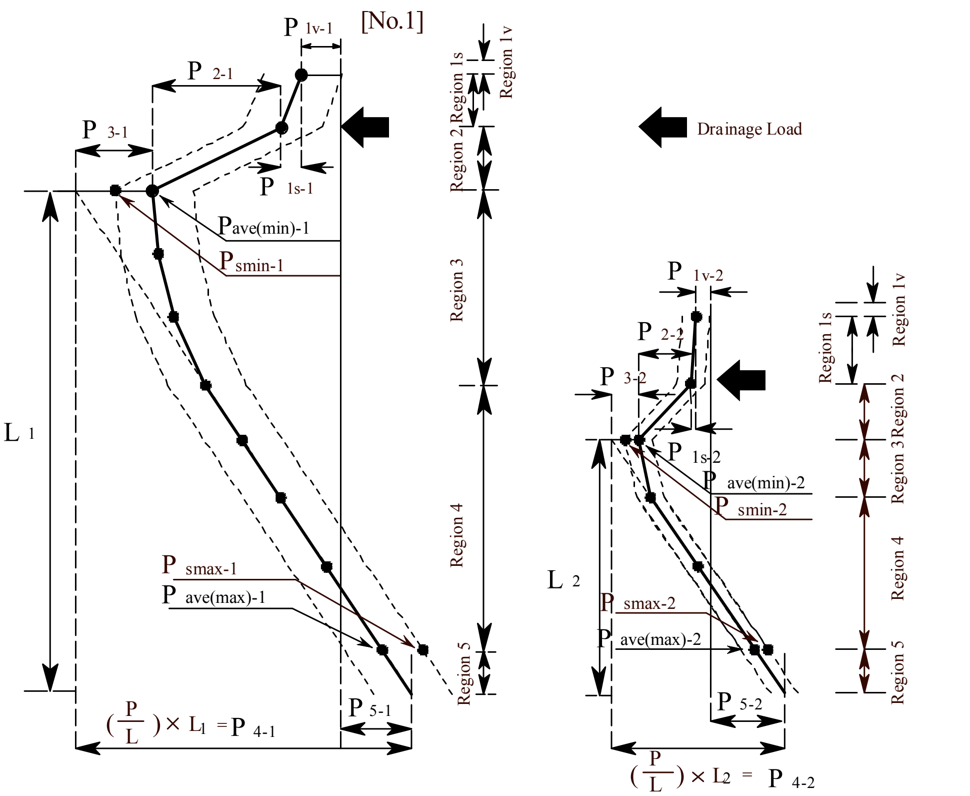


(1) Single Drainage



(2) Combined Drainage Loads (from two stack systems)

Fig.4 Pipe Pressure Fluctuations - Examples



(1) Model of drainage stack No.1

(2) Model of drainage stack No.2

Fig.5 Pressure Distribution Models

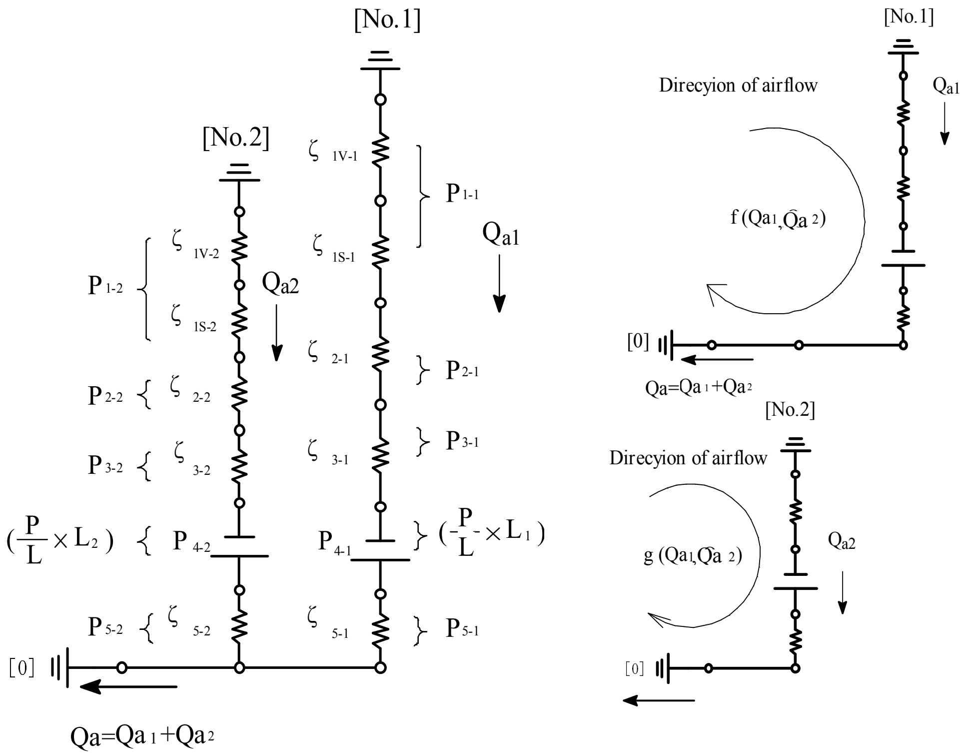


Fig.6 Model of Combined Drainage Loads from Two Stack Systems

Table 3 Formulae of Combined Drainage Loads Pipe Network

$$\frac{P}{L}=AQai+B \cdots(1) \qquad Pn\text{-}i=\zeta n\text{-}i\times\frac{\rho}{2}\times\left(\frac{Qai}{As}\right)^2 \cdots(2)$$

$$P_{1V\text{-}i}=\zeta_{1V}\text{-}i\times\frac{\rho}{2}\times\left(\frac{Qai}{As}\right)^2 \cdots(3) \qquad P1s\text{-}i=\zeta 1s\text{-}i\times\frac{\rho}{2}\times\left(\frac{Qai}{As}\right)^2 \cdots(4)$$

$$f(Qa1,Qa2)=\left(\left(\frac{P}{L}\right)\times L_1\right)-(P_{1\text{-}1}+P_{2\text{-}1}+P_{3\text{-}1}+P_{5\text{-}1})\cdots(5)$$

$$g(Qa1,Qa2)=\left(\left(\frac{P}{L}\right)\times L_2\right)-(P_{1\text{-}2}+P_{2\text{-}2}+P_{3\text{-}2}+P_{5\text{-}2})\cdots(6)$$

$$\boxed{\begin{array}{l}\left(\left(\frac{P}{L}\right)\times L_1\right)\leftarrow P4\text{-}1\\ \left(\left(\frac{P}{L}\right)\times L_2\right)\leftarrow P4\text{-}2\end{array}}$$

$$P_{5\text{-}1}=\zeta_{5\text{-}1}\times\frac{\rho}{2}\times\left(\frac{Qa1+Qa2}{As}\right)^2\cdots(7)$$

$$P_{5\text{-}2}=\zeta_{5\text{-}2}\times\frac{\rho}{2}\times\left(\frac{Qa1+Qa2}{As}\right)^2\cdots(8)$$

P/L : Suction per 1 m [Pa/m]	ρ : Air-tightness [kg/m^3]
A,B : Constant per drainage load flow rate	As : Drainage stack cross-section[m^2]
$P_{n\text{-}i}$: Pressure loss per region [Pa]	A_H : House drain cross-section [m^2]
$\zeta_{n\text{-}i}$: Airflow-resistance coefficient per region	Li : Stack length to the balance point
$P_{1V\text{-}i}$: Vent end pressure loss [Pa]	Qai : Vent airflow rate [m^3/s]
$\zeta_{1V\text{-}i}$: Vent resistance coefficient	$P_{5\text{-}i}$: Suction [Pa],
$P_{1S\text{-}i}$: Vent linear section pressure loss [Pa]	n : Region No.(1,2,3,5)
$\zeta_{1V\text{-}i}$: Vent end resistance coefficient	i : Drainage stack No.1 or No.2

3.2 Prediction of Psmax and Psmin

SHASE-S218 defines the maximum and minimum pressure, Pmax and Pmin, which are generated within a drainage stack system and which are measured at each floor level, to be the **maximum system pressure** (Psmax) and the **minimum system pressure** (Psmin). SHASE-S218 also specifies the pressure reference to be ±400Pa and determines flow capacity by the maximum possible drainage flow rate. Based on previously calculated Pave(max) and Pave(max) and standard deviations of pressure fluctuation σ1 and σ2, Pamax and Psmin are acquired using formulae (8) and (9). N1 and N2 are experiment constants.

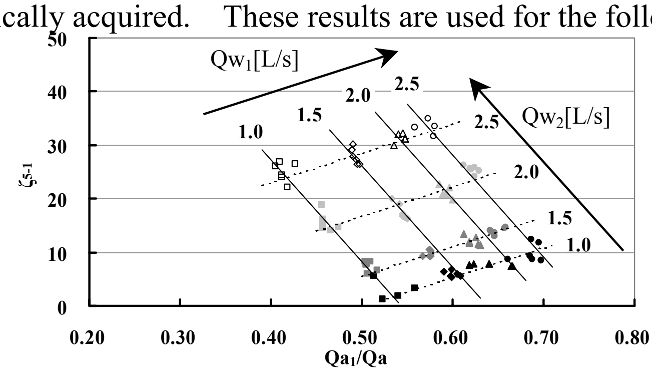
Psmax＝Pave（max）＋σ1×N1……………(8)

Psmin＝Pave（min）＋σ2×N2 ……………(9)

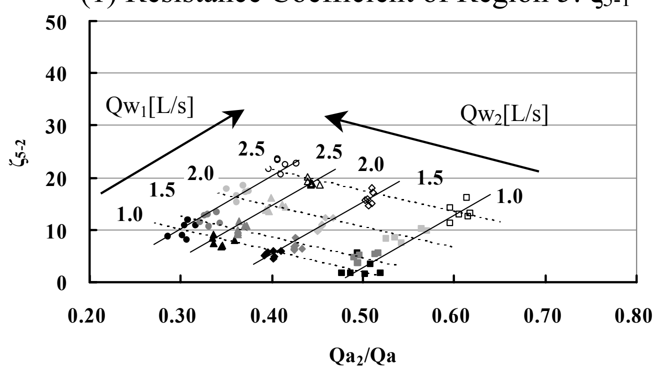
4. Results and speculation

4.1 Combined flow resistance of the house drain

A key analysis point is to acquire the combined flow resistance of the house drain. **(1) and (2)** in **Fig.7** show the ratios of airflow rates Qa1 and Qa2 of two stacks against airflow resistance coefficients $\zeta_{5\text{-}1}$ and $\zeta_{5\text{-}2}$ of region 5, where drainage flows are combined, plus a total airflow rate Qa (airflow ratios (Qa1/Qa) and (Qa2/Qa)). All degrees of drainage load flow rates QW1 and QW2 are also plotted on the graphs. The quantitative data on ratios between airflow resistance coefficients $\zeta_{5\text{-}1}$ and $\zeta_{5\text{-}2}$ of region 5 and airflow rates under different conditions of combined drainage loads have been mathematically acquired. These results are used for the following computations.



(1) Resistance Coefficient of Region 5: $\zeta_{5\text{-}1}$

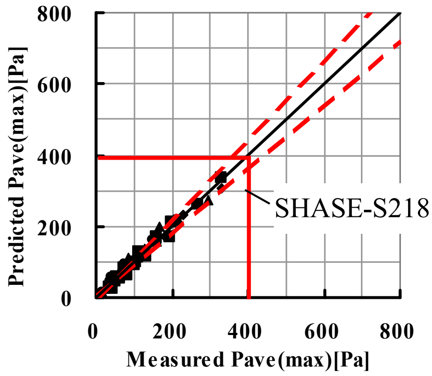


(2) Resistance Coefficient of Region 5: ζ_5-2

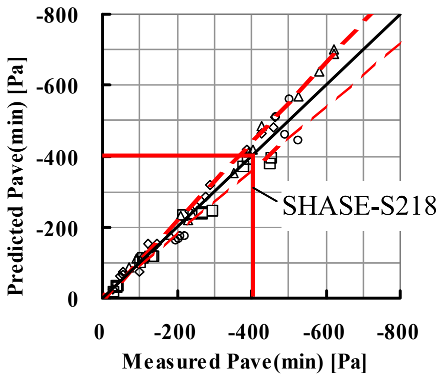
Fig.7 Resistance Coefficients of Region 5 (combined drainage loads from two stack systems)

4.2 Prediction of Pave(max) and P ave(min)

Airflow resistance coefficients $\zeta_{5\text{-}1}$ and $\zeta_{5\text{-}2}$ of region 5 were acquired in 4.1, which were applied to each formula shown on Table 3 in order to predict Pave(max) and Pave(min). **Fig.8 (1)** and **(2)** show comparisons between the predicted values and the values actually measured. The possibility of the close matching of predicted Pave(max) and Pave(min) to measured values has been demonstrated.



(1) Predicted Pave(max)



(2) Predicted Pave(min)

Fig.8 Average Pipe Pressure Values (Pave(max) and Pave(min)) by Prediction (between two stack systems)

4.3 Prediction of Psmax and Psmin

Fig.9 clarifies the relationship of standard deviation σ with Psmax, Psmin, Pave(max) and Pave(max). By applying formulae (1) and (2), the results N1=4.7 and N2=-2.9 were acquired. **Fig.9** also includes the results with the application of a single drainage from stack system No.1 (not joined by another drainage load from another stack system) and N1 required for calculating Psmin can be regarded as -2.9 with or without combined drainage loads. However, N1 required for acquiring Psmax is 4.7, which is nearly twice as high as 2.4 with the application of a single drainage. This implies that compared to when a single drainage is applied, pipe pressure fluctuation becomes more extreme with the application of combined drainage, which means that there needs to be an evaluating method of positive pressure different from that of negative pressure. Shown in **Fig.10 (1)** and **(2)** are comparisons between Psmax and Psmin predicted by applying formulae (1) and (2) and actual measurements. The accuracy of predicted results against the actually measured values has been demonstrated.

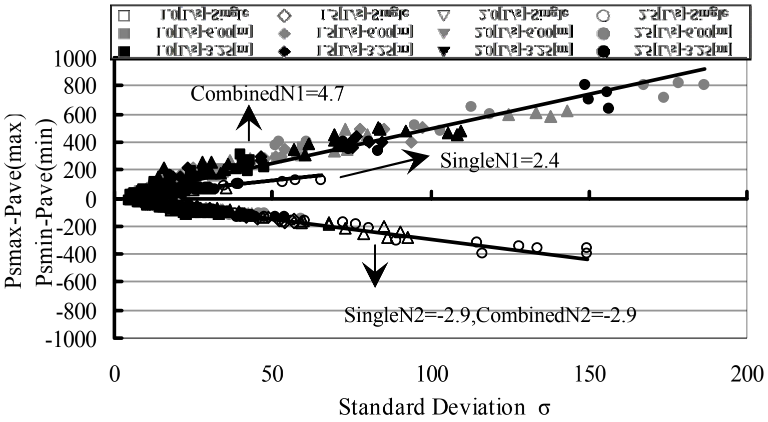
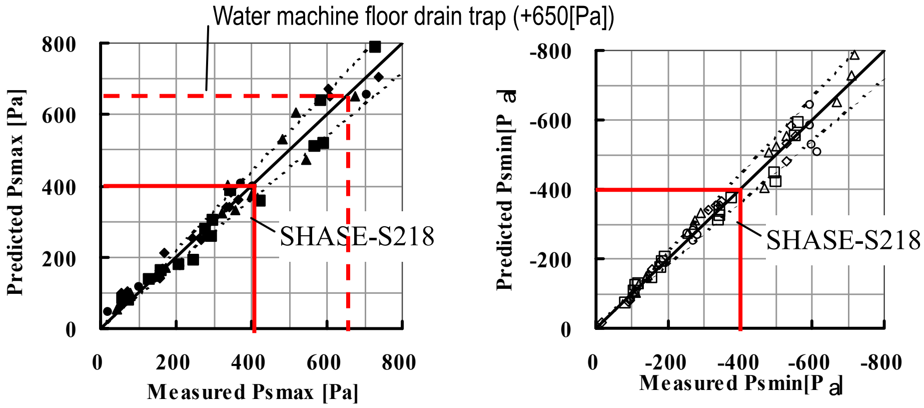


Fig.9 Psmax, Psmin and Standard Deviation (between two stack systems)



(1) Predicted Psmax (2) Predicted Psmin

Fig.10 System Pressure Values (Psmax and Psmin) by Prediction (between the stack systems)

4.4 Flow capacity curve

Fig.11 shows a total drainage load flow rate ∑Qw measured in the secondary house drain where drainage flows were combined, and Psmax and Psmin predicted in stack system No.1 against actual measurements. The reference range is also shown between ±400Pa, specified SHASE-S218, and +650Pa, a new breakage point for bathroom P-traps. SHASE-S206 stipulates the minimum pitch for 125mm-diameter house drains to be 1/150 where the allowable flow rate is 4.2L/s, and when the pipe pitch is 1/100, the allowable flow rate is 5.1L/s, thus the predicted values correspond to the actually measured values very well. However, with +400Pa as a reference, the allowable flow rate of house drain becomes 3.5L/s approx., falling to well below SHASE-S206-specified 4.2L/s.

Fig.12 illustrates, for reference, the relationship between ∑Qw and Psmax as well as the relationship between the trap water level fluctuation and the maximum value of Hmax. Trap water bursts above a pressure level of +650Pa but not around +400Pa. This suggests the revision of allowable levels for positive pressure more accurately stipulated as well as the development of traps with improved water-sealing performance. There is also a necessity for developing an adjusting method of the standard flow capacity for drainage stacks while taking into account loads created by combined drainage flows, plus a designing method of the secondary house drain.

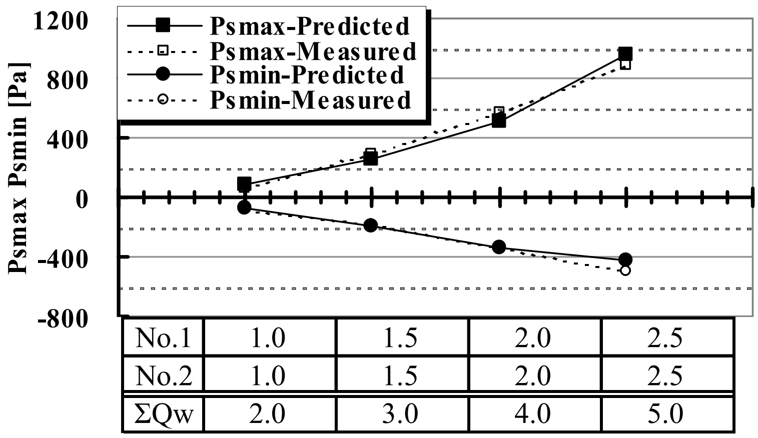


Fig.11 Flow Capacity Curve (Drainage Stack System No.1)

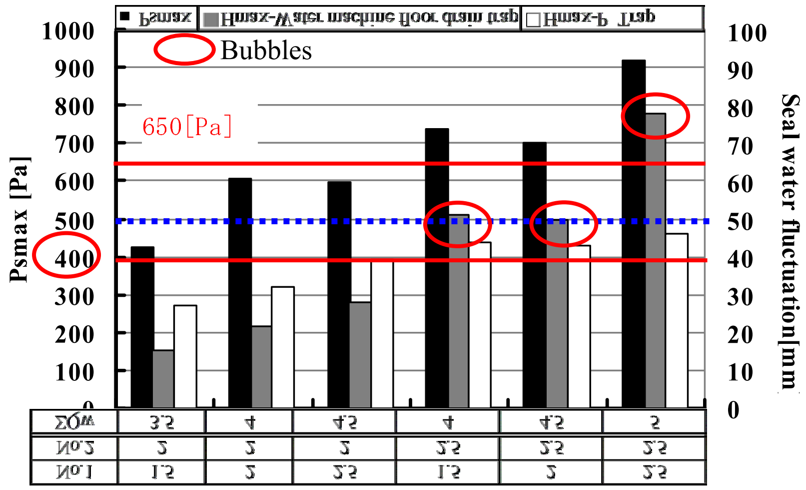


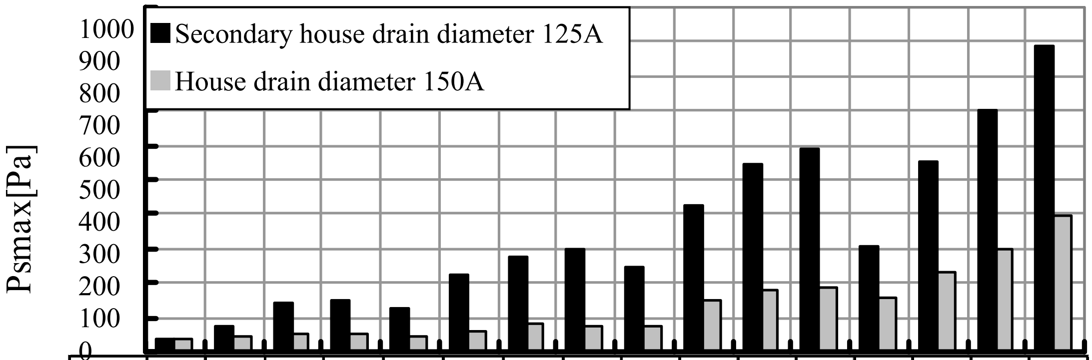
Fig.12 Psmax and Hmax (combined drainage loads from two stack systems)

5. Pressure relaxation

The following explains a method, which is applied to the secondary house, to relax Psmax generated at lower floor levels and its effectiveness.

5.1 Enlargement of the house drain diameter

Fig.13 shows the relationship between a total load flow rate ∑Qw and Psmax when the diameter of the secondary house drain is 125mm and 150mm. The results were reached when drainage flows were combined from drainage stack systems No.1 and No.2. When the exiting diameter of 125mm was enlarged by one level to 150mm, Psmax became relaxed by +29Pa to 487Pa. This is considered to be due to the loosening of pipe blockage, which is caused by combined drainage flows, securing a better airflow.



No.1	1.0	1.5	2.0	2.5	1.0	1.5	2.0	2.5	1.0	1.5	2.0	2.5	1.0	1.5	2.0	2.5
No.2	1.0	1.0	1.0	1.0	1.5	1.5	1.5	1.5	2.0	2.0	2.0	2.0	2.5	2.5	2.5	2.5
ΣQw	2.0	2.5	3.0	3.5	2.5	3.0	3.5	4.0	3.0	3.5	4.0	4.5	3.5	4.0	4.5	5.0

Drainage Load Flow Rate Qw_1+Qw_2[L/s]

Fig.13 Psmax Comparison by House Drain Diameter

(Combined drainage loads from two stack systems)

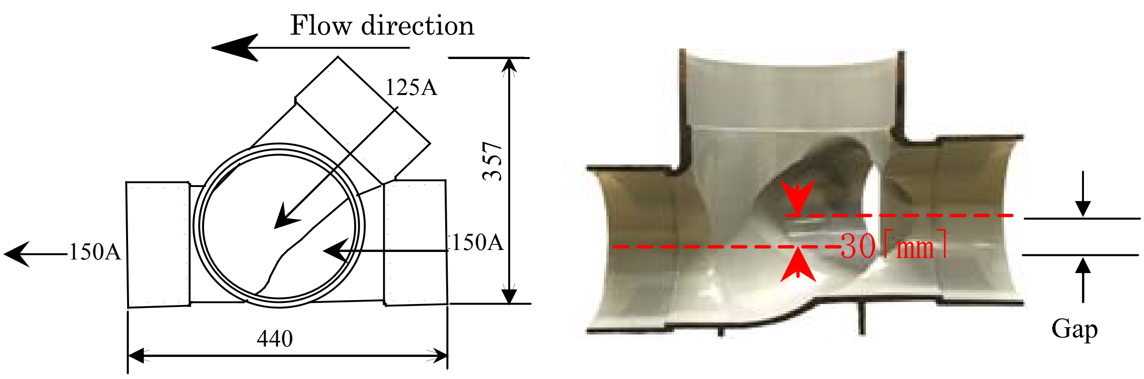
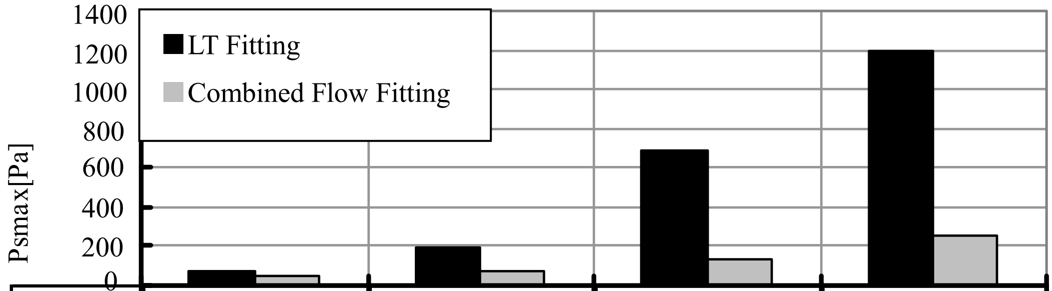


Fig.14 Combined Flow Fitting

5.2 Development of combined flow fittings

Fig.15 compares the relationship between ∑Qw and Psmax when the standard fitting (LT-type) and a combined flow fitting (see **Fig.14**) are used for a 150mm-diameter secondary house drain. The results were reached when drainage flows were combined using three drainage stack systems No.1, No.2 and No.3. The use of the combined flow fitting relaxes Pmax by +24.6 to +940Pa, i.e. 32 to 78% compared to the standard fitting. Even at a drainage flow rate of 7.5L/s, which exceeds the allowable flow rate of 6.8L/s for 150mm-diameter secondary house drains stipulated by SHASE-206, Pmax sustains +253Pa below the reference of +400Pa specified by SHASE-S218. There is a gap of 30mm between the upper flow and the lower flow around the fitting area and as shown in **Fig.15** (2), the gap suppresses the ratio of pipe blockage (the filling ratio of water), which is caused by combined drainage flows, as well as preventing back flows. It suggests that the decrease of resistance to obstruct drainage flows relaxes positive pressure.



No.1	1.0	1.5	2.0	2.5
No.2	1.0	1.5	2.0	2.5
No.3	1.0	1.5	2.0	2.5
ΣQw	3.0	4.5	6.0	7.5

Drainage Load Flow Rate $Qw_1+Qw_2+Qw_3$ [L/s]

(1) Psmax

No.1	1.0	1.5	2.0	2.5
No.2	1.0	1.5	2.0	2.5
No.3	1.0	1.5	2.0	2.5
ΣQw	3.0	4.5	6.0	7.5

Drainage Load Flow Rate $Qw_1+Qw_2+Qw_3$ [L/s]

(2) Pipe Blockage Ratio

Fig.15 Comparison by fitting type at the flow-combining point

(Combined drainage loads from three systems)

6. Summaries

The influence of combined drainage loads (positive pressure) to drainage capacity was evaluated when a large-diameter house drain was connected to multiple drainage stack systems for high-rise buildings. A relaxation technique of positive pressure was also explored. Stated below is the knowledge and information acquired by the experimentation.

(1) An experimental apparatus was created in order to examine the influence of combined drainage flows over the flow capacities of drainage stack systems. The characteristics of positive pressure fluctuation by combined drainage loads were also identified.

(2) A model was proposed to predict pipe pressure, which is an index for evaluating the flow capacities of drainage stack systems when multiple drainage flows are combined. The model enabled the prediction of maximum system pressure values (positive pressure) and minimum system pressure values (negative pressure) within pressure fluctuations. The model also enabled the matching of

predicted values to actual measurements with very satisfactory accuracy.

(3) In developing a relaxation method of the influence of combined drainage loads in the house drain, the relaxing effect of diameter enlargement and the application of combined flow fittings (to prevent back flows) was confirmed.

(4) It concluded that the reference value for positive pressure (+400Pa or +650Pa) would need a review and the development of new traps with enhanced water-sealing performance would be required.

Acknowledgements

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The Function of Traps and Assessment of Drainage Gas

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Abstract

This report reviews the role of traps by reassessing the design method of the current drainage system in view to preventing seal break, and at the same time evaluates harmful effects and unpleasantness of drainage gas based on the result of investigation of actual conditions of drainage gas which causes indoor air contamination. This report explores optimum conditions for preventing drainage gas taking the current status of traps in consideration, and sheds some light on hazardous substances contained in drainage gas based on the results of investigation.

Keywords

drainage system; trap; drainage gas; assessment; investigation

1 Introduction

The drainage system is designed in such a way that it ensures smooth discharge of waste water and prevention of seal break (the condition under which air is able to pass through the trap as a result of increased seal loss). However, in reality, there have been cases of drainage gas (sewer gas) entering indoors resulting in contamination of indoor air. On the other hand, as the environment consciousness of users heightens, they are becoming increasingly sensitive to offensive odor around the fixtures and drainage system. At the same time sanitation in kitchens in establishments such as restaurants has been strictly specifies. The present trap mechanism for preventing seal break is not perfect in responding to such demands.

We have been examining the role of traps by reassessing the design method of the current drainage system in view to preventing seal break, and at the same time evaluates harmful effects and unpleasantness of drainage gas based on the result of investigation of actual conditions of drainage gas which causes indoor air contamination[1, 2]. In the midst of this investigation, there occurred an epidemic outbreak of SARS in Amoy Gardens, a high-rise residential building in Hong Kong in April 2003. The inspection team from Department of Health of Hong Kong noted seal break caused by evaporation as a contributing factor in the transmission of the disease[3]. This incident seriously challenged the structural safety of the current traps and drainage system in general making it our obligation to devise a safe and reliable plumbing system.

This report explores optimum conditions for blocking drainage gas taking the current status of traps in consideration, and sheds some light on hazardous substances contained in drainage gas based on the results of investigation.

2 Current Statuses of Traps and Their Future Prospects

2.1 Traps: Their Past and Present

Traps are used in a drainage system in such a way that collected wastewater acts as a seal against drainage gas, preventing it from entering indoors. The seal water traps (traps with seal water), currently used widely in various drainage systems, have no electric or mechanical device. Since it requires no energy to operate, it makes the most sustainable apparatus used in a system.

The appearance of this marvelous apparatus led to the invention of WC in the late 18th century. By the end of the 19th century, particularly in Great Britain, traps were incorporated into all fixtures, which made it possible to prevent seal break caused by induced siphonage, and resulted in the establishment of the modern drainage system with the individual vent system as its main style. This system was equipped with drainage stacks for both soil water and wastewater. The recent SARS epidemic reminds us of the fact that Indian cholera outbreaks contributed to the development of this system, and we cannot help having the history-repeats-itself feeling. Since then until the beginning of the 20th century, various mechanical traps and seal water traps with partitions had been developed; most of them disappeared as mechanical parts deteriorated and broke down after a very short period of use. It was an inevitable consequence of the limited materials and technological expertise available at the time.

Since the early of the 20th century, the increasing number of skyscrapers has begun to be built in the major U.S. cities. To prevent pipes from freezing, piping was installed inside the building as opposed to outside piping commonly seen in buildings in the Great Britain at the time[4]. The diameter of drainage and vent pipes also had to be determined precisely to reduce piping space and to counteract induced siphonage, which tended to build up as the height of the building increased; as a result of such vicissitudes, American National Plumbing Code was compiled. Troublesome mechanical traps and traps with partitions were discarded, and the minimum seal depth was standardized at 50mm. Adoption of individual vent system successfully nullified seal break caused by induced siphonage and self-siphonage, but it did not resolve seal break due to evaporation (apparatuses which replenished the water lost by evaporation were invented but were not used widely).

Though a kind of vent system may be different, such a fundamental way of thinking about traps is almost the same in other countries.

2.2 Need to Assess Trap Performance and Future Prospects

The performance of traps is closely associated with not only the drainage capacity of each drainage apparatus but also that of the entire drainage system. The trap performance is inversely proportional to the performance of the drainage system.

Good trap performance reduces the load on the drainage system. Conversely if trap performance is poor, enormous compensatory load may be placed on the drainage system.

However, no reliable method for assessing trap performance has been established, nor is there a foolproof method for preventing seal break. The properties of drainage gas have not been clarified either. In this state of confusion and uncertainty, we are required to take the following steps in order to improve the situation.

(Step 1) Determining Risk Level of Drainage Gas
Is drainage gas truly hazardous as well as unpleasant? If risk level of drainage gas is extremely high, we have to find a way to prevent it from entering indoors or human body at all cost. If the risk level is low, its infrequent entrance may be permissible. Since the level of risk depends on the various factors such as the type of building and drain water, and the location within the drainage system, the risk level must be determined based on ample data derived from investigations of actual conditions with toxicity and unpleasantness into consideration.

(Step 2) Determining Sanitary Requirements for Various Types of Buildings/Rooms
High levels of sanitation are required for dwelling houses, hotels and restaurants. On the other hand, the concentration of hazardous substances is closely associated with air-tightness and ventilation of enclosed space, and concentration lowers as substances diffuse over a large area. The sanitation level required for a particular location (e.g. a building, a room) must be determined taking these factors into consideration. In places where the sanitary requirements are high, drainage gas must be blocked completely; where sanitary requirements are not so high, it may be tolerated with less aversion.

(Step 3) Determining Requirements of Drainage System in Designing
In designing a drainage system, its requirements are determined based on the corresponding hazard level and sanitary requirements of the building or location where it is installed.

(Step 4) Assessment and Display of Trap Performance
The performance of a trap's ability to block drainage gas is evaluated in terms of its resistance to seal break caused by induced siphonage, self-siphonage and evaporation. The performance of a trap is displayed based on the results of such evaluation.

(Step 5) Adoption of Optimum Trap

Requirements of a drainage system and performance of a trap are compared and an appropriate trap is selected. If no traps which satisfy the requirements of a drainage system are found, either a new trap with higher performance must be developed or some supplementary means must be incorporated in the drainage system.

In following the above steps, the limitations of existing traps can be seen. One century ago, when mechanical traps and seal water traps with partitions were dropped, developers were highly motivated to create a new device. With the same eagerness and much advanced materials and technology, it will not be difficult to create high-performance traps to meet more demanding requirements for blocking drainage gas in the modern drainage system.

3. Investigation of Drainage Gas in the Hotel

3.1 Purpose of Investigation

Substances and odors of drainage gas taken from sump pits in man holes in Tokyo have been analyzed and reported in an effort to prevent foul odor in building pits. As for drainage gas from public sewers, the generation and concentration of hydrogen sulfide have been investigated intensively to prevent accidental inhalation and corrosion of pipes. Malodorous density of septic tanks have also been investigated and reported. However, investigation and analyses of indoor air and air taken from main units of the sump pit, grease interceptors, drainage pipes have been rare. To compensate for lack of data, malodorous substances contained in the wastewater and drainage gas of various drainage systems in buildings (drainage pipes, grease interceptors, sump pits) and bathroom air were analyzed and their toxicity and unpleasantness evaluated. The following describes the methods and results of investigation conducted to evaluate concentration of pollutant substances in wastewater, the concentration and density of malodorous substances in drainage gas in sump pits for kitchen wastewater in the hotel.

3.2 Methods of Investigation and Analysis

The hotels investigated are summarized in Table 1. Kitchen wastewater from tenants is processed at a kitchen wastewater treatment plant by contact aeration system using biologics products, and then released into the sewage system. The capacity, design conditions of inflow flow and discharge, average real load are shown in Table 2. 3 soil pits with capacity of 2.3, 2.4, 1.0 m^3 each, and 4 wastewater pits with capacity of 5.5, 3.7, 4.0, 7.8 m^3 each were provided. The cleaning cycle for each pit is 3 times/year and that for a grease interceptor is once a month.

As is shown in Table 3, measurements were made in summer and winter; in 1 soil pit (capacity 2.3 m^3), 1 wastewater pit (capacity 5.5 m^3), and the kitchen raw wastewater pit in summer, and in the kitchen raw wastewater pit and pit of kitchen wastewater treatment plant in winter.

For wastewater of each pit, temperature, pH, CODMn, BOD, SS, total nitrogen were measured, and drainage gas was checked for concentrations of ammonia, hydrogen sulfide, methyl mercaptan, sulfide methyl, methyl disulfide, trimethylamin, propionic

Table 1 - The hotel investigated

location	maritime zone of Tokyo
year completed	1999 June
number of stories	ground floors: 21, underground floors: 3
number of rooms / area of floors	830 rooms / 70,574m^2
restaurants	Japanese food (21F), Chinese food (20F), Western food (1F)

Table 2 - Kitchen waste water treatment plant

capacity [m^3]	raw waste water pit: 30.2, treatment pit: 254.6, bio-core pit: 5.0
method of treatment system	contact aeration system using biologics product
process of treatment system	screen + flow adjustment pit + contact aeration pit + precipitation pit
design conditions of inflow	pH: 5-9, BOD: 400-600mg/L, SS: 200-300mg/L
design conditions of discharge	pH: 5-9, BOD: 300mg/L, SS: 200mg/L (estimated)
average real load	restaurants of the hotel: 267m^3, restaurants of tenants: 267m^3

Table 3 - Outline of investigation

items	summer investigation	winter investigation
period	2002.8.27	2003.1.27
date of previous cleaning	2002.6.11	2002.12.10
pits measured	soil pit, wastewater pit, kitchen raw wastewater pit	kitchen raw wastewater pit, kitchen wastewater treatment pit

acid, normal butyric acid, normal valeric, and isovaleric acid. Odor sensory tests were also conducted and odor concentration was checked by triangle odor bag method.

3.3 Results and Discussion

The results of water quality analysis (temperature, pH and concentrations of pollutant substances) are presented in Table 4, and concentrations of malodorous substances and odor concentrations in Table 5.

Table 4 - Results of water quality analysis

items of water quality [mg/L]	summer investigation			winter investigation	
	soil pit	wastewater pit	kitchen raw wastewater pit	kitchen raw wastewater pit	kitchen wastewater treatment pit
Water temp. [°C]	15	16	18	17	16
pH [-]	8.6	5.5	5.5	5.4	7.4
COD_{Mn}	83	188	245	229	23
BOD	110	530	1000	620	23
SS	181	156	845	312	33
tot. nitrogen	88.1	16.1	24.3	17.1	5.0

Table 5 - Concentrations of malodorous substances and odor concentration of drainage gasses in pits

malodorous substances [ppm]	summer investigation			winter investigation	
	soil pit	wastewater pit	kitchen raw wastewater pit	kitchen raw wastewater pit	kitchen wastewater pit
ammonia	0.1	0.1	0.2	0.3	0.1
hydrogen sulfide	0.058	1.2	38.5	4.65	0.083
methyl mercaptan	0.013	0.194	1.64	0.556	0.005
sulfide methyl	0.006	0.017	0.104	0.066	0.015
methyl disulfide	0.001	0.007	0.014	0.012	<0.001
trimethylamin	<0.002	<0.002	<0.002	<0.002	<0.002
propionic acid	0.005	<0.001	0.008	<0.001	<0.001
normal buthric acid	0.004	0.002	0.003	<0.001	<0.001
normal valeric acid	0.0011	<0.0009	0.0014	<0.0009	<0.0009
isovaleric acid	<0.0009	<0.0009	<0.0009	<0.0009	<0.0009
odor concentration [-]	420	3100	23000	4200	170

The soil water in sump pits was found to be alkaline and all the items related to water quality were within the normal range. Of all the substances checked in the drainage gas, normal butyric acid was rated at odor intensity 3.5, hydrogen sulfide and methyl mercaptan at 2.5, and trimethylamin and isovaleric acid at below 1. Odor concentration indicated 420 (odor index approximately 26), which is six times as high as odor intensity of 3.5.

The water inside the wastewater pits showed strong acidity, and BOD was close to 600mg/L, the standard value for discharge released into the sewage system. Hydrogen sulfide and methyl mercaptan indicated the odor intensity of 3.5 or more; ammonia, sulfide methyl and normal butyric acid 2.5 or more; methyl disulfide 1.0 or more. Odor concentration indicated 3100, nearly 70 times as high as odor intensity of 3.5.

All the water quality related values in the kitchen raw wastewater pit were higher in summer than in winter with BOD in summer greatly exceeded the emission standard value, and SS was also high. Acidity was high both in summer and winter accounting for high intensity of hydrogen sulfide. The malodorous degree in drainage gas was also higher in summer with the concentration of hydrogen sulfide 38.5ppm. Such high concentration of hydrogen sulfide may cause adverse reactions in human body such as coughing and forming of phlegm. The odor intensity of methyl mercaptan was rated at 3.5 or higher. As a result odor concentration indicated 23000.

The pH of water inside the kitchen wastewater treatment pit showed neutral, and BOD was far blow the emission standard value, which indicates adequate processing has been effected at least in winter. Consequently, the concentrations of malodorous substances contained in the drainage gas were considerably low.

4 Conclusion

All drainage systems except for underground drainage operate by gravity, which makes them ultimate energy saving systems. The downside is that any toxic substances or harmful bacteria may find their way into the system, and they will be emitted in drainage gas. Traps, which prevent drainage gas from entering indoors, do not require any energy to operate. However on the other hand, this excellent system entails some uncertainties, lacking adequate performance to meet the growing needs of the modern plumbing system.

This paper proposed some ways to reconstruct the existing drainage system into the system with certainty, and as a starting point evaluated the toxicity and unpleasantness of drainage gas through actual investigations conducted on the drainage systems in hotels.

The authors intend to continue this type of investigation to assess the hazard level of drainage gas. At the same time a reliable way of assessing the performance of traps needs to be established. Presently the matter is under discussion by the committee of the Society of Heating, Air Conditioning and Sanitary Engineering.

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6 Presentation of Authors

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The active control and suppression of air pressure transients within building drainage and vent systems.

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Abstract

The propagation of air pressure transients within building drainage and vent systems due to both normal and inadvertent changes in water and entrained airflows may deplete appliance trap seals and establish potentially lethal cross contamination paths. Transient interaction with dry traps and other faulty system components also increases this risk. Trap seal depletion depends upon the air pressure – time history at the trap/network interface. Traditional trap seal protection involves venting this interface to atmosphere, by a dedicated connection to a roof level vent stack termination or the introduction of a vent stack cross connected to the system wet stack. These techniques may be categorized as passive. This form of control depends on reflected transients from the atmospheric boundary condition arriving at the trap and cannot protect against the potential damage due to the passage of the initial transient through the network. Local active control by the use of Air Admittance Valves is not accepted by all existing national codes.

Surge theory and practice supports active control by suppression devices at the protected interface as the optimum solution. Such a design transformation requires pressure transient simulation at the interface and knowledge of the characteristic of any active control device. This paper illustrates the application of air pressure transient analysis to predict the pressure at the system/trap interface and determine the practicality of active control to limit both suction and positive transient pressure excursions. The applied transients will be generated by system flow changes, surcharge and events external to the network, for example sewer surcharge or roof level wind shear. The operational characteristics of existing devices will be included and the necessity to retain an open roof vent stack termination will be critically assessed.

Keywords

Pressure transient simulation, drainage vent system, cross contamination, surge control.

1. Introduction.

This paper introduces the concept of active air pressure transient control and suppression to the design of building drainage and vent systems and particularly the retention of appliance trap seals. Active control, through the provision of air admittance valves and variable volume containment devices to control negative and positive transient propagation respectively would eliminate roof penetrating open terminations and costly venting cross connections and would provide the designer with a palate of options that reflect the impact of modern surge suppression technology as a means of reducing system complexity, increasing system reliability and reducing installation cost and space requirements. The central importance of trap seal retention as a barrier to infection spread and cross contamination, as identified in the 2003 Amoy Gardens SARS outbreak, reinforces the need to provide both simulation tools and transient control and suppression devices. The paper draws upon suppression experience from the wider arena of pressure surge as a means of controlling the low amplitude air pressure transients generated by drainage system operation and identifies the need to suppress both positive and negative air pressure transients to retain trap seal protection and ensure system reliability.

1.1 Theoretical *rationale* for active transient control

Low amplitude air pressure transients propagate throughout building drainage and vent systems as a result of appliance discharge to the network and/or external pressure fluctuations such as remote surcharging in the sewer network. Traditionally these transients are prevented from driving the ingress of possibly contaminated air into habitable space by the use of appliance water trap seals, usually 50 or 75 mm in depth, and by the provision of vent connections to an open roof termination. Such system designs have their roots in the Victorian obsession with odour ingress as a precursor to possible infection and ignore the fundamental principles of pressure transient propagation and control

The response of an appliance trap depends entirely upon the local pressure – time history at the trap to system interface. Relief would be most efficient if applied locally, either by inwards relief to offset negative pressures or by the provision of containment to absorb positive air pressure transients. Current codes require cross connection from the appliance to a vent stack terminating external to the building and introduce a round trip travel time for any relief wave. The route and detailed design of the vent will limit its effectiveness – a long small diameter vent is effectively no vent. More important is the realisation that in order to reach the open vent termination the transient to be relieved or suppressed will have passed and affected all the trap seals in the network. Current design therefore ignores the basic precept of surge protection that the relief device must be positioned between the source of the transient and the appliance to be protected, however this is inevitable as the external open vent termination must be above the level of any possible open window or other route into habitable space.

The amplitude of transient propagation within drainage and vent systems will be low and may be determined from existing pressure surge theory; an instantaneous surcharge that closes an airpath generates a 40 mm water gauge transient per m/s of destroyed airflow from the Joukowsky equation,

$$\Delta p = \rho c u \qquad (1)$$

linking surge pressure to destroyed velocity, fluid density and wave speed. Negative transients due to the passage of appliance discharge down the system vertical stacks will depend upon the stack diameter, the peak water flowrate, the total discharge volume and the profile rise time. The low amplitude does not minimize the implications of design failure; in the 2003 SARS outbreak pressure transients capable of overcoming a 50 mm trap seal contributed to the spread of the infection.

2. Mathematical basis for the simulation.

Air pressure transient propagation depends upon the rate of change of the system conditions. Increasing annular downflow generates an enhanced entrained airflow and lowers the system pressure. Retarding the entrained airflow generates positive transients. External events may also propagate both positive and negative transients into the network.

The annular water flow in the 'wet' stack entrains an airflow due to the condition of 'no slip' established between the annular water and air core surfaces and generates the expected pressure variation down a vertical stack. Pressure falls from atmospheric above the stack entry due to friction and the effects of drawing air through the water curtains formed at discharging branch junctions. In the lower wet stack the pressure recovers to above atmospheric due to the traction forces exerted on the airflow prior to falling across the water curtain at the stack base. Relationships defining these mechanisms have been identified and used in the development of the simulation model, AIRNET, to allow the application of the finite difference method of characteristics to predict the time dependent air pressure regime in the system as a result of appliance discharge.

The application of the method of characteristics to the modelling of unsteady flows was first recognised in the 1960s[(1)]. The resulting solution of the St Venant equations of continuity and momentum has been applied to free surface drainage flows as well as entrained airflows and waterhammer[(2,3)]. The relationships defined by Jack[(4)] allows AIRNET to model the traction force exerted on the entrained air. Extensive experimental data allowed the definition of a 'pseudo-friction factor' applicable in the wet stack and operable across the water annular flow/entrained air core interface to allow combined discharge flows and their effect on air entrainment to be modelled. The airflow entrained in the lower levels of the wet stack may exceed that appropriate to the annular water flows present in the upper levels. The variable friction factor allows the lower level annular flow to provide airflow entrainment and hence a rising air pressure while in the upper levels this air is effectively drawn down past a slower moving water film that impedes its entrainment, and leads to an observed reduction in air core pressure levels.

The propagation of air pressure transients in building drainage and vent systems is defined by the St Venant equations of continuity and momentum[(3)],

$$c^2\, \partial u / \partial x \;+\; [2/(\gamma-1)\, c\, [\, \partial c / \partial t + u\;\; \partial c / \partial x] \;=\; 0 \qquad (2)$$

$$[2/(\gamma-1)\, c\;\; \partial c / \partial x \;+\; [\, \partial u / \partial t \;+\; u\, \partial u / \partial x\,] \;+ 4\, f\, u\, |\, u\, |\, / \,2D \;=\; 0 \qquad (3)$$

These quasi-linear hyperbolic partial differential equations are amenable to finite difference solution once transformed via the Method of Characteristics into finite difference relationships, equations 4 to 7, that link conditions at a node one time step in the future to current conditions at adjacent upstream and downstream nodes, Figure 1.

For the C^+ characteristic : $$u_P - u_R + \frac{2}{\gamma - 1}\left(c_P - c_R\right) + 4 f_R u_R |u_R| \frac{\Delta t}{2D} = 0 \qquad (4)$$

when $$\frac{dx}{dt} = u + c \qquad (5)$$

and the C^- characteristic : $$u_P - u_S - \frac{2}{\gamma - 1}\left(c_P - c_S\right) + 4 f_S u_S |u_S| \frac{\Delta t}{2D} = 0 \qquad (6)$$

when $$\frac{dx}{dt} = u - c \qquad (7)$$

where the wave speed c is given by $c = (\, \gamma p/\rho)^{0.5}$ (8)

(Note : in the dry stack f_R and f_S are determined from the Colebrook White relationship, however in the wet stack f_R and f_S are functions of time, location and annular water downflow and hence act as drivers in the simulation by generating the entrained air flow within the stack[(4)]).

These equations involve the air mean flow velocity, u, and the local wave speed, c, due to the interdependence of air pressure and density. Local pressure is calculated as –

$$p_{local} \;=\; [\; (p_{atm} / \rho_{atm})\;\; (\,\gamma/c^2_{local})^{\gamma}\;\;]^{1/(1-\gamma)} \qquad (9)$$

Figure 1 illustrates the Courant Criterion linking internodal distance to time. Only one St Venant characteristic equation can exist at a boundary. Equations linking airflow conditions to applied water flow or other system parameters are necessary to provide a solution at each pipe termination. While transient propagation is driven by the water / entrained airflow interface, these boundary conditions determine transient transmission and reflection within the network, Suitable equations link local pressure to airflow or to the interface oscillation of trap seals, Table 1. The boundary equation may also be determined by local conditions: the Air Admittance Valve opening and subsequent loss coefficient depends on the local line pressure prediction. Boundary conditions may therefore also be categorised as active or passive – active boundaries depend on local conditions while passive boundaries depend on system specification only, -open ends leading to constant pressure zones. The relief of negative pressures is traditionally provided by vent connections to atmosphere – a passive solution. Active attenuation would be an inwards Air Admittance Valve (AAV) of a form currently available to designers but not universally accepted by national code bodies.

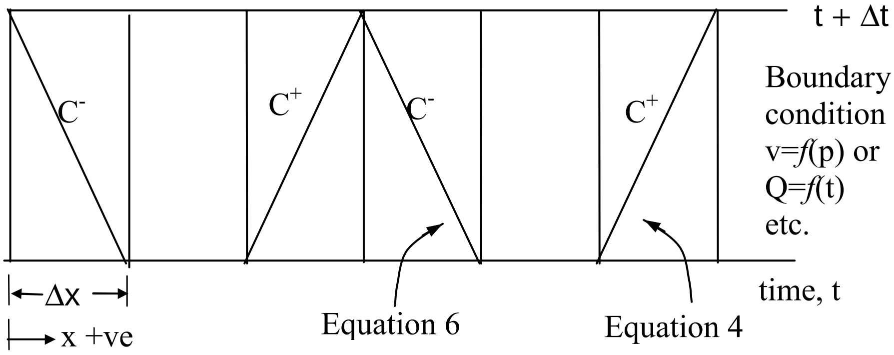


Figure 1. St Venant equations of continuity and momentum allow airflow velocity and wave speed to be predicted on an x-t grid as shown. Note Δx<1.0 m, Δt < 0.003s.

Open end exit	Set p_{local} = atm.	Solve with available C^+ equation 4.
Dead end exit	Set $u_{local} = 0.0$	Solve with available C^+ equation 4.
AAV exit	$p_{local} > p_{open}$	Treat as a dead end exit.
	$p_{local} < p_{open}$	Solve $(p_{local}–atm)=K0.5\rho u_{local}^2$ with equation 4
Trap seal exit	No trap seal loss	Solve trap F=mass*acc. equation with C^+
	Air path due to trap displacement.	Set p_{local} = atm and solve with C^+
	Depleted trap	Set p_{local} = atm and solve with C^+
PAPA exit	Bag at line pressure	Volume = 0.0, p = line pressure
	Bag filling, p=atm	Sum inflow to determine bag volume
	Bag pressurizes	Use gas Law Equation with bag volume and solve with C^+ to determine bag pressure.
Base of stack (entry)	Empirical Δp vs. Q_w	Solve empirical relationship between back pressure, applied water flow and entrained airflow with available C^- equation 6
Sewer pressure (entry)	Base of stack	Impose sewer pressure and solve with C^- equation 6
Wind shear exit	Top of stack	Impose variable atmospheric pressure and solve with C^+ equation 4

Table 1. Boundary conditions.

Empirical data identifies the AAV opening pressure, its loss coefficient during opening and at the fully open condition. Appliance trap seal oscillation is treated as a boundary condition dependent on local pressure. Deflection of the trap seal to allow an airpath to, or from, the appliance or displacement leading to oscillation alone may both be modelled. Reductions in trap seal water mass during the transient interaction may also be included.

The variable volume flexible bag containment device is a recent addition to the model. Initially the 'bag' is held deflated by the suction pressure in the stack, inflow velocity zero. Rising pressure due to the arrival of a positive transient causes the bag to open and partially inflate. Once fully inflated the bag acts as a pressurized boundary obeying the Gas Laws.

3. Active transient control

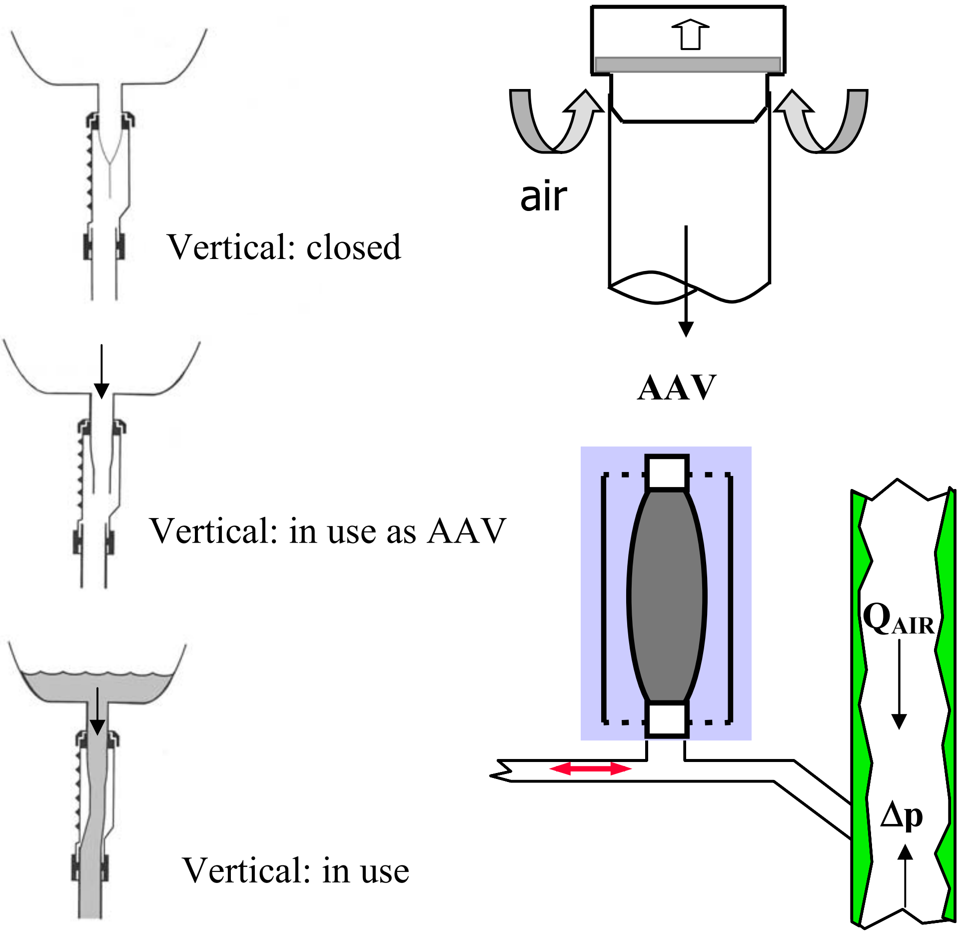
The venting of building drainage networks has been a concern for over a hundred years. Early venting featured individual appliance connection directly to the external atmosphere via dedicated vent stacks terminating above the roof line. The need to minimize external pipework due to both climatic considerations and the advent of taller buildings led to a progressive reduction in vent complexity, evidenced in the UK by the introduction of the single stack system in the 1960s(5). Further reductions in venting provision were introduced from the mid 1980s with the introduction of local air admittance valves installed within the habitable space to allow inwards air pressure relief. Active transient control extend this approach to include both positive and negative transient suppression as a means of trap seal retention and the prevention of cross contamination of habitable space from the drainage and vent system. Figure 2 illustrates the range of control devices currently available: the diaphragm operated air admittance valve and the sheath water less trap that doubles as an AAV and the positive air pressure attenuator (PAPA) or flexible containment volume capable of absorbing transients until its bag becomes pressurized.

Figure 3 illustrates a 10 storey building drainage and vent system featuring either a separate vent stack with cross connections to the wet stack (Modified One Pipe network), or a single stack system both with and without air admittance valves and positive air pressure attenuators. The dotted pipes indicate the modified one pipe vent stack and cross connection arrangement. For simplicity all pipes are 100 mm diameter and each interfloor height is 3 m. Most branches are 2 m long except for the PAPA connection at 250 mm.

3.1 Response to negative transients.

Figure 4 illustrates the air pressure vs. height profile up the stack for each system 2 seconds into the event. This is a 'snapshot' of the pressure in the stack during transient propagation. The modified one pipe system demonstrates the minimum reduction in stack pressure while the single stack with AAV obviously operates at a lower system pressure due to the loss incurred by drawing air into the network through the AAV at the top of the stack. As the results presented represent conditions at a particular instant in the simulation, pressure waves are present that appear as variations from the smooth profile often illustrated for stack pressure response to steady annular downflow. Figure 4 also illustrates the entrained airflow present at 2 seconds – the vent stack carries a proportion of the total airflow entrained, while in the Single Stack with AAV system inflow to the stack is distributed.

Figure 5 illustrates the trap seal deflections and overall seal retention during and following the appliance discharges represented by the water downflows shown. These transients are generated by changing water flow – there are no surcharge events. The minimum seal deflection and maximum retention occurs in the single stack and AAV system, confirming the efficiency of active transient control in relieving local negative pressures at the trap. **Note - to provide direct comparison the results for several simulations are presented sequentially by shifting the time axis by 10 seconds for each case in Figures 5 to 8.**



Waterless sheath trap **Flexible containment volume.**

Figure 2. Active air pressure transient suppression devices to control both positive and negative surges.

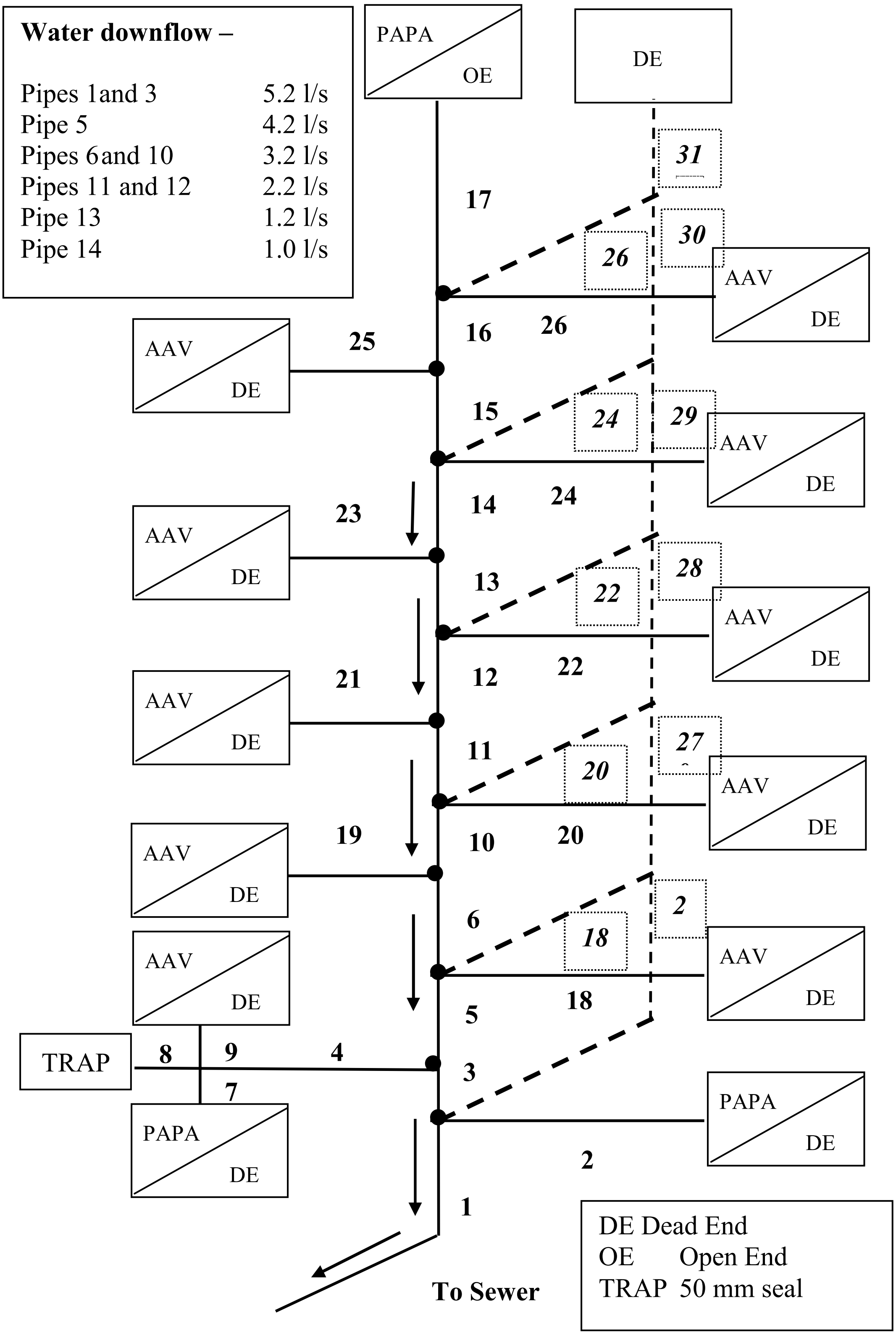


Figure 3. Single stack with and without active control cf. modified one pipe system.

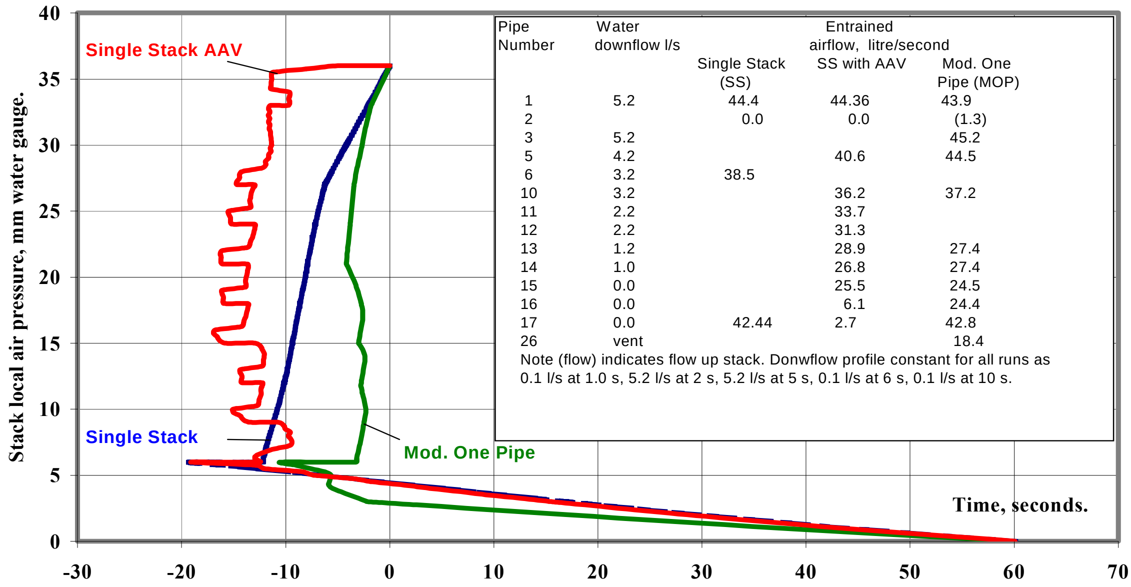


Figure 4 Air pressure profile up the vertical stack for each of the three networks considered 2 seconds into the downflow.

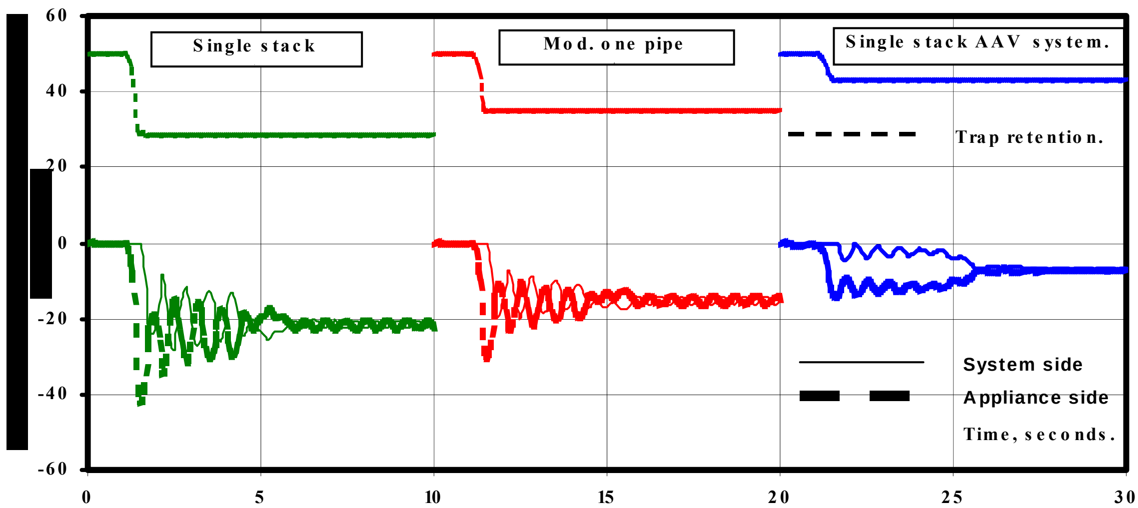


Figure 5. Trap seal deflection demonstrating the efficacy of the AAV active surge control to minimize negative transient effects.

3.2 Response to positive transients.

Figure 6 illustrates positive air pressure transient propagation following a surcharge at the base of the stack. The minimum trap seal deflection and maximum seal retention again occur within the network provided with active surge control in the form of both AAV and PAPA installations. The containment volume is 8 litres on pipe 2 and 4 litres on pipe 7.

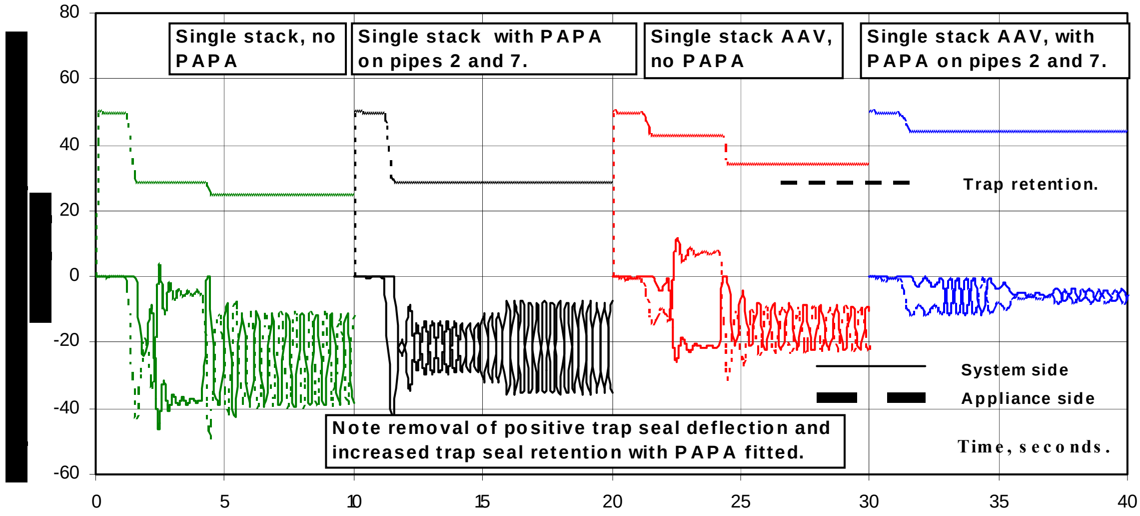


Figure 6. Trap seal deflection as a result of a surcharge at the base of the stack to demonstrate the efficacy of variable volume containment active surge control.

The active control offered by the PAPA variable volume containment device is achieved by providing an alternate path for the entrained airflow in the stack, thus delaying the pressure rise associated with surcharge. This effect is clearly shown in Figure 7 where the 'bag' volume and inflow are reproduced. It will be seen that the full bag volume is used on pipe 2 while the PAPA mounted on the branch to protect the trap, pipe 7, only partially inflates.

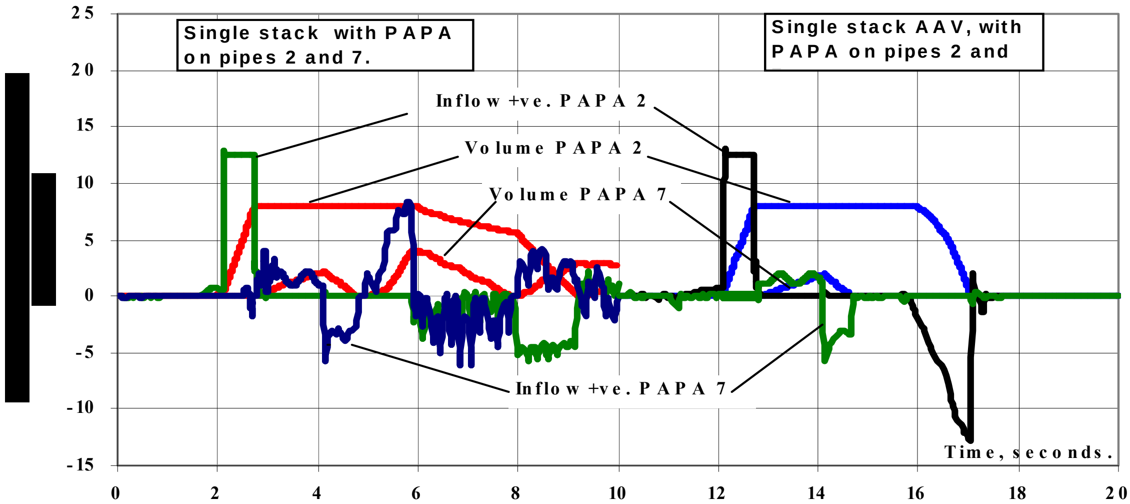


Figure 7. PAPA containment volume and air inflow vs. time following a surcharge at the base of the stack.

Marginally lower air pressures in the vertical stack following stack base surcharge are predicted with AAV's fitted in addition to the PAPA's. This is due to the distributed air inflow demonstrated in Figure 4. The full Joukowsky pressure rise is not communicated to the top of the stack. The rapid but not instantaneous closure of each AAV propagates a negative transient that may be superimposed on the positive reflection generated once the AAV is fully closed. Figure 8 demonstrates the delay in transmitting the pressure surge as the containment volume inflates. The simulation also demonstrates that the branch PAPA effectively prevents any positive transient reaching the protected trap seal.

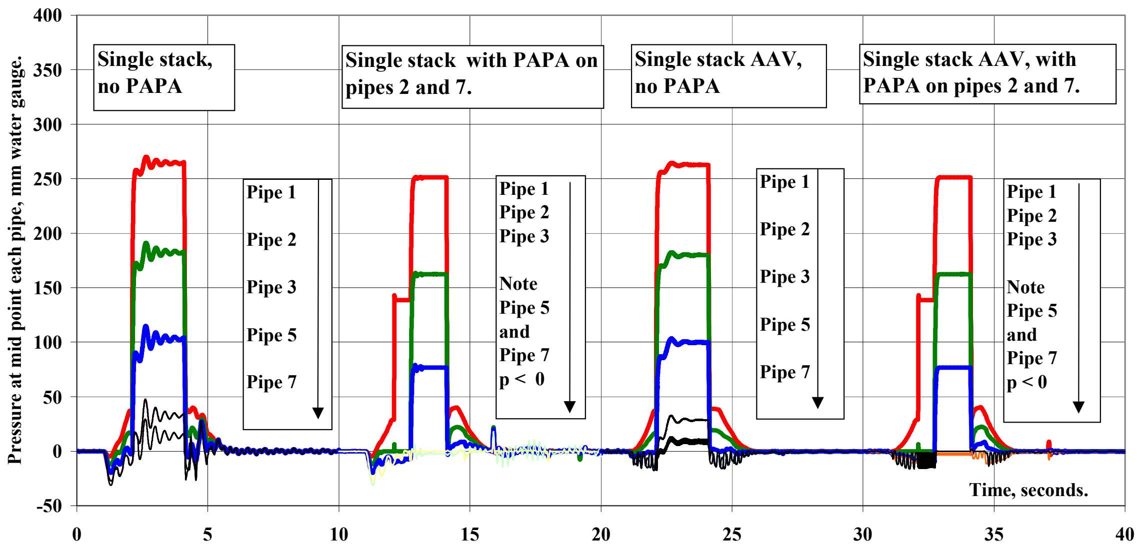


Figure 8. Air pressure levels in the vertical stack and side branches following a stack base surcharge illustrating the efficacy of the containment volume attenuator.

4. Conclusions.

The venting provision for both 'new build' complex building drainage networks and the large refurbishment and change of use sector is a major contributor to the cost of building drainage systems. Conservative views among some national code bodies, developers and designers have prolonged the use of historic 'rule of thumb' and steady state design criteria that ignore the transient nature of air pressure propagation within the vent system. However simply taking the position that there is over provision without regard to the transient nature of the process is also insufficient. This paper has demonstrated the inclusion of transient flow simulation, both within the design process and as a means of ensuring a 'safe' design. It has also introduced the concept of active surge control, an essential step if drainage and vent systems are to respond to a new range of design criteria that includes simplicity and lower costs for installation and materials as well as security. Active control by AAV and flexible containment devices has been demonstrated to be practical and efficient and the analysis of system operation by modern simulation has been shown to be fast, robust and reliable, forming the basis for future advances in drainage and vent system design.

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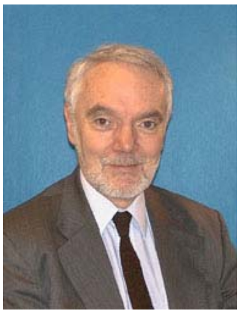

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A survey of the sanitation load for domestic high-rise building estates in Hong Kong

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Abstract

A reasonably accurate estimation on the sanitation load is necessary for designing an effective and healthy drainage system. This is particularly important for developed cities, such as Hong Kong, having many high-rise residential buildings. Load estimation method based on the 'fixture unit' approach has been established and used for the load estimations. However, design data in practice have not been examined for various architectural designs and user behavioral patterns in high-rise residential buildings nowadays. In this study, the probable drainage loads in 14 high-rise buildings of five low-cost residential estates are investigated. A face-to-face interview has been conducted in 2003-2004 and the discharge flow rates of the installed sanitary appliances were measured in 597 apartments. The probable number of sanitary appliances discharging simultaneously is determined with the 'fixture unit' approach and compared with the design values used for the buildings. This study proposed the probable drainage demands for some high-rise residential buildings in Hong Kong. The database is useful for evaluating various drainage system designs in high-rise residential buildings for cities having a high population density.

Keywords

Sanitation load, high-rise residential buildings, survey

1 Introduction

Hong Kong is a developed city having a high population of 6.7 million and limited area of 1067 km^2 (Hong Kong Census and Statistics Department 2001). The tiny portion (20%) of flat land for construction has led to a concentrated high-rise environment with a very high population density. The tallest residential buildings in Hong Kong are Sorrento (tower 1: 75 floors, 256 m high; tower 2: 66 floors, 236 m high, both are completed in 2003), The Harbourside (75 floors, 255 m high, completed in 2003), The Harbourfront Landmark (70 floors, 233 m high, completed in 2001) and The Belcher's towers 1-6 (61-63 floors, 221-227 m high, completed in 2001) (Skywscrapers.com 2004). Apart from the residential buildings in private sector, many government funded residential buildings are constructed with heights over 140 m. In order to design an effective building drainage system, a reasonably accurate estimation for the drainage loads is necessary (Swaffield and Galowin 1992; Wise and Swaffield 2002).

Over the past 40 years, load estimation for drainage pipe sizing based on the probability of using outlet simultaneously P_d and the design discharge flow rate of the outlet q_d (L/s) at a limiting failure rate λ (e.g., 0.5-1%) has been adopted in many drainage designs (Laws of Hong Kong 1997; Plumbing services design guide 2002; Swaffield and Galowin 1992; Wise 1973; Wise and Swaffield 2002). Various investigations were conducted to determine these two design parameters (p_d and q_d) and a 'fixture unit' approach was adopted for drainage pipe sizing (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002). The design data from the investigations on low-cost housing were used to determine the pipe sizes of plumbing and drainage systems (Hunter 1940). The Building Research Establishment conducted an investigation into the use of sanitary appliance and the flow rate distribution of water supply in local authority flats of five floors in an 18-storey block in North London (Webster 1972). These works provided the statistical basis for design data formulation of building drainage system designs, and later works in the USA and in the UK have attempted to improve the available database (Butler 1991; Hunter 1940; Konen 1985; Swaffield and Galowin 1992; Webster 1972). However, these data might not be suitable for some high-rise residential buildings in Hong Kong nowadays due to the various architectural designs and user behavioral differences. Pertinent modifications on the design values for local buildings must be determined carefully and supported with systematic research studies on the drainage system demands of the buildings.

Following the massive outbreak of the Severe Acute Respiratory Syndrome (SARS) in early 2003, the drainage system in high-rise residential buildings has become a major concern. The suspected contaminated single stack system was accused of transporting the virus into living units through the same stack. The additional wastewater from washing, cleaning and sterilization has increased the drainage loads. Therefore, review the system design to cater for the actual building demands is urgently required. For the initial step, the development of a database for estimating the probable drainage loads in buildings has been proposed (Wong and Mui 2004). This study investigates the probable loads of the drainage systems in 14 high-rise buildings of five typical residential estates in Hong Kong. The usage patterns and discharge flow rates of the installed domestic sanitary appliances in 597 apartments were measured. The time of probable discharge, mean time between usages, probability of simultaneous discharge and the probable discharge flow rate of the appliances were determined. With the survey results, the probable flow rate in a typical drainage stack and the corresponding size of the stack are determined by the 'fixture unit' approach and compared with the design values commonly used for local buildings (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002).

2 Design approach

The probabilistic approach was used to study the simultaneous discharge from a group of sanitary appliance outlets for a common drainage stack (e.g., CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002; Webster 1972). If an outlet has repeated cycles of discharge with an average discharge time t_d (s) and the average time interval between discharges T_d (min), the probability of the outlet discharging p_d at any instant is,

$$p_d = \frac{t_d}{60T_d} \quad \text{… (1)}$$

Assume the discharge action is binomially distributed; the probability of N outlets discharging out of M identical outlets is given by,

$$_M P_{d;N} = C_N^M p_d^N p_o^{\ M-N}; \quad M \geq N \quad \text{… (2)}$$

where,

$$C_N^M = \frac{M!}{N!\,(M-N)!} \quad \text{… (3)}$$

The probability of the outlet not discharging p_o at that instant is,

$$p_o = 1 - p_d \quad \text{… (4)}$$

A system would be designed for N (out of M installed) appliance outlets discharging simultaneously. This system is considered as ‘engineering unsatisfactory’ (i.e., ‘failure’) if more than N appliances are discharging at any instant. The failure rate λ is determined by the sum of the probability that more than N appliances discharging simultaneously,

$$\lambda = P(N+1) + P(N+2) + \ldots + P(n-1) + P(n) = \sum_{i=N+1}^{n} P_i\,; \quad N < M \quad \text{… (5)}$$

An independent use of the appliance at random times is assumed and the failure rate could be interpreted as the proportion of the time that (N + 1) or more outlets discharges simultaneously. The number of the simultaneously discharging appliances N can be determined for the probability of discharging P_d at an allowable failure rate λ with equation (5).

Newton’s interpolatory divided-difference formula for equally-spaced nodes (known as Stirling’s formula) would be applied to solve the binominal distribution (Bull 1956, CIBSE 1988) and yield the result with an error function (Zwillinger 1996),

$$\sum_{Mp_d-z}^{Mp_d+z} P = \operatorname{erf}\left[\frac{z}{\sqrt{2Mp(1-p_d)}}\right] \quad \text{… (6)}$$

where, z is the number of standard deviations σ away from the mean that will result in the least value of N is not exceeded more than the limiting failure rate λ set. For the limiting failure rate set at $\lambda = 0.01$,

$$N = Mp_d + 1.8\sqrt{2Mp(1-p_d)} \qquad \ldots (7)$$

where, p_d is the probability of simultaneous operation for the appliance.

Alternatively, the result would be approximated by the normal distribution (Breese 2001) for $\lambda = 0.01$,

$$N = Mp_d + z\sigma \qquad \ldots (8)$$

For the limiting failure rate $\lambda = 0.01$, the corresponding value of z is 2.33. It is suggested z = 2.5 is a 'safer' choice in practice because the normal approximation would underestimate the probable number of appliances simultaneous in operation N in small systems, e.g., M < 30 (Breese 2001; Zwillinger 1996),

$$N = Mp_d + 2.5\,\sigma \qquad \ldots (9)$$

The standard deviation of appliances in operating σ is,

$$\sigma = \sqrt{Mp_d(1-p_d)} \qquad \ldots (10)$$

This is very close to those approximated by the error function that,

$$N = Mp_d + 2.55\sigma \qquad \ldots (11)$$

Some appliances, e.g., washbasins, sinks or bathtubs might be filled up (using a plug) before discharging the water (known as a 'plugged flow'). The discharge time t_d (s) of the appliance i would be determined by the probability of filled-up discharge P_f and the operating time of the water tap t_a (s),

$$t_{d,i} = (P_f t_d + P_u t_a)_i \qquad \ldots (12)$$

where, P_u is the probability of appliance discharge without using a plug,

$$P_f + P_u = 1 \qquad \ldots (13)$$

The discharge time for a filled-up appliance t_d (s) for the appliance i that is filled with water at a fraction ϕ_a of its capacity V_a (m^3) is determined by,

$$t_{d,i} = \left(\frac{1000V_a\phi_a}{q_d}\right)_i \qquad \ldots (14)$$

where, q_d (L/s) is the discharge flow rate for the appliance filled with water and can be measured experimentally (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002; Wise 1973).

A typical drainage system involves more than one appliance type and each appliance type would associate with different usage patterns and the discharge probabilities. A system of Discharge Unit (DU) was used to take into account the differing probabilities (Breese 2001; BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002). The same design flow rate q_D (e.g., 10 L/s) would be produced from a group of a number appliance M_i installed or from a group of an equivalent number of hypothetical appliances M_h, which has a discharge unit of 1.

$$q_D = (Nq_d)_i = (Nq_d)_h \quad \text{… (15)}$$

The discharge unit of the appliance DU_i is,

$$DU_i = \frac{M_i}{M_h} \quad \text{… (16)}$$

where,

$$M_i = \left(\frac{N - z\sigma}{p}\right)_i \quad \text{… (17)}$$

The total load of a drainage stack is the sum of the discharge units for all the connected appliances. Relationship between discharge units and actual flow rates was established by utilizing the steady free surface flow equations and the depths of flow were calculated for various pipe gradients and diameters (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Hunter 1940; Plumbing services design guide 2002; Swaffield and Galowin 1992; Wise and Swaffield 2002). Graphical presentation or mathematical expressions in determining the total discharge flow rate for the stack $\Sigma q_{d,i}$ (L/s) with the total discharge units ΣDU_i were provided in design guides (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988) to determine the drainage stack size. The discharge flow rate $\Sigma q_{d,i}$ (L/s) can be related by,

$$\sum q_{d,i} = C_1 + C_2\left(\sum DU_i\right)^{C_3} \quad \text{… (18)}$$

where, C_1, C_2 and C_3 are constants as shown in Table 1 (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988).

Table 1: Constants for determining the probable discharge flow rate

Design guide	Application range	C_1	C_2	C_3	Correlation coefficient R
IOP (1977)	$70 \le DU < 158$	0.9	0.0061	1	0.9941
	$158 \le DU \le 6500$	0	0.073	0.64	
IOP (1987)	All DU	0	0.0458	0.666	NA
IOP (2002)	All DU	0	0.5	0.5	NA
BS5572 (1994)	$100 \le DU \le 20000$	2.3895	0.0622	0.6659	0.9999
BSEN 12506 (2000)	All DU	0	0.5	0.5	NA
Wong and Mui (2004)	$70 \le DU < 158$	0.9	0.0061	1	NA
	$158 \le DU \le 6500$	0	0.073	0.64	

NA = Not applicable

The appliance with a relatively long discharge time (e.g., 10 minutes) would be considered as a continuous flow q_c (L/s) in determining the stack size (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988),

$$\sum q_{d,i} = q_c + C_1 + C_2\left(\sum DU\right)^{C_3} \quad \ldots (19)$$

The flow capacity of stack q_s (L/s) with the stack diameter D_s (mm) is given by (Wyly and Eaton 1961),

$$q_s = 31.9\phi_s^{5/3} D_s^{8/3} \quad \ldots (20)$$

where ϕ_s is the fraction of the cross-sectional area of the stack occupied by the water. The capacity of a stack flowing at quarter full (i.e., ϕ_s = 1/4) is shown in Table 2 (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988). In this study, a probable growth of water consumption (10%) in future 10 years is assumed in determining the maximum discharge units allowed in a drainage pipe in Table 2 (Hall *et al.* 1988). Additional discharge to stack may be due to 2 components: extended duration of discharge at the design flow rate; or increased quantity of discharge with the same probability of use. For simplicity, the increment of the design flow rate in a stack is taken to be the same proportion of the water consumption increment.

Table 2: Design capacities of a main vertical drainage pipe

Stack diameter D_s (mm)	Maximum allowable discharge unit			Maximum allowable flow rate (L/s)	Maximum allowable discharge unit	Maximum allowable flow rate (L/s)
	This study	Plumbing service design guide (1977)	Plumbing service design guide (1987)	Plumbing service design guide (2002)	BS5572 (1994)	BSEN12056 (2000)
100	950	1200	750	7.3	750	7.3
125	2200	2800	2500	N/S	2500	10
150	4900	6000	5500	18.3	5500	18.3
175	9700	Not specified				N/S
200	16700					27.3

3 Survey

Five typical high-rise residential building estates in Hong Kong are selected at various geometrical locations, the building age and architectural designs in order to study the usage patterns and the details of the building drainage appliances. The five estates provide 26,500 apartments and the population is 113,000 persons (Hong Kong Census and Statistics Department 2001; Wong and Mui 2004). A total of 1,300 households were randomly invited for this study. Their apartments were using common stacks in 14 high-rise buildings of 38-42 floors with the height up to 150 m. Invitation letters were sent to introduce the objectives of this study, survey period and the survey details. Representatives in 597 households were participated in a face-to-face interview survey conducted in 2003-2004.

A total of 1,300 apartments were visited and the 597 occupants were interviewed. The details of the interview were summarized in Appendix. The occupant load variations during a day throughout a week were surveyed. Most of the interviewees were the major users of the sanitary appliances in the apartment as they stayed in home of longest resident time. During the interview, they were asked to provide information for the usage patterns of the day prior to the interview, and the hourly usage patterns on weekdays, weekend, Sunday and holiday with the corresponding activities. The average time between appliance demands was surveyed. The frequency of using a plug of the appliance and the fill-up level were recorded. The appliance type, physical size and the brand name were recorded. The average flow rates of the water taps installed at sink, washbasin, shower and bath were measured with sample operations by the occupants, and the discharge time and the refilling time of a WC cistern were measured.

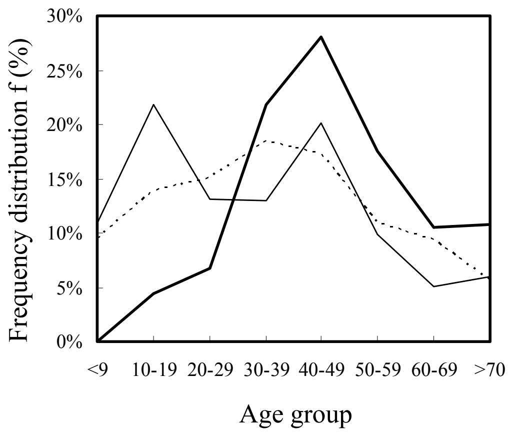


Figure 1: Age group of the respondents

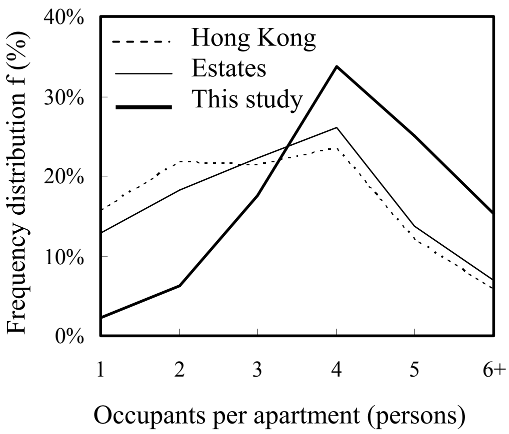


Figure 2: Occupant load

4 Results and discussion

Figure 1 shows the age distribution of the 597 interviewees. Not much surveyed samples felt within the younger age groups as compared to the distributions of the all 5 estates and population of Hong Kong. It is reported that the average number of occupant per household is 4.2 with the distribution shown in Figure 2. In contrast, the average family size of Hong Kong was 3.1 with the distribution shown in the figure, as recorded in 2001. The surveyed maximum occupant load factor (OLF) is very close to the design limits of 4.5-9 m^2/person as shown in Figure 3 (Buildings Department 1996; Wong 2003). The survey sample is considered to be representative to the population for age group ≥ 30. The occupant load variations in weekdays and holiday of the sample apartments are shown in Figure 4. A higher occupant load for weekdays but similar variations for holidays were found for this study, as compared to the previous study for residential buildings (Wong 2003).

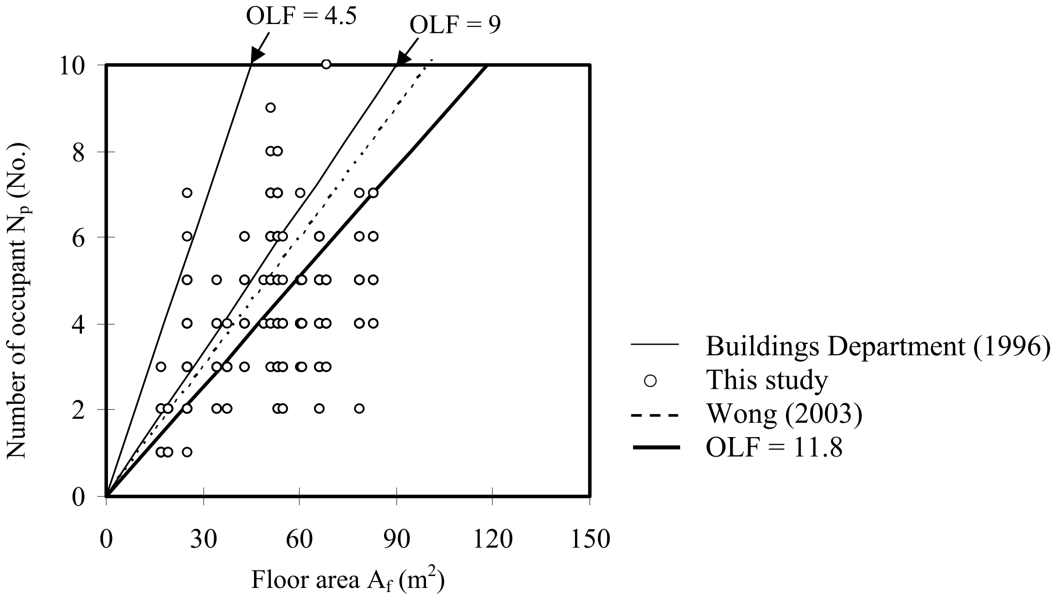


Figure 3: Occupant load factor of residential buildings in Hong Kong

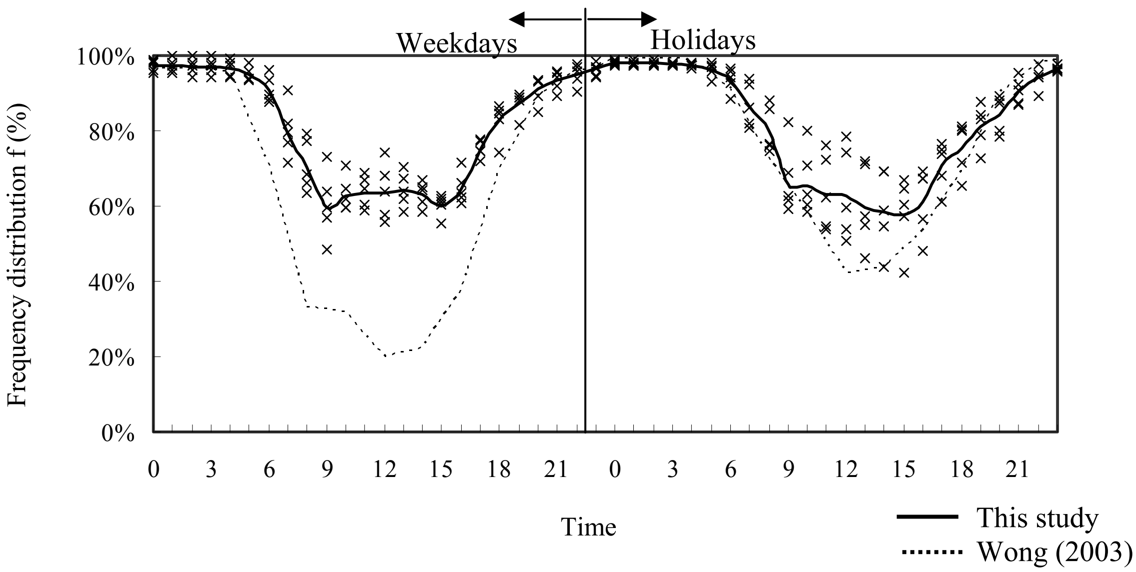
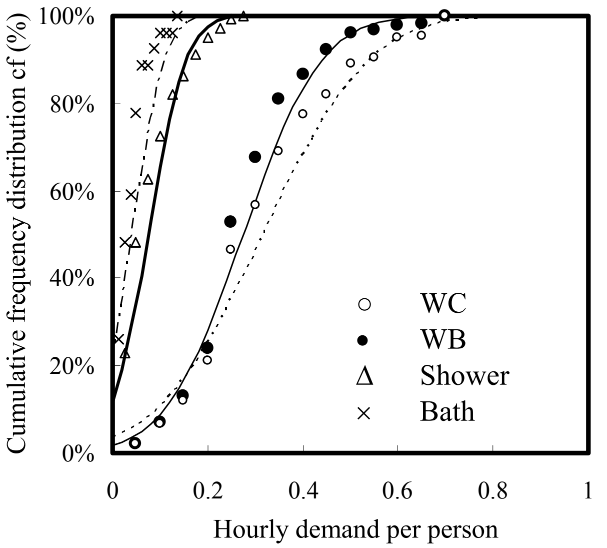


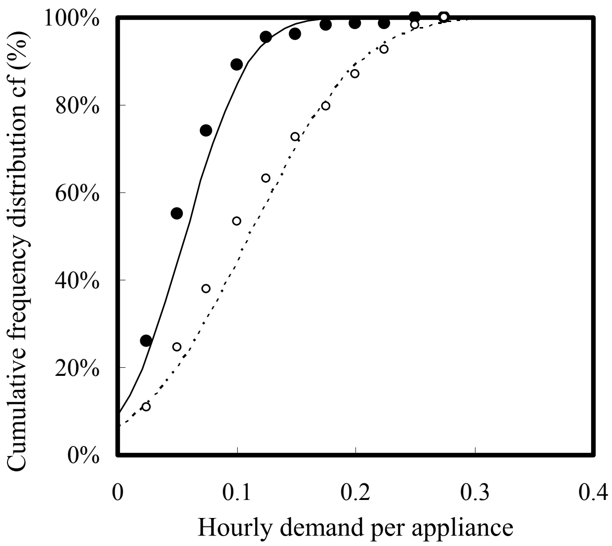
Figure 4: Occupancy variation in weekdays and holidays

The hourly demands for the sanitary appliances are shown in Figure 5. It is reported that the maximum hourly demands per person for WC, washbasin, shower and bath are 0.88, 1.14, 0.29 and 0.28, respectively. The average demands of WC and washbasin were compared with the expected average demand reported by the interviewees as an indicator to confirm the validity of the responses. The expected average demands of WC and washbasin are 3.00 and 3.01 hours, respectively, with the frequency distributions shown in Figure 6. The corresponding expected hourly demands are 0.33 per person for both WC and washbasin and consistent with the average demands calculated from the surveyed usage patterns, which are 0.28 and 0.32 per person for WC and washbasin, respectively. The demands for washing machines and sinks would be on unit basis, and only one washing machine and one sink were found in each apartment. The maximum hourly demands of the washing machines and sinks are 0.25 and 0.41 per appliance, respectively.



Appliance	Surveyed maximum, sample mean, standard deviation
	No./(person hr)
WC	0.875, 0.275, 0.130
WB	1.139, 0.317, 0.175
Shower	0.288, 0.075, 0.063
Bath	0.281, 0.042, 0.053

(a) WC, washbasin, shower and bath



Appliance	Surveyed maximum, sample mean, standard deviation
	No./(appliance hr)
Washing machine	0.25, 0.056, 0.043
Sink	0.406, 0.111, 0.073

● Washing machine
○ Sink

(b) Washing machine and sink

Figure 5: Hourly demands of some domestic appliances

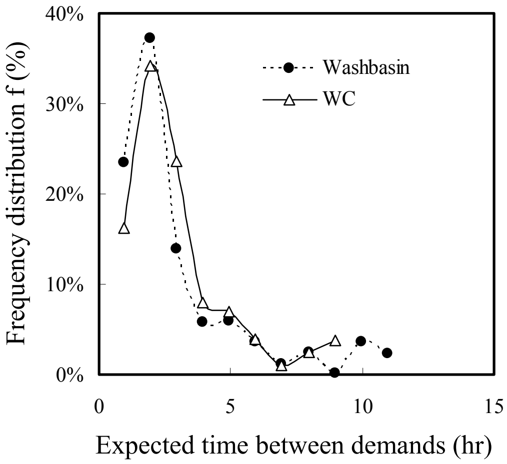


Figure 6: Expected time between demands for WC and washbasin

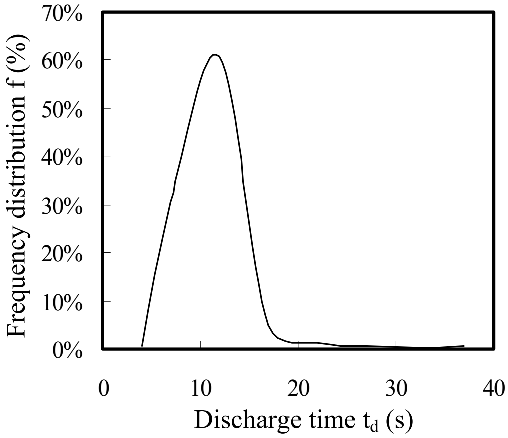


Figure 7: Discharge time for a WC flushing

Interestingly, user may flush more than once after the use of a WC as shown in Table 3. The discharge time per flushing is shown in Figure 7. It is reported that 9 L flushing cistern was installed in all the surveyed apartments. The frequency distribution of the average discharge flow rate in Figure 8 shows that the maximum average discharge flow rate is 2.1 L/s, which is consistent with the design values (1.2 to 2.27 L/s) used in current practice (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Plumbing services design guide 2002). The surveyed average discharge flow rate is 0.85 L/s.

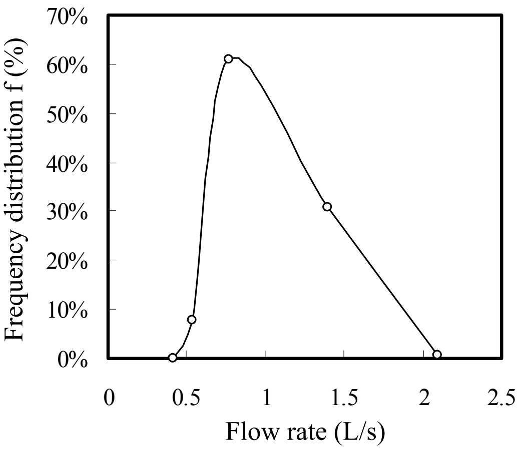


Figure 8: Average discharge flow rate of a WC flushing

Table 3: Number of flushing operations per demand of a WC

No of flushing	Frequency (%)
0	0
1	82.2
2	16.4
3	1.3

Table 4: Probability of fill-up an appliance before discharging

Probability	Washbasin	Sink	Bath tub
< 0.25	73.7 %	51.7 %	94.5 %
0.25 – 0.49	15.7 %	26.7 %	2.5 %
0.5 – 0.74	4.5 %	0.3 %	1.2 %
≥ 0.75	6.1 %	21.3 %	1.6 %

Table 5: Fill-up level of an appliance before discharging

Fill-up level	Washbasin	Sink	Bath tub
< 0.25 full	16.6 %	4.1 %	9.5 %
0.25 – 0.49	64.5 %	56.4 %	38.1 %
0.5 – 0.74	16.6 %	33.7 %	40.5 %
≥ 0.75	2.3 %	5.8 %	11.9 %

A washbasin, sink or bath would be filled up before the water is discharged. The fill-up probabilities of the appliances are shown in Table 4 and the probable fill-up levels are shown in Table 5. The results show that the appliances would not be filled up frequently. Many users reported that the bathtub would be used as a shower. They also expressed that more than one baths/showers would be taken a day and the frequency distribution is shown in Figure 9. This is very different from the survey results for other regions that the demand ranged from 0.07 to 0.7 baths per day with an average of 0.4 baths per day (Ligman *et al.* 1974; Webster 1972).

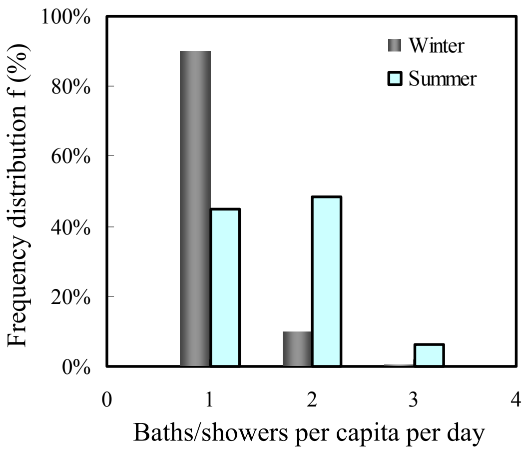
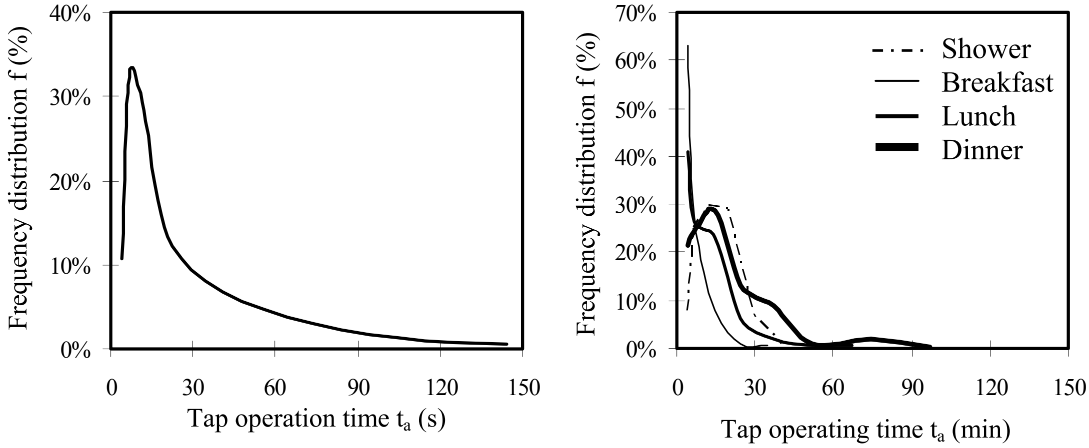


Figure 9: Number of baths or showers taken per day for a person



(a) Washbasin (b) Sink and shower

Figure 10: Water tap operating time

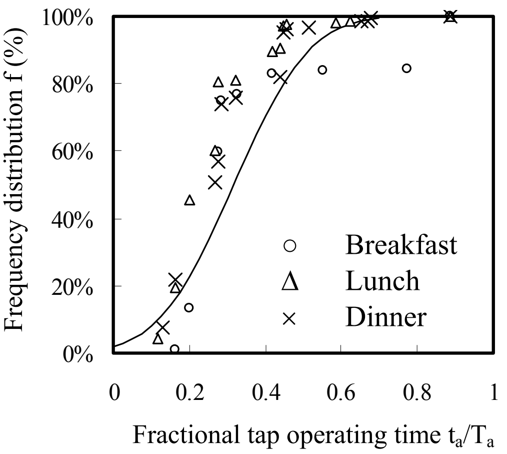
Table 6: Preparation of meal

Normally prepare a meal?	Breakfast	Lunch	Tea	Dinner
Yes	34.8 %	56 %	0 %	94.5 %
No	65.2 %	44 %	100 %	5.5 %

The water tap operation time for a washbasin, shower and sink is shown in Figure 10. The operating time of a shower water tap is between 4 to 40 minutes, with the average of 12 minutes. The tap operating time of a washbasin varying from few seconds (e.g., for hand washing) to over 2.5 minutes were recorded with an average operating time of 12.3 s. The operating time of a sink water tap would be closely related to the meal preparation, cooking and related activities. It is noted that people in Hong Kong would boil tap water for drinking purposes. The survey showed that about 1/3 households would normally prepare breakfast, 1/2 would prepare lunch and almost all would prepare dinner as shown in Table 6. The tap operating time was classified for breakfast, lunch and dinner preparation and is shown in Figure 10. The tap operating time of the sink t_a (s) would be correlated with the meal preparation time T_a (s).

Figure 11 shows the distribution of the fractional tap operating time (normalized by the preparation time T_a). A correlation for the tap operating time t_a (s) with correlation coefficient of 0.904 is obtained,

$$t_a = 0.315 T_a \qquad \ldots (21)$$



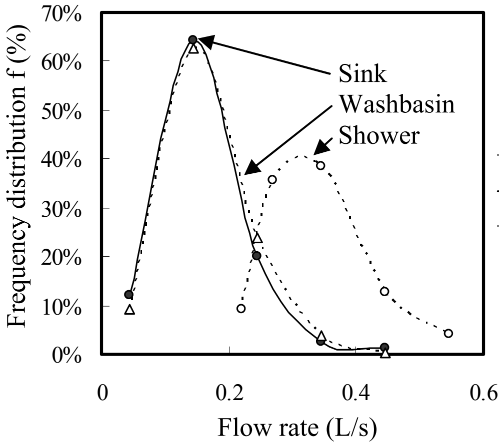


Figure 11: Water tap operating time per preparation time for a meal

Figure 12: Flow rate of water tap

The water tap discharge flow rates for showers, sinks and washbasin are shown in Figure 12. The corresponding average flow rates are 0.3, 0.17 and 0.16 L/s and match with the design values (0.1-0.3 L/s for shower head and bath, 0.15 L/s for taps at sink and washbasin) in design guides (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Laws of Hong Kong 1997; Plumbing service design guide 2002).

A relatively congested usage pattern (e.g., for WC and washbasin) was indicated from this survey as the intervals is slightly shorter than the 1200 s adopted in design guides (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Laws of Hong Kong 1997; Plumbing service design guide 2002). It is reported that longer operations of water taps at shower and sink were found. In fact, people in Hong Kong would take a longer shower. The survey also showed that much water would be consumed at the sinks.

The survey results were then used to derive the probabilities of discharge and the discharge flow rates of the domestic appliances as summarized in Table 7. The design values used in practice for local residential buildings are listed in the table for comparison. The probable discharge flow rates due to a number of appliances are shown in Figure 13 and compared with those determined with the design practice (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Laws of Hong Kong 1997; Plumbing service design guide 2002). The predicted discharge flow rates of this study for WCs and washbasins are at the low side among the predictions while the predictions for sink, shower, bath and washing machine show reasonable consistencies.

Figure 14 shows a typical arrangement of the domestic appliance in local residential high-rise buildings that a drainage stack and a ventilating pipe are provided. It is a common design for small apartments with one washroom and one kitchen. The stack collects wastewater from the two adjacent apartments of each floor. Cross ventilating pipes would be installed between the drainage stack and the ventilating pipe at every three floors.

Table 7: Design drainage loads for typical domestic sanitary appliances

Appliance	This study	Plumbing service design guide (1977)	(1987)	(2002)	BS5572 (1994)	BSEN 12056 (2000)
			Probability P			
WC	0.0084	0.004	Not specified	Not specified	0.0059 - 0.03	Not specified
Washbasin	0.0128	0.01			0.0083	
Sink	0.167	0.015			0.0208	
Shower	0.555	0.2			0.25	
Bath	0.0112	0.015			0.167-0.0417	
Washing machine	0.065	N/S			0.02-0.125	
			Discharge flow rate (L/s)			
WC	0.85	2.27	Not specified	1.2-2	1.2-1.8	2
Washbasin	0.23	0.34		0.3	0.6	0.3
Sink	0.26	0.75		1.3	0.9	0.6
Shower	0.32	0.08	0.1-0.45	0.4-1.3	0.07-0.15	0.4-0.5*
Bath	1.07	1.06	Not specified	1.3	1.1	0.6
Washing machine	0.6	Not specified		0.6	0.6	0.6
			Discharge Unit			
WC	4	6	6	1.2-2	4-7	2
Washbasin	1	1	1	0.3	1	0.3
Sink	9	3	3	1.3	7	0.6
Shower	13	1	Not specified	0.4-1.3*	<1**	0.4-0.5*
Bath	5-12#	6	7	1.3	7	0.6
Washing machine	13	Not specified	4	0.6	3-18	0.6

* With plug; ** Use flow rate for design; # Use as a shower is allowed;

The design discharge flow rates of the buildings are shown in Figure 15. It is noted that the no discharge flow rate was recommended for washing machine in the design guide (Plumbing service design guide 2002) (1977 edition). Good agreements were found among predictions with the current design guides for a building up to 20 floors. This study proposed higher probable discharge flow rates of drainage stack for high-rise residential buildings in Hong Kong because a higher probability of simultaneous discharge would be encountered.

The corresponding stack size for the discharge flow rate is determined and shown in Figure 16. The sizes determined by the design guides are shown for comparisons (BS5572 1994; BSEN12506 2000; CIBSE Guide 1988; Laws of Hong Kong 1997; Plumbing service design guide 2002). It is observed that a larger stack size would be determined with the new editions of design guides. In general, the required stack size would be one grade larger than those predicted by the previous guides. For a building with the typical arrangement up to 60 floors, the required stack size lays between the recommended sizes of the current design guides. A larger drainage stack would be required for the building over 60 floors.

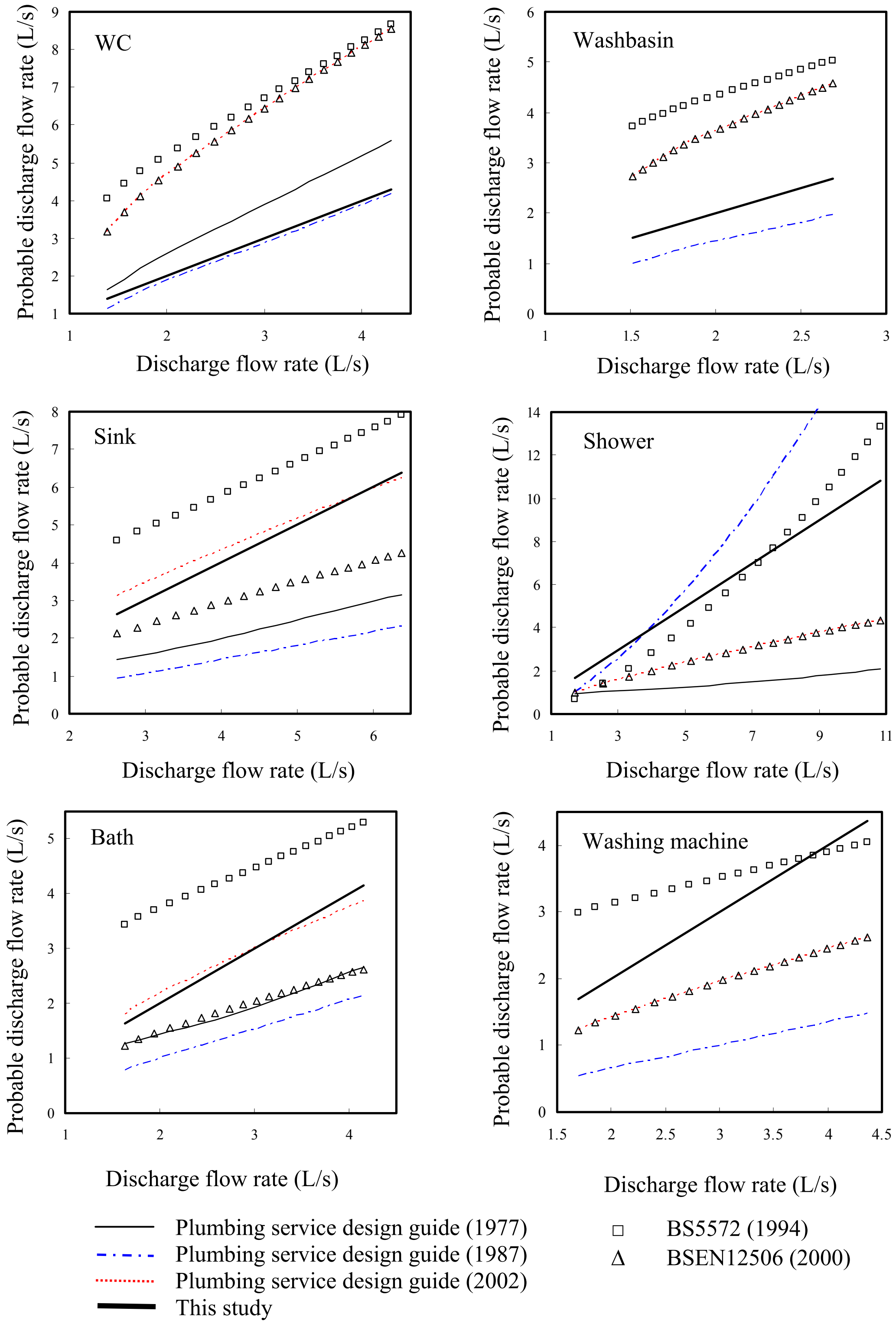


Figure 13: Comparison of the probable discharge flow rate at a group of appliances

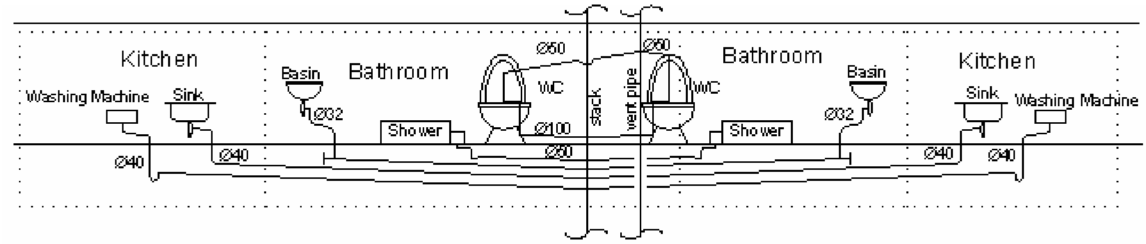
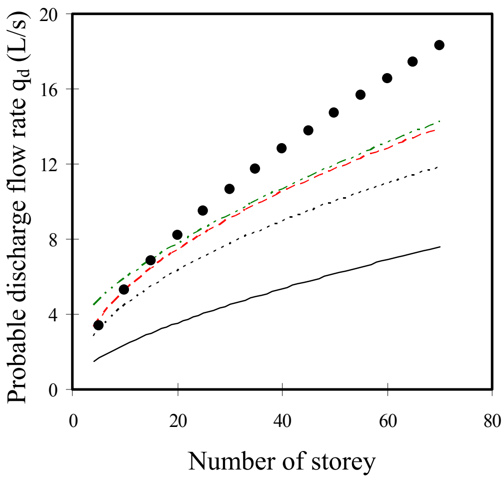


Figure 14: Typical arrangement of domestic appliance in residential buildings



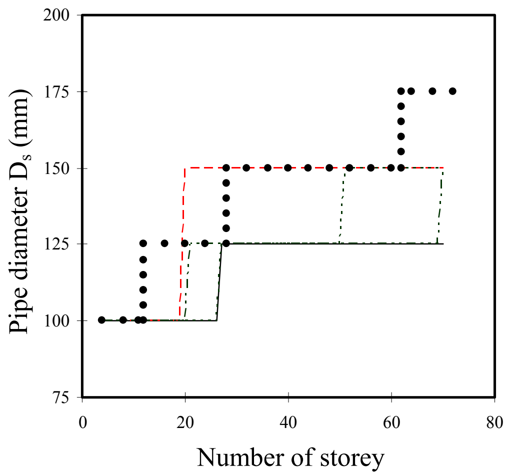


Figure 15: Probable discharge flow rate **Figure 16: Main drainage pipe diameter**

5 Conclusion

The drainage load must be accurately estimated in order to design a good drainage system for high-rise residential buildings. Design values used in current practice might not account for different architectural designs and user behavioral patterns for a city having a dense living environment, such as Hong Kong. With the survey results from the five typical high-rise residential building estates in Hong Kong, building drainage loads are derived with the fixture unit approach. The probable discharge flow rates for the appliances typically arranged in the low-cost residential high-rise buildings are examined. The implications on the required drainage stack size are discussed and compared with those calculated with the design data currently used for local buildings. It was found that good predictions were made with the current design values for typical residential buildings up to 60 floors. A larger drainage stack would be required for typical high-rise residential buildings in Hong Kong. This study provides a database of drainage loads in high-rise residential buildings in Hong Kong and enables further studies on the drainage system designs for cities having a high population density.

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7 Appendix Interview survey

1. Survey date and time
2. Apartment details: Location of flat, building height, number of storey, apartment floor area, number and location of escape staircases
3. User details: Age group, gender, occupant load, occupation, occupant load variations in last week,
4. Sanitary provisions: Number of toilets, water closets, washbasins, bathtubs, showers, sinks, washing machines, model of the appliances, appliance capacity, and duration of discharge for WC cistern
5. Usage pattern records for toilets, water closets, washbasins, bathtubs, showers, sinks, washing machines yesterday, in hourly basis
6. Average usage rate and occupant time of toilets, water closets, washbasins, bathtubs, showers, sinks, washing machines
7. Frequency in filling up the appliance before discharging, for bathtub, sink, washbasin and the level of filling
8. Number of flushes after the use of WC
9. Operating time of water tap at sink, shower, bathtub and washbasin for certain activities specified
10. Cooking activities: Number breakfast, lunch, tea, dinner, etc. prepared a day, preparation time and tab operation time

8 Presentation of Authors

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Investigation and numerical modelling of roof drainage systems under extreme events

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Abstract

In April 2003 the UK Engineering and Physical Sciences Research Council (EPSRC) and a diverse group of interested parties began funding a number of major projects looking at the impacts of climate change on the built environment, transport and utilities. One of these projects, entitled AUDACIOUS, is concerned with the impact of climate change on all aspects of urban drainage systems. The main objective of this project is to develop a set of numerical models to simulate the performance of urban drainage systems under the type of extreme rainfall events associated with climate change. Once developed, it is intended to utilise such models in a diagnostic design capacity, to assist in the formulation of strategies to improve the performance of new and existing urban drainage systems under different climate change scenarios.

This paper details the work that has been undertaken at Heriot-Watt University as part of the AUDACIOUS project. To date, this has involved the development of a numerical model to simulate the performance of roof drainage systems (both conventional and siphonic) under extreme rainfall events. The necessary experimental work is described, and the development of the model is detailed. Comparisons between model output and laboratory data are illustrated. Finally, conclusions are drawn regarding the progress to date, and plans for the next stage of the project are outlined.

Keywords

Roof Drainage; Extreme Events; Simulation

1 Introduction

AUDACIOUS stands for Adaptable Urban Drainage: Addressing Changes in Intensity, Occurrence and Uncertainty of Stormwater. As such it aims to investigate the key effects of climate change on the performance of existing urban drainage systems, and hence provide the models and guidance necessary to identify and rectify the types of operational problems associated with climate change. Successful completion of these aims depends primarily on the generation of realistic data describing typical and extreme future rainfall patterns, and the development of the numerical models necessary to route this rainfall through urban areas. The drainage models currently under development within AUDACIOUS include: a modified hydrology model, an interlinked sewer/surface runoff model, a local drainage model and a roof drainage model. The generation of the rainfall data and the development of the first three models is detailed elsewhere[1,2], whilst the remainder of this paper is concerned with the roof drainage model.

2 Basic principles and current design practice

There are basically two different types of roof drainage system, namely conventional and siphonic. Both types of system essentially comprise of three interacting components: the roof surface, the rainwater collection gutters and the system pipework. Each of these components has the ability to substantially alter the runoff hydrograph as it is routed through the system.

The design of the roof surface is usually within the remit of the architect rather than the drainage designer, highlighting that structural and/or aesthetic concerns often take precedence over performance criteria.

The hydraulic design of gutters is complicated by the presence of the sloping water surface profile, the form of which can only realistically be determined with recourse to some form of numerical model. Consequently, current design methods for gutters installed in conventional drainage systems are based primarily on empirical relationships[3] and the assumption of free discharge at the outlet. Little additional guidance is given in the standards for the design of gutters in siphonic systems, and the onus is firmly on the system designers to ensure adequate capacity; this is normally ensured by the laboratory testing of specific gutter outlets.

With respect to system pipework, the relevant standard[4] (BS EN 12056-3:2000) specifies that downpipes in conventional systems should run no more than 33% full. Similarly, the flow conditions within offset pipes must also normally be free surface, with BS EN 12056-3:2000 specifying that offsets run no more than 70% full. Current design practice for siphonic systems assumes that, for a specified design storm, a siphonic system fills and primes rapidly with 100% water[5]. This assumption allows siphonic systems to be designed utilising steady state hydraulic theory, normally in the form of simple computer programs. The steady flow energy equation is employed[6], with the elevation difference between the gutter water level and the point of discharge being equated to the head losses in the system. However, steady state design methods are not truly applicable when a siphonic system is exposed to a rainfall event below the design criteria, or an event with varying rainfall intensity. Furthermore, current design methods cannot account for commonly occurring operational problems, such as the blockage of outlets and the submergence of the system exit due to downstream flooding.

3. Description of research

As mentioned previously, the main aim of the work detailed herein was to develop a numerical model, capable of accurately simulating the operational performance of roof drainage systems. As such, it was envisaged that the model would have to be able to route rainfall from roof surfaces down to ground level. To achieve this, it was necessary to undertake both experimental and numerical work.

Experimental data concerning the performance of conventional systems during extreme rainfall events is very scarce. It was therefore necessary to undertake laboratory based experimental work to determine the operational characteristics of conventional systems under such conditions. In contrast, the performance of siphonic systems under all types of rainfall events is relatively well understood [7]. Consequently, no further siphonic experimental work was required.

In terms of numerical modelling, it was necessary to develop new subroutines to simulate the flow conditions on roof surfaces, along gutters and within conventional systems. Much of the developmental work concerning siphonic systems has already been completed during previous research projects[7]. However, the complexity of the existing computational subroutines often leads to numerical instabilities, restricting its general applicability and resulting in extended computational run times. Consequently, it was necessary to simplify the modelling techniques associated with siphonic systems.

4. Laboratory investigations

As the capacity of conventional roof drainage systems is controlled primarily by the capacity of the gutter outlets, the main purpose of the laboratory work was to investigate the flow conditions in the vicinity of the outlets, and their dependence on gutter cross-sectional characteristics.

4.1 Experimental apparatus and procedure

Experimental work was undertaken using the test rig detailed in Figure 1. Spatial constraints within the laboratory limited the maximum gutter length to 1.95*m*, but this was considered sufficient to investigate outlet flow conditions. To ensure realistic flow conditions, each gutter was fed via a rear supply trough and a simulated sloping roof. Pressure transducers were installed in the base of the gutters to measure flow depths and, where appropriate, in the base of the overflow tank to measure gutter overtopping. In addition, magnetic induction flowmeters were used to measure the gutter inflow rates. The transducers and flowmeters were connected to a PC based data acquisition system, capable of sampling data at frequencies of up to 30*kHz*. Where possible, the pipework was transparent, allowing direct observations of relevant flow conditions.

Using the equipment detailed above, laboratory experiments were undertaken to determine the flow conditions arising with four representative gutter/downpipe configurations, namely:

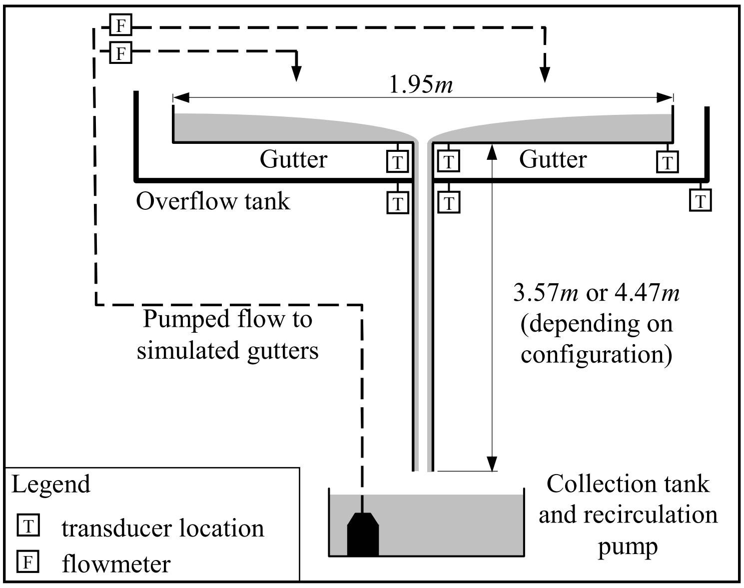

Figure 1. Laboratory test rig

- Gutter A and 64*mm* diameter downpipe - trapezoidal cross-section (80*mm* sole width, 112*mm* top width, 60*mm* height). A typical standard gutter used in conventional systems for small scale developments.
- Gutter B and 110*mm* diameter downpipe - true half round cross-section (150*mm* diameter, 75*mm* height). A typical standard gutter used in conventional systems for large scale developments.
- Gutter C and 64*mm* diameter downpipe - rectangular cross-section (600*mm* sole width, 300*mm* deep) with a custom made outlet set flush to the gutter sole. A typical wide, specialist gutter used in conventional and siphonic systems for very large or prestigious developments.
- Gutter C and 110*mm* diameter downpipe - gutter details as above.

In addition to the normal setup, with the gutter connected directly to the downpipe, experiments were also undertaken with each configuration and the following system elements connected immediately downstream of the outlet: a collection hopper, a minor offset (two 45° bends in series), a major offset (two 45° bends connected by a short length of pipework). The presence of the overflow tank meant that configurations incorporating the standard gutters could be subjected to flow loading far in excess of that necessary to cause gutter overtopping. As Gutter C was the overflow tank itself, it was not possible to allow this section to overtop. Hence, the experiments undertaken using Gutter C were stopped when the water depth approached the overtopping level.

4.2 Experimental results

Figure 2 illustrates typical data collected from the laboratory experimental work undertaken using Gutter A (64*mm* diameter downpipe). As shown, the outlet depths with and without a collection hopper were similar. In fact, the experimental data indicates that the flow conditions were also unaffected by the presence or severity of any offset. The higher upstream depths shown in Figure 2 also confirm the form of the water surface profile discussed previously, i.e. sloping down towards the outlet. Visual observations made during the experimental work indicate that the conditions throughout the system remained free surface. The maximum capacity of this configuration was approximately 4.5*l/s*; where maximum capacity is defined as the maximum downpipe flow rate, irrespective of whether the gutter is operating normally or overtopping.

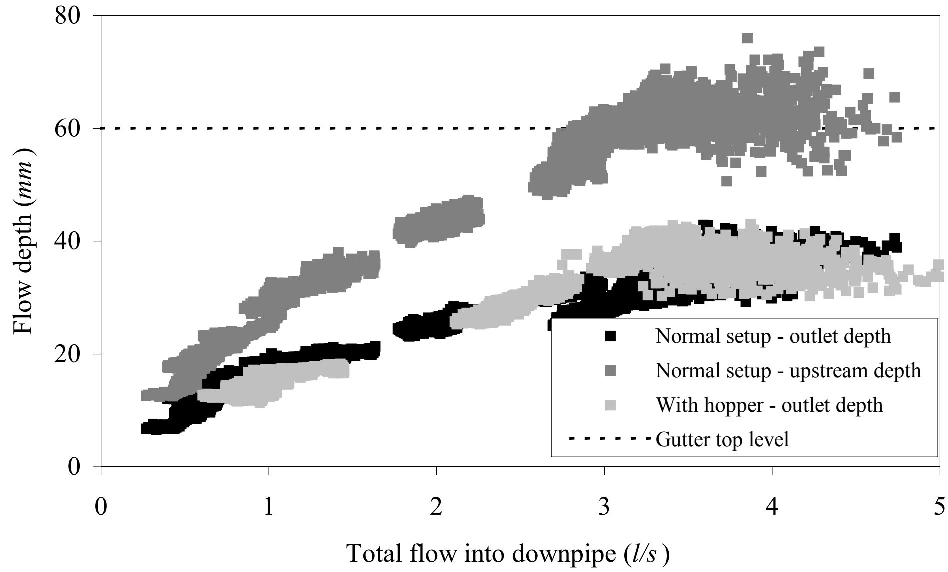

Figure 2. Measured flow depths in Gutter A (64*mm* diameter downpipe) – with and without collection hopper

The experimental data and visual observations obtained with Gutter B (110*mm* diameter downpipe) followed the same pattern set by Gutter A, i.e. flow conditions appeared to be unaffected by the downstream pipework and were free surface throughout. The maximum capacity of this configuration was approximately 7*l/s*. In contrast, the experimental data collected with Gutter C (64*mm* diameter downpipe) indicate that the flow conditions were influenced by the configuration of the downstream pipework. As shown in Figure 3, the presence of a collection hopper significantly reduced the capacity at outlet depths above approximately 50*mm*. It can also be seen that the minor and major offset configurations also resulted in reductions to system flow rates. Visual observations made during the experimental work indicate that, once the outlet depth had reached a certain level, the flow conditions within the downpipe became a full bore mixture of water and entrained air. This transition was marked by visual and audible air entrainment into the downpipe, a phenomenon that gradually decreased as the gutter depths increased. The maximum capacity of this gutter/downpipe configuration was approximately *19l/*s, above which it threatened to overtop. Similar flow conditions were observed with Gutter C and the 110*mm* diameter downpipe, although the gutter depths never approached the overtopping level and large quantities of air continued to be entrained into the downpipe. This was considered to be because the capacity of this configuration was greater than the available laboratory pumping capacity (approximately 26*l/s*); it seems reasonable to assume that the gutter would overtop, and the volume of entrained air would decrease significantly, at higher gutter inflow rates.

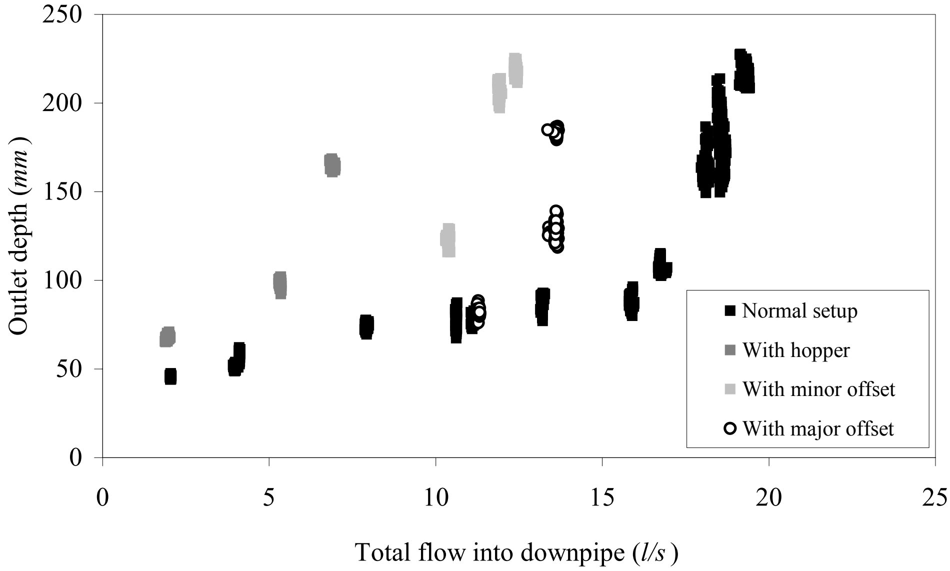

Figure 3. Measured outlet depths in Gutter C (64*mm* diameter downpipe) - various setups

In view of these unexpected observations of full bore flow conditions within configurations incorporating Gutter C, a pressure transducer was installed in the wall of the 110*mm* diameter downpipe. The data collected from this transducer highlighted the negative system pressures that indicate the onset and establishment of siphonic conditions within the downpipe (above gutter depths of approximately 50*mm*).

Figure 4 illustrates the experimental data obtained for all four gutter/downpipe configurations.

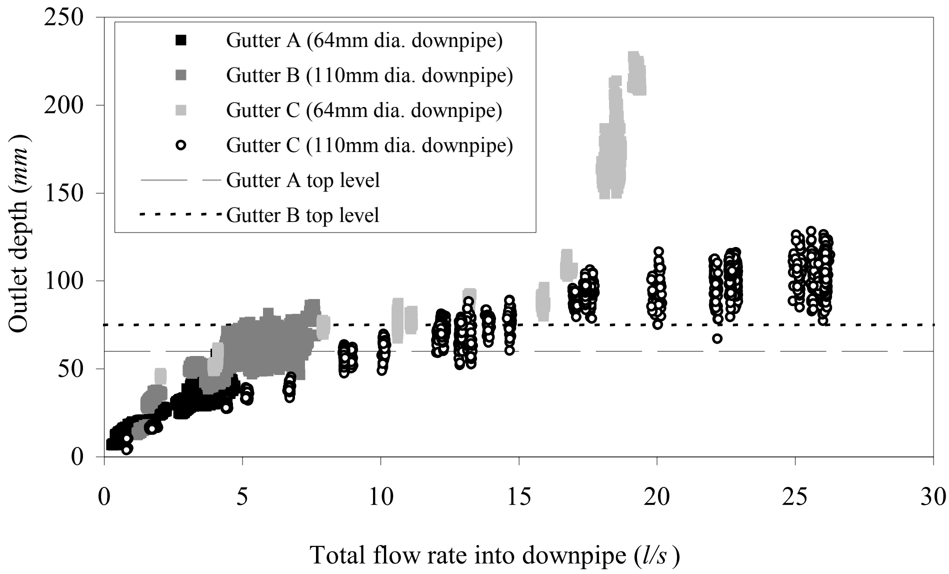

Figure 4. Measured outlet depths for all gutter and downpipe configurations - normal setup

As shown, the outlet depths for both of the standard gutters (A and B) approached, and sometimes exceeded, the gutter top levels at relatively low flow rates (less than 7.5*l/s*). The sloping water surface profile meant that these high outlet depths corresponded to even higher upstream depths, which resulted in gutter overtopping. The data shown for Gutter C illustrates the far greater capacities associated with these configurations. Whilst the shape of the data plot associated with Gutter C and the 64*mm* diameter downpipe indicates that the maximum capacity has been achieved, the data associated with Gutter C and the 110*mm* diameter downpipe suggests that significantly more capacity is available. It is considered that the greater capacity of the wide Gutter C is because it's design enables full bore flow conditions to develop in the downpipe, leading to siphonic action and the resulting higher flow rates. The most obvious reason for this is that the high flow depths possible in Gutter C help to constrict/break direct air paths into the downpipe, hence encouraging the formation of full bore conditions. The second reason is that the relatively large sole width of Gutter C, in terms of the diameter of the outlet, means that flow can readily enter the downpipe all around the circumference of the outlet, again encouraging the formation of full bore conditions. In contrast, the effective sole width of the standard gutters are approximately equal to the diameter of the outlet, and flow can therefore really only enter the downpipe from either side of the outlet.

5. Numerical modelling

In order to accurately simulate the performance of roof drainage systems, it was necessary to develop a numerical model incorporating a roof flow module, a gutter flow module and a pipework module.

5.1 Roof flow module

The roof flow module utilises a kinematic wave approach[8] to the routing of rainfall over sloping roof surfaces and into the gutters. Although less accurate than a full dynamic approach, the relatively large surface areas involved mean that anything more complex would result in unfeasibly long computational run times. In addition to variable rainfall conditions, the module can also account for different roof geometries (area, slope, roughness) and the effect of wind driven rain. Furthermore, by utilising the Horton infiltration formulation[8], the module can also simulate the basic effects of green roof surfaces, i.e. the module calculates the quantity of rainfall that infiltrates into a green roof rather than running off into a gutter. Whilst the above approach is applied to roof surfaces supplying gutters, flat roofs connected directly to downpipes are treated slightly differently. A simple volumetric based approach is used to determine the quantity of rainwater falling on a roof during any given interval. This data is used to calculate the corresponding depth of water on the roof, which then controls the flow rate into the connected downpipe(s).

5.2 Gutter flow module

The gutter flow module utilises the method of characteristics solution technique to the continuity and momentum equations of one dimensional, unsteady flow in open channels with lateral inflow[9]. When employing this approach, boundary conditions (BCs) are required to describe the conditions occurring at all system boundaries, namely: the upstream/downstream ends of a gutter, an open gutter outlet and a fully/partially closed gutter outlet. The BC for the ends of a gutter is very straightforward, as there is no flow past the gutter end, and the velocity is thus zero.

The form of the BC for an open gutter outlet depends on the type of system, the gutter dimensions and the prevailing flow conditions. Dealing first with conventional systems, the experimental data confirms that the outlet depth in a standard gutter (Gutter A or B) is equal to the relevant critical depth of the flow, irrespective of whether the gutter is operating normally or overtopping. Hence the BC for standard gutters is critical depth at the outlet. The experimental data obtained with the wide gutter (Gutter C) indicates that, whilst the flow in the connected downpipe remains free surface, the outlet depth may be described by the weir equation detailed in BS EN 12056-3:2000, which is based on extensive laboratory data collected in the 1980s[3]. Once the flow in the downpipe becomes a full bore mixture of water and entrained air, the conditions within the gutters and the connected pipework become inextricably linked, and must therefore be analysed together. This may be achieved by solving the available characteristic equation[#] at the entry to the downpipe with an empirical expression linking gutter flow depth to entrained air flows. The necessary empirical relationships, for both the 64*mm* and 110*mm* downpipes, were developed by analysis of the experimental data. Hence the BC for wide gutters is weir flow up to a certain gutter depth, followed by full bore flow with a variable air content. With respect to open outlets in siphonic systems, the necessary BCs have already been developed as part of previous research projects. Essentially, they follow the same pattern as wide gutters in conventional systems, the only differences being that the empirical relationships linking entrained air content to gutter depth are slightly different, due to the due to the inclusion of a (air restricting) baffle plate. Although no experimental work was undertaken for outlets on flat roofs, it seems reasonable to treat these in a similar fashion to those in wide gutters, as the outlet would normally be surrounded by water in much the same way as a wide gutter section.

For both conventional and siphonic systems, a BC was required for fully/partially closed outlets in order to represent outlets that may become blocked. This is a particular problem with siphonic systems, due to the design of the outlets and the relatively small diameter of the downpipes. In the case of total blockages, the BC is straightforward, as the flow through the outlet is simply set to zero. With partial blockages, the process is slightly more complicated, but essentially involves specifying a percentage figure to represent the proportion of pre-blockage flow that can pass into the downpipe.

5.3 Pipe flow module

In order to avoid the type of stability and run time problems associated with the existing siphonic roof drainage model, the new pipe flow module utilises a two step approach to the routing of rainfall from gutter level to the ground. Under free surface gutter conditions, the flow in both conventional and siphonic systems is free surface, and is

[#] A characteristic equation is an expression that links conditions at one computational node at one time to those at an adjacent node, one time step in the future thus simply routed to ground level assuming annular flow within downpipes. However, when the conditions at the gutter outlets become full bore, the flow in both conventional and siphonic systems is assumed to become full bore. The method of characteristics solution technique is then used to solve the continuity and momentum equations of one dimensional, unsteady full bore flow [9]. By utilising this two step approach, it is not possible to accurately model all aspects of siphonic system operation, particularly with respect to the priming process and the pulsing conditions characteristic of sub-design events. However, it seems to reasonable to assume that, when exposed to an extreme event, a siphonic system will prime rapidly and will not exhibit pulsing conditions. As the primary purpose of the model is to simulate the conditions occurring due to extreme events, the small errors involved in this approach are not considered particularly significant.

Again boundary conditions are required to allow the full bore solution to proceed. General forms of the necessary BCs have been developed during previous research projects[10], and hence required only minor modifications to be added to the new model. These BCs are equally applicable to both conventional and siphonic systems, and include: a system entry BC (linked to the gutter outlet conditions and with variable air entry), a blocked outlet BC (with variable degree of blockage), a 90° bend BC, a diameter change BC, a three pipe junction BC and a system exit BC (including allowance for a submerged discharge or discharge to a sealed manhole).

5.4 Model output

Figure 5 shows a comparison between the measured and predicted outlet depths and overtopping rates for Gutter A (64*mm* diameter downpipe) when the inflow to the gutter was approximately 5.9*l/s*.

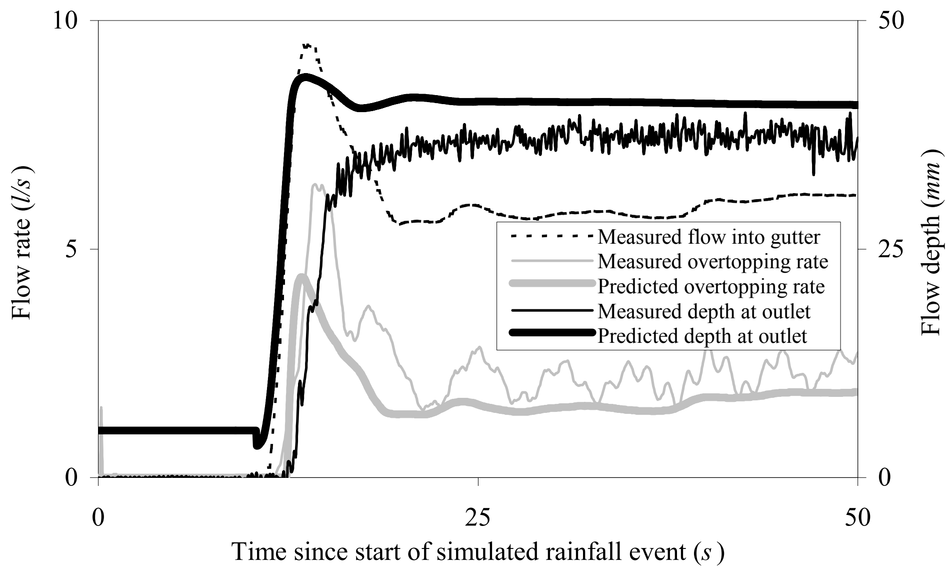

Figure 5. Measured and predicted conditions in Gutter A (64*mm* diameter downpipe) – normal setup

As shown, the predicted outlet depth compares well to the measured data, the only significant difference being due to the 'fictitious' initial baseflow necessary to commence the simulation (0.1*l/s*). The predicted gutter overtopping rates also compare well to the measured data, the only significant difference being due to the highly turbulent initial 'surge', as the gutter first overtops. As the model simulates one dimensional flow conditions (along the gutter length), it is not possible to predict variations in flow conditions across the gutter, let alone the type of turbulent surge illustrated in Figure 5. The minor discrepancies between the 'cyclical' measured overtopping rates and the 'steadier' predicted rates are again considered to be as a result of turbulent gutter conditions. Figure 6 shows a comparison between the measured and predicted outlet depths for Gutter C (110*mm* diameter downpipe), when the inflow to the gutter was reduced in steps from an initial 26*l/s*. As shown, the predicted depths compare well to the measured data at all gutter inflow rates.

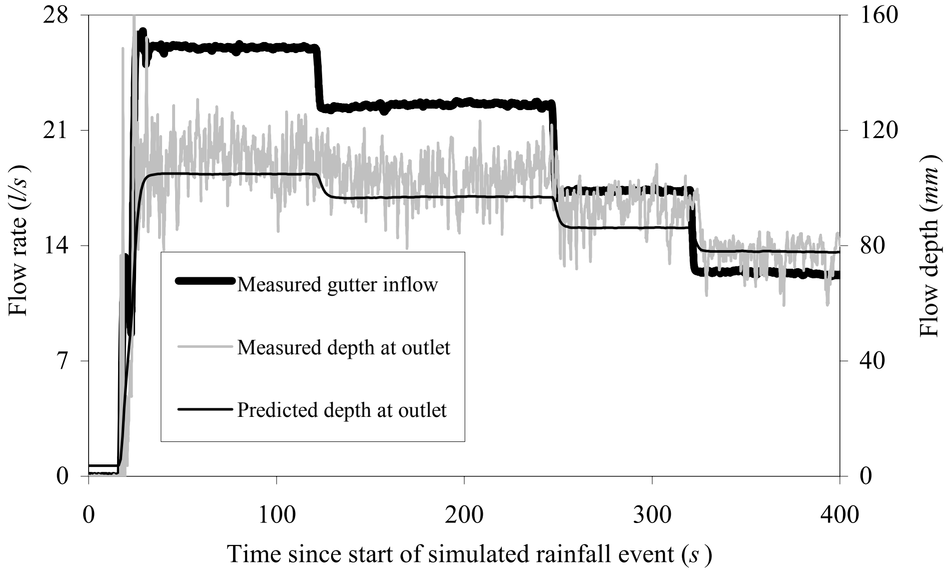

Figure 6. Measured and predicted outlet depths in Gutter C (110*mm* diameter downpipe) – normal setup

Figure 7 illustrates a typical application of the model to the analysis of a conventional roof drainage system. This figure shows the simulation results obtained when a gutter connected to four downpipes is subjected to rainfall events with intensities of 75 and 100*mm/h*. As shown, during the less intense event, the system performs well and no overtopping is predicted. However, during the more intense event Figure 7 illustrates that the depths will exceed the gutter top level at certain points, resulting in gutter overtopping and effective system failure.

6. Conclusions and recommendations for further work

The conclusions of this ongoing research project may be summarised as follows:

- No numerical model exists to simulate the performance of conventional systems, and only basic models are commercially available for siphonic system analysis.

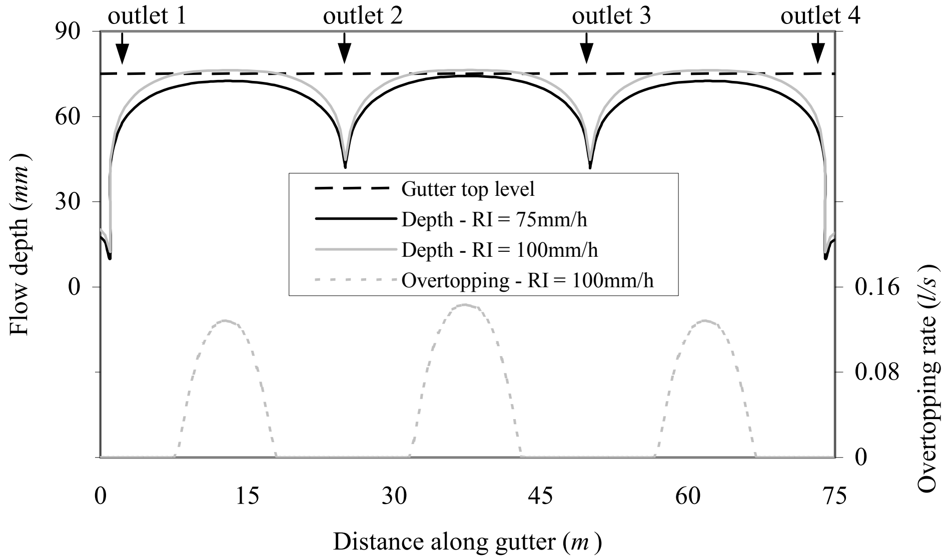

Figure 7. Predicted gutter depths and overtopping rates for a 75*m* section of Gutter B connected to four 110*mm* diameter downpipes (roof area = 650m^2)

- Gutters installed in conventional systems may be classified, in terms of their performance characteristics, as standard (low maximum depth, sole width ≈ outlet diameter) or wide (high maximum depth, sole width >> outlet diameter).
- Conventional systems incorporating standard gutters will always operate under free surface conditions, irrespective of rainfall intensity or gutter overtopping.
- Conventional systems incorporating wide gutters will operate under free surface conditions up to a point, after which they operate in a similar manner to siphonic systems approaching their design point; that is, the flow through the outlets and downpipes becomes essentially full bore, with the entrained air content of the flow gradually decreasing with increasing gutter depths. In the absence of more extensive experimental data, it seems reasonable to assume that a gutter with a maximum depth of 150*mm* and a sole width three times its outlet diameter could be classified as wide.
- The formation of full bore flow conditions within conventional systems incorporating wide gutters may mean that many existing systems have a far higher capacity than their design values. Although this may be beneficial from roof drainage point of view, the increased flow rates exiting the downpipes may result in unwanted consequences further downstream, e.g. surcharging of the collection sewers.
- Utilisation of a two step approach to the modelling of conditions within roof drainage systems enables the performance of such systems to be accurately simulated under extreme events.

The roof drainage model is now essentially complete. Once data describing the type of extreme events that may occur in the future has been generated, the model will be used to assess the performance of representative, existing systems. The results of this work will then be used to develop strategies to help alleviate the resulting operational problems, and to help inform the development of a whole life cycle costing model for roof drainage systems. Further work is clearly required to more accurately quantify the dimensions necessary for a gutter, within a conventional system, to be classified as wide. Additional work is also required to ascertain whether the conclusions drawn with respect to circular pipework herein, are equally applicable to pipework with a square cross section.

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Presentation of authors

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