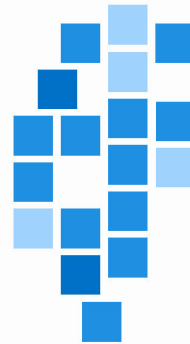




WATER SUPPLY and DRAINAGE for BUILDING

2006 CIB W062



32nd International Symposium

September 18-20, 2006
Taipei, Taiwan

 Organized By/



CIB
International Council for
Research and Innovation
in Building and Construction



NTUST
National Taiwan University of
Science & Technology



ABRI
Architecture & Building Research
Institute, Ministry of Interior

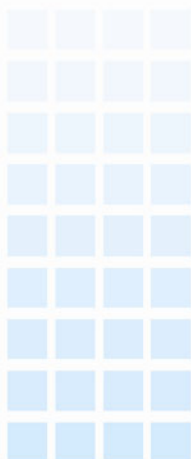


TTA
Taiwan Toilet Association



NSC
National Science Council





Taipei, Taiwan
CIB W062



WATER SUPPLY and DRAINAGE for BUILDING

Monday, 18 September 2006

8 30 Registration

9 00 Welcome of participants, Opening: Yi-Yang Lee (Minister of Interior), Ming-Chin Ho (Chairman of ABRI), Shi-Shuenn Chen (President of NTUST), K De Cuyper (Corrdinator of CIBW062), Andrew Baldwin(Representative of CIB)

Session A : Sustainability, Resources and Systems Management

Chairman: *Mr. De Cuyper and Dr. Ming-Chin Ho*

9 20 A1 Introduction to Green Building Policy in Taiwan
M.C. Ho, C.Y. Chiu / Taiwan

A2 Study on water conservation by water saving fixtures
T. Kondo, S.Iwamoto, N.Ichikawa, M.Kamata / Japan

A3 Measurement survey and analysis of water and energy consumption and carbon-dioxide emissions from the detached houses in Nagano City
Y. Asano / Japan

A4 Environmental assessment of residential buildings with emphasis in water conservation
M. S. O. Ilha, O.M.Gonçalves, L.H.Oliveira, L.A.Ywashima / Brazil

10 20 Questions & Answers

10 40 Coffee Break

Session B : Environmental Impact, Rainwater Collection and Evaluation

Chairman: *Prof. Kiya and Dr. L. Jack*

10 50 B1 Indicators of water supply and drainage systems in Brazilian low income dwellings considering environmental sustainability
L.H.Oliveira,O.M.Gonçalves,M.S.O.Ilha, R. P. Reis / Brazil

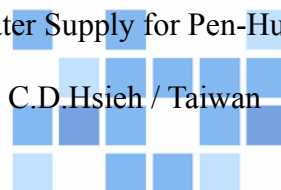
B2 Comprehensive Verification Method for Rainwater Recycling Systems that Enable the Refurbishment of Urban Building Stock
M.Otsuka, M.Yuzawa, K.Nochi, T. Aoi, Y.Minami / Japan

B3 Examination on Outflow Rate, Infiltration Rate and Reservation Rate of Rain Water in the Region Used Geographical Information System in Case of Kawagoe City Area
H.Kose, K.Nakajima / Japan

B4 Rainwater Potential for Domestic Water Supply for Pen-Hu Island, Taiwan
C.H. Liaw, L.M. Chan, W.M. Huang, C.D.Hsieh / Taiwan

11 50 Questions & Answers

12 10 Lunch



WATER SUPPLY and DRAINAGE for BUILDING

Session C : Calculation Model, Computational Methods and Application Software

Chairman: Prof. Swaffield and Prof. Asano

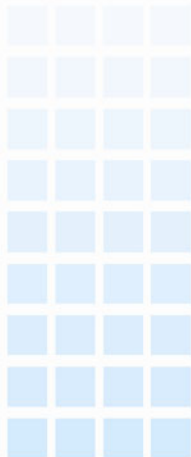
- 13 40 C1 Simulation of water demands provides insight
E.J.M. Blokker, W.G. van der Schee / Netherland
- C2 Artificial Neural Network Analysis for Reliability Prediction of Regional Runoff Utilization
S.C. Lee , H.T. Lin / Taiwan
- C3 Positive Pressure Prediction Method for Drainage Systems with Special Fittings with Consideration of Combined Drainage Loads inside the House Drain
T. Suzuki, M. Otsuka / Japan
- C4 Simulation of multi-physics flow patterns in a single drainpipe of gravity drainage systems -A preliminary CFD study
W. R. Chang, C. L. Cheng, J. T. Wang / Taiwan
- 14 40 Questions & Answers
- 15 00 Coffee Break

Session D : Drainage System (interior/ exterior) , Specific Equipments

Chairman: Dr. Galowin and Dr. Wong

- 15 20 D1 Study on the Carrying Performance of the House Drain Using a Food Waste Disposer
Y. Minami, M. Otsuka / Japan
- D2 A comparison of modelling techniques and supporting data for the prediction of air pressure changes in building drainage and ventilation systems
L.B. Jack, C. Cheng, W.H. Lu / Scotland
- D3 The transport of deformable solids at low flush volumes within building drainage networks.
J.A. Swaffield, J.A. McDougall / Scotland
- D4 A Breathing Pipework System – Building Drainage Pipework System
Ir Lonnie S H Cheung / Hong Kong
- D5 Study on transportation performance of main drain with low flash water closet in buildings
C. L. Cheng, C. J. Yen, K. C. Ho, W. H. Lu , J. R. Ho / Taiwan
- 16 35 Questions & Answers
- 17 00 Closure of Day 1 technical sessions
- 18 30 Welcome Dinner

Taipei, Taiwan
CIB W062



WATER SUPPLY and DRAINAGE for BUILDING

Tuesday, 19 September 2006

Session E : Drainage System, Diagnosis and Risk Management

Chairman: Prof. Petrešin and Prof. Otsuka

- 
- 9 00 E1 Rainwater System in TAIPEI 101
Y. T. Hsu, I. M. Wang / Taiwan
- E2 Solids in building drainage stacks: A potential cause of air pressure transients?
M. Gormley / Scotland
- E3 Transient defect identification in building drainage and vent systems – an application of pressure transient theory and practice
D.A. Kelly, J.A. Swaffield, L.B. Jack, D.P.Campbell, M. Gormley / Scotland
- E4 Problem of Air and Water Backflow in High-rise Building Drainage System
W.T. Chan, K.C. Law, S.W. Wong / Hong Kong
- E5 A case study of air pressure fluctuations in drainage stacks of high-rise residential buildings
L. T. Wong, K. W. Mui / Hong Kong
- 10 15 Questions & Answers
- 10 40 Coffee Break

Session F : Water supply and other water systems

Chairman: Prof. Gonçalves and Prof. Murakawa

- 11 00 F1 Biofilms/Corrosion Survey in Water Pipes
L. S. Galowin / U.S.A
- F2 Sanitary water systems diagnosis
F. Derrien / France
- F3 Modeling system demands for domestic flushing in residential buildings
K.W. Mui, L. T. Wong / Hong Kong
- F4 Visualization of water distribution systems in 4D
M.Nekrep Perc, E. Petrešin / Slovenia
- 12 00 Questions & Answers
- 12 20 Lunch
- 



Taipei, Taiwan
CIB W062

WATER SUPPLY and DRAINAGE for BUILDING

Session G : Sanitary, Hot Water and Materials

Chairman: **Dr. Derrien and Mr. M.H. Wu**

- 13 45 G1 Multiphase flow characteristics of a siphonic roof drainage system under part load conditions
A. Öngören, R. Materna / Switzerland
- G2 Calculation Method for the Loads of Cold and Hot Water Consumption in Office Buildings based on the Simulation Technique
S.Murakawa, H.Takata, K.Sakamoto / Japan
- G3 A Study on the Hot Water Consumption in a Hot Spa Facility
N.Yamamoto, S.Murakawa,H.Takata / Japan
- G4 CFD Simulation on Stagnant Area in Bathtubs at Spa Facility
N. Ichikawa, Y. Kondo, Y. Nagasawa, T.Ogasawara / Japan
- G5 Change in Water Consumption in a Quarter of a Century and Study on Water Load Calculation Method
S. Kosaka / Japan

15 00 Questions & Answers

15 25 Coffee Break

Session H : Standardization, Certification, Regulations

Chairman: **Prof. Kamata and Prof. Cheng**

- 15 45 H1 Research and standard for the Air-Gap in Japan
F. Kiya, K.Yamada, S.Yanagimura, K.Maejima, H.Kose / Japan
- H2 Study on Maximum Flow Rates and Sizing Method of Overflow Pipes in Water Tanks
X.W. Wang, F. Kiya, K. Maejima, S. Yanagimura, C. Yoneda / Japan
- H3 Shower head design: Increasing performance at lower flow rates
D. Woolf, I. Pau, M. Shouler / United Kingdom
- H4 Provision scales of sanitary accommodation in public toilets
L. T. Wong / Hong Kong
- H5 The Proposals for Design of Humanized Public Toilet
M.H. Wu / Taiwan

17 00 Questions & Answers

17 30 Closure of the technical sessions

19 00 Conference Banquet

Taipei, Taiwan
CTB W062

Introduction to Green Building Policy in Taiwan

Ming-Chin Ho (1), Chiung-Yu Chiu (2)

(1)ho@abri.gov.tw

(2)ccy@abri.gov.tw

(1)Architecture and Building Research Institute, Ministry of the Interior, Taiwan

(2)Architecture and Building Research Institute, Ministry of the Interior, Taiwan

Abstract

This paper briefly introduces the green building policy and its practices in Taiwan. The policy includes the establishment of the green building evaluation system and labeling system that can accommodate subtropical and tropical climatic conditions and a series of green building promotion programs. The promotion programs cover a wide range of implementation on new buildings, existing buildings, building materials, education, training, as well as international cooperation and exchange. The promotional experiences in Taiwan can be provided as a strong reference in policy-making, budgeting, and administration for national green building development, particularly for subtropical and tropical countries.

Keywords

Green Building, Policy, Subtropical

1 Background

Over the past decade, green building has become one of the most efficient measures to pursue a sustainable built environment. Various evaluation methods, assessment tools, and certification systems were developed worldwide. Taiwan, such as some developed countries, confronted with both global and local challenges of climate change and environmental impact. Therefore, the government had to take concrete actions to ensure a better living environment and the nation's sustainable development. In 1995, the Architecture and Building Research Institute (ABRI), established under the supervision of the Ministry of the Interior, was the organization dedicated to be in charge of architectural research in many aspects, including planning, disaster prevention, fire safety, structural engineering, construction technology, as well as building environmental control. In response to the public concern of the deteriorating living environment, the ABRI proposed the Green Building and Living Environment Technology Research Plan that initiated green building related research projects, including energy saving, water conservation, waste reduction, and ecological environment protection. One major outcome of the research plan is to establish a green

building evaluation system that is capable of accommodating subtropical/tropical climate and local environmental issues in Taiwan. The system was announced in 1998. One year later, a labeling system for green building certification was established as well. The evaluation and labeling system was thus adopted by the Ministry of the Interior as a national standard for green building certification. It was still a voluntary mechanism in the very first two years, however.

The turn point was in 2001 that the evaluation and labeling system became a mandatory regulation. The Green Building Promotion Program ratified by the Executive Yuan, which is the major green building policy in Taiwan, required green building certification for all new buildings in the public sector. The mandatory requirement started from the central government buildings and extended to all public-owned buildings in 2003. Furthermore, the green building regulation was officially involved into the Building Regulation in 2004 and has been effective since January 2005, which means compulsory green building design was extended to the private sector. In addition to green building design, building materials are one of the major components of the entire building industry. Therefore, a green building material evaluation and labeling system was established and implemented in 2004. In July 2006, at least five percent of green building material utilization was adopted in the Building Regulation too. All the efforts that have been lasting around ten years reveal a new opportunity for constructing a more sustainable living environment and upgrading the traditional building industry.

Prior to discussing the Green Building Policy in Taiwan, several local environmental issues should be addressed. First of all, recent studies showed that the climate in the cities of Taiwan was getting warmer and warmer because of inappropriate policies for urban environment and building industry in the past. Overcrowded urban population, shortage of green spaces, impermeability of the living environment, and inefficient building design for energy consumption have all caused the very climatic problem. The higher temperature of the urban environment significantly aggravates cooling energy consumption and carbon dioxide emissions, and accelerates the green house effect in the city. Besides, Taiwan is highly dependent on imported energy, which percentage is over 97. The building industry accounts for almost 29 percent of nation's total energy consumption. Therefore, the green building evaluation system and policy needs to be incorporated with proper building energy saving techniques and regulations.

Second, Taiwan receives abundant rainfalls that the average annual precipitation is more than 2,500 mm. The amount of water per capita, however, only reaches one sixth of the world's average. According to the United Nation's records, Taiwan is typically one of the areas lacking of water. Therefore, from water resources perspectives, the green building policy and its related strategies in Taiwan should be focused on water conservation and reuse issues.

Third, the immense market of reinforced concrete building, that occupies more than 90 percent of the entire construction market, is one of the biggest environmental killers in Taiwan. Reinforced concrete construction is essentially considered as a high-polluted building method for its enormous energy and resource uses. Despite the aggregate market of 110 million tons per year in Taiwan, legal aggregate excavation can only supply 42% (46 million tons) of the actual demand. It implies that 58 percent aggregate

is obtained from illegally excavated sources. Even worse, 80 percent of the alleged illegal aggregate is reported excavated from rivers. The fact not only makes Taiwan the second highest rank of cement consumption in the world, but also indirectly brings on many disasters, such as flooding, landslides, and bridge collapses. The large amount of cement uses also results in the generation of 11 million tons of construction wastes per year.

With respect to the evaluation system for building environments, a variety of environmental assessment methods have been proposed over the last decade. The compatibility of these systems that are developed within temperate or frigid regions with Subtropical Taiwan, however, needs to be investigated. The evaluation system for green buildings in Taiwan should be simplified and localized, in order to accommodate with the climatic characteristics (high humidity and high temperature), and correspond to Taiwan's local environmental issues, energy saving and water conservation, in particular.

2 Green Building Evaluation System

Green building is now a specific term for environment-friendly and sustainable buildings in Taiwan. Its definition is a healthy and comfortable building that is capable of efficiently reducing the consumption and natural resources, and the pollution caused by wastes during the life cycle of the building. In this way, Green Building does not only mean to put plants around buildings, but also reveal an overall and sustainable design concept.

In order to examine the environmental performance of the building, an appropriate evaluation system that is accommodating with the subtropical/tropical climate in Taiwan should be developed. Therefore, the ABRI came up with an evaluation system for Green Buildings that was first announced in 1998 and comprised of seven evaluation categories, green, soil water content, energy saving, water conservation, CO₂ emission reduction, construction waste reduction, and sewer and garbage improvement. Over the past few years, the ABRI modified the evaluation system via further introducing two new indicators in addition to the original ones, Biodiversity and Indoor Environment Quality. An evaluation system, integrated with nine categories, was thus established in 2003. These indicators can be divided into four categories, Ecology, Energy Conservation, Waste Reduction, and Health (known as EEWH system). The evaluation indicators are listed in Table 1.

Table 1 - Indicators for Green Building Evaluation in Taiwan

Climate	Water	Soil	Energy	Materials	Indicators	Evaluation Items (unit)
*	*	*	*		1.Biodiversity	Ecological net, biological habitat, plant diversity
*	*	*	*		2.Green	CO ₂ absorption (kg-CO ₂ /(m ² .40yr))
*	*	*	*		3.Soil water content	Water contentment of the site (-)
*	*		*	*	4.Energy conservation	ENVLOAD、Req、PACS、energy saving techniques
*		*	*	*	5.CO ₂ emission Reduction	CO ₂ emission of building material (kg-CO ₂ /m ²)
		*		*	6.Construction waste reduction	Waste of soil, construction, destruction(-), recycling material(-)
		*	*	*	7.Indoor Environment Quality	Acoustics, Light and Ventilation, Building Materials
*	*		*		8.Water conservation	Water usage (L/person), hygienic instrument with water saving (-)
	*			*	9.Sewage and garbage	Sewer plumbing, sanitary condition for garbage gathering

Source: Chen et al, 2004

The above nine indicators are evaluated independently in order to reply to the various environmental impacts upon the earth. Each category has some quantitative calculation methods, equations and criteria for the evaluation judgment. This system has been simplified, quantified and localized for the subtropical climate of Taiwan and is regarded as a standard evaluation method for Green Buildings by the Taiwan Government. Quantitative indicators and the corresponding criteria are described as follows.

2.1 Biodiversity

Biodiversity is the first indicator of the revised evaluation system. The evaluation items include ecological nets, biological habitats, plant diversity, and soil ecology. Since the purpose of this indicator is to protect biodiversity and environmental balance in a large-scale ecosystem aspect, the indicator is not applied for the development site that is less than two acres. The standards for passing the indicator's requirements vary by the area where the site is located. The environment surrounding the site is more sensitive; the qualifying threshold for this indicator is higher.

2.2 Green

The Green indicator introduces the CO₂ absorption factor as the conversion unit for different types of plantings, such as trees, shrubs, climbers etc. The CO₂ absorption factor, which is evaluated over a building life cycle of 40 years, can quantify any types of green design because the total planting effect can be converted into a single CO₂ absorption index. As a qualified green design for Green Building, the total CO₂ planting absorption should reach a high level, with a planting rate greater than 50% of its open space and a CO₂ absorption efficiency higher than 600 kg-CO₂/(m².40yr).

2.3 Soil Water Content

The Soil Water Content indicator is introduced for maintaining water retention and

infiltration of the building site. An index for the permeable ratio λ of a constructed site in comparison to a bare site is adopted to evaluate the water content capacity of the site. The calculation of the permeable ratio λ is expected to encourage permeable pavement, ponds, permeable lowlands, and gardens on impermeable floors or rooftops in the site design. A building project can pass the requirement of the indicator if the permeable site design is greater than 80% of its open space.

2.4 Energy Conservation

The Energy Conservation indicator is the most sophisticated field in the Green Building evaluation system. This indicator mainly focuses on the energy performance of the building envelope, cooling, and lighting, which occupy over 80% of the total building energy consumption. The building envelope energy performance evaluation is quite convincing because the evaluation method, ENVLOAD (thermal load of envelope) and Req. index, have been involved in the Building Regulation of Taiwan. The PACS (Performance of Air Conditioning System) method is also well established in the air conditioning field in Taiwan. The lighting energy can easily be evaluated based on the average illumination usage calculation per square meter of floor area. In the Green Building evaluation, the energy saving rates for these three indices, the building envelope energy performance, cooling and lighting, should be greater than 20% of the average energy consumption.

2.5 CO₂ Emission Reduction

The CO₂ Emissions Reduction indicator is an important tool for reducing pollution emissions through a clean building materials and construction design. A Green Building candidate should emit 10% lower than the average CO₂ emissions from reinforced concrete buildings through a more logical and efficient design for the structural system and low energy materials. This evaluation can especially encourage lower environmental impact structures, such as lightweight steel structured buildings, industrialized construction methods or wooden buildings.

2.6 Construction Waste Reduction

The Construction Waste Reduction indicator is utilized in evaluating solid waste and particle pollution, from basement excavation, construction and demolition in the life cycle of the building. A certified green building or project is required to cut 10% of the soil waste, construction waste, destruction waste, and to reduce 40% of the construction particles, in comparison with the average waste emissions from reinforced concrete buildings. This evaluation can encourage more natural site design with fewer landscape changes, less basement excavation, and low pollution construction, such as industrialized building methods and steel or wooden buildings. Recycled materials, such as recycled blocks, tiles, aggregate, are particularly encouraged in the destruction waste evaluation.

2.7 Indoor Environment Quality (IEQ)

The Indoor Environment Quality indicator focuses on the evaluation concerning

building acoustic environments, lighting and ventilation environments, as well as building materials. The indicator also encourages the utilization of green building materials, which are natural, ecological, and recycled. The criteria are developed based on an expert system approach. The summation of the score of each evaluation item multiplying by its corresponding weight factor can be calculated. The full score, without extra credits, is 108 points. A building obtaining 60 points can be considered passing the IEQ indicator.

2.8 Water Conservation

The Water Conservation indicator is aimed at saving water resources. Many types of water saving hygienic instruments, such as water closets, bathtubs, showers, etc., are encouraged in the evaluation. Water recycling systems for wastewater or rainwater are especially encouraged in the calculation as well. As a certified green building or project, the calculated saving rate for water resources should be greater than 20%, or the adoption rate of water saving instruments should be greater than 80%.

2.9 Sewage and Garbage Improvement

The Sewage and Garbage Improvement indicator does not evaluate sewer and garbage biotechnology but focuses on the landscape design or detailed improvements for sewer plumbing and sanitary condition of garbage holding areas. This indicator involves stringent regulations for proper sewer and daily use water plumbing, and evaluates the landscape environment and garbage recycling system in residential communities.

In addition to the evaluation system, the ABRI also developed a Green Building Labeling system for green building certification. The Green Building Labeling System consists of two parts: Green Building Label for completed buildings, and Green Building Candidate Certificate for building projects. The minimum requirement for Green Building certification is to pass two prerequisites (energy conservation and water conservation), and two optional indicators from among the other seven indicators. To date, 115 buildings have been certified as Green Buildings, and 937 projects have received Candidate Certificates. Total building floor areas reached 12.30 million m², electricity saving 333 million KWH that equals to 219 million CO₂-kg, and water saving 13.57 million ton per year.

3 Green Building Promotion Program

Since sustainable development became the major policy of Taiwan government, the Executive Yuan of Taiwan established the Commission on Sustainable Development in 1996 to come up with related guidelines and programs. The concept of Green Building and its corresponding policies were thus initiated and being involved into the National Development Plan-Challenge 2008 as one of the major priority works. The objective of the program is to promote green buildings that can protect ecological environment so as to build Taiwan as a “Green Silicon Island.” These policies essentially forge a comprehensive mechanism providing resources, research, guidance, training, and education to support the adoption of green building in Taiwan. The major work emphasizes on site ecological environment technology, construction waste reduction, building energy conservation, natural resource usage, indoor environmental quality

control, and green building demonstrative projects. The contents of the Green Building Promotion Program in Taiwan are summarized as follows.

3.1 Mandatory Green Building design for all new buildings

The promotional strategy is to initiate green building design with public buildings and to encourage private sectors to adopt the green building concept, so as to gradually evolve a mechanism for the entire building industry. Mandatory green building design for all new governmental buildings of central government was required in 2001, and for local government buildings in 2003. These regulations have shown a significant saving on electricity and water consumption. In comparison with the governmental budget for green building certification, only 43,750 US dollars per year, the benefit cost ratio is actually great than 110. The policy proves to be a very efficient measure to promote green building and to enhance the performance. Further in 2004, the Building Regulation involved a green building chapter and became effective since 2005. The overall green building regulations was thus completed.

3.2 Subsidize Green Building Improvement Projects for Existing Buildings

Existing buildings possess a dominated percentage of all buildings in Taiwan. Therefore, the green building remodeling work is one of the major promoting items in the Green Building Promotion Program. By the end of 2005, 64 green remodeling projects have been undertaken for official buildings and public schools. The green remodeling projects include (1) the building envelope energy saving improvement work, such as rooftop heat insulation and installation of sun shading devices, (2) the ecological protection work, such as the increase of permeability and the application of constructed wetlands combined with the function of wastewater treatment and reuse, (3) the adoption of water efficient appliances, etc.

Several remodeling cases are illustrated as below. Figure 1 presents one of the green remodeling projects for governmental buildings in a before-and-after context. The left picture shows that the original planting area, and the right one shows that the utilizing the crushed waste concrete as permeable pavement materials of parking lots. This is one of the strategies to adopt recycled materials and to remain the permeability and capability of water retention of the building site.



Figure 1- Example of green remodeling project

From 2002 to 2005, the projects also replaced with more than 3,000 water-saving

faucets and toilets that totally conserved 30% to 60% water resources, shown in Figure 2, and installed rainwater reuse facilities. One example in Chiang Kai Shek Memorial Park shows the water reuse for irrigation can save 3,000 USD water bills and slow down the storm water for about 1.5 hours, as Figure 3.



Figure 2-Utilization of water-efficient appliance in all remodeling projects



Figure 3- Installation of rainwater reuse irrigation facilities

The other important program of the Green Building Policy is the HVAC improvement project. By the end of 2005, the ABRI has completed 62 buildings with air-conditioning improvement projects. Its procedure is, first, to measure the performance of existing systems. The second step is to analyze the air-conditioning load and its type. The optimal capacity for efficient operations can thus be estimated. Total energy saving can reach 40 percent. In addition to green remodeling and HVAC improvement projects, three pilot projects for IEQ and energy saving have been completed as well. Besides, 257 projects for building envelope and heat insulation and more than 10 projects for indoor air quality improvement were completed over the past four years as well.

3.3 Technology Development, Promotion, and Commercialization for Recycling Building Materials

The ABRI established the testing and processing laboratories for recycling building materials and initiated with plans for product promotion and commercialization. A variety of recycling building materials have been developed under the support of this program, including compressed concrete paving units, recycled grid bricks, wood-like building materials, fire resistance boards, etc. The program will focus on the mechanism for technology transfer and mass production of recycled building materials in the next stage.

3.4 Establish Green Building Material Evaluation and Labeling System

The Green Building Material Evaluation and Labeling System was launched in March

2004. Four types of materials can be considered as green building materials, which are able to agree with ecological, healthy, recycled, and high-performance (for example, high permeability and noise insulation) concepts. Supported by this system, the indoor environment quality of buildings can be gradually enhanced through the increasing adoption of green building materials.

3.5 Promote Green Building Concepts to Architects, Professionals, and the Public

The ABRI promotes the green building concept through a series of activities, including seminars, training courses, conferences, technical tours, excellent Green Building Award competition, and Green Building Expo. All of these efforts are expected to efficiently transform the built environment in Taiwan.

3.6 Green Building Chapter in the Building Regulation

Following the mandatory regulation of green building in the public sector, the green building design requirement was officially involved into the Building Regulation in 2004 and has been effective since January 2005, which means compulsory green building design was extended to the private sector. At the first stage, the design standard in the Building Regulation is slightly less than that of the green building evaluation system in order to achieve a wider promotion and application. Moreover, at least five percent of green building material utilization has been adopted in the Building Regulation since July 2006.

3.7 International Cooperation and Knowledge Transfer

In order to promote the development experiences and latest research of green building, the ABRI assisted in forming Taiwan Green Building Council as an exchange platform and joined World Green Building Council. Through actively participating in major international events, working meetings, presentations, and discussions, the green building evaluation tool and design concepts for subtropical regions can be shared with the international communities. The ABRI also regularly conducted green building forums and annual subtropical green building international conference, so that the information of the advanced research and innovative technology undertaken by many scholars and professionals in the countries of subtropical and tropical climate zones can be transferred and learned from each other.

4 Conclusions

All the regulations and projects derived from the green building policy are expected to carry out a dramatic conversion in the traditional building and material industries. The policy also brings out many opportunities for architects, professional consultant services, and the entire construction industry. For example, for architects and professionals, today we may declare that “know nothing about green buildings, get no cases for your business.” Moreover, in the building market, we can hardly find any 12-litre toilet since it has been replaced by new water efficient appliance. The market of water efficient appliance has actually been rising about 40%. In conclusions, for promoting green building design, the government has developed some relevant programs. For example, a

standard manual for Green Building evaluation was published and distributed widely to building designers, teachers, architects and contractors trained in Green Building design. Meanwhile, all of new buildings in Taiwan, both in the public and private sector, are required with mandatory green building design. Based on the promotion program, many green remodeling and improvement projects for existing public buildings and schools are currently in progress. Significant savings on electricity and water resources have been achieved year after year. The Green Building policy in Taiwan has proved to be a crucial path toward a lower environmental impact and more sustainable future for our descendants. The ABRI will continue strengthening and extending the green building policy to green community, green city, and, ultimately, green country.

5 References

- Architecture and Building Research Institute, *Good to be Green*, Ministry of the Interior, 2006.
- Architecture and Building Research Institute, *Introduction to Green Remodeling Projects for Governmental Buildings*, Ministry of the Interior, 2004.
- Architecture and Building Research Institute, *Evaluation Manual for Green Buildings in Taiwan, 2003 New Edition*, Ministry of the Interior, 2003.
- Architecture and Building Research Institute, *Green Challenge of Living Environment*, Ministry of the Interior, 2003.
- Executive Yuan, *Green Building Promotion Programs (Revised)*, 2004.
- Jui-Ling Chen and Chiung-Yu Chiu, "Green Building Policies in Taiwan," *Proceedings of the Conference on Sustainable Building South East Asia*, Kuala Lumpur, Malaysia, April, 2005.
- Jui-Ling Chen and Hsien-Te Lin, Policy and Evaluation System for Green Building in Subtropical Taiwan, inTA Conference, Singapore, 2004.

6 Presentation of Authors

Ming-Chin Ho is the Director General of the Architecture and Building Research Institute, Ministry of the Interior. Dr. Ho was appointed to this position in May 2006. As the Director General, Dr. Ho is responsible for the overall administration and management of a variety of architectural research plans, such as building technology, environmental control, and disaster prevention and mitigation. His current research focuses on urban disaster prevention, intelligent buildings, and green building policy.



Chiung-Yu Chiu is the Researcher of the Architecture and Building Research Institute, Ministry of the Interior, being responsible for the development of green building rating system and building environmental control. Dr. Chiu received her Ph.D. degree from the University of Texas at Austin in 2002. Her current research focuses on building acoustic measurement method analysis and green building promotion.



Study on water conservation by water saving fixtures

T.Kondo(1), S. Iwamoto(2), N.Ichikawa(3), M.Kamata(4)

(1) tkondo@kanagawa-u.ac.jp, (2) iwamos01@kanagawa-u.ac.jp

(3) nichij@js7.so-net.ne.jp, (4) kamata@arch.t.u-tokyo.ac.jp

(1) Department of Architecture, Faculty of Engineering, Kanagawa University, Japan

(2) Department of Architecture, Faculty of Engineering, Kanagawa University, Japan

(3) Department of Architecture, Graduate School of Urban Environmental Sciences, Tokyo Metropolitan University, Japan

(4) Department of Architecture, Graduate school of Engineering, The University of Tokyo, Japan

Abstract

For the purpose of evaluating the performance of water saving fixture, water and energy conservation effects of water saving fixtures were examined by subject experiment. Water saving fixtures are thermostatic mixing faucet and shower head with stop button for shower in a bathroom, and spray flow and aerator flow faucet and stop valve by foot switch or sensor for dishwashing in a kitchen.

The effect of thermostatic mixing faucet compared with two valve faucet is that thermostatic mixing faucet could save water when adjusting hot water temperature and flow rate to optimum condition. The effect of shower head with stop button is that hot water could be saved by using stop button on shower head to stop hot water easily when unnecessary. The effect of spray flow and aerator flow faucet is that optimum flow rate is decreased by using these faucets. The effect of stop valve by foot switch or sensor is that hot water could be saved by using stop valve to stop hot water easily when unnecessary.

As a result of subject experiment, water was saved 1.0L by using thermostatic mixing faucet when hot water temperature and flow rate were adjusted each time to optimum condition. Hot water was saved 14.1L by using shower head with stop button. Hot water was reduced by 27.3% compared with using normal shower head. Hot water was reduced 29.1% by using spray flow faucet, and 3.7% by using aerator flow faucet. Hot water was reduced 8.3% by using stop valve by foot switch, and 5.2% by using stop valve by sensor. These water saving fixtures are effective for water and energy conservation.

Keywords

Water saving fixture, Thermostatic mixing faucet, Showerhead with stop button, Spray flow faucet, Aerated flow faucet, Sensor stop valve, Foot switch stop valve

1 Introduction

For the purpose of evaluating the performance of water saving fixture, water and energy conservation effects of water saving fixtures were examined by subject experiment. We used subjects to evaluate a shower faucet that was expected to cut hot water use. The experiment determines the ability of a thermostatic mixing faucet to reduce the amount of water wasted in adjustment of temperature and flow rate. We also performed a shower experiment to determine the water saving effect of a showerhead with an on/off button.

We also used subjects to evaluate a kitchen faucet that was expected to reduce hot water use. Subjects used a faucet with flow pattern options of spray flow or aerated flow, and with on/off control systems that included a foot switch stop valve and a sensor stop valve. An experiment using a combination of the flow pattern and the on/off control function with the highest water saving performances was also conducted.

2 Effect of Thermostatic Mixing Faucet

2.1 Experimental method

Table 1 summarizes the experiment and Figure 1 indicates the types of shower faucet used in the experiments. The experiments were conducted in a prefabricated bathroom unit installed in laboratories. The waiting room and dressing room were air-conditioned to 23°C in winter and 26°C in summer.

Water temperature and flow rate were adjusted by the two different shower faucets, a two-valve faucet and a thermostatic faucet, to determine the amount of water wasted. Undressed subjects adjusted the water temperature and flow rate by spraying shower water onto their hands and other parts of their bodies and then reported when they had obtained their desired temperature and flow rate. The amount of hot and cold water used up until the time the subject declared that the adjustment was finished was considered to be the amount of water wasted.

The temperature of the hot water output from the electric water heater was preset at 60°C, and the main hot water pipe was filled with hot water before the experiments began. The water temperature of cold water supply, hot water supply and after mixing, and the flow rate of cold and hot water supplies were measured at intervals of 2 seconds.

Table 1 - Summary of the experiment for shower faucet

Case		Winter	Summer
Experiment period		2003/2/8-3/8 2004/3/1-3/18	2003/8/15-9/8 2004/7/20-8/10
Number of subjects	Male	27	22
	Female	28	24
	Total	55	46
Number of subjects by usual usage faucet	Two valve faucet	35	35
	Thermostatic faucet	15	7
	Other	5	4

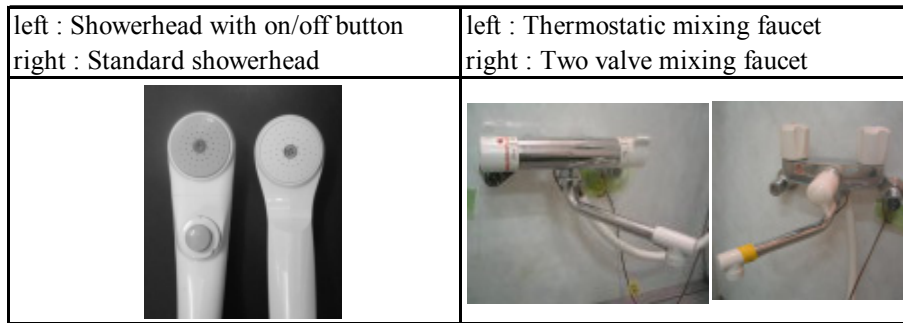


Figure 1 - Shower faucets for shower experiment

2.2 Experimental results

Figure 2 and table 2 show the average amount of water wasted. Figure 3 and table 2 show the amount of water saved and water saving rate in the experiments by the use of a thermostatic faucet versus the two-valve faucet depend on the types of faucet the subjects uses at their houses. The water saving effect of the thermostatic faucet was confirmed in all cases. A classification of the types of faucets being used at the subjects' houses showed that subjects who used thermostatic get larger amount of water saved than those who used two-valve faucets especially in winter. On average, there was no seasonal difference in the amount of water saved. The average amount of water saved by controlling the shower temperature and flow rate per single operation by using thermostatic mixing faucet was about 1.0 L.

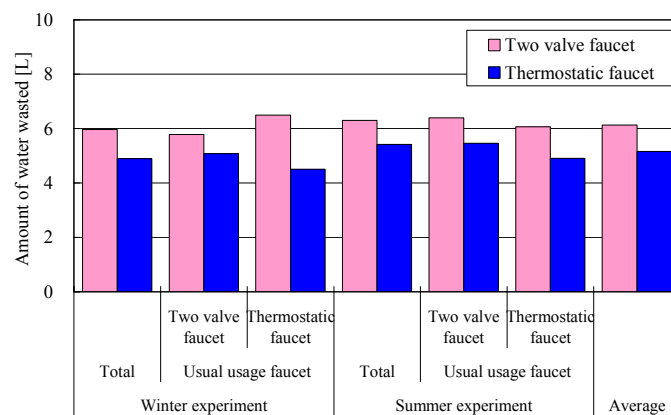


Figure 2 - Amount of water wasted

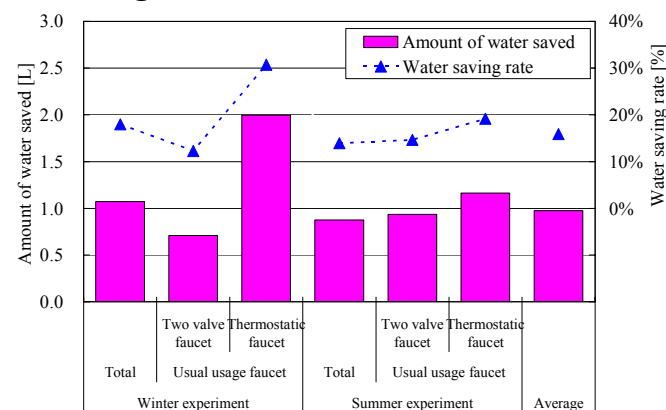


Figure 3 - Amount of water saved and water saving rate

Table 2 - Water saving effect of thermostatic mixing faucet

Case	Subject		Amount of water wasted [L]		Amount of water saved [L]	Water saving rate
			Two valve faucet	Thermostatic faucet		
Winter experiment	Total		5.97	4.89	1.07	18.0%
	Usual usage faucet	Two valve faucet	5.79	5.08	0.71	12.3%
		Thermostatic faucet	6.50	4.50	2.00	30.7%
Summer experiment	Total		6.30	5.42	0.88	13.9%
	Usual usage faucet	Two valve faucet	6.39	5.46	0.94	14.6%
		Thermostatic faucet	6.06	4.90	1.16	19.2%
Average			6.13	5.16	0.97	15.9%

3 Effect of Showerhead with Stop Button

3.1 Experimental method

The amount of hot water consumed when taking a shower was compared when using two types of showerhead, a standard type and one with a stop button. The standard showerhead and the stop button one were used along with a water-saving spray plate for all types of shower head. Subjects washed their faces, hair, and bodies and reported through an intercom when they had completed each washing activity. Subjects were told to shower for as long as usual when they used the standard type of showerhead. When they used the showerhead with the stop button, they were instructed to turn off the hot water supply when they did not need water. The experiments were conducted on 2 days. A thermostatic faucet was used with both types of showerhead. Before each experiment began, the water was heated up so that the subjects did not have to waste water by running the faucet while waiting for hot water to reach the showerhead. The experimental bathroom and subjects are the same as that of experiment of thermostatic mixing faucet in section 2.

3.2 Experimental results

Figure 4 shows the total amount of water consumed in each shower experiment. Figure 5 indicates the amount of water saved and water saving rate by season and sex. In all the cases, the amount of water consumed decreased when using the showerhead with the stop button, thus confirming the water-saving effect of this device. On average, amount of water consumed is 51.8L using standard showerhead. Compare to this, it is 37.7L using showerhead with stop button. Male subjects, who consumed more water than females, achieved a higher water saving rate. The water saving rate and amount of water saved in male subjects are 33.9% and 18.3L. Those in female subjects are 20.1% and 10.0L. The water saving rate and amount of water saved for males and females combined is 27.3% and 14.1L.

Figure 6 shows the flow rate, and Figure 7 shows the time for hot water output. In the case of male subjects, the showerhead with the stop button had a slightly lower flow rate. And it took shorter time for hot water output by both male and female subjects. On average, both of the showerhead with the stop button reduced the time for hot water output by about 24%, a value that had a large water-saving effect. The optimum temperature to the subjects of hot water using the showerhead with the stop button was 1.5 °C lower than using the standard showerhead (Figure 8). These differences in flow

rate and water temperature could be attributable to the impact of the subjects' adjustments of flow rate and temperature and to the frequencies with which they turned off the shower; however, these issues are still under review.

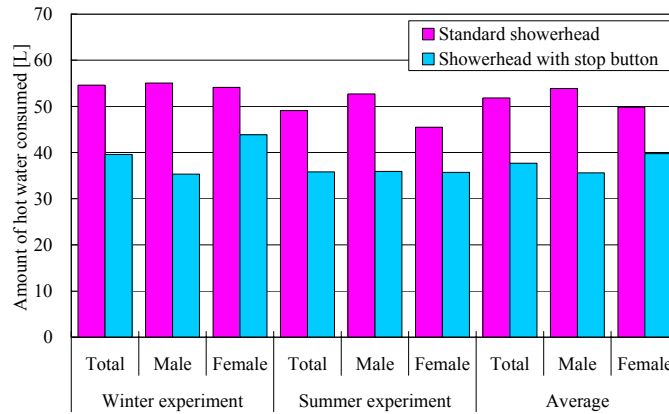


Figure 4 - Amount of water consumed

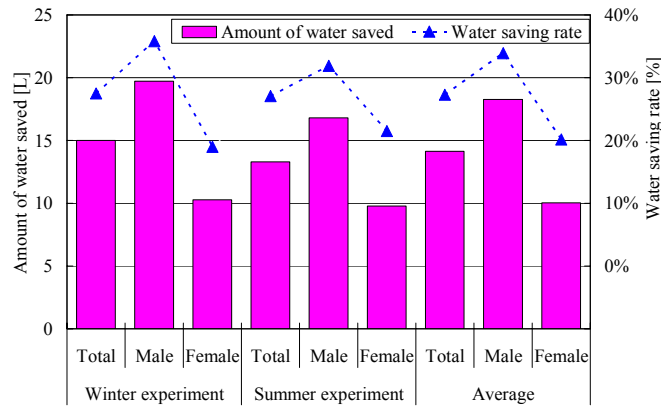


Figure 5 - Amount of water saved and water saving rate

Table 3 - Water saving effect of showerhead with stop button

Case		Amount of water consumed [L]		Standard deviation [L]		Amount of water saved [L]	Water saving rate
		Standard showerhead	Showerhead with stop button	Standard showerhead	Showerhead with stop button		
Winter experiment	Total	54.6	39.6	20.3	14.6	15.0	27.5%
	Male	55.0	35.3	21.2	15.3	19.7	35.8%
	Female	54.1	43.8	19.5	13.9	10.3	19.0%
Summer experiment	Total	49.1	35.8	14.2	12.1	13.3	27.1%
	Male	52.7	35.9	17.3	14.5	16.8	31.9%
	Female	45.5	35.7	11.1	9.8	9.8	21.5%
Average	Total	51.8	37.7	17.3	13.4	14.1	27.3%
	Male	53.9	35.6	19.2	14.9	18.3	33.9%
	Female	49.8	39.8	15.3	11.9	10.0	20.1%

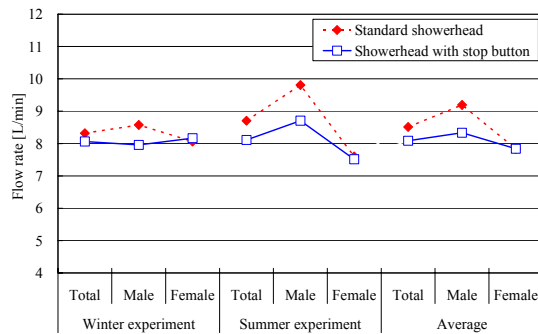


Figure 6 - Flow rate

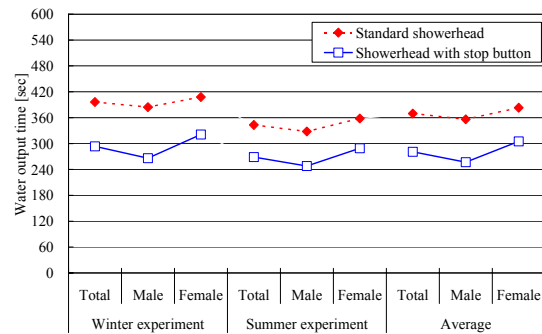


Figure 7 - Hot water output time

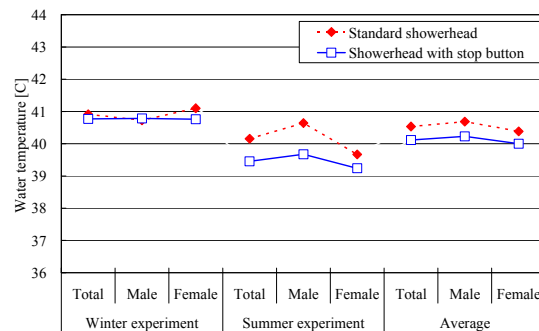


Figure 8 - Hot water temperature

4 Effect of water saving kitchen faucet by flow pattern for dishwashing

4.1 Experimental method

Two different experiments, an experiment using different flow patterns and one using different on/off control functions were performed. A straight flow faucet and single lever faucet were used as standards, as shown in Figure 9 and 10. Other conditions used in the experiment are; spray or aerated as a water flow pattern, and an automatic infrared sensor stop valve and a foot switch stop valve as a form to stop the water. Each of these devices was evaluated for water saving performance.

Table 4 summarizes the experiment. The subjects were housewives aged from 38 to 63 years; 22 subjects in the flow pattern experiment and the on/off control function experiment conducted in winter, 24 in the flow pattern experiment in summer and 20 in the on/off control function experiment in summer. 12 subjects in the winter experiment and 22 subjects in the summer experiment performed both the flow pattern experiment and the on/off control experiment on different days. The experiments were conducted using a kitchen in the laboratory. The temperature of the hot water output from the electric water heater was preset at 60 °C, and the hot water pipe to the faucet was filled with hot water before the experiments began so that the subjects did not have to waste water by running the tap while waiting for hot water to reach the faucet. The water temperature of cold water supply, hot water supply and after mixing, and the flow rate of cold and hot water supplies were measured at intervals of 2 seconds. Each experimental session was videotaped to check for kinds of dishwashing act.

Each subject washed dishes using each faucet device once. The experiment was performed using three different flow patterns or three different on/off control functions

on the same day, and the order of each device was varied across the subjects. A sponge, scrubbing brush, detergent, washing bowl with the capacity of 5 liter, paper towel, and rubber gloves were given to each subject for use as needed. The subjects were instructed to wash exactly as they routinely did. They regulated the hot water temperature and flow rate in both the flow pattern and the on/off control function experiments at their own discretion. They were also told to use the sensor stop valve or foot switch stop valve when turning off the tap, and to turn off the tap as frequently as possible when they were not using water. Table 5 shows the types of tableware and foods for contaminations for dishwashing experiment. Four place settings (a total of 44 items) were allocated to each subject per load. The types of dishes and contamination method complied with the methods of testing performance of quality housing components for dishwashers by the Center for Better Living, Japan.

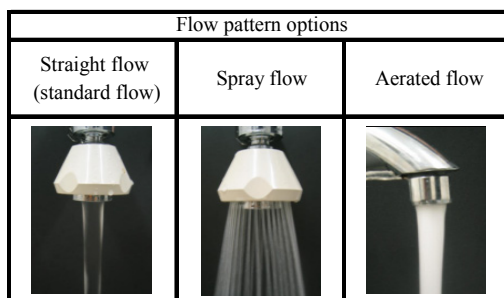


Figure 9 - Flow patterns of faucet

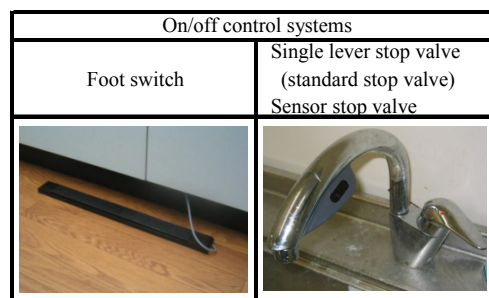


Figure 10 - On/off control stop valves

Table 4 - Summary of the experiment for kitchen faucet

Case	Flow pattern experiment		On/off control function experiment		Water saving fixtures combination experiment
	Winter experiment	Summer experiment	Winter experiment	Summer experiment	Winter experiment
Experiment period	2003/12/16 - 12/28	2004/8/23 - 9/10	2003/12/16 - 12/28	2004/8/23 - 9/10	2005/1/11 - 1/14
Water saving fixture	Standard flow		Standard stop valve		Standard faucet
	Spray flow		Sensor stop valve		Water saving fixtures in combination
	Aerated flow		Foot switch stop valve		
Number of subjects	22	24	22	20	10

Table 5 - Tableware for dishwashing

Types of tableware	Tableware (Foods for contaminations)
Glasses	Glass (Milk, Tomato juice), Teacup (Green tea)
Plates	Large plate (Curry, Law egg), Medium plate (Pork cutlet with sauce), Small plate (Ham and eggs)
Bowls	Rice bowl (Rice), Soup bowl (Miso soup)
Eating irons	Chopsticks (Rice), Spoon (Curry, Law egg)
	Knife and fork (Pork cutlet with sauce, Ham and eggs)

1 place setting consists of each tableware.

4.2 Experimental results of flow pattern experiment

Figure 11 and table 6 indicates the amount of water consumed. Figure 12 and table 6 shows the amount of water saved and water saving rate in the flow pattern experiment. For the standard flow pattern, the amount of water consumed during the summer was greater than in the winter. On the other hand, the faucet with the spray flow showed a

reversed trend. On average, amount of water consumed using standard flow was 31.5L, that using spray flow was 22.1L, and that using aerated flow was 30.3L. Water saving effect was confirmed using spray flow. The water saving rate and amount of water saved compared with the standard flow pattern was 16.9% and 5.0L in the winter and 41.3% and 13.9L in the summer. However, in an interview after the experiment some of the subjects said that spray flow faucet were inconvenient to use because of water splash. The aerated flow gave 8.6% and 2.9 L of water-saving rate and amount of water saved in the summer, but in the winter they did not have any effect on water use. The average water saving rate and amount of water saved was 29.1% and 9.4L for the spray flow faucet and 3.7% and 1.3L for the aerated flow one. The flow rate, hot water output time and hot water temperature are shown in the figure 13 to 15. The faucet with the spray flow had a lower flow rate. There were no significant differences in the hot water output time or the hot water temperature.

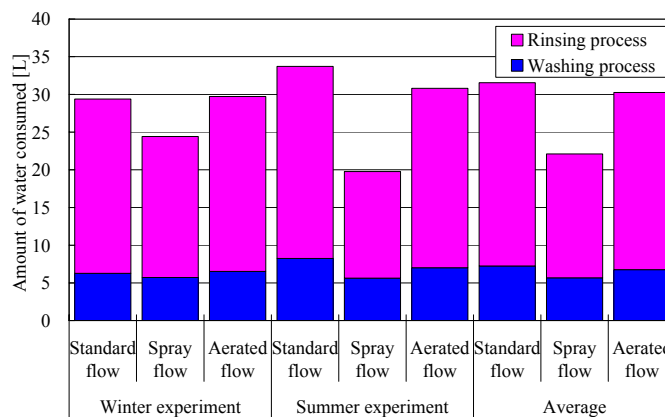


Figure 11 - Amount of water consumed in flow pattern experiment

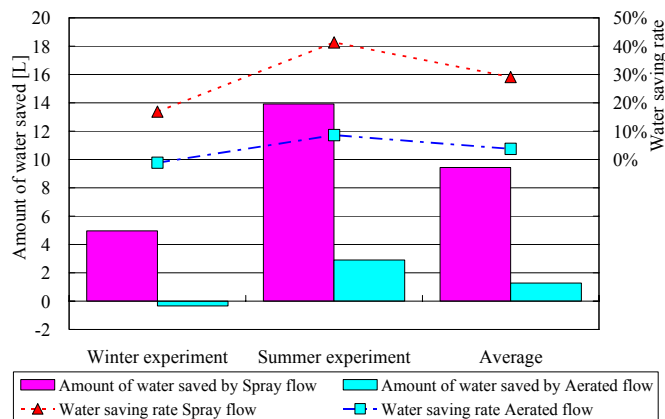
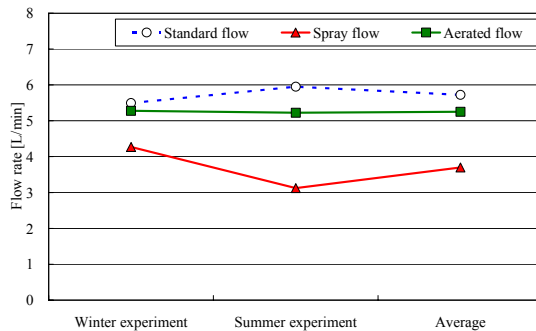
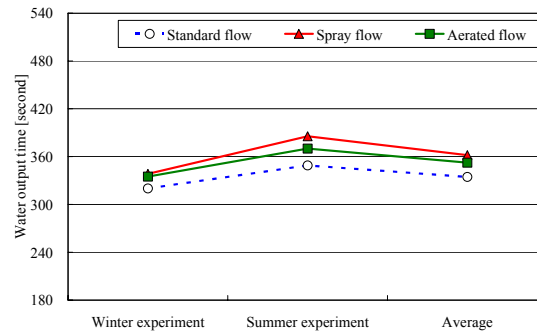
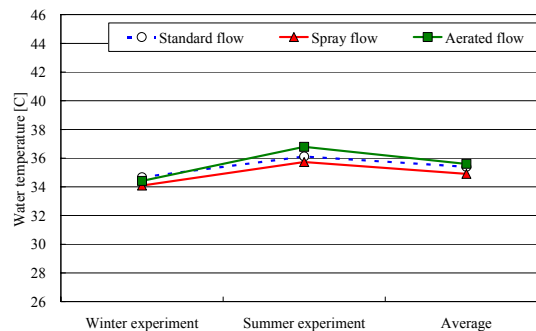


Figure 12 - Amount of water saved and water saving rare in flow pattern experiment

Table 6 - Water saving effect in flow pattern experiment

		Standard flow	Spray flow	Aerated flow
Winter experiment	Amount of water consumed [L]	29.4	24.4	29.7
	Amount of water saved [L]	-	5.0	-0.3
	Water saving rate	-	16.9%	-1.1%
Summer experiment	Amount of water consumed [L]	33.7	19.8	30.8
	Amount of water saved [L]	-	13.9	2.9
	Water saving rate	-	41.3%	8.6%
Average	Amount of water consumed [L]	31.5	22.1	30.3
	Amount of water saved [L]	-	9.4	1.3
	Water saving rate	-	29.1%	3.7%

**Figure 13 - Flow rate in flow pattern experiment****Figure 14 - Water output time in flow pattern experiment****Figure 15 - Water temperature in flow pattern experiment**

4.3 Experimental results of On/off control function experiment

Figure 16 and table 7 indicates the amount of water consumed. Figure 17 and table 7 showed the amount of water saved and the water saving rate in the on/off control function experiment. There was no seasonal difference. On average, amount of water consumed for standard stop valve was 31.5L, that for sensor stop valve was 29.8L and that for foot switch stop valve was 28.9L. The water saving rate and amount of water saved were 5.2% and 1.7L for the sensor stop valve, 8.3% and 2.6L for the foot switch stop valve. The flow rates, hot water output time, hot water temperature are shown in the figure 18 to 20. The sensor stop valve or foot switch stop valve was expected to reduce output time, but this reduction was only about 15 seconds. It was about 5% of total output time. These results might be attributable to the frequent on/off control of the water by the subjects, who were motivated by their increased awareness and reflected their routine behavior.

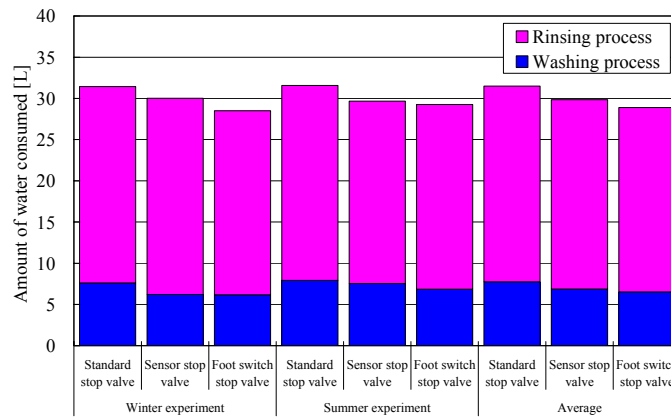


Figure 16 - Amount of water consumed in on/off control function experiment

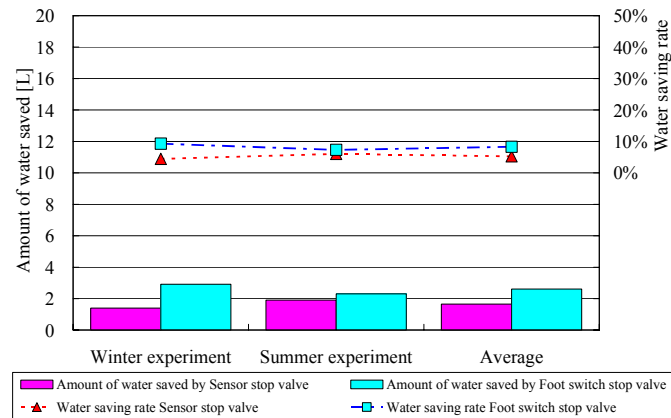


Figure 17 - Amount of water saved and water saving rate in on/off control function experiment

Table 7 - Water saving effect in on/off control function experiment

		Standard stop valve	Sensor stop valve	Foot switch stop valve
Winter experiment	Amount of water consumed [L]	31.4	30.0	28.5
	Amount of water saved [L]	-	1.4	2.9
	Water saving rate	-	4.5%	9.3%
Summer experiment	Amount of water consumed [L]	31.6	29.7	29.3
	Amount of water saved [L]	-	1.9	2.3
	Water saving rate	-	6.0%	7.3%
Average	Amount of water consumed [L]	31.5	29.8	28.9
	Amount of water saved [L]	-	1.7	2.6
	Water saving rate	-	5.2%	8.3%

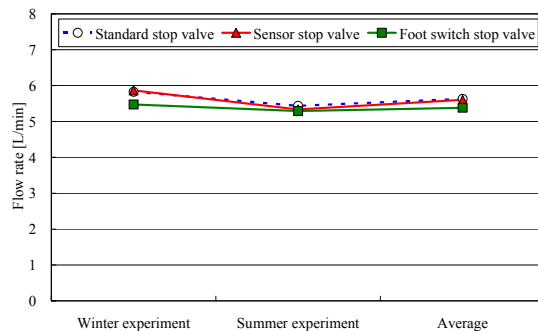


Figure 18 - Flow rate in on/off control function experiment

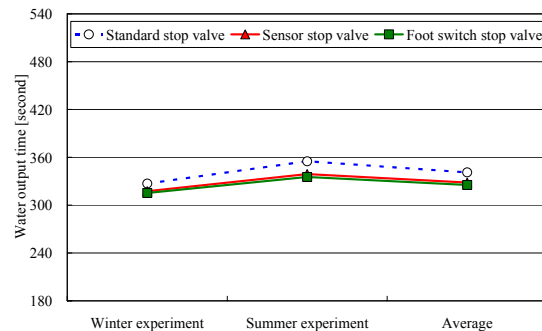


Figure 19 - Water output time in on/off control function experiment

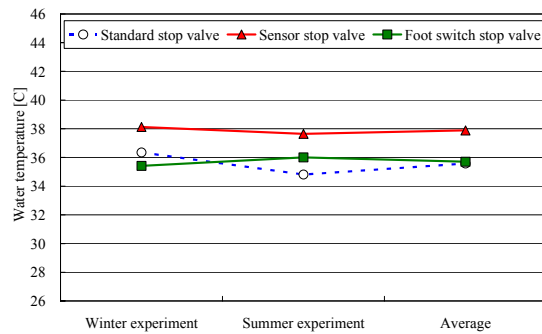


Figure 20 - Water temperature in on/off control function experiment

5 Effect of different types of water saving fixtures in combination

5.1 Experimental method

An experiment was conducted using a faucet with a spray flow and a foot switch stop valve in combination: both had proved effective in conserving water in the flow pattern experiment and the on/off control function experiment. The summary of experiment is shown in table 4. Ten subjects who had consumed amounts of water close to the average using a standard faucet in the summer experiment were assigned to the winter experiment. An experiment using a standard device was also performed. The other experimental conditions were the same as those in the on/off control function experiment.

5.2 Experimental results

Figure 21 and table 8 shows the amount of water consumed and flow rate. Amount of water consumed for standard faucet was 29.5L, and that for water saving fixture in combination was 16.5L. The water saving rate and amount of water saved was 44.0% and 13.0L. The additive effect of the water saving rate from the flow pattern experiment and that from the on/off control function experiment was confirmed.

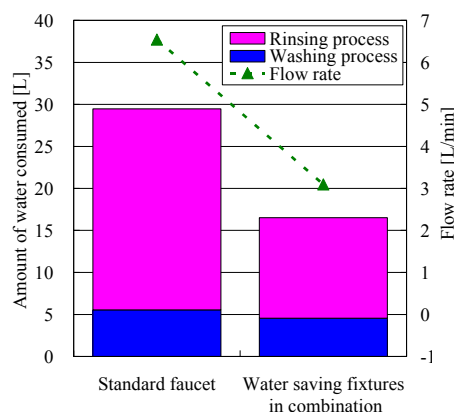


Figure 21 - Amount of water consumed and flow rate in water saving fixtures combination experiment

Table 8 - Water saving effect in water saving fixtures combination experiment

	Standard faucet	Water saving fixtures in combination
Amount of water consumed [L]	29.5	16.5
Amount of water saved [L]	13.0	
Water saving rate	44.0%	
Flow rate [L/min]	6.5	3.1
Water temperature [C]	34.6	36.4

6 Conclusion

We conducted an experiment using water saving shower faucets to determine its hot water saving effects, and we obtained the following results.

1. The saving of 1.0L of water per single adjustment was achieved when subjects used a thermostatic faucet instead of a two-valve faucet to regulate shower water temperature and flow rate.
2. On average, 27.3% (14.1 L) water saving rate was achieved by using a showerhead with a stop button.

The following findings were obtained from the experiments using different types of kitchen faucet.

1. The water saving rate of each device was as follows: spray flow faucet, 29.1% (9.4 L); aerated flow faucet, 3.7% (1.3 L); sensor stop valve, 5.2% (1.7 L); and foot-switch stop valve, 8.3% (2.6 L).
2. For the spray flow faucet, the flow rate and the amount of water consumed were lower in summer than in winter; however, there was no seasonal difference for other devices.
3. The combination of spray flow faucet and foot switch stop valve achieved water saving rate of 44.0% (13.0 L), confirming the additive effect.

7 References

1. M.Nagaishi, M.Otsuka, Examination of the water saving effect of the faucet with water aerator, AIJ Journal of Technology and Design, No.13, pp.141-146, 2001.7
2. T.Kondo et al., Study on methods of designing shower heads, AIJ Journal of Architecture and Planning, No.563, pp.61-67, 2003.1

8 Presentation of Author

Takeshi Kondo is a research associate at Department of Architecture, Faculty of Engineering, Kanagawa University. He is a researcher on a range of hot water supply especially in houses.



Measurement survey and analysis of water and energy consumption and carbon-dioxide emissions from the detached houses in Nagano City

Y. Asano (1)

(1) yasanok@gipwc.shinshu-u.ac.jp

(1) Shinshu University, Faculty of Engineering, Department of Architecture and Building engineering, Japan

Abstract

The energy consumption has been greatly influenced according to the life style of the residents, the type of hot water supply systems, though the control of the energy consumption is important.

The authors analyzed the relations between the residents' life style and energy consumption rooted in the comparative study. This research is based on the results of the measurement survey in the detached houses actually constructed in Nagano City. Basic materials to review the method of reducing carbon-dioxide emissions which accompanied the energy consumption were arranged by analyzing those measured data. The results were clarified as follows.

(1) Water and energy consumption, and the indoor thermal conditions in three detached houses were cleared from June to December in 2005.

(2) The energy consumption for the hot water supply in Nagano City located in cold region in winter has increased, as well as there was a negative correlation between the energy consumption for hot water supply and the daily mean temperature.

Keywords

Green house gas; life style; hot water supply; energy consumption.

1 Introduction

As for global warming with the green house gas, it extremely becomes a serious subject, and the reduction is important now. Carbon dioxide occupied 94% of the amount of the green house gas exhaust in Japan, and the 13.5% of carbon dioxide is emitted from the home. It is necessary to investigate the current state of carbon-dioxide emissions in the house. The energy consumption would be controlled to reduce carbon-dioxide emissions in the house. On the other hand, the energy consumption is greatly influenced by resident's life style, air conditioning, and how to use the equipment of supplying hot water. Then, it should make comparative study of the way of living and the energy consumption. There are characteristics in the energy consumption of a house depending

on climates of region built on, and the investigation in a lot of regions is needed. In this research, the life style and energy consumption were investigated, and the realities were understood as to three detached houses in the Nagano City. Moreover, it is important work because it would reduce the energy consumption and carbon-dioxide emissions in the future to analyze the relations of them.

2 Investigation procedure

The authors investigated the energy and water consumption of three detached houses in Nagano city. Four periods had been set for a measurement in 2005-2006. Those were June 15th - July 6th, July 22nd - August 12th, November 7th - 28th and February 6th - 27th. Since No.3 was later built, the measurement started from November 7th - 28th.

Table 1 Details of objects

	No.1	No.2	No.3
Location	Nagano	Nagano	Nagano
Square	144m ²	137m ²	162m ²
Stories	2	2	3
Family (age)	M(59),F(55) M(27),M(25)	M(44),F(37) F(7),F(5)	M(27),F(30) F(2),F(0)
Investigation beginning day	June 14 th /2005	June 11 th /2005	Sep. 9 th /2005
Measured points of temp.	3	5	3
Characteristics of energy source	Natural gas and electric power	Only electric power	Only electric power

3 Measurement results

3.1 Electric power consumption

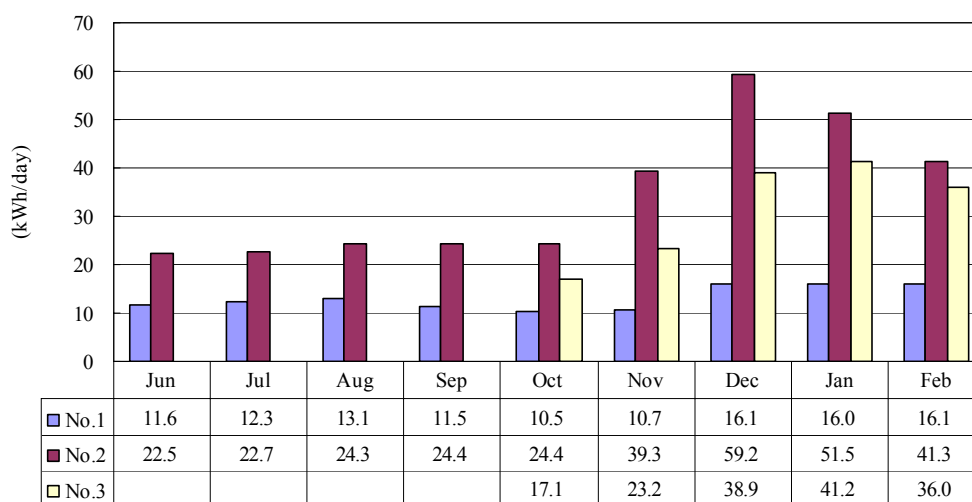
The electric power consumption per minute was measured with a clamping wattmeter. Hot water supply system of No.2/No.3 was the heat pump using CO₂ as heating medium. Table 2 and Table 3 show the electric power consumption per day of each house. No.1 had a lot of consumption on July 22nd - August 11th, and No.2 had a lot of consumption on November 7th - 28th. The monthly electric power consumption had increased in winter season, which is shown in Figure 1.

Table 2 Electric power consumption (kWh/day)

Periods	No.1		No.2		No.3	
	mean	S.D.	mean	S.D.	mean	S.D.
15/6 - 5/7	11.66	1.05	22.67	1.57		
22/7 - 11/8	13.58	2.33	24.75	2.85		
7/11 - 28/11	10.55	0.98	41.00	6.17	25.29	4.61
6/2 - 27/2	15.27	3.42	40.05	4.57	33.57	7.71

Table 3 No.2 and No.3 Electric power consumption (day and night, kWh)

Period	No.2				No.3			
	day		night		day		night	
	mean	S.D.	mean	S.D.	mean	S.D.	mean	S.D.
15/6 - 5/7	13.99	1.28	8.68	0.88				
22/7 - 11/8	16.35	3.05	8.40	0.98				
7/11 - 28/11	26.95	4.60	14.05	2.97	11.40	2.17	13.88	2.95
6/2 - 27/2	22.69	4.31	4.31	2.50	17.18	5.65	16.39	3.86

**Figure 1 Monthly electric power consumption**

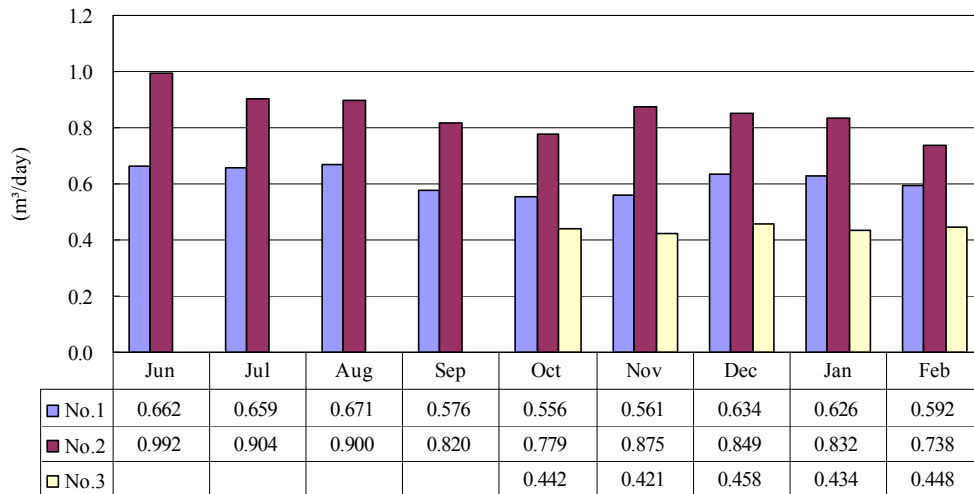
3.2 Water consumption

Water consumption per day of each house is shown in Table 4. And monthly water consumption is shown in Figure 2.

Amount of water consumption per day of No.1 and No.2 had increased in summer, but decreased in autumn. Monthly mean amount of water consumption per day of No.1 and No.2 was the least in October.

Table 4 Water consumption (m³/day)

Periods	No.1		No.2		No.3	
	mean	S.D.	mean		mean	S.D.
15/6 - 5/7	0.64	0.19	0.97	0.17		
22/7 - 11/8	0.67	0.17	0.98	0.21		
7/11 - 28/11	0.56	0.13	0.91	0.25	0.44	0.14
6/2 - 27/2	0.60	0.14	0.74	0.11	0.44	0.16

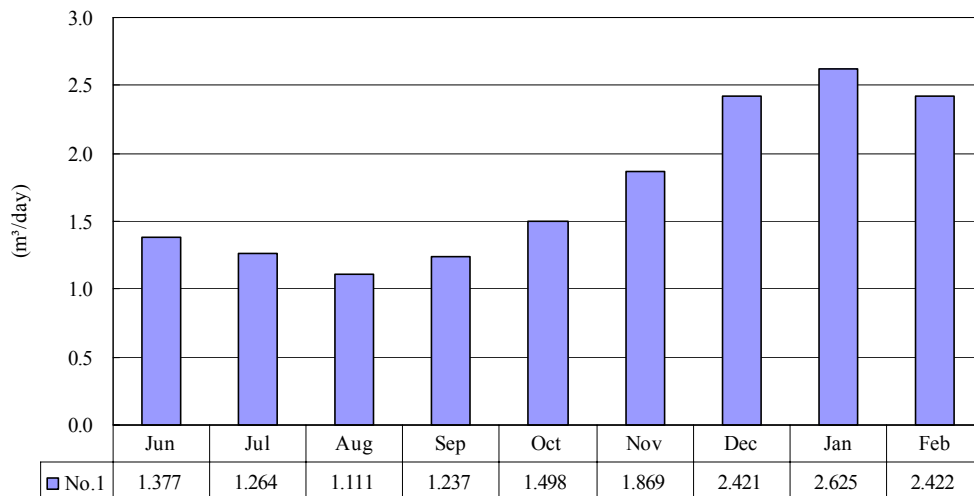
Figure 2 Monthly water consumption (m³/day)

3.3 Natural gas consumption

The natural gas was used for cooking and hot water supply in a kitchen and a bathroom of No.1. The amount of gas consumption (Table 5 and Figure 3) was the fewest in summer, and increased on November 7th - November 28th. Amount of natural gas consumption per month was few in August, and increased most in December.

Table 5 Gas consumption (m³/day, No.1)

Periods	mean	S.D.
15/6 - 5/7	1.31	0.46
22/7 - 11/8	1.10	0.28
7/11 - 28/11	1.89	0.45
6/2 - 27/2	2.43	0.48

Figure 3 Monthly gas consumption (m³/day)

4 Comparison of the electric power consumption at daytime and night

The electric power consumption at nighttime (23:00-7:00) was compared with it in the daytime (7:00-23:00) of No.2 and No.3. Electric power charge was ¥7.22 /kWh (€0.05/kWh) at nighttime, while it was ¥18.46 /kWh - ¥25.47 /kWh (€0.128/kWh - €0.176/kWh) in daytime. Table 6 shows the contractual coverage of the electric power charge. The ratio of consumption per day between at nighttime and in whole day on November was 34.3% in No.2 and 54.9% in No.3, shown in Table 7. The ratio of electric power consumption (night/whole day, October - February) of No.2 and No.3 is shown in Table 8. Users can setup the step to heat the water by heat pump using CO₂ while only at night or in anytime of whole day. Since the amount of the hot water prepared at night was not enough in November in No.2, the electric power was consumed additionally for heating the water in daytime. However the amount of the hot water prepared at night was enough in No.3 shown in Table 9. The electric power consumption of No.3 is shown in Figure 4.

Table 6 Contractual coverage of electric power in No.2/No.3

Contractual coverage			Plan
Upper limit			6 kVA
Basic charge (¥)			1200
Utility rate (¥/kWh)	Day time	1 - 90kWh	18.46
		91 - 230kWh	23.67
		231kWh -	25.47
	Night time		7.22

* not included tax

Table 7 Electric power consumption in daytime and night time(7/11 – 27/7)

	Daytime (kWh/person)		Night (kWh/person)		Ratio of night time (%)
	mean	S.D.	mean	S.D.	
No.2	6.74	1.15	3.51	0.74	34.3
No.3	2.85	0.54	3.47	0.74	54.9

Table 8 Ratio of electric power consumed in night time

	Ratio of night time (%)	
	No.2	No.3
Oct.	38.5	48.9
Nov.	34.5	54.4
Dec.	30.2	46.0
Jan.	39.5	43.7
Feb.	43.0	46.5

Table 9 Electric power consumption for hot water supply (7-11 – 27/11)

period	Consumption (kJ/min)		Ratio of hot water (%)
	Hot water	else	
Daytime (7:00 - 23:00)	7.2	41.76	1.5
Night time (23:00 - 7:00)	68.4	35.28	65.9

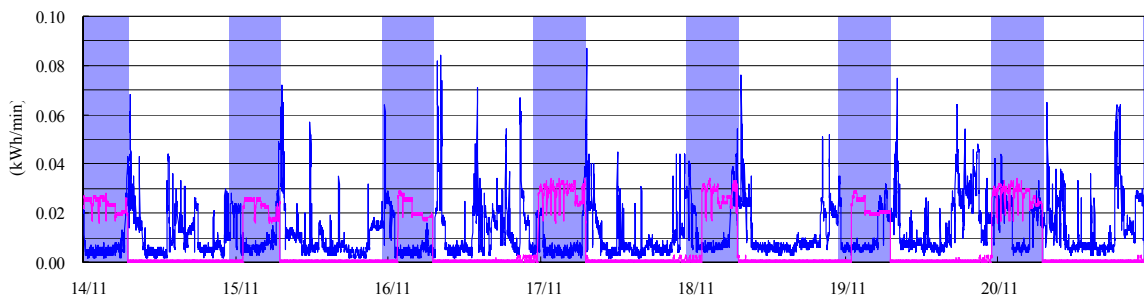


Figure 4 Variation of electric power consumption of No.3 (14/11 - 20/11)

5 Amount of energy consumed for heating water

5.1 Amount of gas consumption and monthly mean temperature

The relation between the amount of gas consumed in No.1 and monthly mean temperature was remarkable, since the coefficient of correlation was -0.98. Table 10 is shown the gas consumption and outdoor air temperature averaged in each month.

Table 10 Monthly gas consumption and outdoor air temperature

	Gas consumption(MJ/day)	Temperature (°C)
Jun.	63.19	23.05
Jul.	58.04	23.85
Aug.	50.97	25.69
Sep.	56.79	22.38
Oct.	68.75	15.45
Nov.	85.78	7.39
Dec.	111.12	-0.45
Jan.	120.49	-1.37
Feb.	111.18	1.13
C.C	r = -0.98	

5.2 Amount of electric power consumption and monthly mean temperature

The relation between the amount of electric power consumed in No.3 and monthly mean

temperature was remarkable, since the coefficient of correlation was -0.99. Table 10 is shown the electric power consumption for heating water and outdoor air temperature averaged in each month.

Table 11 Monthly electric power consumption and outdoor air temperature

	Electric power consumption (MJ/day)	Temperature (°C)
Sep.	7.94	21.58
Oct.	16.43	15.45
Nov.	30.99	7.39
Dec.	49.15	-0.45
Jan.	57.22	-1.37
Feb.	50.28	1.13
C.C	r = -0.99	

The variance-covariance matrix of electric power consumption for heating water and outdoor temperature from September 10th to December 26th was follows:

$$\begin{vmatrix} Sx_1^2 & r \\ Sx_1x_2 & Sx_2^2 \end{vmatrix} = \begin{vmatrix} 24.2 & -0.819 \\ -35.6 & 66.4 \end{vmatrix}$$

x_1 : the amount of electric power consumption (kWh/day)

x_2 : daily mean temperature of outside air

It is understood that electric power consumption for heating water has increased in dropping the outdoor temperature (Figure 5), and the correlation was -0.89.

5.3 City water temperature and outdoor air temperature

Figure 6 is showing the city water temperature and air temperature, those were averaged in monthly in Nagano city. The correlation coefficient was 0.97.

6 carbon-dioxide emissions

Figure 8 shows the carbon-dioxide emissions, which values were converted from amount of electric power and water consumed monthly in No.2 and No.3. Those increased in winter season. Figure 9 shows the carbon-dioxide emissions, which values were converted from amount of gas and water consumed monthly in No.1. Those increased in winter season, too.

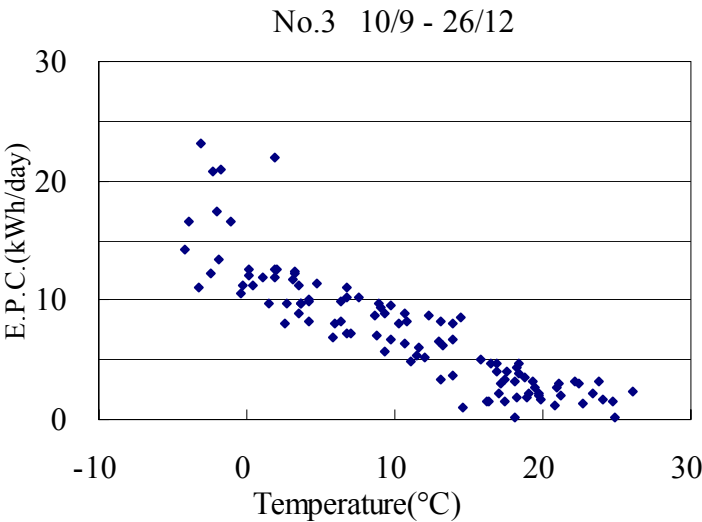


Figure 5 Amount of daily electric power consumption and daily mean outdoor air temperature

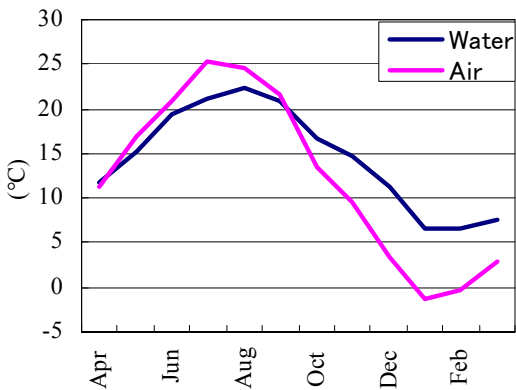


Figure 6 Temperature of city water

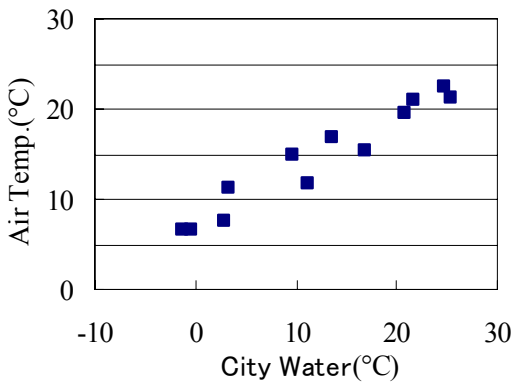
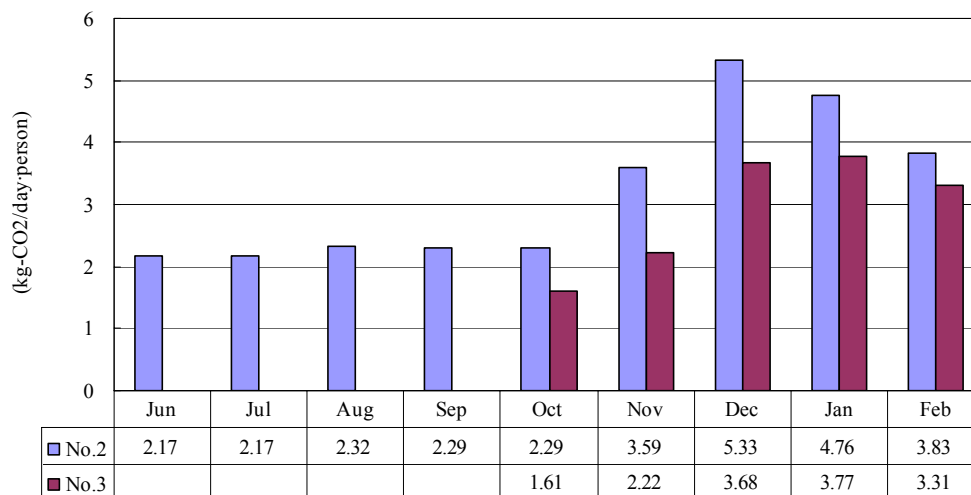
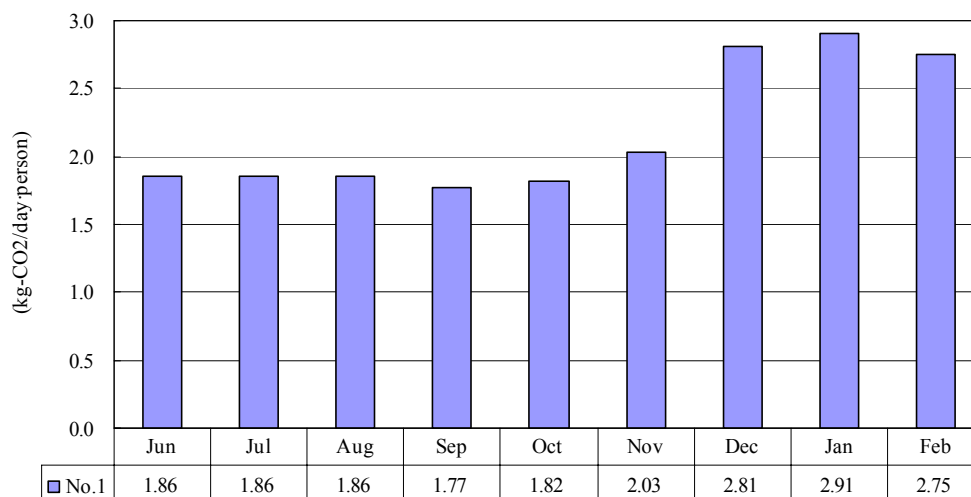


Figure 7 Correlation of City water temperature and Air temperature

Figure 8 CO² emissions by consumed electric power and water of No.2 and No.3Figure 9 CO² emissions by consumed gas and water of No.2 and No.3

7 Life style and electric power consumption

Husband and wife of No.3 had been out of the house in the evening. Residence time of them and the electric power consumption from 18:00 – 20:00 are shown at Table 12 and Figure 10. A peak of electric power consumption appeared in cooking time. The behaviors before/after meal are preparation and putting away. Variation of electric power consumption and the periods of preparation/putting are indicated at Figure 12 and 13. Kitchen in No.3 were totally appointed by electrical machines, those were microwave and electromagnetic cooking table, etc.

Table 12 Resident time of family in No.3 and electric power consumption from 18:00 to 21:00

	Resident time (hour)		Electric power consumption (MJ)
	wife	husband	
14/11	0.5	0	3.9
15/11	0.5	0	2.7
16/11	2.25	0.5	9.9
17/11	0.25	0	3.7
18/11	0.75	0	8.1
19/11	3	2.5	19.5
20/11	2.5	2.5	16.2

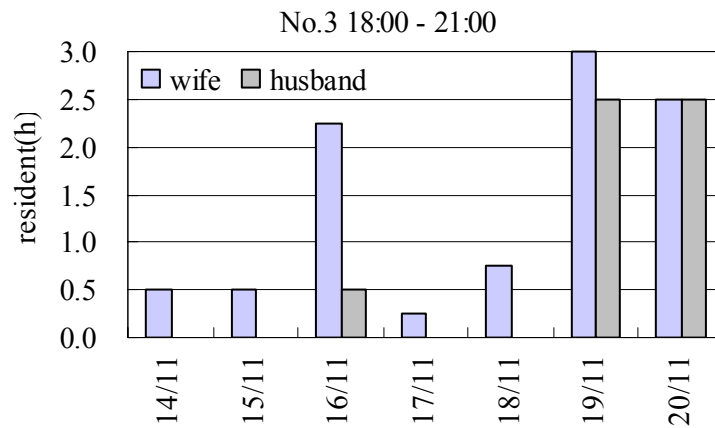


Figure 10 Resident time in No.3 from 18:00 to 21:00

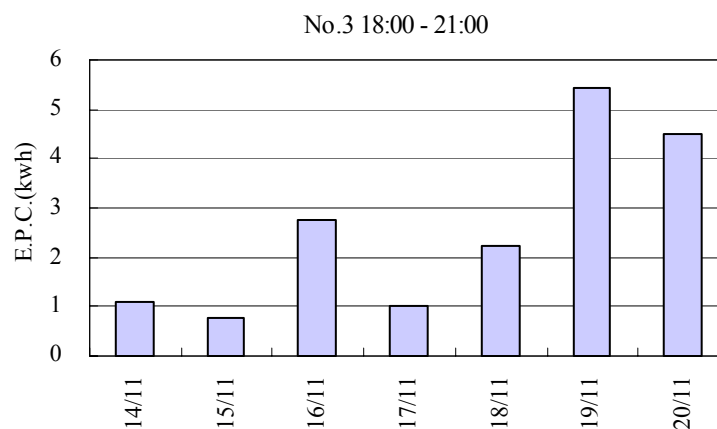


Figure 11 Electric power consumption in No.3 from 18:00 to 21:00

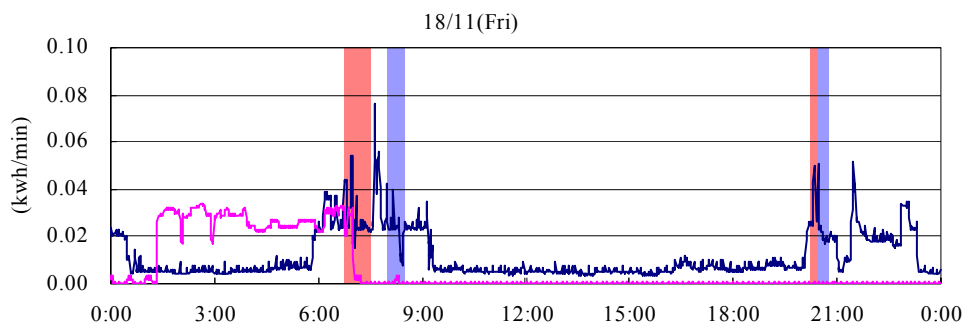


Figure 12 Variation of electric power consumption and cooking periods in weekday

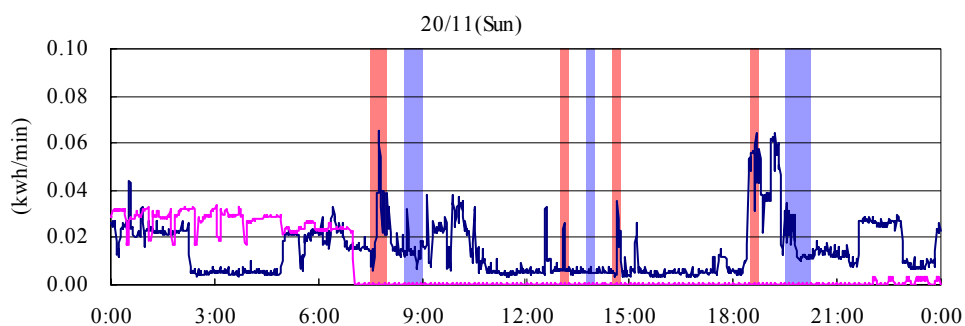


Figure 13 Variation of electric power consumption and cooking periods in Sunday

7 Considerations

7.1 Water and energy consumption

Electric power consumption increased greatly in No.2 in December and January, because of room air heating and hot water demand. It increased in August because of room air cooling, too. In No.3, the amount of the electric power consumption has increased according to the city water temperature drop, because of the outdoor temperature drop. The seasonal variation of the amount of the water consumption was not so large, and water consumption of No.1 / No.2 in October was the smallest.

The energy consumption for supplying hot water of the detached house in Nagano city would be growing, because this city is located in the cold region of Japan.

Amount of electric power/gas consumption in winter had increased, and carbon-dioxide emissions had increased along with it, too.

7.2 Life style and energy consumption

The ratio between the night load and the day load of electric power in No.3 was larger than No.2, because the period of consumption for heating water in No.3 was almost in night. The family of No.3 had been away from home from 18:00 to 21:00, but all people of No.2 had been at home after 18:00 and stayed together in a living room under air conditioning.

8 References

- 1) <http://www.meti.go.jp/>
- 2) <http://www.city.nagano.jp/ikka/w-soumu/index.html>
- 3) <http://www.data.kishou.go.jp/etn/index.html>
- 4) <http://web.archive.org/web/20040203180455/>
- 5) <http://www.env.go.jp/earth/kakeibo/kakei.html>

9 Presentation of Author

Yoshiharu Asano is a professor of Shinshu University. He teaches and conducts research in the department of Architecture and Building Engineering, Faculty of Engineering. He specializes in building equipment, water supply and drainage in buildings and specially controlled installations.



Environmental assessment of residential buildings with emphasis in water conservation

M. S. O. Ilha (1), O. M. Gonçalves (2), L. H. Oliveira (3), L. A. Ywashima

(1) milha@fec.unicamp.br

(2) orestes.goncalves@poli.usp.br

(3) lucia.oliveira@poli.usp.br

(4) ywashima@yahoo.com.br

(1),(3) School of Civil Engineering, Architecture and Urban Design, Department of Architecture and Building, State University of Campinas - UNICAMP, Sao Paulo, Brazil.

(2), (4) Civil Construction Engineering Department, University of Sao Paulo - USP, Sao Paulo, Brazil.

Abstract

Construction, operation and demolition of buildings represent one of the most damaging human activities in the global environment nowadays. Water use is one of the most representative environmental loads to be considered. Some countries have their own building environmental assessment system, which main goal is to stimulate higher environmental performance levels of both existing and new buildings, considering mainly the office building. These assessment systems have not only an exclusive water use approach (inside and outside of the building), but also regards water subject as environmental impact, sustainable sites and so on. This article shows the topics of the main assessment systems concerning water use and presents a proposal of a Brazilian assessment system for residential buildings.

Keywords

Environmental assessment, sustainability; residential building.

Introduction

The petroleum crisis in the 1970s resulted in a number of efforts to make buildings more energy-efficient. This first generation of the so-called “green” buildings, despite presenting several innovations, was experimental and presented deficiencies. (LEHRER, D.; 2004).

According to what was pointed out by Silva (2003), the expression Green Building was proposed to encompass all the initiatives related to the creation of buildings using resources efficiently, with a predominant focus on the use of energy; these should be

comfortable and present a longer service life, adapting to changes according to users' needs and allowing disassembling at the end of the building life cycle, so as to increase the service life of the components by means of their reuse or recycling.

Also, still according to the author mentioned above, the expression "green building" is frequently mistakenly used alternately with the expression Sustainable Building. The term *green* refers exclusively to the ecological dimension (or environmental sustainability) of sustainable construction, which is a more comprehensive concept, also contemplating social and economic dimensions.

Currently, sustainable buildings have to meet a series of requirements besides energy efficiency, concerning the health and comfort of their occupants, impacts on the urban infrastructure and on the places they are implemented, added to those generated by the materials used and by the construction activities, use, operation and demolition of the buildings.

Civil construction was one of the different sectors of society which, as from the environmental goals defined in world conventions held since the 1980s, consolidated with the issuing of Agenda 21 in 1992, elaborated interpretations of this document, having its specificities in focus.

The macro-complex of the civil construction industry (construction industry itself and all the industrial segments directly connected with its activities), which is one of the most expressive sectors in the economy, responding for about 10% of the GDP, is also a great pollution generator. As pointed out by John (2000), "there is no sustainable development without sustainable construction; owing to that, any society that seeks to attain a more sustainable development necessarily has to go through the establishment of specific environmental policies for civil construction".

Among the most relevant interpretations of Agenda 21, the CIB Agenda 21 on Sustainable Construction stands out; in it, one of the main requisites of sustainable construction is the reduction in resources consumption (energy, materials, soil and water). More specifically, concerning the water issue, this document states that the main challenge concerning potable water is the optimization related to its use and the consequent reduction in the volume of sewage generated (CIB, 2000).

The concern with the optimization of water usage is not restricted to the civil construction sector, though. On the one hand, it is known that most of the water available on Earth is seawater and that 2.5% correspond to freshwater and, on the other hand, the increase in demand, caused by the world population growth (150% between 1950 and 2000, specially regarding the urban portion, which rose from 29 to 47% in the same period) and cumulative processes of predatory use (use intensification, wastes and pollution) have caused serious supply problems in different countries.

Brazil has 12% of the world water and 53% of the water in the American continent; however, these resources are not equally distributed along the whole of its continental territory: 80% of the national water resources lie in the basins of the Amazonas, Sao Francisco and Parana rivers.

Moreover, the urban infrastructure for water and sewage serves a small amount of the population. Although 98% of the Brazilian municipalities count on some type of water supply service, only 64% of residences are served. In the case of sewer system, the situation is a little worse: 52% of the municipalities count on sewer system, which serves 35% of dwellings. An even more serious aspect is the coverage of the sewage treatment system, where approximately 10% of the municipalities treat only part of the sewage generated, there being municipalities in which 100% of the sewage generated is dumped *in natura* into rivers and seas.

Facing this scenario of non environmental sustainability, similar to that of other countries, it is urgent to adopt actions that contribute to water conservation in buildings, be it built stock or be it in new projects.

Technical Standardization is an important instrument that establishes parameters for water conservation. However it usually considers only its minimum requirements. As pointed out by Larsson (2004), any discussion on building performance (including environmental performance) has to take into consideration that designers and contractors have to meet the requirements of the final users. It is important that the final user demands higher performance levels.

Therefore, according to the author mentioned above, the issue that remains is: which measures could be implemented together with the already existing ones and that would lead all, or most of those involved in the productive chain, to attract significantly higher levels in the different subjects related to sustainable construction? On the other hand, it is necessary to develop mechanisms that allow users to tell the difference between buildings with different performance levels.

In this sense, the assessment and rating systems of the buildings environmental performance and sustainability assumes a fundamental role.

Brazil does not yet count on any implemented environmental performance assessment and classification system. There are proposals in this sense, developed by research groups from different universities. In other countries, a different situation is found: according to Silva (2003), every European country, besides the United States, Canada, Australia, Japan and China (Hong Kong) – counts on a building environmental performance assessment and classification system.

Among the subjects considered in the systems mentioned, water conservation always assumes a prominent role, for the reasons aforementioned. And, within this subject, the actions contemplated may be divided into two main sub items: rational use and the use of alternative sources.

Inserted in this context, this article presents a survey of the issues related to the water supply and drainage systems in buildings as well as the water usage present in the main assessment systems available in different countries, grouping them into major subjects. As from this survey, and having in mind the local characteristics, topics are indicated that should, according to the authors, be contemplated in the formulation of a Brazilian environmental assessment system, concerning the subject under focus, having as study object the residential typology. The discussion on the form of assessment is not the scope of this study, but only the items that should be contemplated for the typology in question.

2 Buildings environmental performance assessment and rating systems

Silva (2003) states that the sustainable construction must seek a balance among the economic viability, the environmental limitation, and the needs of society.

According to the author mentioned, “internationally, an increasing number of real estate and construction sector companies glimpses business opportunities related to the environment, be it for minimizing risks, for acting ahead of changes in legislation, or be it for sustaining a positive corporative image. The greatest challenges and opportunities refer to the added value concerning environmental values, as, although the importance attributed to *green* values has increased, environmental arguments are not enough to “sell” a project”.

Within this context, the implementation of building environmental assessment systems also presents market advantages, as summarized in Table 1.

Table 1 - Uses of buildings assessments and advantages offered by their implementation.

Application of buildings assessments	Advantages offered by their implementation
• Tools for marketing; • Support to implement environmental management systems • Specification of building environmental performance; • Design aid; • Establishment of environmental performance standards; • Environmental assessments	• Improvement of the image/recognition of companies and professionals that use more sustainable design and construction techniques ; • Increase of the market for buildings and construction products with major environmental performance; • Base for the definition and understanding of the sustainable building concept; • Easy access for financial support and new markets or strengthening of the actual niche, long run business perspective; • Reduction of long run costs (use of financial and natural resources) and profits increase, indoor environment quality and clients satisfaction, reduction of risks (including financial ones) ; • Stimulus for increasing new and old buildings performance level; • Knowledge of the current state of the building considering its environmental impacts in order to identify good opportunities to promote improvements

Source: Silva (2003)

There is at least one buildings environmental assessment system in several countries, among which can be pointed out:

- BREEAM - Building Research Establishment Environmental Method: English environmental certification for commercial buildings.
- CASBEE – Comprehensive Assessment System for Building Environmental Efficiency: Japanese environmental certification for new buildings;
- EcoHomes – The environmental rating for homes: United Kingdom environmental certification, corresponds to the residential version of the BREEAM certification, being applicable to single-family residences and multi-family residential buildings, either new or improved;
- H&E – Certification Habitat et Environnement: French environmental certification of residential developments;

- HQE – Certification Bâtiments Tertiaires – Démarche HQE Bureau et Enseignement: French environmental certification for office or school projects;
- Green Building Tool – Gbtool – sustainability assessment methodology defined by an international consortium of researchers - International Initiative for Sustainable Built Environment (iiSBE), 2005 version;
- Green Star: Australian environmental certification for commercial buildings *Class 5¹*, either new or improved;
- LEED – Leadership in Energy & Environmental Design: USA environmental certification, applicable to new constructions and improvements;
- LEED for Homes – corresponds to the residential version, being applicable to initially new single-family residences; a posterior adaptation for multi-family residential buildings and also those undergoing improvement will be provided later.

Besides these, the existing systems in Canada, Germany, Denmark, Sweden, Finland, China (Hong Kong) and Taiwan may be mentioned.

Most of the methodologies formerly listed are applicable, mainly (or exclusively), to the assessment of office and/or commercial buildings in general, which count on a greater complexity than that of the residential building. The following systems are applicable to the residential typology (either or not exclusively): CASBEE, GBTool, EcoHomes, H&E e LEED for Homes.

According to what has already been pointed out, the form of assessment contained in the systems researched does not constitute the scope of the present study. Information on this sense can be found in Silva (2003), and Foliente; Seo; Tucker (2006).

2.1 Assessment of water supply and drainage systems and water usage

The importance given to the reduction of the environmental impacts caused by the water supply and drainage systems in buildings as well as the water usage in building environmental water supply assessment systems varies mainly depending on the condition of each region or country.

Cheng (2004), for example, mentions that in the methodology existing in Taiwan, revised in 2003, water conservation is the most critical of the nine indexes assessed.

In general, each environmental assessment system has an exclusive chapter dedicated to water conservation, involving rational use (use of saving technologies at the fixtures, submetering, leakage detection systems, etc.) and the use of alternative sources (use of rainwater and water reuse).

From the analysis of the systems listed in the previous item, the requirements related to water supply and drainage systems in building and water usage may be grouped in the following categories:

¹ Office buildings used for professional or commercial ends, excluding stores, parking lots, storehouses, laboratories, public buildings (hospitals, schools) and the like.

- a) adaptability, functionality and maintainability: corresponds to the accessibility to conduct the replacement of components when necessary and the availability of information for the building users, be they technical or not, so as to facilitate the operation;
- b) reliability: refers to the maintain the building systems performance in case of disaster;
- c) costs: is concerned with the limitation on the building operation costs;
- d) energy: refers to the efficiency of the water heating system, both in terms of employing energy-efficient equipment and of the adequate insulation of pipes and other components, besides monitoring the consumption;
- e) selection of products, materials and constructive processes: refers to the selection of products, constructive processes, materials with low emissions of air pollutants, with low use of refrigeration, with small amounts of water incorporated, etc.;
- f) site selection and interference of the building with its surroundings: the concern, in this case, is with the implementation of the building in areas with a potential for flooding and the contamination of the water courses nearby as well as the underground water, among others;
- g) load on the local infrastructure (rainwater): involves the temporary retention of rainwater, with or without later reuse; treatment of water of superficial outflow before dumping and water infiltration for aquifer recharge;
- h) load on the local infrastructure (sewage): deals with the limitation in sewage volume generated and foresees a treatment system;
- i) health, air and water quality: guarantee of potable water quality and of measures to prevent contamination by the bacterium *Legionella Pneumophila*;
- j) water conservation: refers to the measures which, on the one hand, optimize the consumption of potable water (for example: installation of saving components, leaking detection systems, submetering to allow monitoring the consumption, efficient irrigation systems) and, on the other hand, incentive the employment of alternative sources for less noble uses of water (use of rainwater and reuse of grey water).

Table 2 presents a summary of the main items contemplated in the categories presented, collected by means of consulting the existing documents on each system researched. Some topics, considered important by the authors of the present paper and included in methodologies that are not developed to assess residential buildings were also included. Thus, to make analysis easier, the systems contemplating the assessment of residential edifications, either exclusively or not, were identified in the Table mentioned.

Table 2 - Measures mitigate the environmental impacts related to water supply and drainage systems and to the water usage.

Methodology for assessing building sustainability		BREEAM	CASBEE	EcoHomes	H & E	HQE	GBTool	Green Star	LEED	LEED for homes
Applicable to the assessment of residential buildings			X	X	X		X			X
Category	Actions									
adaptability, functionality and maintainability	Provision of a guide covering information relevant for the ‘non-technical’ building manager (including building systems)	X								
	Design with simplicity (conception, construction and access facility for the maintenance) to maintain the building systems performance					X				
	Provision of walls covering in the sanitary appliances surroundings				X					
	Indication of the number of the sanitary appliances in function of the population forecast				X					
	Provision of accessible valves that permit to isolate parts of the building system for maintenance				X					
	Ease of water supply and drain pipe renewal		X							
	Adaptability of the building in the long run and dismount ease					X				
	Provision of as-built drawings and documentation on building systems for the maintenance staff and owners						X			
	Provision of the equipment manuals for the maintenance staff building systems and owners	X					X			
Reliability	Building systems design for maintaining its functions in the event of a natural disaster or major accident.		X							
Costs	Limitation of the annual operation costs						X			
Energy	Provision of the efficient water heating system (insulation of the pipes and components, distances from the water heater and the use point, consumption monitoring)		X		X					X
	Provision of the gas submetering system		X							

Table 2 - Measures mitigate the environmental impacts related to the water supply and drainage systems and to the water usage. (continued).

Methodology for assessing building sustainability		BREEAM	CASBEE	EcoHomes	H & E	HQE	GBTool	Green Star	LEED	LEED for homes
Category	Actions									
Selection of products, materials and constructive processes	Selection of easy maintenance products					X				
	Selection of products, systems and constructive processes in compatibles with the life cycle of the building					X				
	Specification of the renewal interval for major equipment and services		X							
	Selection of low environmental impact products					X				
	Selection of certified products or products with a technical reference				X	X				
	Use of materials that do not change the physical and chemical characteristics of the water					X				
Selection of products, materials and constructive processes	Selection of products with minimum embodied water						X			
	Restriction of gas emissions (ozone depleting substances)- insulation products		X					X		X
	Selection of HVAC systems with do not use refrigerant									X
	Selection of equipments that limit CO ₂ emissions	X	X	X			X			
	Use of CO ₂ emissions monitoring system		X						X	
	Use of low NOx equipments types	X	X	X						
	Use of low SOx equipments types		X							
	Use of plants to absorb NOx, SOx and dust.		X							
	Limitation of formaldehyde pollution sources					X				
	Limitation of the use of CFC e HCFC	X	X	X		X	X			
	Use of atmospheric purification systems, such as photo catalysis and soil cleaning.		X							
	Existence of an operation monitoring plan for the air pollution		X							
Site selection	Site selection to avoid lands vulnerable to flooding						X			
	Site selection to avoid lands close to water						X			
	Specification of practice to minimize the risks of pollution to ground and watercourses/municipal systems	X					X			

Table 2 -Measures mitigate the environmental impacts related to the water supply and drainage systems and to the water usage. (continued).

Methodology for assessing building sustainability		BREEM	CASBEE	EcoHomes	H & E	HQE	GBTool	Green Star	LEED	LEED for homes
Category	Actions									
Site selection	Limitation of the resources consumption (water and energy) in the building construction					X				
	Design features to limit cumulative thermal changes to lake water or sub-surface aquifers						X		X	
Load on the local infrastructure (rainwater drainage)	Incentivar medidas para aumentar infiltração da água de escoamento superficial no solo		X	X		X	X		X	X
	Prevision of temporary retention of rainwater	X	X	X		X	X			X
	Prevision of retention of flooding water without treatment						X		X	
	Prevision of treatment of water of superficial outflow before dumping					X		X	X	
	Prevision of flooding water treatment								X	
	Design features to avoid flood in the site and surroundings					X				
Load on the local infrastructure (sewage)	Design features to limit liquid effluents from building operations sent off the site						X	X	X	
	Prevision of the sewage treatment system	X	X						X	
Health, air and water quality	Assurance of potable water availability when there is no public water supply system						X			
	Prevision of water treatment to avoid corrosion and calcification of the components					X				
	Design features to isolate potable and non-potable water systems, to avoid cross connections					X				
	Use of different colors to identify potable and non-potable water systems					X				
	Design accessible hot water systems, for ease maintenance OR design hot water systems that reduce the contamination by Legionella Pneumophila	X								
	Prevision of the features to control the hot water temperature to avoid users scalding and contamination by Legionella Pneumophila					X				
	Do not use water cooling towers to avoid the risks of Legionella Pneumophila		X					X		

Table 2 - Measures mitigate the environmental impacts related to the water supply and drainage systems and to the water usage. (continued).

Methodology for assessing building sustainability		BREEAM	CASBEE	EcoHomes	H & E	HQE	GBTool	Green Star	LEED	LEED for homes
Category	Actions									
Water conservation	Limitation of the water volume consumed by agent	X		X			X			
	Limitation of the use of potable water in less noble uses					X				
	Prevision of an accessible water submetering system or a remote water submetering system	X	X		X		X	X	X	
	Prevision of water submetering system for public areas, landscaping irrigation, and floor cleaning.				X					X
	Prevision of leakage detection system at least for the main points	X								
	Use of water saving equipments	X	X			X		X	X	X
	Use of low-flow water closets				X					
	Use of electronic water closets and urinals (presence detector)	X								
	Limitation of the water flow in the sanitary appliances – use of pressure restrictors				X	X				
	Prevision of efficient landscaping irrigation system (dripping system)				X		X	X	X	X
	Use of plants that do not need irrigation or that need less water limitation of the landscaping area									X
	Design to reduce potable water consumption for testing of the building's fire sprinkler systems.							X		
	Design to reduce potable water consumption due to water-based cooling systems							X		
	Users education for the equipments operation and maintenance									X
	Prevision of a minimum use of rainwater in substitution of the potable water		X				X		X	
	Prevision of rainwater system for landscaping irrigation			X	X			X	X	X
	Prevision of rainwater system for water closet discharge				X					
	Prevision of gray-water system		X				X	X	X	X
	Prevision of black water system		X					X		
	Prevision of gray-water system at least for use of washing machine for landscaping irrigation, in accordance with local standards and codes									X

3 Assessment of the water supply and drainage systems in Brazilian low income residential buildings

Generally, all the requirements listed in Table 2 should be considered in dwellings environmental assessment systems. The following requirements are considered indispensable:

- a) adaptability, functionality and maintainability: existence of designs presenting simple conception and execution with accessibility to the maintenance points and guaranteeing the owners the availability of user's manual with "as built" design with procedures and scheduling for the maintenance of the system;
- b) costs: reduction of execution, operation and maintenance costs, by means of the adequate choice of materials and components;
- c) energy: water heating systems designs with the use of alternative sources with lower environmental impact than electric power;
- d) selection of products, materials and constructive processes: specification of certified products or those counting on technical reference;
- e) selection of the place for the project and interference of the building with its surroundings: choosing a place that is not vulnerable to flooding and distant from water courses to avoid contamination; reducing the risk of contamination of underground water and water courses;
- g) load on the local infrastructure (rainwater drainage): foreseeing systems for collecting and using rainwater with surplus conducted to infiltration systems;
- h) load on the local infrastructure (sewage): guaranteeing adequate sanitary sewage treatment systems;
- i) health, water quality: guaranteeing potable water in private systems; guaranteeing drinking water quality by means of the adequate separation of alternative waters systems; use of different colors and even materials to distinguish between drinking and non-drinking water systems.
- j) water conservation: foreseeing the installation of saving components in the fixtures; foreseeing efficient irrigation system; specifying vegetation that requires little water; stimulating the use of rainwater for activities not requiring drinking water; discouraging water reuse except for the direct use of rinsing water from clothes washing for washing other clothes, washing the floor or garden irrigation, until the system is consolidated and can ensure the safety of users.

4 Final Comments

Researchers from other Brazilian universities, including the two institutions of which the authors of this article are members of, are conducting a similar survey to the one presented in this work in relation to the other topics contemplated in the building assessment systems, such as energy, selection and consumption of materials, among others. This survey will generate proposals on topics also to be considered in the environmental assessment methodology for low income dwellings. As a result of this research, expected to be provided by mid 2007, a proposal for an assessment system will be formulated, together with manuals aiming at the different phases of the buildings life cycle, having as major goal the sustainable construction of these buildings.

5 References

- BREEAM - BRE's Environmental Assessment Method. Breeam offices 2005 Design & procurement. Assessment prediction checklist. BRE, 16 Feb 2005. 17p. At.: <http://www.breeam.org/offices.html>
- CASBEE - Comprehensive Assessment System for Building Environmental Efficiency. CASBEE for New Construction Tool-1 (2004 Edition). At.: <http://www.ibec.or.jp/CASBEE/english/index.htm>.
- Certification Bâtiments Tertiaires – Démarche HQE® Bureau et Enseignement, Référentiel technique de certification Bâtiments Tertiaires – Démarche HQE® Bureau et Enseignement. At.: <http://www.cstb.fr/frame.asp?URL=/hqe/>.
- Certification Habitat et Environnement. Habitat & Environnement. Référentiel Millésime 2005. Paris, Qualitel, 307 p. At.: http://www.cerqual.fr/pro/habitat_environnement/referentiel.html.
- EcoHomes – The environmental rating for homes. EcoHomes Guidance 2005 1.1. March 2005. 116p. At.: http://www.breeam.org/pdf/EcoHomes2005Guidance_v1_1.pdf.
- CHENG, C. L. Water Environment Issues and Sustainable Strategy in Taiwan. In: The International Workshop **cSUR**, Tokyo. 2004.
- CIB–Agenda 21 para a construção sustentável – tradução de I. Gonçalves e T. Whitaker; ed. de G. Weinstock e D. M. Weinstock. São Paulo, 2000.
- FOLIENSTE, G.; SEO, S; TUCKER, S. Guide to environmental design and assessment tools. At.: <http://www.auspebbu.org>.
- Green Building GBTool. At.: <http://www.iisbe.org/>.
- Green Star™. Green Star™ Office Design v2. At.: <http://www.gbcaus.org>.
- JOHN, V. M.. Reciclagem de resíduos na construção civil: contribuição à metodologia de pesquisa e desenvolvimento. Tese (livre-docência). Escola Politécnica da Universidade de São Paulo. 2000.
- LEEDTM – Leadership in Energy & Environmental Design. Rating System. Version 2.1. November 2002. 67p. At.: http://www.usgbc.org/Docs/LEEDTMdocs/LEEDTM_RS_v2-1.pdf.
- LEHRER, D.. Sustainable Design. Facility Design and Management Handbook. 2004.
- SILVA, V. G. Avaliação da sustentabilidade de edifícios de escritórios brasileiros: diretrizes e base metodológica. Tese (doutorado). Escola Politécnica da Universidade de São Paulo. 2003.
- LARSSON, N. An overview of green building rating and labelling systems. In: I Conferência Latinoamericana de Construção Sustentável e 10º Encontro Brasileiro de Tecnologia do Ambiente Construído. São Paulo. 2004.

5 Presentation of main authors

Marina S. de Oliveira Ilha is Associate Professor at School of Civil Engineering, Architecture and Urban Design, State University of Campinas, Department of Architecture and Civil Construction. She has Post-doctorate Degree in Civil Engineering. She teaches and conducts research in plumbing and fire protection systems.



Orestes Marracini Gonçalves is Professor at the University of São Paulo - USP, Brazil, Department of Civil Construction Engineering and Coordinator of the Building Systems Engineering Research Group of USP



Indicators of water supply and drainage systems in Brazilian low income dwellings considering environmental sustainability

L. H. Oliveira (1), O. M. Gonçalves (2), M. S. O. Ilha (3), R. P. Reis (4)

(1) lucia.oliveira@poli.usp.br

(2) orestes.goncalves@poli.usp.br

(3) ilha@fec.unicamp.br

(4) rpareis@terra.com.br

(1), (2) Civil Construction Engineering Department, University of Sao Paulo, Sao Paulo, Brazil.

(3) School of Civil Engineering, Architecture and Urban Design, Department of Architecture and Building, State University of Campinas, Sao Paulo, Brazil.

(4) School of Civil Engineering, University Federal of Goiás, Goiânia, Brazil.

Abstract

The development of an environmental assessment system requires the identification of some indicators in order to establish adequate performance levels for the buildings. In this context, this paper presents some water use indicators for low income houses in Brazil, obtained by means of field investigation, developed in a sample of houses located in four different cities. Basically, data were collected from an exploratory research including structured interviews with the house owners and an evaluation of the water supply systems. Results indicate an average water consumption indicator of 90-110 L/person per day and a water leakage index rating from 5 to 30 %. The main water leakages were found in the toilets and in the lavatory faucets, which represent low values of water loss index - less than 10%.

Keywords

Water use; environmental assessment system; low income dwellings.

1 Introduction

Excessive consumption and losses of natural resources, in the case of water supply and drainage systems contribute towards increasing environmental impacts, one of them being water shortage.

In the context of buildings, a way of lessening the environmental impact, in what concerns water is the adoption of alternatives that aim at the reduction of losses and

excessive use of materials, components and resources in the construction, use, operation and maintenance phases.

The development of buildings sustainability assessment systems worldwide aims at contributing to the reduction of social, economic and environmental impacts. According to Silva (2003), almost every European country, besides the United States, Canada, Australia, China (Hong Kong) and Japan, count on a building environmental performance assessment and rating system.

The building sustainability assessment methodologies utilized for the residential typology present, among others, the following requirements concerning water supply and drainage systems in buildings to reduce environmental impacts (CASBEE, 2004; EcoHomes, 2005; LEED for Homes, 2005):

- limiting water consumption per consumer agent;
- using water saving equipment;
- implementing a rainwater harvesting system for toilet flushing, washing machines, watering gardens and landscape areas etc.;
- implementing grey water reuse systems that normally collect grey-water from shower, bath and tap water and recycling this for toilet flushing;
- implementing an irrigation system with main shutoff valve, sub-meter and other measures;
- stimulating measures to increase rainwater infiltration in the soil;
- specifying certified products or those counting on technical reference;
- guaranteeing accessibility for maintaining systems and components;
- promoting water heating system efficiency considering both the equipment and the thermal insulation of piping and components.

In Brazil, researchers are developing a methodology for assessing the sustainability of low income dwellings, having in mind the great housing deficit and the technological alternatives that have been used in this building typology which, besides reducing the service life, contribute towards the occurrence of environmental impacts such as: water and electric power shortage, interference with the urban drainage, sound pollution, air quality deterioration, among others.

Considering that the development of a sustainability assessment system requires indicators to render different performance levels adequate, this field research was conducted to characterize mainly water uses, materials and components utilized in water supply and drainage systems in a sample of single-family low income dwellings of located in four Brazilian cities. With these data, it is possible to propose parameters that define more precisely the sustainability level of a dwelling concerning the water requirement.

1.1 Environmental adequacy– contribution of water supply and drainage systems

When dealing with buildings sustainability, it is the buildings systems role to contribute towards minimizing the consumption of resources such as water, gas and energy. The Brazilian standard project “Performance of residential buildings up to five-storey – Part 6: water supply and drainage systems” (CE 02.136.01.008, ABNT, 2004), recommends the reduction of water consumption in domestic equipment and, consequently, of water demand from public supply system and the its consequent volume of sewage for

treatment, without compromising public health or the users degree of satisfaction for this reason.

In order to render water use sustainable, and to increase the system service life and thus reduce the environmental impacts caused by the construction of buildings, it is necessary to know the problems and critical points of this building typology so as to efficiently structure a sustainability assessment system as a support at the decisions concerning the actions to be implemented. Therefore, knowing the water consumption indicator constitutes one of the main parameters for assessing technologies and procedures that may be applied to the system that will reduce water wastage in dwellings.

1.1.1 Water consumption indicator - WCI

Concerning the WCI values, for this typology of building, these values are presented as follows, for obtaining the higher number of credits, according to two sustainability assessment systems:

- EcoHomes (2005), United Kingdom, maximum value of 30 m³/bedspace/year or 82 liters/person/day for all dwellings in the development;
- NABERS (2001), Australia, consumption of up to 20m³/person/year, or 55liters/person/day.

In Brazil, the researches by Vimieiro (2005), conducted in the city of Belo Horizonte and those by Carvalho *et al.* (2005), conducted in the city of Goiânia, respectively attained the values of 79 liters/person/day and 86 liters/person/day. It can be observed that WCI values obtained in these researches would reach the maximum number of credits if assessed by the EcoHomes system (2005).

1.1.2 Hydraulic pressure

Considering that the hydraulic pressure influences water consumption and, therefore, the WCI value, the French sustainability assessment system Habitat & Environmental (H&E, 2005) recommends as maximum hydraulic pressure the value of 300 kPa. In this item, the NBR 5626 (ABNT, 1998) recommends the maximum value of 400 kPa for static pressure at any point in the system and of 10 kPa for dynamic pressure at any fixture, with the exception of the toilet tank, which may be of 5 kPa and that of the flush valve, which must be of 15 kPa.

It can be remarked that these limit values of static pressure are still high for water usage at the fixtures since they contribute towards great flow rate values. Peres (2006) verified that the users considered adequate the dynamic pressure value of 20 kPa in multi-family residential building.

1.1.3 Quality of materials and components

Another factor that influences the service life of the building system is the quality of its materials and components. A good quality system presents a lower leakage rating, which may imply, in itself, longer service life for the other subsystems, such as flooring and wall renderings. There is no reference of a research conducted to investigate this

theme in such a building typology. It can be observed, however, that a large number of constructions opt for low-cost materials and components, which do not always present good quality.

In Brazil, the Programa Brasileiro de Qualidade e Produtividade no Habitat (PBQP-H – Habitat Brazilian Quality and Productivity Program) helps users acquire materials and components in compliance with the Associação Brasileira de Normas Técnicas (ABNT – Brazilian Association of Technical Standards), by means of dissemination in the *site* <<http://www.cidades.gov.br/pbqp-h/fabricantes.htm>> of the qualified and non-qualified companies for the production of the different components used in the building.

1.1.4 Procedures related to water use and to the system maintenance

The water use procedures are practically as important as the use of water saving materials and components produced by qualified companies. Adequate use procedures imply reduction in water consumption and correct maintenance procedures imply guaranteeing water quality and longer service life for the system and, in many cases, also a reduction in water consumption.

2 Objective

This paper aims to present some water indicators of Brazilian single-family low income dwellings.

3 Methodology

The methodology used was a field research, developed in a sample of 77 low income dwellings located in four Brazilian cities characterized by different climate, social and economic conditions. Structured visits and interviews were conducted with one of the users of the dwellings researched. During the visit, the water supply and drainage systems were also inspected. The main parameters of interest for the investigation are the ones presented as follows.

- Urban infrastructure existing in the place;
- Socioeconomic indicators;
- Procedures for water use in sanitary environments;
- Water consumption indicator - WCI;
- Characteristics and age of the building;
- Rate of permeable area in the lot – RPA;
- Compliance of piping and sanitary equipment with technical standards;
- Type of water supply system and how many fixtures are fed;
- Procedures for hydraulic system maintenance;

This assessment was developed by means of the elaboration of a pilot questionnaire, which was initially applied to five dwellings. After this stage, adjustments were made in the questionnaire above mentioned and then applied to the dwellings in the sample. In the data collection, the priority was to interview the housewife or the person in charge of the activities related to water use in the house.

3.1 Sampling

The 77 dwellings researched, were randomly chosen, in neighborhoods of the following Brazilian cities and respective regions, as illustrated in Figure 1: Goiânia, Center-West; Palmas, North; Paulínia and Itajubá in the Southeast region. It can be observed that one of the restrictions of the sample was to select single families dwelling in one lot. This criterion was adopted due to the following reasons: different procedures related to water use and the absence of the dwellers during the research, which would make data collection difficult.



Figure 1 – Brazilian Regions and cities that had low income dwellings included in the sample composition.

3.2 Indicators used

To assess water consumption, the following indicators were considered.

3.2.1 Socioeconomic indicators

To assess the degree of influence of socioeconomic aspects in the dwellings water consumption, the following indicators were collected: number of dwellers, family income and the users' degree of education.

It should be stressed that, for the socioeconomic indicators, characteristic values were determined, that is, minimum, maximum, average and most frequent (modal value).

3.2.2 Water consumption indicator – WCI

It is the ratio between water consumption at a certain period and the number of consumer agents within the same period, in L/person/day. The WCI values were obtained from the arithmetic mean in the interval of Equation 1.

$$I = M \pm 2 \cdot DP \quad (1)$$

In which:

I = interval for determining the final average WCI value;

M = arithmetic mean of the WCI values in the sample;

DP = standard deviation of the sample.

It should be noted that, initially, the average WCI values for the last six to ten months for each dwelling were obtained before the beginning of the research. The standard deviation for the values of the consumption indicator was calculated and the new average value was calculated, considering the values within the interval in Equation 1. For the average value of the sample in the four cities, the same procedure was conducted.

3.2.3 Permeable area rate – PAR

It is the ratio between the addition of the permeable area of the lot (lawns, flower, fruit and vegetable gardens, soils, etc.) and the area of the plot, according to Equation 2.

$$PAR = \frac{\sum AP}{AT} \times 100(\%) \quad (2)$$

Being:

AP = $\sum$ permeable areas (lawns, flower, fruit and vegetable gardens, soils), m²;

AT = area of the plot, m².

3.2.4 Leakage rate – LR

It is the ratio between the number of fixtures presenting leakage and the total number of fixtures in the system, according to Equation 3.

$$LR = \frac{\sum Puv}{Pu} \times 100(\%) \quad (3)$$

Being:

Puv = fixtures presenting leakage;

Pu = total number of fixtures.

3.2.5 Loss rate due to leakage – LRL

It is the ratio between the volume of water losses due to leakage of a system at a certain period and the water consumption in the system in the same period, according to Equation 4.

$$\text{LRL} = \frac{\sum P_v}{\text{CMd}} \times 100(\%) \quad (4)$$

In which:

P_v = daily volume of loss due to leakage;

CMd = average daily consumption.

4 Analysis of results

The results obtained in the sample constituted of 77 dwellings located in four Brazilian cities and indicated in Figure 1 are presented below.

4.1 Urban infrastructure

All the dwellings in the sample count on the following public utilities: potable water, power supply as well as paved roads with the exception of 14 dwelling units in the city of Goiânia, which do not count on paved roads. The drainage system of the dwellings in the Goiânia and Palmas samples is connected to sinkholes, without septic tank. Nevertheless, the dwellings in the cities of Paulínia and Itajubá, count on a public sewer system. Thus, 60% of the dwellings in the sample have their sanitary sewage collected, but none of them counts on a Sewage Treatment Plant.

4.2 Characteristics of the dwellings and of the population

The main characteristics of the dwellings and of the population are presented as follows:

- except for the 19 dwelling units in Itajubá, all the dwellings have been constructed less than 15 years ago;
- most of the dwellings are built in lots with an area that varies from 150 m² to 240 m²;
- most of the dwellings have a built area inferior to 100 m²;
- the highest frequency of dwellers per residence is of four people and the average value is 4.2 dwellers per residence;
- the most frequent family income, 43% of the sample, is in the range comprehending values between 136 and 545 American dollars;
- the population of the sample shows to have as most frequent education level incomplete fundamental school (comprehending elementary and middle school).

4.3 Permeable area rate – PAR

The sample researched presented two situations: the dwellings in the more densely populated region, the Southeast region, present PAR values less than 15% and the dwellings in the regions with lower population densities, Center-West and North, present PAR values over 30%, value that should be the minimum recommended for this building typology.

4.4 Water consumption indicator in the dwellings of the sample

The average value of water consumption indicator is of 114 L/person/day, and the ones outside the interval in Equation 1 are excluded. Figure 2 presents the WCI values obtained in the sample dwellings in the four cities researched and the average value obtained.

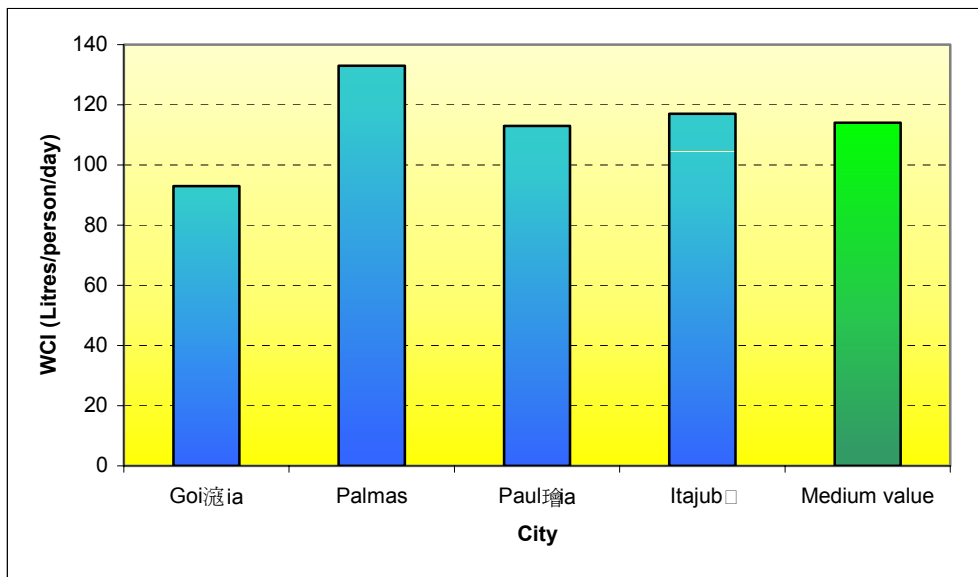


Figure 2 – Water consumption indicator WCI in the samples of the four Brazilian cities researched: Goiânia; Palmas; Paulínia and Itajubá and the average value.

4.5 Characterization of the water supply and drainage systems in buildings

This item presents the characteristics of the systems, quality of materials and components, water wastages and procedures related to water use in the dwellings of the sample.

4.5.1 Water supply system

The dwellings of the sample present as the most frequent water supply system, Figure 3, the combination type - direct and indirect, with an upper reservoir and some fixtures directly connected to the public water main: mainly the garden and the laundry sink faucets. However, about 10% of the sample count on direct system, which contributes towards higher pressure values at the fixtures and, consequently, higher outflow values.

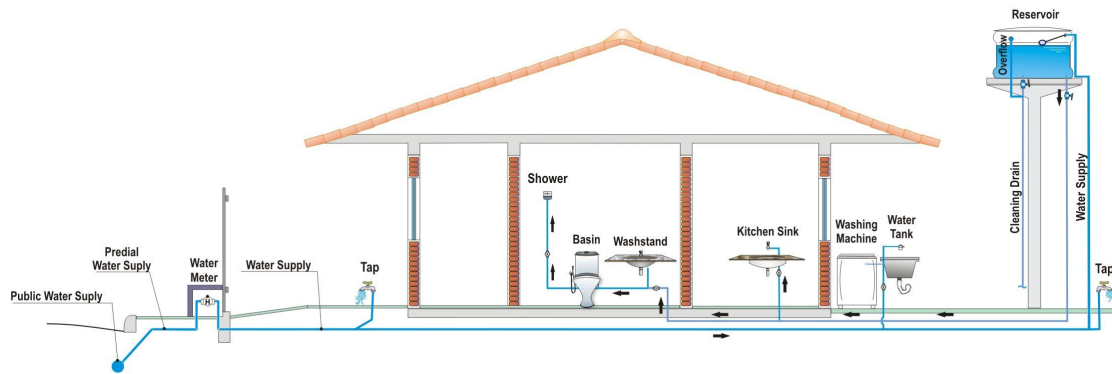


Figure 3 – Water supply system of combination type – direct and indirect.

4.5.2 Components in compliance with the Brazilian Technical Standards

Since the quality of materials and components is directly related to the system service life, materials and components were surveyed and their compliance with the technical standards of the Associação Brasileira de Normas Técnicas – ABNT were verified, by means of the site <http://www.cidades.gov.br/pbqp-h/fabricantes.htm>, as is commented as follows. The rates of compliance of the main components of water supply and drainage systems are presented as follows.

a) Toilets

All the toilets are in compliance with the ABNT Technical Standards, according to the Sector Report nº 23 (2005). 30% of the brands of the toilets surveyed were not identified, as the respective names of the manufacturers were not visible. Therefore, the rate of compliance of the toilets observed is of 100%.

b) Flush components for toilets

The most frequent component to flush toilets in the sample dwellings is the upper flush tank with manual flushing. It should be observed that the toilets with close-coupled tanks and with flushing valves were found. All these components presented a ratio above 60% of compliance with the standards.

c) Faucets

All the faucets of the lavatory, kitchen sink and laundry sink were surveyed; however, it was not possible to verify all their respective brands. Nevertheless, it should be pointed out that the visual aspect provides signs of poor quality.

d) Showers

The dwellings in the sample most frequently present instantaneous electric showerheads, all of them in compliance with the ABNT Technical Standards. It is noted that, owing to the high temperature in the city of Palmas, most of the residences count only on cold water showerheads.

e) Pipes

More than 60% of the PVC pipes identified are qualified according to the Sector Report nº 66 (PBQP-H, 2005).

f) Maintenance procedures

- Water reservoir cleaning

The water reservoir cleaning is indispensable for maintaining the water quality and is recommended by NBR 5626 (ABNT, 1998) to be conducted every six months. However, most of the dwellings researched conduct this procedure only on yearly basis.

- Grease trap cleaning

This problem is more serious than the lack of maintenance, that is, about 30% of the dwellings in the sample do not count on this element in the drainage system, and among the dwellings counting on this element, maintenance is carried out only once a year.

e) Water wastage

- Leakage rate - LR

The values of the leakage rates in fixture appliances, except for the showerheads, were respectively: toilets (LR > 20%); lavatory (LR < 10%) and kitchen sink (LR < 10%). A high leakage rate in toilets must be observed.

f) Procedures related to water use

- Rainwater use

Only 20% of the population studied showed any interest in making use of rainwater and this would be destined to washing the floor and watering the yard.

The use of rainwater in this type of dwelling has little acceptance due to the constant warnings made by health agents concerning the *aedes aegypti* mosquito. This occurs because the collection of rainwater in large metal containers, buckets and other improvised containers used to be very frequent, contributing towards dengue fever epidemics.

- Water reuse

The existence of simplified water reuse was verified, being that the more frequency found was the reuse of the rinsing water from clothes washing for washing the floor for instance.

5 Final Comments

The first results of the present research point out that the values of referential indicators that may contribute towards structuring an environmental assessment system for the Brazilian low income dwellings, concerning water, are:

- one of the main problems presented by the population of the sample studied is the deficiency in urban infrastructure in what concerns collection and treatment of sanitary sewage and, therefore, favoring the contamination of the surface and underground water;

- considering water losses due to leakage, an WCI value equal to 90 L/person/day can be considered as scoring reference in the water use item, with a possibility for increasing the scoring in function of the reduction of this value;
- as to the PAR values, most of the lots in the samples from the Center-West and North regions present PAR above 30%, which shows signs of good rainwater infiltration capacity. Nevertheless, the samples from the Southeast region present low PAR value. An incentive would thus be adequate for improving the permeable areas with green areas or by means of infiltration systems, which would contribute towards controlling superficial outflow, reducing floods, and contributing towards recharging underground water;
- concerning the compliance of materials and components with technical standards, it was verified that most of the supplying companies identified are qualified; however, the need for improvement in the quality of faucets and bottom flaps of close-coupled tanks and flush tanks have to be emphasized, as this would contribute towards the reduction in leakages in toilets;
- as to the maintenance of the system, cleaning the reservoir and the absence of grease traps are considered critical points;
- foreseeing the installation of water saving components; however, only the certified ones or those counting on technical reference;
- as to the water heating system, the insertion of other types excepting the instantaneous electric showerheads is fundamental;
- incentive of use of adequate rainwater harvesting systems, without jeopardizing public health, and reducing the probability of flooding.

5 References

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **CE 02.136.01.008:** Desempenho de edifícios habitacionais de até cinco pavimento – Parte 6: Sistemas Hidrossanitários. Rio de Janeiro, julho 2004.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS (ABNT). **NBR 5626:** Desempenho Instalação predial de água fria. Rio de Janeiro, 1998.

BREEAM Office BRE. **EcoHomes:** The environmental rating for homes: Worksheets. Watford, UK, March 2005. 116 p. Disponível em: <http://www.breeam.org/pdf/EcoHomes2005Guidance_v1_1.pdf>. Acesso em 25 maio 2006.

CARVALHO, D. A.; JACÓ, R.V.; BEGOTTO, R.A.O. **Otimização do uso da água em domicílios de baixo custo.** 2006. 66 f. Projeto final de curso (Graduação em Engenharia Civil) – Universidade Federal de Goiás, Goiânia, 2005.

CASBEE – Comprehensive Assessment System for Building Environmental Efficiency, CASBEE for New Construction Tool-1, 2004 Edition). Disponível em: <<http://www.ibec.or.jp/CASBBE/english/index.htm>>. Acesso em 26 maio 2006.

HABITAT & ENVIRONMENT (H&E). **Référentiel Millésime 2005.** Paris, Qualitel, 307p.307p. Disponível em: <http://www.cerqual.fr/pro/habitat_environnement/referentirel.html>. Acesso em 26 maio 2006.

PERES, A.R.B. **Avaliação durante operação de sistemas de medição individualizada de água em edifícios residenciais.** Goiânia, 2006. 158f. Dissertação (Mestrado em Engenharia) – Universidade Federal de Goiás, Goiânia, 2006.

PROGRAMA BRASILEIRO DE QUALIDADE E PRODUTIVIDADE NO HABITAT (PBQP-H). Relatório Setorial nº 66. Disponível em <<http://www.cidades.gov.br/pbqp-h/fabricantes.htm>>. Acesso em julho, 2005.

PROGRAMA BRASILEIRO DE QUALIDADE E PRODUTIVIDADE NO HABITAT (PBQP-H). Relatório Setorial nº 25. Disponível em <<http://www.cidades.gov.br/pbqp-h/fabricantes.htm>>. Acesso em julho, 2005.

NATIONAL AUSTRALIAN BUILDINGS ENVIRONMENTAL RATING SYSTEM (NABERS, 2001). December 2001. 97 p.

SILVA, V.G. **Avaliação da sustentabilidade de edifícios de escritórios brasileiros: diretrizes e base metodológica.** São Paulo, 2003. Tese (Doutorado em Engenharia Civil) – Escola Politécnica, Universidade de São Paulo, São Paulo, 2003.

VIMIEIRO, G. V. **Educação ambiental e emprego de equipamentos economizadores na redução do consumo de água em residências de famílias de baixa renda e em uma escola de ensino fundamental.** Belo Horizonte, 2005. 106 f. Dissertação (Mestrado em Engenharia) – Universidade Federal de Minas Gerais, Belo Horizonte, 2005.

US GREEN BUILDING COUNCIL. **LEED for Homes Program.** Rating System for Pilot Demonstration, Versão 1.72. September 8, 2005, 127 p. Disponível em: <<http://www.usgbc.org/showFile.aspx?DocumentID=855>>. Acesso em 26 maio 2006.

6 Presentation of main authors

Lúcia Helena de Oliveira is lecturer and researcher in Building Systems at the University of Sao Paulo, Brazil, Engineering School, Department of Civil Construction Engineering.



Orestes Marracini Gonçalves is Professor at the University of São Paulo - USP, Brazil, Engineering School, Department of Civil Construction Engineering and Coordinator of the Building Systems Engineering Research Group of USP



Comprehensive Verification Method for Rainwater Recycling Systems that Enable the Refurbishment of Urban Building Stock

**Masayuki OTSUKA (1), Masanobu YUZAWA (2),
Keiko NOCHI (3), Takeshi AOI (4), Yusuke MINAMI(5)**

(1) dmotsuka@kanto-gakuin.ac.jp

Prof., Dept. of Architecture, College of Engineering, Kanto-Gakuin Univ., Dr.Eng.

(2) myuzawa@kanto-gakuin.ac.jp

Prof., Dept. of Architecture, College of Engineering, Kanto-Gakuin Univ., M. Eng.

(3) nochi@kanto-gakuin.ac.jp

Research Assoc., Dept. of Civil and Environment Engineering, Kanto-Gakuin Univ., Dr. Eng.

(4) m0543001@kanto-gakuin.ac.jp

Graduate Student, Graduate School of Engineering, Kanto-Gakuin Univ.

(5) minami-y@jcom.home.ne.jp

SEKISUI HOUSE, LTD., Dr. Eng.

Synopsis

Global warming is caused by CO₂ emission and the construction industry is responsible for 30% of all CO₂ emissions that are produced in Japan. The “scrap and build” approach has conventionally applied to building construction but now there should be more of a focus on the extended use of the existing buildings (building stock) by refurbishment so as to encourage the reduction of CO₂ emissions. For this purpose, the development of symbiosis technology, which integrates construction and equipment technologies to enable the refurbishment of building stock, is needed.

Under such circumstances, this study has been conducted as part of the research

project where building refurbishment using symbiosis technology was experimented on the Osawa Memorial Institute of Architectural Environmental Engineering, an old laboratory which was constructed on the premises of Kanto Gakuin University approximately 36 years ago.

With a particular focus on the use of rainwater recycling systems this paper reports the following:

- (1) The renewal of the existing building and water supply/drainage system and a proposed planning method for the construction of a rainwater/drain water recycling system using the building stock
- (2) The evaluation of the reduction of potable water consumption as well as the water quality and safety to the effect of the abovementioned system after a seven-months operation.
- (3) Further discussion about the extended use of rainwater for visual environmental improvement of the building, water sprinkling for wall and rooftop greening and the reduction of heat load of air-conditioning during summer

Keywords

Rain Water Recycling Systems, Refurbishment of Urban Building Stock, Water Quality, Water Saving, Non-Potable water

1. Introduction

Upon the refurbishment of the Osawa Memorial Institute of Architectural Environmental Engineering, an old laboratory which was constructed on the premises of Kanto Gakuin University approximately 36 years ago, this study made an attempt to plan and construct a rainwater recycling system. After the completion of the construction the system was operated for approximately seven months during which time water saving and water quality control effects of the system were examined. The water-saving effect was assessed by calculating the substitution rate of potable water with rainwater against the total water consumption. The performance of water quality control was also assessed by analyzing the quality of the water in the rainwater tank, non-potable water tank and the non-potable water gravity tank and by examining water quality changes in relation to the number of days elapsed and the effect of chlorine disinfection. Further discussion was also held about future issues including the consideration of the use of rainwater for visual and sensuous environmental enhancement and for the reduction of heat load of air-conditioning into construction planning.

2. Outline of the refurbishment plan and the rainwater recycling system

2.1 Refurbishment of the experimental building

Table 1 shows the description of the experimental building and Photo 1 shows the exterior of the experimental building before and after refurbishment. As illustrated in Fig.1, the refurbishment plan is characterized by the idea of covering the building with “double-skin façade” and the idea of growing climbing roses against the building walls for both visual effect and energy conservation, i.e. creating shade in summer and insulating the building by preserving heat in winter.

Table 1 Description of the experimental building

Location	Kanazawa, Yokohama, Kanagawa, Japan
Intended use	University Laboratory
Structure	4-storey RC building, 1-storey penthouse
Total floor space[m ²]	733.0[m ²]
Rooftop space [m ²]	300.0[m ²]
Water consumption	Weekdays and Saturdays

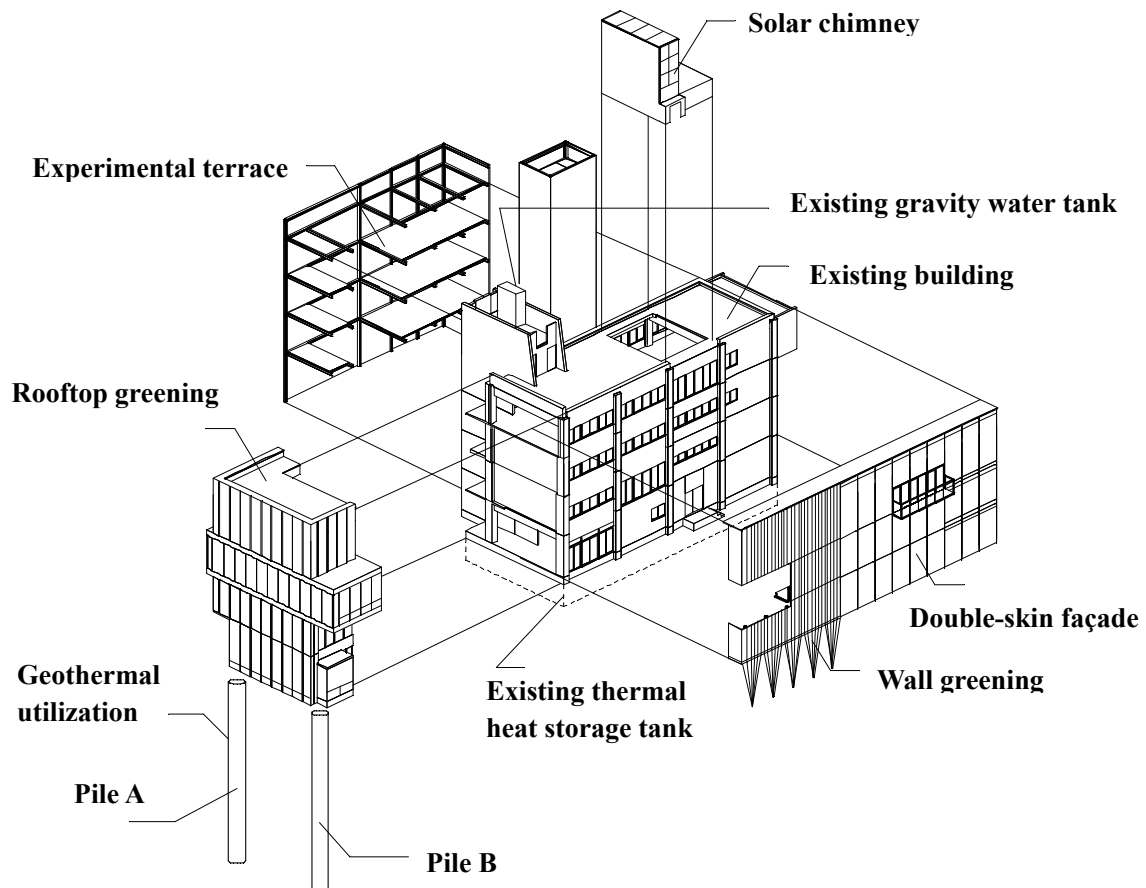


Fig.1 Refurbishment plan schematic using the existing building



(a) Before refurbishment



(b) After refurbishment

Photo 1 Experimental building (west side)

2.2 Equipment planning of the rainwater recycling system

The rainwater recycling system was installed to the experimental building. **Fig.2** shows the schematic of the water supply system which was used before refurbishment and **Fig.3** illustrates the schematic of the rainwater recycling system which was incorporated in the building structure after refurbishment. The system was designed with a particular focus on the following:

- (1) Before refurbishment there were four rainwater stacks (diameter: 100mm) along a wall of the building by which rainwater on the rooftop was drained into the rainwater drainage pipe and carried into the drainage pipe. The system installed after refurbishment is intended to recycle rainwater, which is collected from the rooftop of the experimental building using the roof drain for recycling by a dual siphonic rainwater drainage system (pipe diameter: 50mm).
- (2) The rainwater drainage system is neatly arranged in a compact pipe shaft unit, as shown in **Photo 2**, which is attached to the exterior wall surface, ensuring easy construction and maintenance.
- (3) As shown in **Photo 3**, the aged thermal heat storage tank, which was placed in the basement, was upgraded with waterproofing work so that it could be used for rain water and non-potable water. The potable water gravity tank was also converted to a non-potable water tank.
- (4) As illustrated in **Fig.3**, rainwater first goes into the grit chamber to be stored in the rainwater tank. The rainwater is then filtered, disinfected with chlorine and stored in the non-potable water tank to be transferred to the water gravity tank. This

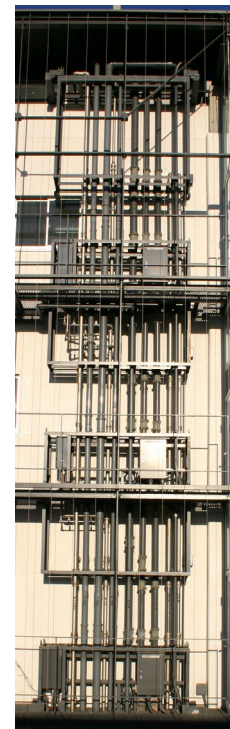


Photo 2
Pipeshaft unit

rainwater recycling system also enables the recycling of wastewater, such as water used for washing hands, using the same method, i.e. the above water treatment and storage in the rainwater tank.

- (5) Non-potable water may be used for vacuum suction toilets and pressure-assisted toilets with water-saving equipment, plant watering and drainage testing. **Table 2** lists various water volumes consumed by different applications, which were estimated when planning the rainwater recycling system.

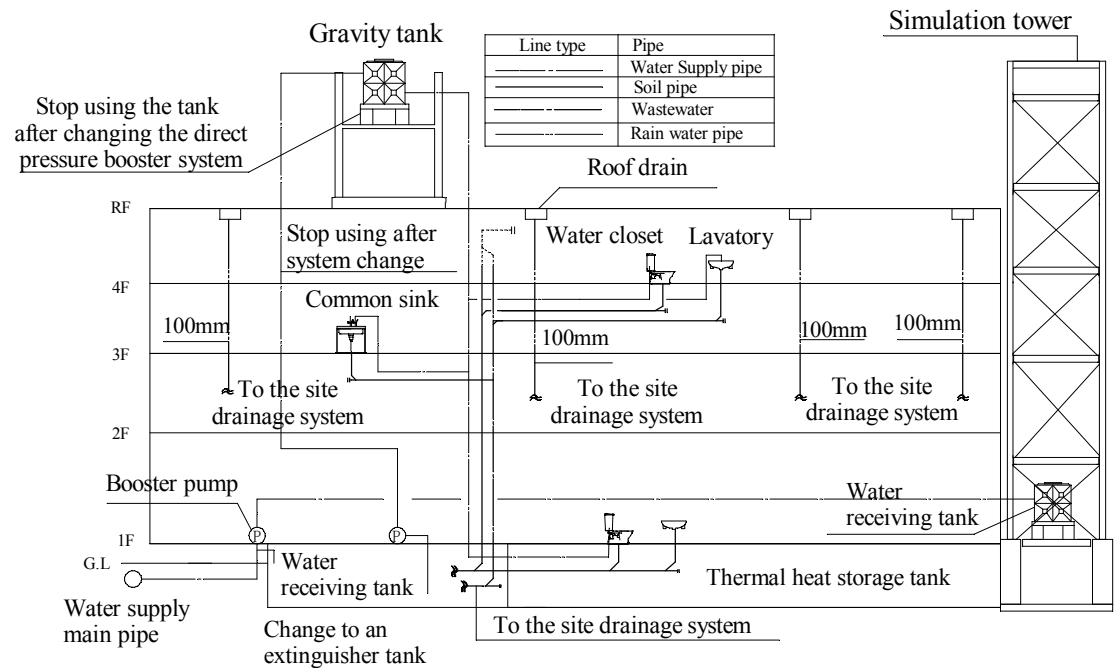


Fig.2 Rainwater recycling system before refurbishment

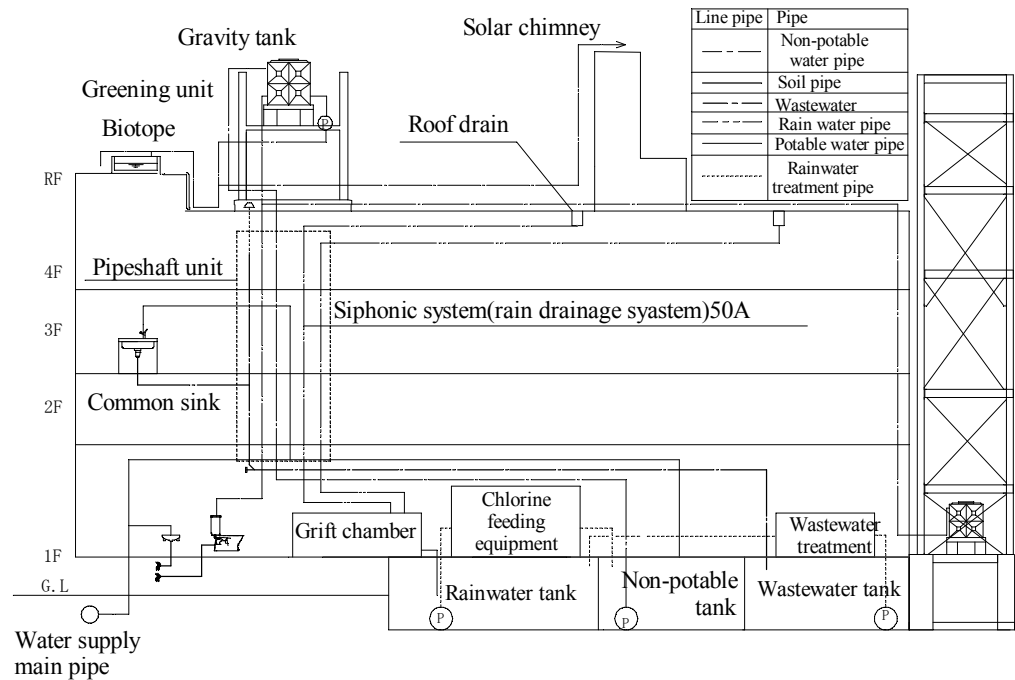


Fig.3 Rainwater recycling system after refurbishment



(a) Before refurbishment



(b) After refurbishment

Photo 3 Thermal heat storage tank

Table2 Calculation of water consumption by different applications

Application	Fomula	Predicted volume [m ³ /Day]
① Urinal flush	$6[\text{L}/\text{time} \cdot \text{person}] \cdot 0[\text{person}] \cdot [\text{time}/\text{day} \cdot \text{person}]$	0.36
② Water closet flush	$8[\text{L}/\text{time} \cdot \text{person}] \cdot 0[\text{person}] \cdot [\text{time}/\text{day} \cdot \text{person}]$	0.24
③ Plant watering	$9.5\text{L}/\text{m}^2 \cdot \text{Area to be watered } 52.7[\text{m}^2]$ $9.5[\text{L}/\text{m}^2/\text{day}] \times 52.7[\text{m}^2]$	0.50
④ Drainage testing (indoor)	Water volume for cleaning 8L $8[\text{L}/\text{time}] \times 100[\text{times}/\text{day}]$	0.80
⑤ Drainage testing (tower)	Total flow x drainage time = flow for testing/day Water for testing is recycled. The above volume of water is replaced every 7 days. Water consumption/day $3360[\text{L}] / 6\text{days}$	0.56
⑥ Hand washing (potable water)	$4.5[\text{L}/\text{time}/\text{person}] \times 30 [\text{persons}] \times 3[\text{times}/\text{person}]$	0.41
⑦ Non-Potable water Predicted consumption/day	①+②+③+④+⑤	2.46

3. Items to measure and record

The items to measure and record are (1) weather data, (2) water volume of each tank to record fluctuation, (3) consumption of potable water and non-potable water and (4) the quality of the water in each tank. The recording was carried out according to a potable water testing method for a period of six months between June 29 and December 26 of 2005. Further details are in **Table 3**.

Table 3 Items to record

	Item	How to measure and record
1	Weather data	Outside air temperature, rainfall, humidity, wind direction/speed, amount of global solar radiation. Measure every hour.
2	Water level of each tank	Use an ultrasonic water level sensor to measure the water level every 10 minutes. Acquire a water level fluctuation by conversion.
3	Water consumption by application	Use a pulse meter installed to the non-potable/potable water system to acquire the water volume by conversion. Measure every 10 minutes.
4	Water quality-related	Measure pH value, DO, transparency, water temperature and free residual chlorine daily. Measure coliforms, <i>Legionella sp.</i> , general bacteria, and heterotrophic plate count twice a month. Refer to a potable water testing method.

4. Results and speculation

4.1 Results of the water volume survey

(1) Comparison of precipitations

The average annual precipitation of the Yokohama area, where the experimental building is located, is approximately 1500[mm/year]. **Fig.4** shows precipitation data which was recorded in the area monthly and annually between 2004 (before refurbishment) and 2005 (after refurbishment). The summer of 2004 (before refurbishment) recorded low precipitation but because of three typhoons in October it was boosted to 1483[mm] by December. The summer of 2005 (after refurbishment) brought typhoons and torrential rain creating 50mm precipitation/day three times but because of low precipitation in the autumn precipitation accumulated to 1000[mm] within six months by December, which was around the average.

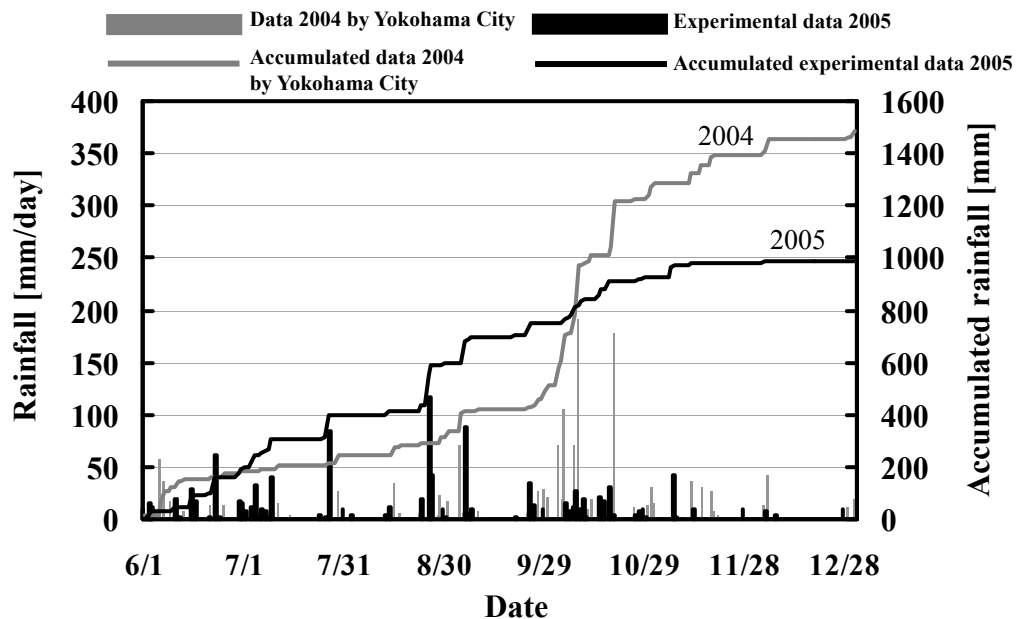


Fig.4 Rainfall comparison 2004 and 2005

(2) Comparison of water consumption by application

Fig.5 is a graph showing the consumption of potable water recorded monthly and yearly between 2003 and 2005. The water consumption of 2005 (after refurbishment) indicates the total water volume of non-potable water and potable water. 200m³ of potable water, which is a rather large amount, was consumed during August and September of 2004 intensively for drainage testing prior to the refurbishment of the experimental building. This resulted in an annual water consumption of 434m³. The water consumption of 2005 exceeded that of 2003. This is because drainage testing for the vacuum toilet system began in 2005 while the number of people using the building rooms increased, so did the water spraying facilities for the rooftop and ground greening scheme.

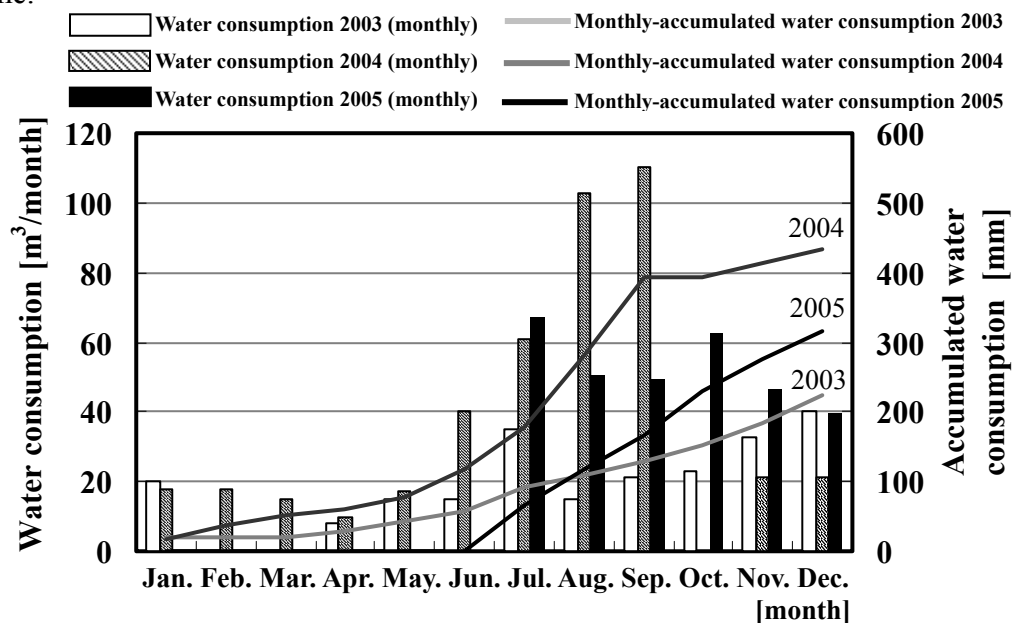


Fig.5 Water consumption survey on the experimental building (2003- 2005)

(3) Water consumption in relation to the number of months elapsed

Fig.6 shows amounts of rainwater, both collected and drained away, and water consumption by each system, all of which were measured in 2005 in relation to the number of months elapsed. During a period of six-months between June and December the collected rainwater was measured to be 144.5m³, the rainwater overflow was 30.0m³, and the non-potable water consumption was 234.0m³. The potable water consumption was measured to be 92.0m³ and the total volume of water consumed by the entire building was 326.0m³. A low precipitation rate of 11mm/month in December reduced the water volume stored in the rainwater tank, not enough to treat and feed the non-potable water tank. Luckily, the water remaining in the non-potable water tank was sufficient to get through the month.

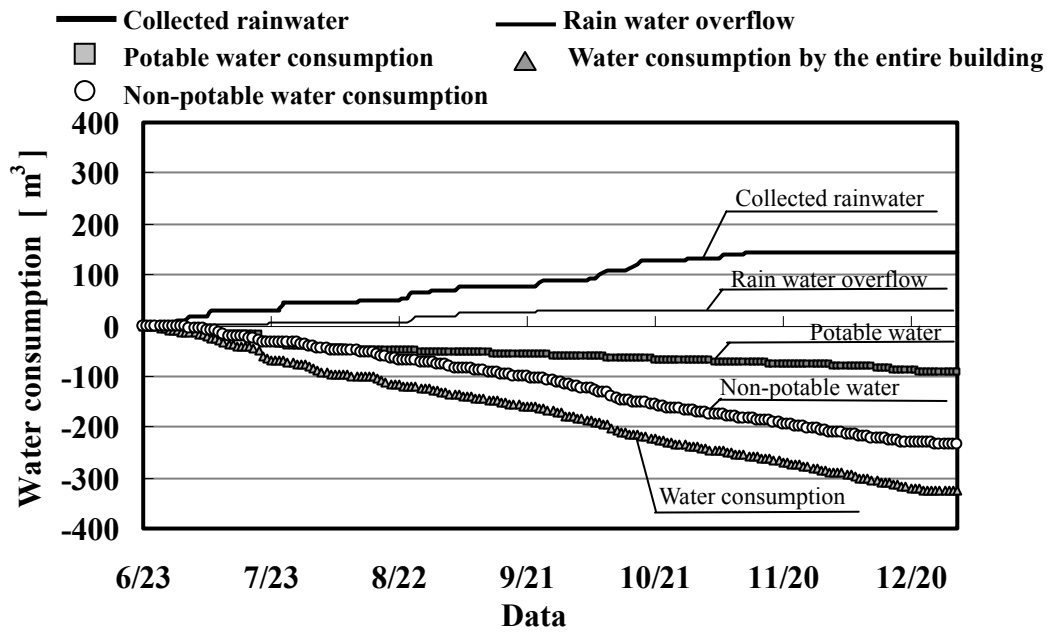


Fig.6 Water consumption in the experimental building (Jun. 2005 – Dec. 2005)

(4) Substitution rate of potable water

Fig.7 shows water consumption in proportion to water application. The consumption of potable water against the overall water consumption in the experimental building was 28.2%, from which the substitution rate of potable water was calculated to be 71.8% based on the rate of water consumption by the entire building and the rate of non-potable water consumption. It was unique to the experimental building that daily water consumption was rather significant due to the drainage testing, but the testing was conducted using nothing but rainwater and the use of potable water for hand washing and experiments was suppressed. Hence, it was acknowledged that the recycling of rainwater and wastewater worked effectively, retaining the substitution rate of potable water to 71.8% (234m³ during the survey period), which ensured the refurbishment of the building highly efficient for water saving purposes.

4.2 Results of the water examination

(1) The quality of the water in each tank

The quality of water in each tank was tested and the results are listed in **Table 4**. The testing aimed to identify the deterioration of water quality in relation to a retention period and the adequacy of disinfections. The pH value of the water in each tank was measured to be 6.9 - 7.2 (neutral), satisfying the non-potable water quality standards (5.8 - 8.6pH). Meanwhile, the concentration of DOC (dissolved organic carbon) fell in the range of 4.1 - 5.5[mg/L], which more or less corresponds to the tap water quality standards (5[mg/L]). Consequently, these results suggest that the physicochemical effect on the quality of water in each tank is insignificant, i.e. the water quality is stable as

non-potable water.

The water in each tank, with physicochemical properties as explained above, was also tested for the presence of bacteria. Shown in **Fig.8** is the concentration of bacteria in the rainwater tank (before disinfections) in relation to the number of days elapsed. Heterotrophic plate count, which are easy to multiply in oligotrophic environments and, increase from 10^3 [CFU/mL] to 10^5 [CFU/mL] by the sixth month of accumulation in the tank, maintaining high concentration values, while *Legionella sp.*, the cause of *Legionella sp.* infection,

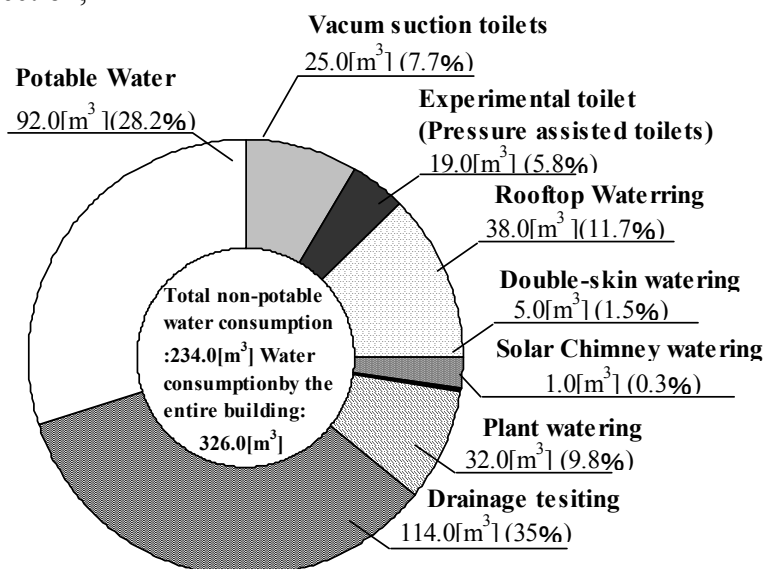


Fig.6 Water consumption in the experimental buildings (2003- 2005)

Table 4 Results of the water quality test on the Osawa Memorial Institute

	Rainwater tank	Non-potable tank	Wastewater tank	Gravity tank	Biotope
Water temperature [℃]	16.2~25.6 ^{*1)} 22.72 ^{*2)}	16.9~25.7 23.2	14.1~25.3 22.4	7.4~27.6 23.9	4.8~28.6 21.9
Exterior	Clear and colourless	Clear and colourless	Slightly yellow	Smell of sewer	Clear and colourless
Odour	Smell of algae	Smell of algae	Smell of algae	Smell of sewer	Smell of algae
Transparency [cm]	50 over	50 over	50 over	50 over	34~50
pH value { }	6.7~7.2 6.9	6.9~7.3 7	7.0~7.3 7.1	7.0~7.6 7.2	6.8~7.4 7.1
conductivity [μ S/cm]	73~179 102	95~220 140	148~199 188	95~230 144	107~238 138
DOC [mg/L]	2.76~5.42 4.09	3.61~5.69 4.22	3.26~7.76 5.51	3.64~5.96 4.71	3.5~6.7 4.4
SS [mg/L]	0.58~3.89 1.08	0.07~0.84 0.29	0.3~5.22 3.38	0.14~1.5 0.38	0.28~23.8 0.95
Total chlorine [mg/L]	-	0.58~5 1.1	-	0.28~1.8 0.93	0.02~0.05 0.04
Free residual chlorine [mg/L]	-	0.04~2.3 0.55	-	0.03~0.61 0.22	0.01~0.03 0.01
General bacteria [CFU/mL]	1? 0 ² ~2? 0 ⁴ 2? 0 ³	ND~7? 0 ³ ND	1? 0 ² ~5? 0 ³ 1? 0 ³	3? 0 ¹ ~2? 0 ³ 2? 0 ²	2? 0 ¹ ~6? 0 ³ 9? 0 ²
Heterotrophic plate count [CFU/mL]	5? 0 ³ ~2? 0 ⁵ 5? 0 ⁴	ND~2? 0 ⁵ 1? 0 ²	1? 0 ⁴ ~4? 0 ⁵ 5? 0 ⁴	1? 0 ² ~1? 0 ⁵ 7? 0 ¹	6? 0 ² ~4? 0 ⁵ 3? 0 ⁴
Coliforms [CFU/mL]	6~410 78	ND~2 ND	1~235 15	ND~2 ND	ND~375 16
<i>Legionella sp.</i> [CFU/100mL]	ND~130 25	ND~3 ND	ND~190 25	ND~1 ND	ND~15 5

*1) Top row: min. to max. *2) Bottom row: average ND : no detection

was detected recording the maximum value of 130 [CFU/100mL]. In addition, the coliforms, an indicator of fecal contamination, was detected indicating the maximum value of 410 [CFU/mL]. The results of the bacterial examination therefore imply that an appropriate disinfection method is necessary to treat rainwater to be used as non-potable water.

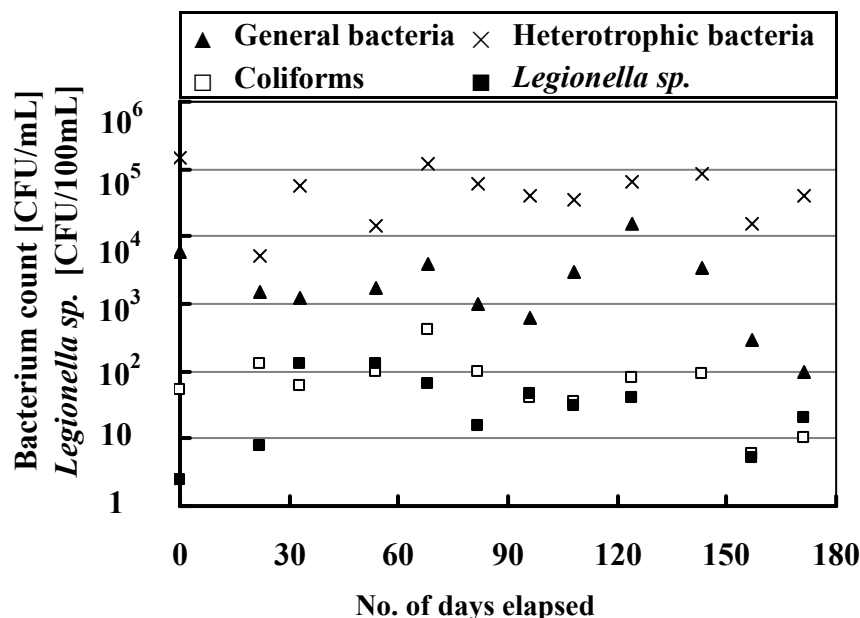


Fig.8 Concentration of bacteria in the rainwater tank in relation to the number of days elapsed

(2) Chlorine disinfection of the non-potable water tank and gravity water tank

Chlorine was placed in the non-potable water tank and the gravity tank. The effect of chlorine disinfection in the non-potable water tank is shown in **Fig.9** in relation to the number of days elapsed and **Fig.10** shows the effect of chlorine disinfection in the gravity water tank in relation to the number of days elapsed. No *Legionella sp.* was detected in either tank for a period of approximately six months. The coliforms was detected, but only twice (detection rate: 17%), indicating 1 - 2[CFU/mL]. The concentration of general bacteria was also detected falling under the allowable value by the tap water quality standards (100[CFU/mL] or below), indicating a good effect of the chlorine disinfection, with the exception of a certain period of time when the disinfection was inadequate. Incidentally, the level of free residual chlorine was retained to 0.03 - 0.61[mg/L](median: 0.22[mg/L]) under the same condition. The above findings suggest that the level of free residual chlorine ideal for disinfection is 0.1 - 0.5[mg/L]. The water in the non-potable water tank and in the gravity water tank was used for WC flushing, water spraying for rooftop greening, water spraying for the double-skin façade and the solar chimney, drainage testing and water spraying for roses

and sedums. It was fairly safe to use the water for these applications from the bacteriological point of view.

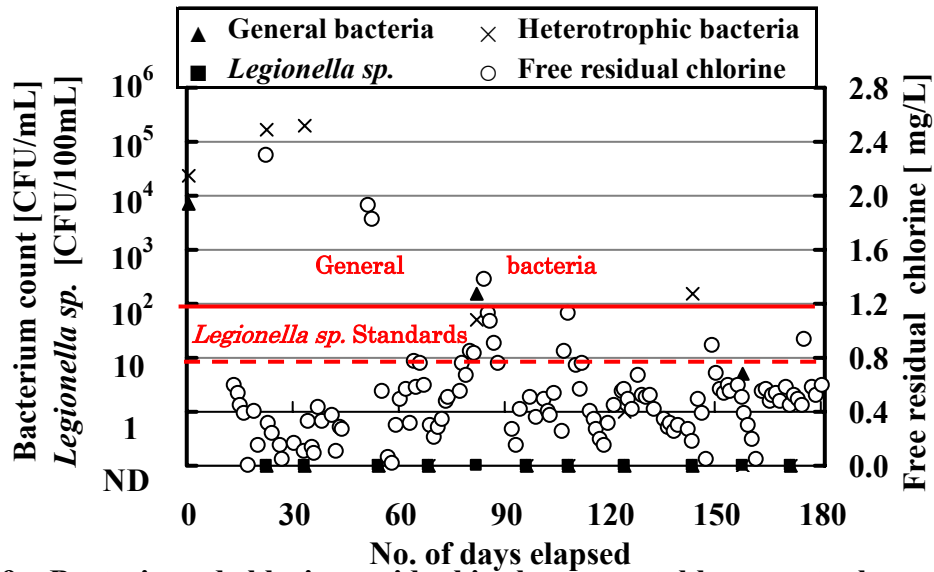


Fig.9 Bacteria and chlorine residual in the non-potable water tank in relation to the number of days elapsed

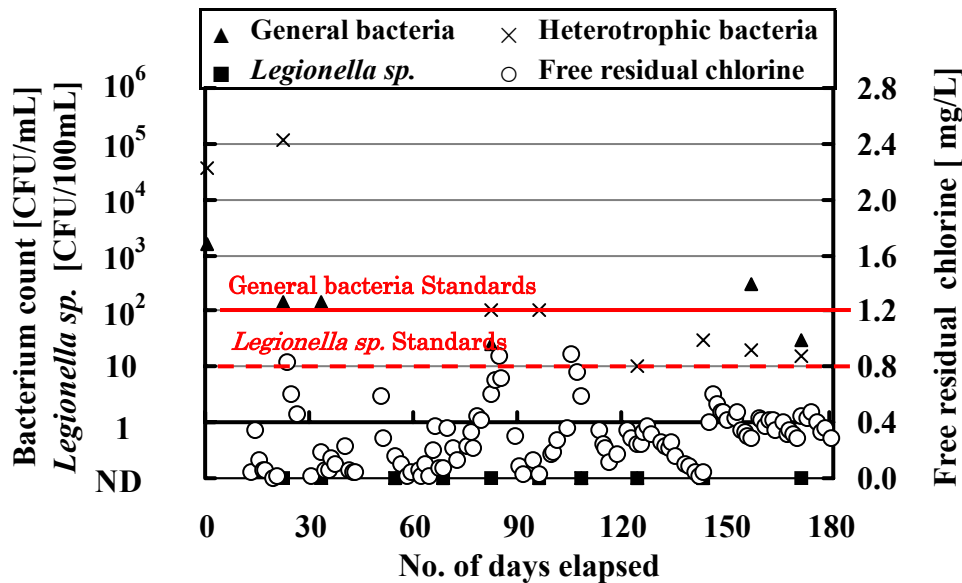


Fig.10 Bacteria and chlorine residual in the non-potable gravity tank in relation to the number of days elapsed

4.3 The reduction of heat load of air-conditioning and application to plant watering

Photo 4 shows the double-skin surface with and without water sprayed over it during summertime. Spraying the double-skin surface, which becomes very hot in direct sun, with bacteria-free, safe water has a temperature-reducing effect, possibly cutting back on heat load of air-conditioning. **Photo 5** shows the west wall of the experimental building where climbing roses are growing, benefiting from the water spraying system. **Fig.11** shows the amount of water consumed for rose watering, precipitation and the

height of a climbing rose in relation to the number of days elapsed. The findings suggest that the safe use of rainwater widens a range of applications in areas of sanitation, architectural design and air-conditioning.

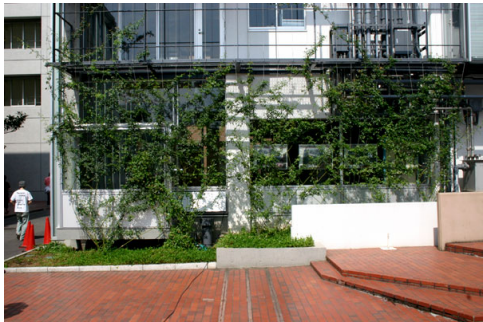
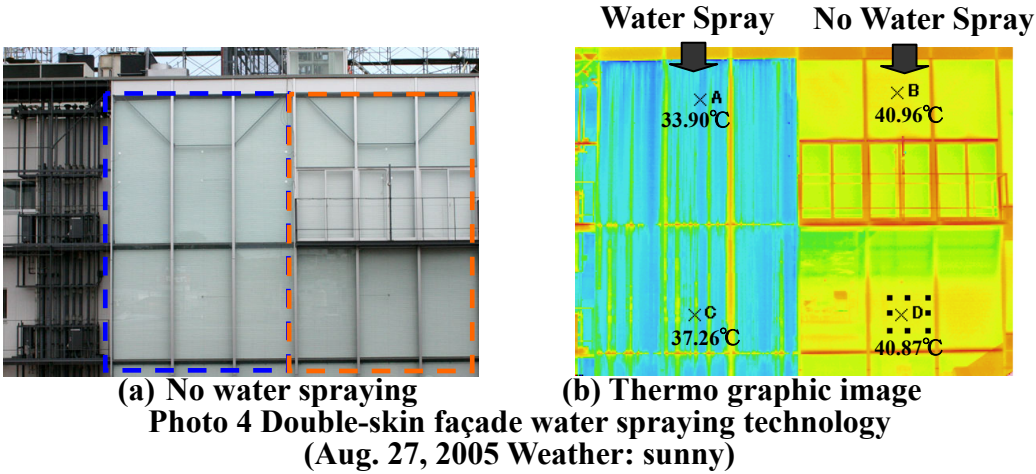
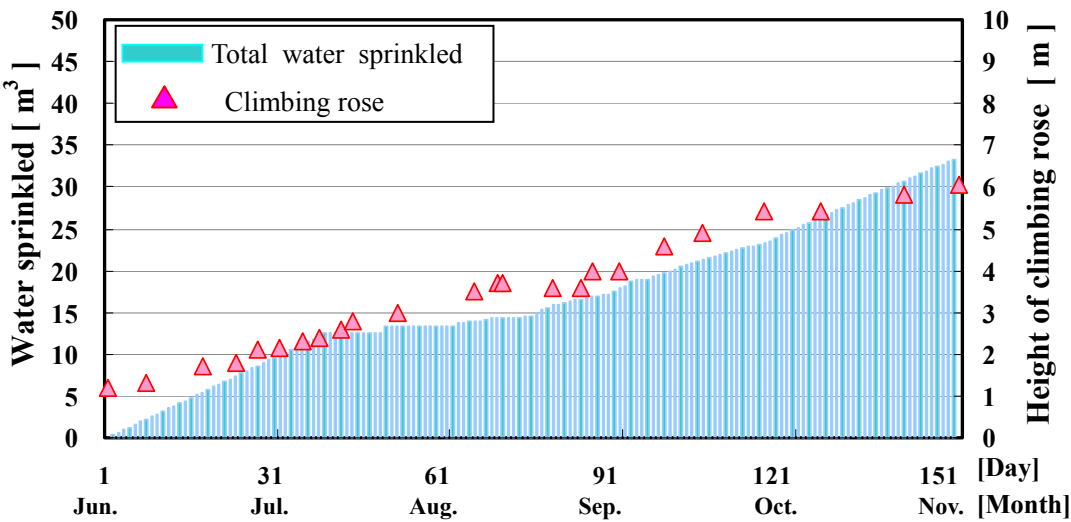
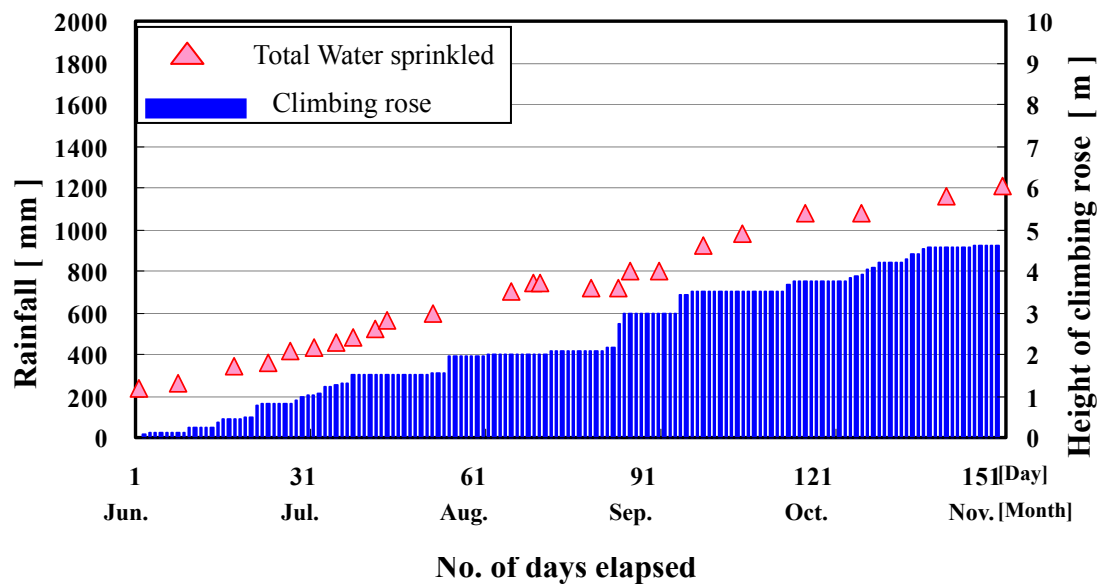


Photo 5 Wall greening
(approx. 12 months after planting. Photo taken on Jun. 27, 2006)



(1) Water consumed for rose watering in relation to the height of climbing rose



(2) The amount of rainfall in relation to the height of climbing rose

Fig.11 Water consumed for rose watering, precipitation and the height of climbing rose in relation to the number of days elapsed

5. Summary

The application of the rainwater drainage system upon the refurbishment of a building implies a wide use of rainwater in areas of sanitation, construction, air-conditioning and many more. To be more precise, the following were clarified:

- (1) The consumption of non-potable water (234m³) was broken down into rainwater 81% and treated wastewater 19%.
- (2) The substitution rate of potable water consumed by the entire building was 71.8%. The consumption of potable water was reduced by replacing it with non-potable water.
- (3) 300mm precipitation during the rainy season was sufficient to operate the rainwater recycling system fully between late June and early August, satisfying all water applications within the building. A shortage of rainwater in the rainwater tank became apparent in December and onwards. Further discussion is necessary about the recycling of wastewater.
- (4) The concentration of DOC in the non-potable water tank was 4.7[mg/L] and this low value indicated that the water quality was stable.
- (5) Chlorine disinfection demonstrated the detection of general bacteria 25-300 [CFU/mL], Heterotrophic plate count 10 - 100[CFU/mL], and the coliforms ND - 2[CFU/mL]. It also demonstrated no detection of *Legionella sp.*. Consequently, it was indicated that the level of free residual chlorine 0.1 - 0.5[mg/L] is adequate to

ensure the safe use of non-potable water in a bacteriological sense.

- (6) The safe use of non-potable water was demonstrated by spraying it over wall plants and wall surfaces, indicating possibilities of adding features to architectural design and contributing to the reduction of heat load of air-conditioning.

7. Acknowledgements

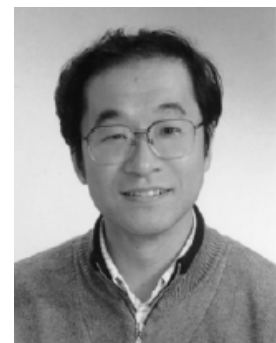
This study was conducted as part of the “Strategic Development Studies of Symbiosis Technologies with the Aim of Urban Construction Stock Reproduction”, the academic frontiers promotion program 2004 by the Ministry of Education, Culture, Sports, Science and Technology.

8. References

- 1) Rainwater Recycling System Design and Practical Application by the Society of Heating, Air-Conditioning and Sanitary Engineering of Japan (1997)
- 2) Planning Standards and Notes for Drainage Water/Rainwater Recycling Systems by the Public Buildings Association (1998) , Study on the Actual Condition of Water Quality Measured at Rainwater
- 3) SHIMMURA Koichi et al. ; Studies of Environmental Technology of Symbiosis for Urban Building Stock Renewal(Part 5 Planning of Rainwater and Drainage Recycle System), Technical Paper of Annual Meeting The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan , II pp. 953-954(2005.9)
- 4) NAGAO Akihiro et al. ; Study on the Saving Water and Management Technique of using Rain Water System, SUMMARIES OF TECHNICAL PAPERS OF ANNUAL MEETING ARCHITECTURAL INSTITUTE OF JAPAN (2006.9)

Presentation of author

Masayuki Otsuka is a professor at the Department of Architecture, Kanto Gakuin University. He is a member of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, academic director) . His current research interests are performances of plumbing systems, drainage systems with food waste disposers in high-rise apartment houses and drainage piping systems for SI (Support and Infill) housing.



Examination on Outflow Rate, Infiltration Rate and Reservation Rate of Rain Water in the Region Used Geographical Information System in Case of Kawagoe City Area

Hiroyuki Kose ⁽¹⁾ and Koshiro Nakajima ⁽²⁾

(1) hkose@eng.toyo.ac.jp, Toyo University

(3) nakajima016@sekisui.jp, Sekisui Chemical Co., Ltd.

Abstract

Using geographic information system (GIS), the Kawagoe region in Japan was examined in the case in respect of the possibility of the rain water utilization in the region. Using the detailed digital information that land use of the every 10 meter mesh was recorded in 15 classification, rate of outflow, infiltration and reservation of rain water in every land use were calculated on the basis of building coverage ratio and literature data of discharge coefficient in two cases in the case in which the rain water storage tank is not founded and case in which it is installed. In addition, by dividing the Kawagoe region into 238 meshes in the 1 km four every quarters, from totaling of each mesh of the land use point number, outflow rate, infiltration rate and reservation rate of the every mesh were calculated. In the Kawagoe region, by the introduction of the rain water storage tank, the result showed that outflow control and utilization of the rain water for 48.7 million m³/year (35.6% of outflow rate and 15.3% of all precipitation) were possible. Still, in this study, all rain water which fell in the roof was able to be stored, and again, all stored rain water was able to be utilized, they were calculated. In the future, it is necessary to carry out the detailed examination considering a size of the rain water storage tank and application of the rain water utilization, a balance of rain water infiltration and rain water utilization.

Keywords

geographic information system (GIS), rainwater, outflow, infiltration, reservation

1. Introduction

The water circulates in respect of the earth, though the steam of the atmosphere becomes rain and snow, and though it descends in ground and water surface, and though it permeates in the underground, and though it flows in respect of the surface. For the hydrologic cycle of these natures, we have made the hydrologic cycle system by the artificiality up for the improvement in safety and convenience of the human concerning river improvement and water use.

Urban improvement and improvement of the hydrologic cycle system by the artificiality caused the result of hurting the natural hydrologic cycle, while it has contributed to human security and comfortable life. By decrease of infiltration plane of the land covers change and change of meteorological phenomena, the problem on urban environments such as increase of largest amount of rainfall, urban flood, depletion of spring water, heat island phenomenon becomes tangible and intends to take these countermeasures.

What becomes the importance in the countermeasure is the appropriate control of the rain water. It is desirable that the possibility of the storage and utilization is examined, while outflow and infiltration capacity of the rain water in the district are clarified, even in the case in which river improvement, water use, environment in future district are considered. However, rain water infiltration, rain water storage, rain water utilization in the building are hard to be called positively making the challenge until now, in Japan. It is effective to temporarily store the rain water in the site with the wide area river channel, when the short-terminable countermeasure is considered. However, the promotion of rain water storage and rain water utilization by the private in the building seems to increase the importance, when the reduction of future public works expenditure is considered.

At reference 1), in making three districts in Tokyo until now to be a case as a macro model of rain water utilization and drainage reuse, the author clarified reclaimed water demand and reclaimed water supply rate in the district from data of building application and the rank. And, simulation on quantity of water balance and residence time of rain water infiltration and rain water storage compatible system in detached house were carried out at reference 2) as a microscopic model of the rain water utilization.

From both viewpoints of the building environment engineering and civil environmental system, by analyzing the extensive district fusing geographic information system (GIS), while these techniques are integrated, this study has done that the district which can effectively carry out the rain water utilization is quantitatively grasped with the final purpose. The technique was applied as a case study in the Kawagoe region of Saitama Prefecture while the technique for examining outflow, infiltration and storage of rain water detailed digital information of 10 m mesh in GIS as the first phase was developed in this paper.

2. Analysis method

2.1 Outline of the Kawagoe region

The Kawagoe City are area of about 109 km², population about 330 thousands core City from the Tokyo which is a capital city to the 30 km category (**Figure 1, Figure 2**). It is geographically almost flat, and many rivers such as Arakawa, Irumagawa, Koazegawa and Shingashigawa River surround the city (**Photo 1**).

It thrives as a castle town by the about 140 front, and the godown built even in now before 100 has mainly been left in the street (**Photo 2**). The railway which approaches Tokyo crosses the city, and the urban district extends in respect of the station center (**Photo 3**). Farm and mixed forest extend on the place away from the station (**Photo 4**).

2.2 Procedure of the analysis

The analysis carried out by “ArcGIS” which is a GIS software by reading “Numerical map 25,000 (Tokyo)” and “Detailed digital information (Metropolitan area in 1994)” which Geographical Survey Institute is making. Land use of the every 10 m mesh has classified 15 into the detailed digital information. In this paper, by making 238 point 1 km meshes of 17 lines 14 rows in order to surround Kawagoe city area in Saitama Prefecture, land use point data number in each mesh was totaled.

The following are shown in **Figure 3** : Map, 1 km mesh and land use of the Kawagoe city area. And, the legend of the land use is shown in **Figure 4**.

On the basis of literature data on building coverage ratio in urban planning, investigation of residential map and discharge coefficient, the proportion of roof plane, green land, non-permeation plane in every land use was calculated. In addition, outflow rate, infiltration rate and reservation rate of rain water were calculated on two cases in the case in which rain water storage tank are not founded and case in which it is installed rain water storage tank in respect of the rain water in the roof plane of the building. Calculation reason in each land use is shown at **Table 1** and outflow rate, infiltration rate and reservation rate in every land use calculated are shown in **Table 2**.

Still, in this paper, the calculation of rate of infiltration is equal to 1- outflow rate, and the evaporation of the water has not been taken into consideration. And, on a part of land use, urban district (district of the oblique line) shown in the numerical map did the mesh as a majority with “city”, it except for was divided with “suburb”, it was calculated.

Then, outflow rate, infiltration rate and reservation rate at the 1 km mesh were totaled from the calculation reason, and intensity figure of the 7 classes was made on the map. And, each top of 10 meshes of outflow rate, infiltration rate and reservation rate was obtained. Above procedure to be a flowchart is shown in **Figure 5**.

3. Result of the case study in the Kawagoe city area

Outflow rate, infiltration rate and reservation rate at the 1 km mesh were totaled, and intensity figure of the 7 classes was made on the map. These are shown from **Figure 6** to **Figure 9**. And, the data which became tops of 10 of each index was arranged at the table. These are shown from **Table 3** to **Table 7**.

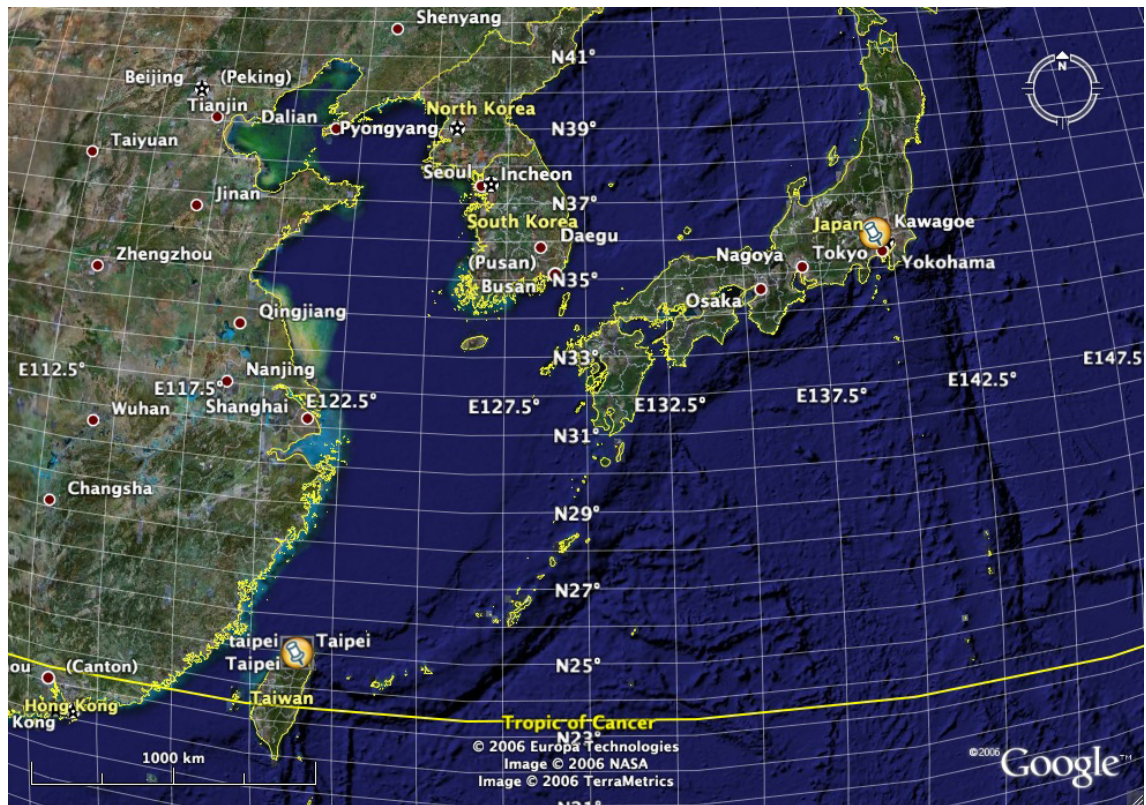


Figure 1 - Positional relation of Taipei and Kawagoe ³⁾



Figure 2 - Positional relation of Tokyo and Kawagoe ³⁾



Photo 1 - Shingashigawa river



Photo 2 - Traditional architectures preservation district of Kawagoe



Photo 3 - Central shopping mall of Kawagoe (Crea Mall)

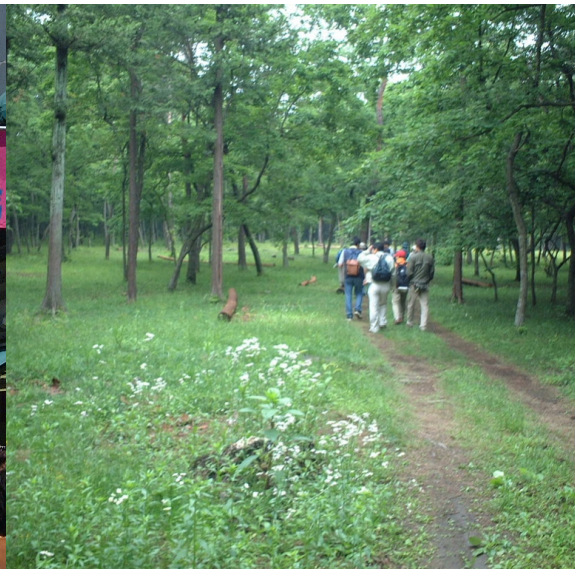


Photo 4 - Controlled mixed forest (Kunugiyama)

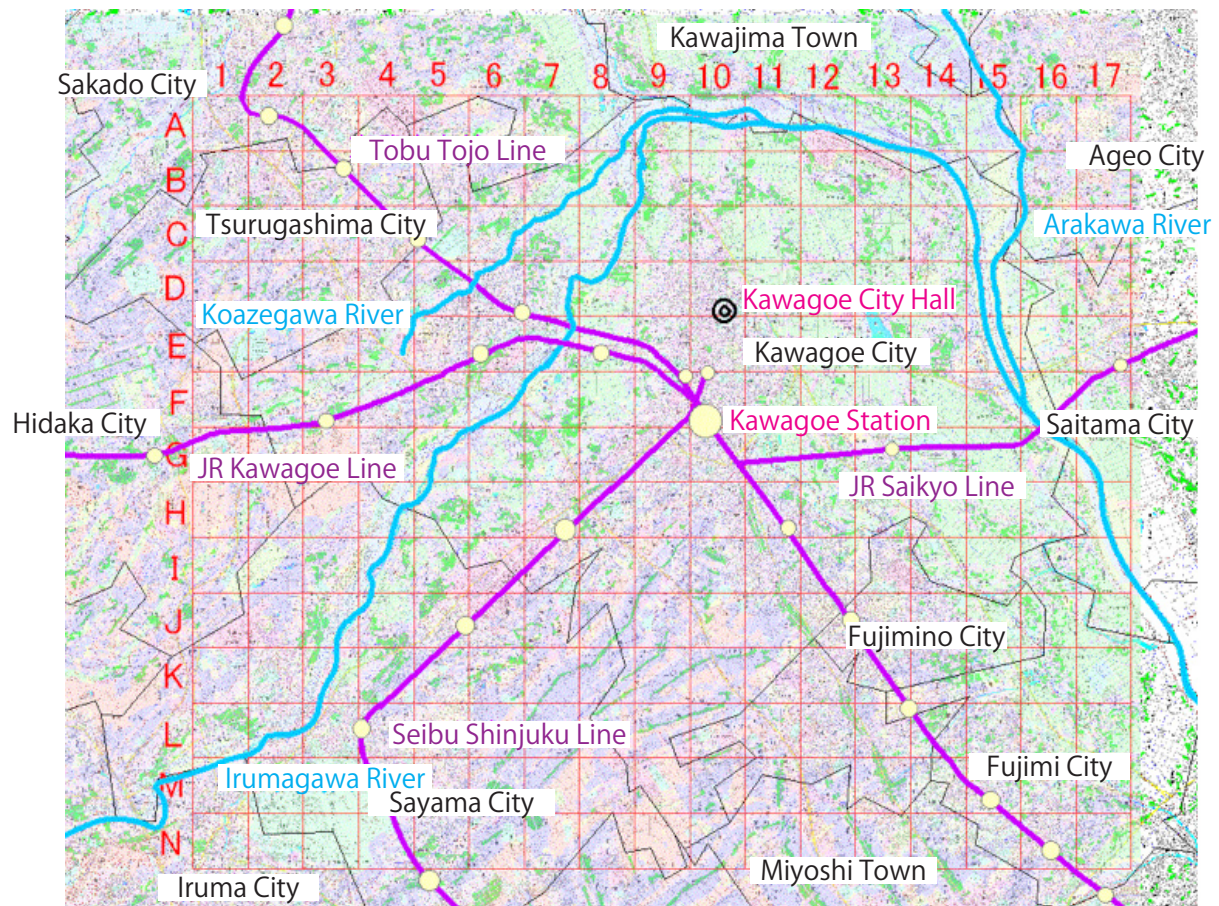


Figure 3 - The land use of 1km and 10m mesh as an analysis range



Figure 4 - The legend of the land use (the numeral is land use CODE)

Table 1 - The calculation reason of the discharge coefficient of each land use

CODE	Land use	Reason of the calculation
a. Thing that it obtained roof plane and green land (infiltration plane), non-permeation plane on the assumption of the land use of outdoor facility and building coverage ratio and obtained discharge coefficient in every land use from each discharge coefficient		
6	Industrial site	The roof plane used 60% building coverage ratio of semi-industrial district, industrial district, industry exclusive area determined in urban planning. And, green land was made to be 20% from the plant location law, and 20% of the remainder was made to be the non-permeation plane.
7*	General row-rise residence zone	Using the building coverage ratio of first kind low rise house exclusive area, second kind low rise house exclusive area, first kind residential area, second kind residential area, semi-residential area determined in urban planning of the Kawagoe City, the roof plane was made to be 50%. The non-permeation plane was made to be 20% [30%] considering parking space, etc.. 30% [20%] of the remainder was made to be a green land.
8*	Dense row-rise residence zone	Using the building coverage ratio of first kind low rise house exclusive area, second kind low rise house exclusive area, first kind residential area, second kind residential area, semi-residential area determined in urban planning of the Kawagoe City, the roof plane was made to be 60%. The non-permeation plane was made to be 20% [30%] considering parking space, etc.. 20% [10%] of the remainder was made to be a green land.
9*	Mid-to-high-rise housing zone	Using the building coverage ratio of first kind crown layer house exclusive area and second kind crown layer house exclusive area determined in urban planning of the Kawagoe City, the roof plane was made to be 50% [60%]. The green land was made to be 30% [20%] considering mainly installing green land such as the park. Remainder 20% [20%] were made to be the proportion of the non-permeation plane.
10*	Commercial and business use land	Since the average of the building coverage ratio was 69%, as a result of investigating 12 averages building coverage ratio in the house map of urban district, it was made to be the 70% building coverage ratio. And, the non-permeation plane was made to be 20%, since the proportion of parking lot is more abounding than the green land. Remainder 10% were made to be the green land plane. [The roof plane used the 80% building coverage ratio of neighbourhood commercial district and commercial district determined in urban planning of the Kawagoe City. 20% of the remainder was made to be the proportion of the non-permeation plane.]
13*	Other public area	60% [70%] was made CODE6,7,8,9,10 [7,8,9,10] considering average building coverage ratio 60% [62.5%] to be the building coverage ratio. The proportion of the green land was made to be 20% [10%]. The proportion of the non-permeation plane was made to be 20% [20%].
b. Result of obtaining direct discharge coefficient (land use except for the building)		
1	Mountain forest, Waste land etc.	Taking mean value of "mountain with the loose gradient" 0.20-0.40 and "sudden and gradient mountain" 0.40-0.60 of reference 3) was made to be 0.40.
2	Paddy field	It was made to be 0.10 from "farm" 0.10 of reference 4).
3	Field,Other farmland	It was made to be 0.10 from "farm" 0.10 of reference 4).
4	Developing land	It was made to be 0.20 from "unimproved ground" 0.20 of reference 4).
5	Open space	It was made to be 0.20 which was an average of "vacant land" 0.10-0.30 of reference 3).
11	Road space	It was made to be 0.85 which was an average of "road" 0.80-0.90 of reference 3).
12	Park and green space	It was made to be 0.20 which was an average of "park and green land" 0.10-0.30 of reference 3).
14	River, Lake etc.	It was made to be 1.00 from "water surface" 1.00 of reference 3).
15	Other	It was made to be mean value of 0.54 of the discharge coefficient of suburb and city as there is no rain water utilization required at CODE1-14.

* is the land use (the numerical value in the parenthesis is adopted in the city) in which the calculation reason differs in city and suburb.

By considering the area proportion from the discharge coefficient (roof plane of 0.90, green lands of 0.2, non-permeation plane of 0.8) of every face on the basis of reference 3) and 4), CODE6,7,8,9,10,13 discharge coefficient calculated it.

CODE1,2,3,4,5,11,12,14,15 discharge coefficient was calculated on the basis of reference literature 3) and 4).

Table 2 - The proportion of land use and independent outflow rate degree of the city and permeability and reservation rate

CASE	No rain water tank	Outflow rate		Infiltration rate	Outflow rate		Infiltration rate
	Rain water tank	Outflow rate	Reservation rate		Outflow rate	Reservation rate	
CODE	Land use	Suburb			City		
1	Mountain forest, Waste land etc.	0.40	0.00	0.60	0.40	0.00	0.60
2	Paddy field	0.10	0.00	0.90	0.10	0.00	0.90
3	Field,Other farmland	0.10	0.00	0.90	0.10	0.00	0.90
4	Developing land	0.20	0.00	0.80	0.20	0.00	0.80
5	Open space	0.20	0.00	0.80	0.20	0.00	0.80
6	Industrial site	0.20	0.54	0.26	0.20	0.54	0.26
7	General row-rise residence zone	0.22	0.45	0.33	0.28	0.45	0.27
8	Dense row-rise residence zone	0.20	0.54	0.26	0.26	0.54	0.20
9	Mid-to-high-rise housing zone	0.22	0.45	0.33	0.20	0.54	0.26
10	Commercial and business use land	0.18	0.63	0.19	0.16	0.72	0.12
11	Road space	0.85	0.00	0.15	0.85	0.00	0.15
12	Park and green space	0.20	0.00	0.80	0.20	0.00	0.80
13	Other public area	0.20	0.54	0.26	0.18	0.63	0.19
14	River, Lake etc.	1.00	0.00	0.00	1.00	0.00	0.00
15	Other	0.54	0.00	0.46	0.54	0.00	0.46

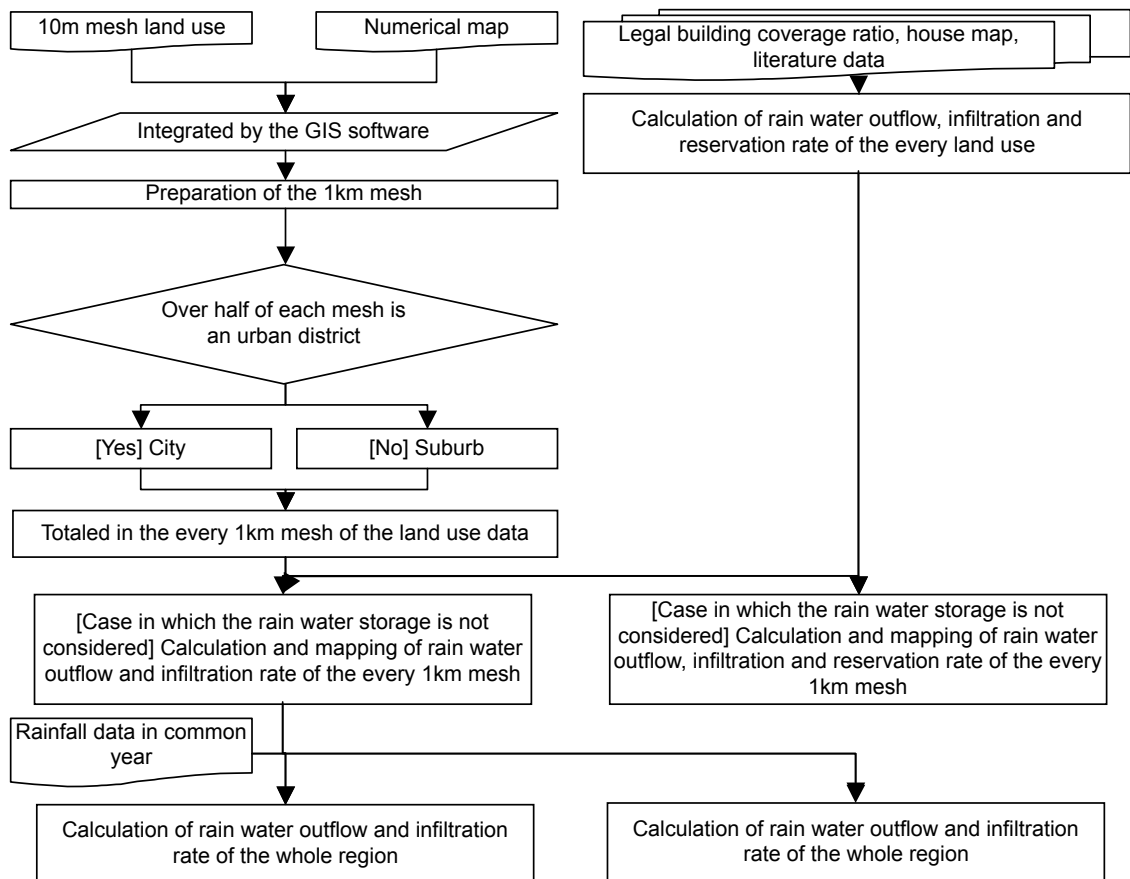


Figure 5 - The flowchart of the analysis procedure

3.1 The case in which the rain water storage tank is not founded

Outflow rate in not founding the rain water storage tank is shown at **Figure 6** and **Table 3**. Outflow rate is high in the district where the urbanization mainly on the central commercial district (along a railway line), and maximum value is 73.1% at F10. Here is a central urban district which is located between Kawagoe station and Honkawagoe station. And, the high value is shown, even if it is put in the riverfront.

In the meantime, the rate of infiltration rises in farm and mixed forest where the development does not advance, and the maximum value is 82.0% at F8 (**Figure 7** and **Table 4**). It is proven that it is distributed in order to avoid these in many districts with the high rate of infiltration, when railway and river are described on the map.

3.2 The case in which the rain water storage tank is founded

The rain water which could collect water in the roof plane calculated outflow rate and reservation rate as a result of entering the rain water storage tank all. Still, the rate of infiltration is identical with 3.1.

The outflow rate in founding the rain water storage tank is shown at **Figure 8** and **Table 5**. Outflow rate is high at a district with the wide riverbed, and 61.1% is maximum at A9 in which 3 rivers have joined here.

The storage of escaped rain water becomes possible in this case, the urbanization advances, and in which it does not found the rain water storage tank, since the catchment area also increases with the increase of the roof area. 41.2% is maximum for the reservation rate at F10 (**Figure 9** and **Table 6**). The reservation rate generally rises in the central area at station front. This value is outflow inhibition ratio of the rain water in the region, and again, it is a maximum of the retard effect of the storm water input to sewerage and river, and in addition, it is theory largest quantity of rain water utilization factor in the district.

4. Conclusion

On the theory, the storm water outflow of about 48.7 million m³ is suppressed from the calculation result by the installation of the rain water storage tank in the Kawagoe city area, when annual average precipitation 1,338 mm in neighboring region for 22 years from 1979 to 2000 was used, and the rain water utilization is possible. This is correspondent to 35.6% of the storm water outflow quantity in not founding the rain water storage tank, and 15.3% of the whole precipitation. Especially, the effect can greatly expect it in the urban district which there are small infiltration planes by the building massing.

Still, in this study, all rain water which fell in the roof in the rain water storage tank was able to be stored, and again, it was calculated as a result of utilizing stored rain water all.

In the future, the detailed examination will be also carried out considering size of the rain water storage tank, application of the rain water utilization, a balance of rain water infiltration and rain water utilization, etc. including problem of the water quality and the energy.

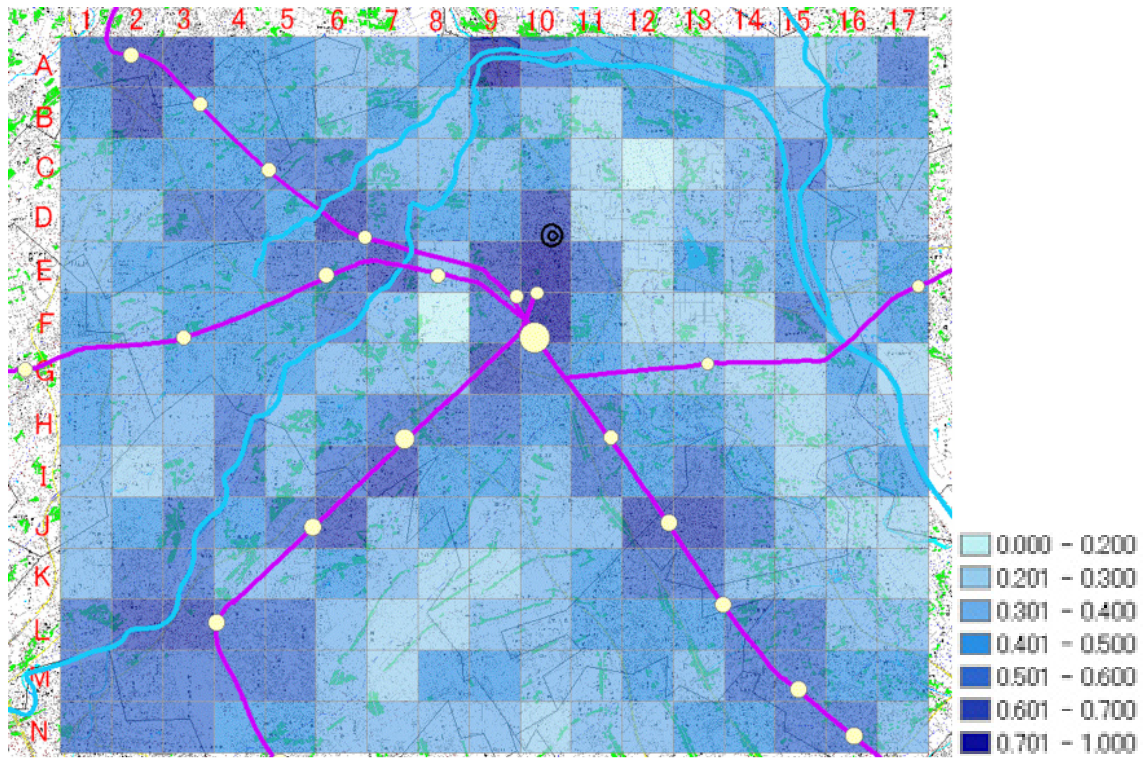


Figure 6 - The intensity figure of the outflow rate in not founding the rain water storage tank

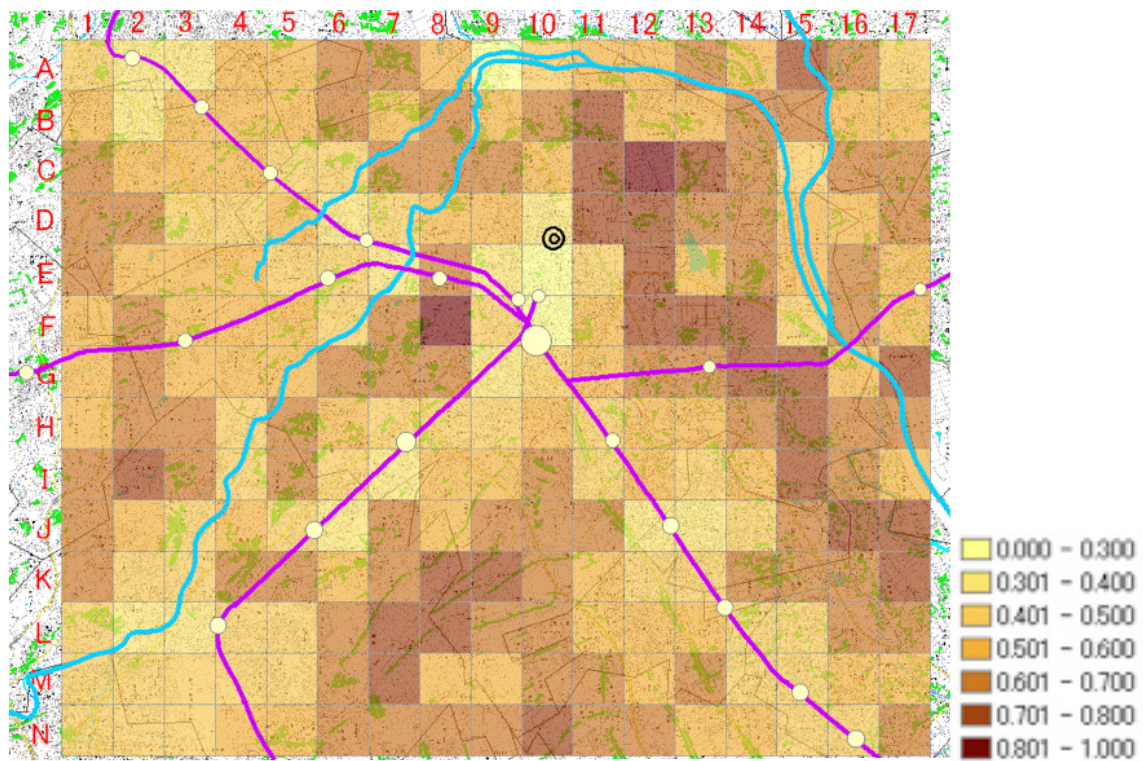


Figure 7 - The intensity figure of the permeability

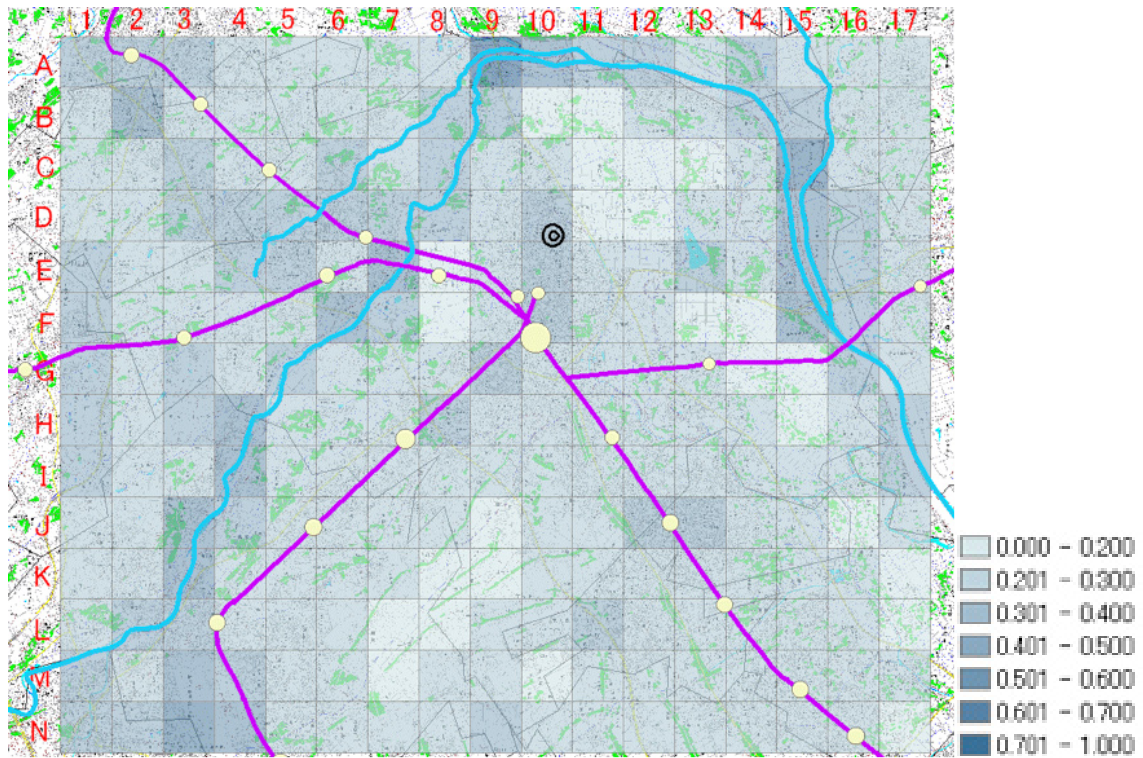


Figure 8 - The intensity figure of the outflow rate in founding the rain water storage tank

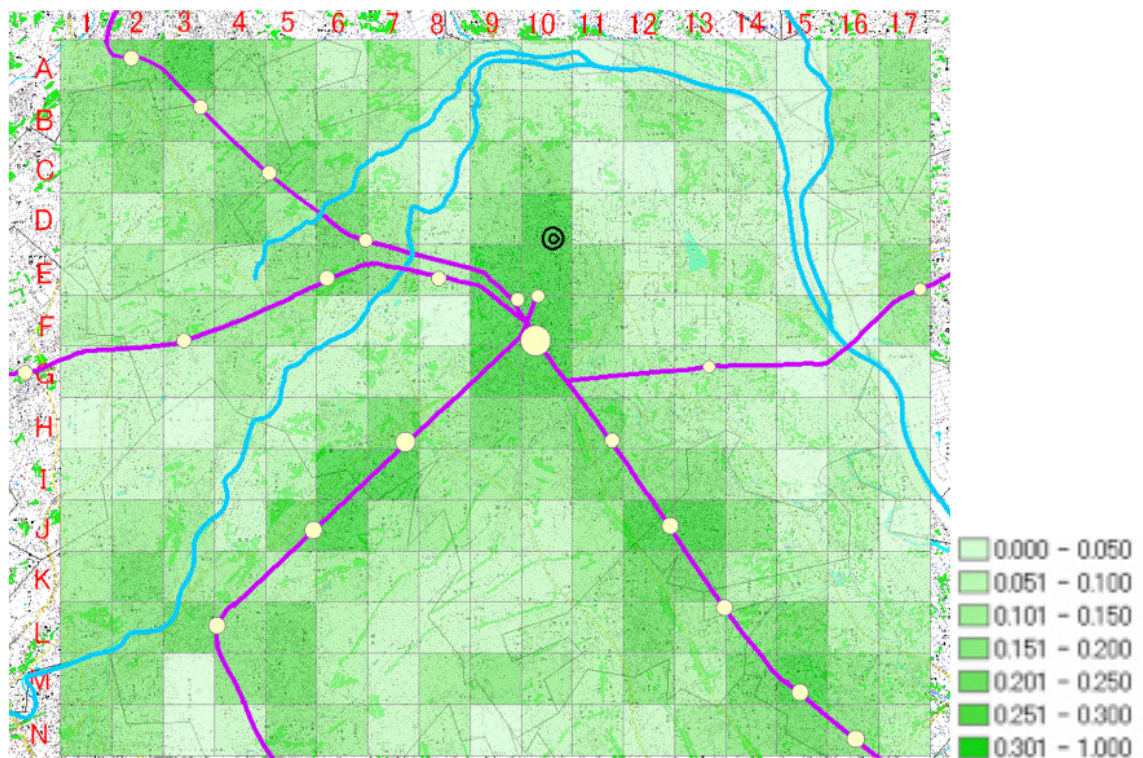


Figure 9 - Intensity figure of the reservation rate

Table 3 - Top 10 districts of the outflow rate in not founding the rain water storage tank

Outflow rate in not founding the rain water tank					Point data number of each land use														
Rank	Row	Column	Outflow rate	Infiltration rate	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	F	10	73.1%	26.9%	3	14	187	0	865	286	3143	61	317	2446	1636	104	938	0	0
2	E	10	72.1%	27.9%	6	15	19	0	507	236	3435	13	158	2129	1493	761	1218	10	0
3	A	9	70.5%	29.5%	22	1603	689	0	372	479	439	68	7	214	478	24	585	5020	0
4	J	13	70.1%	29.9%	5	21	133	8	696	150	2995	167	1520	1189	1331	539	1232	12	2
5	E	7	66.0%	34.0%	55	922	741	0	252	809	1296	228	104	302	1078	507	1219	2487	0
6	L	3	64.8%	35.2%	272	166	438	0	703	277	2739	43	162	1562	1325	456	638	819	400
7	J	6	64.8%	35.2%	315	55	967	0	370	5163	1108	123	134	684	902	43	133	3	0
8	A	3	64.3%	35.7%	469	67	608	0	773	376	1451	575	330	765	1825	196	2492	73	0
9	D	6	64.2%	35.8%	47	136	1054	0	557	49	3524	436	47	790	1732	126	857	644	1
10	B	2	64.1%	35.9%	311	103	868	18	667	290	1867	73	225	1660	3109	450	228	131	0

Table 4 - Top 10 districts of the permeability

Infiltration rate					Point data number of each land use														
Rank	Row	Column	Outflow rate	Infiltration rate	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	F	8	18.0%	82.0%	75	7642	1015	0	97	11	464	34	50	31	381	14	133	52	1
2	C	12	18.8%	81.2%	0	8503	292	17	35	17	119	1	0	133	500	2	78	303	0
3	G	15	20.0%	80.0%	11	8042	435	0	16	43	627	0	0	27	377	0	259	163	0
4	F	13	21.2%	78.8%	42	7412	749	0	39	80	920	53	0	163	483	44	8	7	0
5	L	7	22.0%	78.0%	342	0	7897	0	53	42	724	0	19	136	393	49	246	99	0
6	C	11	22.2%	77.8%	13	7312	770	0	42	60	803	15	0	24	908	46	7	0	0
7	K	17	22.4%	77.6%	35	7116	319	714	29	0	419	4	0	35	326	0	1003	0	0
8	B	11	22.5%	77.5%	56	7019	817	0	163	220	1038	32	0	80	518	33	24	0	0
9	H	15	24.0%	76.0%	245	6438	1071	0	123	141	1122	13	0	116	649	79	3	0	0
10	K	8	24.9%	75.1%	1015	10	6729	1	314	191	984	8	4	145	263	177	7	152	0

Table 5 - Top 10 districts of the outflow rate in founding the rain water storage tank

Outflow rate in founding the rain water tank					Point data number of each land use															
Rank	Row	Column	Outflow rate	Infiltration rate	Reservation rate	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	A	9	61.1%	29.5%	9.5%	22	1603	689	0	372	479	439	68	7	214	478	24	585	5020	0
2	N	3	52.6%	45.1%	2.3%	0	0	1	0	8	0	24	8	0	162	0	0	211	0	9586
3	C	15	50.4%	49.4%	0.3%	0	1324	910	0	34	0	63	0	0	0	270	3546	0	3853	0
4	M	3	49.5%	47.7%	2.8%	137	23	468	0	119	21	438	23	7	16	97	27	92	0	8532
5	A	10	48.1%	46.5%	5.4%	33	2134	2399	0	52	320	473	0	0	53	323	195	223	3795	0
6	F	6	46.0%	44.6%	9.4%	16	1378	2449	9	358	969	431	121	0	240	927	129	7	2966	0
7	I	4	45.7%	45.5%	8.9%	230	842	1545	0	1068	98	1573	0	0	59	718	874	164	2829	0
8	E	7	45.6%	34.0%	20.4%	55	922	741	0	252	809	1296	228	104	302	1078	507	1219	2487	0
9	D	15	45.2%	53.6%	1.2%	0	1181	1038	20	4	0	191	6	0	10	83	4073	41	3353	0
10	E	15	45.1%	51.2%	3.7%	90	461	970	0	1052	69	201	0	152	127	78	3406	174	3220	0

Table 6 - Top 10 districts of the reservation rate

Reservation rate in found the rain water tank					Point data number of each land use															
Rank	Row	Column	Outflow rate	Infiltration rate	Reservation rate	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	F	10	31.8%	26.9%	41.2%	3	14	187	0	865	286	3143	61	317	2446	1636	104	938	0	0
2	E	10	31.4%	27.9%	40.7%	6	15	19	0	507	236	3435	13	158	2129	1493	761	1218	10	0
3	J	13	30.4%	29.9%	39.7%	5	21	133	8	696	150	2995	167	1520	1189	1331	539	1232	12	2
4	J	6	25.6%	35.2%	39.2%	315	55	967	0	370	5163	1108	123	134	684	902	43	133	3	0
5	I	7	24.7%	38.2%	37.1%	387	70	1413	0	331	4956	690	48	147	773	823	85	268	9	0
6	I	6	24.8%	41.6%	33.6%	308	581	1326	0	427	3232	884	79	0	1666	955	308	234	0	0
7	G	9	31.1%	36.6%	32.3%	11	48	778	0	1018	414	3016	424	281	1451	1777	76	702	4	0
8	D	10	30.9%	37.6%	31.6%	20	762	233	0	538	169	3518	68	97	1508	1558	534	834	161	0
9	A	3	32.9%	35.7%	31.4%	469	67	608	0	773	376	1451	575	330	765	1825	196	2492	73	0
10	E	9	29.5%	39.4%	31.1%	19	943	389	0	538	333	3585	431	446	661	1422	255	870	107	1

5. Acknowledgement

This study was carried out in part of University Industry Joint Research Project for Private Universities Matching Fund Subsidy from Ministry of Education, Culture, Sports, Science and Technology “Research Project on Integrated Technology Base System which Advances City Regeneration by the Region Circulation of Construction Stock Material and Biomass Resource of Metropolitan Area and Social System which Supports it”. The research representative is Prof. Tsuyoshi Fujita of Toyo University, and study duration is the 2004 fiscal year - 2008 fiscal year.

The cooperation of Satoshi Masaki which was the Toyo University graduate was got, when this study was advanced. The gratitude is expressed.

6. References

- 1) Hiroyuki KOSE - Examination on the Effective Way of Water Use in the Area by the Use of Land Use Map of Present Condition, 26th CIB-W62 2000 SYMPOSIUM (Brazil), A7, pp.1-12, 2000/9
- 2) Hiroyuki KOSE, Kuniharu YOSHIMOTO and Koshiro NAKAJIMA - Examination of Rain Water Use System in House in Consideration of Infiltration and Reservation, CIB W062 2005 31st International Symposium (Belgium), pp.1-12, 2005/9
- 3) Google Earth (<http://earth.google.com/>)
- 4) Japan Sewerage Association - Basic Discharge Coefficient Standard Value According to Kind of Construction, 2001
- 5) Society of Heating, Air-Conditioning and Sanitary Engineering - Design and Practice of Rain Water Utilization System, Society of Heating, Air-Conditioning and Sanitary Engineering, 1997

Main author presentation

Hiroyuki Kose is the Associate Professor at Toyo University, Department of Civil and Environmental Engineering, Faculty of Engineering. Special fields of study are plumbing engineering, environmental city planning, and environmental design. Since last year, it is engaged in landscape reconstruction on Yamakoshi area of Nagaoka City which received large damage in the Niigata Chuetsu Earthquake on October 23, 2004.



Rainwater Potential for Domestic Water Supply for Pen-Hu Island, Taiwan

Liaw, C. H¹, L.M. Chan, W.M. Huang, C.D. Hsieh²

¹ Respectively, Professor and Graduate Student, Department of River and Harbor Engineering, National Taiwan Ocean University

² Section Chief of Conservation, Water Resources Agency, MOEA.

ABSTRACT

In the offshore islands, the mean annual precipitation is more or less than 1000 mm that is around 40% of main island of Taiwan. In these islands, reservoirs, groundwater, and desalination are main water resources. Due to economic development in these islands, alternative water resources development becomes urgent. Among them, rainwater harvesting becomes more attractive because of its low cost and low environmental impact when developed.

In this study, Pen-hu county, which consists of 64 small islands and has land area of 126.86 km², is selected as the study area. For practical consideration, Maku city and Huchi, Bysha and Chiyu towns are considered. Three different types of rainwater collection and utilization are considered: rooftop for single building, integrated at development site, and community-based in sub-watershed. The usage of rainwater is only for toilet flushing.

Based on the results, total designed rainwater storage volume reaches 34,386 M³, total volume of annual water supply reaches 381,126 M³ and total construction cost requires 259,450,000 New Taiwan Dollars. If other water usages of rainwater are considered, larger rainwater storage volume is needed and more efficiency usage of rainwater is expected.

Keywords

Rainwater harvesting, water supply, water resources, islands.

1 Introduction

The global concern for integration of water resources management in the face of increasing scarcity and demand is evident by a large number of conferences at national and international level. In small islands like Pen-hu that has limited water resources, the expansion of economic development particularly in the tourism and service sectors over the last decade requires a structured approach to the water resources management including an audit of the current water status.

Pen-hu island, located between Taiwan and Mainland China, consists of 64 small islands, has land area of 126.86 km², and is divided into six administration regions: Ma-kun city, Huchi, Bysha, Chiyu, Wunan, and Chimei counties. Among these small islands, only 20 islands are habited. Therefore, three major islands which occupy 104.41 km² are selected in this study. Although the island receives an average annual rainfall of 1,537 mm shown in Table 1, the steep hills and small surface area of the island result in the absence of any perennial streams. Runoff from intermittent streams is stored in several small public earthen dams and ponds which are used primary for public water supply. Groundwater is limited to dug wells which produce fresh water for drinking water and brackish water for non-portable use. Recently, desalination plant has been installed with capacity of 14,150 m³/day. However, due to raise of price of oil, the production cost is increased dramatically.

Table 1 Average Monthly Precipitation at Pen-Hu Meteorological Station (1954-2004)

Unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Ave	86.6	82.7	100.8	119.4	137.5	150.5	174.1	161.5	153.7	153.8	117.3	99.1	1,537

Statistic data from the water supply company in Pen-hu shows that in 2001, total amount of water supply is 16,500 CMD, and water demand will be increased to 28,747 CMD in the year of 2011. In the island, the provision of an adequate quantity of safe drinking water at affordable costs and in a sustainable manners is difficult

since groundwater prospects are poor, operation and maintenance costs of desalination plant are expensive, and available surface water storage sites are limited. These factors suggest that the potential of the rainwater resource should be examined. It may be noted that this potential has not yet been quantified. This paper, therefore, focuses on the potential availability and the costs of rainwater as a contribution to the current debate on the sustainable development of the island's water resources. Also from this study, the short-, middle-, and long-term rainwater development projects can be proposed.

2 Rainwater Harvesting Technologies

The application of an appropriate rainwater harvesting technology makes the utilization of rainwater as a sustainable strategy and appropriate response to the climate conditions and often deficient and deteriorated infrastructure provided by resource-poor areas. Rainwater harvesting has been practiced for more than 4,000 years, and, in most developed and developing countries, is becoming essential owing to the temporal and spatial variability of rainfall.

The term rainwater harvesting refers to direct collection of precipitation falling on the roof or onto the ground providing for domestic water use. It is sometimes used to describe the entire gamut of water harvesting. We shall use it here only in the specific sense. Three different types of rainwater harvesting technologies are described and used in this study:

A). Rooftop Rainwater Harvesting (RRWH)

Traditionally, rainwater harvesting comprises collection of the precipitation falling onto the rooftop of building and storing it in a waterproof tank at ground level or underground for domestic use. The amount of the water, which can be collected out of the total precipitation on a roof, depends on the amount of rainfall, the area of the roof, type of the roof, and collection efficiency.

B). Integrated Site Rainwater Harvesting

Integrated site rainwater harvesting is a special variety of rainwater in which the rain incident on a plot of land including roofs and terrace of buildings at development site. This method is useful in construction site having larger surface area than roof

area with large water demand. Surface rainwater harvesting becomes the majority for freshwater source.

C).Community-Based Rainwater Harvesting in Sub-Watershed

Community surface water harvesting is the most common form of rainwater harvesting practiced in the country. The sizes of the tanks, catchment areas or command areas vary widely. Abandoned mines, quarries, a/o constructed storage tanks become a sink for runoff from the surrounding sub-watershed. They get filled with water and some of it percolates down to recharge the aquifer underneath. They can also be considered as examples of surface water harvesting.

The cost of rainwater harvesting vary from place to place, depending on the size of the storage facilities, material construction and the level of complexity in water quality treatment and means of delivery. The initial capital costs of constructing concrete rainwater storages are generally considered high. This has led to a general perception that the rainwater alternative for portable water is expensive and has thus limited the exploitation of the full potential of rainwater harvesting technology.

3 Rainwater Resource Potential Estimation

In many developed and developing countries, particularly island states, the quantity a/o quality of freshwater resources are constrains to economic development. These countries face the common problem that existing policies and strategies, and the institutions to implement them, are inadequate to meet water use needs and sustainable development. In responding to this problem and to meet the challenge of the future, UN organizations, the World Bank and national governments have joined forces to promote reviews of water policies and support a holistic approach to water resources management. Such holistic and integrated approach to the water resources management requires an assessment of the available water resources.

Water resources assessment includes the identification of potential sources of freshwater supply, comprises the continuing determination of sources, extent, dependability and quality of water resources and the human activities that affect those resources. Such assessment constitutes the practical basis for sustainable management and is prerequisite for the evaluation of the possibilities for development.

Three concepts can be considered in quantifying the domestic rainwater potential

(a) the theoretical potential or rainwater endowment of that area; (b) the available potential; and (c) the practical potential. The theoretical potential refers to total amount of precipitation on the islands. As not all of this water can be harvested, only the precipitation that can be collected on the roofs or other specific catchment areas can be possibly collected. This can be considered the available potential. Some roofs are not guttered because of design and economic considerations. In addition, inadequate storages allow water to be wasted. The water that is collected in the storage tanks for consumption under normal conditions is referred to as the practical potential.

4 Methodology

This research was carried out in four parts. First, estimates of the available rainwater potential were derived from the current land use on the island by GIS technology. Second, a survey of all public buildings in the islands, which include central and local government, education, recreation, parks, water supply company, etc. It was undertaken to estimate the practical rainwater potential. The building was selected from the Pen-hu Interior Department's listing. The practical rainwater potential for buildings is derived from the current building stock on the islands and available and practical roof contributing areas in conjunction with the available storage. Data from the selected buildings were used to develop a relationship between floor space, contributing roof area, construction costs of roof area and current cistern size. These relationships were used to access the economic constraints on the upper limit of the rainwater potential. Per capita consumption was estimated based on the data published by the Architecture Research Institution, Ministry of Interior. Third, for those buildings with large surface area and large water demand, "In situ" rainwater harvesting planning will be considered. Fourth, for those villages along the seashore having the space for installing the storage facilities will be considered to install "community rainwater harvesting" to collect the rainwater from surrounding sub-watershed.

The cost of water in this paper is based on the cost recovery principle. The calculation utilizes the "Present Worth Value" method. In this

approach, the major cost component includes the amortization cost and O&M cost which was estimated as 15% of initial construction cost. The benefit of unit rainwater supply is calculated based on the cost of desalination.

5 Results and Discussions

The available rainwater potential

The theoretical potential rainwater therefore can be estimated by average annual rainfall depth and surface area in the island. The available potential (AP) can be estimated as following equation,

$$AP (M^3) = \text{Catchment Area}(M^2) * \text{Average Annual Rainfall (M)} * \text{Runoff Coefficient} \quad (1)$$

In which runoff coefficient depends on the land use. In order to estimate available potential more reliable, the land use of the island is divided into following 7 categories: grass land, constructed area, forest, dry land, military use, harbor, and others. The runoff coefficients for these land uses can be estimated as 0.2 、0.6 、0.5 、0.36 、0.3, 0.3, and 0.5 respectively. Catchment area corresponding to different land use is measured and estimated by GIS technique which divides the island into 170 sub-watershed ranging from $450 * 10^4 m^2$ to less than $10 * 10^4 m^2$ shown in Figure 1. With these information, the available rainwater potential can be estimated as $42,738,616 M^3$ which is larger than the the total amount of water supply in the island.



Figure 1 Sub-watershed for Pen-hu Island

6 Rooftop Rainwater Harvesting (RRWH)

From the survey, 95 governments owned buildings (including tourist center, aquarium, Jen-shen power plant, etc), 2 colleges, 2 senior high schools, 9 junior high schools, 32 elementary schools, 43 culture and education, 14 parks, and 13 water supply company offices are found. They are located in four different city and towns and are shown in Table 2. After screening from those not available sites, this number reduces to 122. 32 buildings are for short-term; 20 for mid-term; and 70 for long-term.

Table 2 Government Institution, Education, and Major Buildings in Four Different Towns and City

	Government	Education	Culture & Art	Park	Water Company	Total
Ma-Ku City	41	20	10	7	8	86
Huchi	16	9	11	1	2	39
Bysha	21	7	12	6	2	48
Chiyu	17	9	10	0	1	37
Total	95	45	43	14	13	210

More detail survey and design was carried out for those buildings selected for short- and mid-term purpose. The practical or economic scale of roof rainwater catchment system was determined based on the economic principle. These results are plotted as Figure 2 which can provide as a reference for designing of those buildings for long-term purpose. Hence, the total installation capacity of RRWH is 5,418 M³ which can provide freshwater of 53,509 M³ per year. The total construction cost reaches NT\$ 6,338* 10⁴.

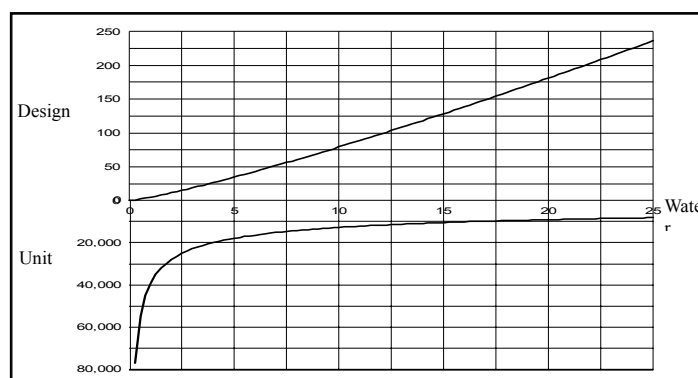


Figure 2 Relationships among Water Demand, Design Storage Capacity, and Unit Construction Cost of Rooftop Rainwater Harvesting System at Pen-hu Islands

7 Integrated Rainwater Harvesting at Development Site

In the survey, we found that four sites: Pen-hu Prison, Kun-in-tin, Agricultural Experiment Farm, Jen-shan Power Plant, which have larger surface compared to roof area. Ground surface provides extra watershed to collect rainwater to increase freshwater supply. Their unit rainwater cost are calculated and shown in Table 3. In the short-term, Kun-in-tin and Agricultural Experiment Farm are recommended. The total construction cost is NT\$ 36,453,923; total storage volume is 4,023M³; total annual amount of water supply is 56,152M³. For the mid-term, Pen-hu Prison and Jen-shan Power Plant are selected. The total construction cost is NT\$ 27,903,529; total storage volume is 3,752M³; total annual amount of water supply is 34,024M³.

Table 3 Cost Analysis at Four Sites for Integrated Rainwater Harvesting Planning

Sites	Available Storage Volume (M ³)	Selected Storage Volume (M ³)	Average Unit Raw Water Cost (NT\$/M ³)
Pen-hu Prison	1,000~2,000	1,500	45.4
Kun-in-tin	-	50	64.4
Agricultural Experiment Farm	>200	2,000	14.2
Jen-shan Power Plant	-	10	145.5

8 Community-Based Rainwater Harvesting in Sub-Watershed

Surface water harvesting (SWH) in sub-watershed is to collect rainwater falling in the sub-watershed and to provide the freshwater to community or village in the outlet of the sub-watershed. Factors affected in selecting watershed include non-reservoir watershed, no highly developed area in the watershed, undistributed vegetation watershed, with existing drainage system, with existing storage system, with large water user, flooding area, etc. Based on above consideration, 14 watersheds in 170 watersheds are selected for further analysis. Among them, 4 watersheds are for short-term purpose; 4 for mid-term, and 8 for long-term. More detail information are shown in Table 4. The procedures for calculating the economic system and unit cost

of rainwater harvesting for short-term watersheds are shown in Table 5 and Table 6. For mid- and long-term watersheds can be estimated using the same procedures. Therefore, total construction will reach NT\$ 131.72 million; total storage volume is 21,193 M³; total annual water supply is 237,441 M³.

Table 4 Preliminary Ranking Order for Installing RWHS for Sub-watershed at Pen-hu Islands

Order	Sub-watershed Number	Area (10 ⁴ m ²)	Location	Ranking	Sub-watershed Number	Area (10 ⁴ m ²)	Location	Ranking
Short	22	444.02	Huchi	1	34	219.44	Ma-Ku City	3
	118	47.85	Chiyu	2	95	76.77	Chiyu	4
Mid	170	89.88	Huchi	5	161	119.80	Huchi	7
	127	58.75	Chiyu	6	24	86.41	Huchi	8
Long	136	68.86	Chiyu	9	143	86.77	Bysha	12
	103	71.78	Chiyu	10	148	50.58	Bysha	13
	147	71.79	Bysha	11	130	84.38	Chiyu	14

Table 5 Water Demand and Population for Short-Term Sub-Watersheds

Sub-watershed Number	Village	Population	Area(10 ⁴ m ²)	Daily Water Demand (CMD)	Water for Toilet Flush (CMD)
22	Hu-Tung	402	77.6	121	36
118	Nai-Ann	1,483	15.7	445	133
34	Shan-Shwei	1,840	19.5	552	166
95	Chu-Wan	936	13.9	281	84

Table 6 Cost Analysis for Short-Term Sub-Watersheds

Sub-watershed Number	Village	Substitution Ratio	Average Unit Raw Water Cost (NT\$/m ³)
22	Hu-Tung	88.3 %	33.8
118	Nai-Ann	74.1 %	35.3
34	Shan-Shwei	68.0 %	28.8
95	Chu-Wan	72.7 %	31.1

9 Conclusions and Recommendations

With the absence of surface water and the inadequate quantity and quality of groundwater in Pen-Hu island, the practice of building rainwater harvesting is a feasible means to ensuring a sustainable and adequate supply of domestic water supply, There is sufficient rain and roof areas on the island to satisfy future water demand.

When the energy cost is raised, the rainwater is more significantly attractive than desalination, while the quality is higher and is free from pollutants. This strengthens the case for promoting the expansion of rainwater harvesting to satisfy future development needs. This system allows people to have control over it, in contrast to the public systems, which have low reliability due to frequent interruptions. Further, rainwater harvesting is sustainable, requires low technical know-how, is environmental friendly and is well adopted on the island.

If the full potential of rainwater as a sustainable water resource is to be achieved, policies that would promote the construction of adequate size storage and quality improvement facilities must be defined and implemented. Full advantage must be taken of the current preference of residences for rainwater as the first choice and the willingness of residences to invest in the construction of storage facilities. If RRCS development guidelines are formulated with sound economic costs analysis to ensure affordability and the design considerations to preserve water quality, users would likely be very happy to comply.

References

- Liaw, C.H. and Y.L. Tsai (2004), Optimum Storage Volume of Rooftop Rain Water Harvesting Systems for Domestic Use, J. of the American Water Resources Association, 40(4):901-912.
- Liaw, C.H., etc (2004), Rainwater Utilization Planning in Offshore Islands (Part 1), Water Resources Agency, Ministry of Economic Affairs, Taiwan ROC (in Chinese).

Simulation of water demands provides insight

E.J.M. Blokker (1), W.G. van der Schee (2)

(1) mirjam.blokker@kiwa.nl

(2) w.g.vd.schee@wolverendros.nl

Abstract

The insights for the design of water systems in buildings are changing. The requirements nowadays for a hygienic and microbiological reliable water system leads to adaptation of the design starting-points. It's important to have knowledge of the demand patterns. KIWA and TVVL developed the stochastic model SIMDEUM to simulate water demands in residential buildings. Aim is to get new insights to design water systems in residential buildings. Measurements in houses are used to validate these simulated demand patterns. The first simulation results are well in line with measured demand patterns.

Keywords

Water consumption, Residential building, Stochastic modelling

1 Introduction

The maximum momentary flow (MMF) per second is an important parameter to design the drinking water distribution system. This is for drinking water systems inside the buildings as well for outside the buildings. In Holland water systems for residential use are calculated by the so called $q\sqrt{n}$ -method. It is based on the number of taps ' n ' (' n ' is a so called tap-unit. One tap can consist of more then one tap-units.) and their standard flow ' q ' (a nominal demand of 0,083 l/s). The model supposes a mathematical relation for simultaneous water use. Theoretically and practically there are doubts about the validity of the $q\sqrt{n}$ -method for the present-day. The model was developed before 1954: the houses were only equipped with a tap in the kitchen and the toilet. The composition of households those days was relative high (3.68 persons a house in 1947). A modern house is equipped with sometimes two toilets, a shower, bath, wash basin, washing machine, dishwasher, and an outside tap in the garden. Nowadays the composition of households is smaller (2.27 persons a house in 2005). With a few adaptations the $q\sqrt{n}$ -formula is used for houses with domestic purposes. Measurements on flows in the main pipes in streets lead also to doubts about the validity of the $q\sqrt{n}$ -method for a group of houses. The $q\sqrt{n}$ -method overestimates the maximum flow. A simulation model is now available to get more insight in the water demand for domestic use of cold and hot water.

2 The simulation model SIMDEUM

In order to simulate the water demand in houses KIWA developed the model **SIMDEUM**. The input of **SIMDEUM** is based on statistical data from research of the domestic water consumption [1], the survey from Statistics Netherlands (CBS) for the composition of the households i.e. number of people, age, sex and type of employment and a time-budget survey from the SCP [2]. It is also possible to put in specific information about the installation in the house (flow, duration of the use and the temperature of the water). For example is a water efficient shower used or a comfort shower?

Measurements of the domestic water flow is not needed for input in the model, but flow measurements of several houses are used to validate the model. This means that the model offers much flexibility for a variety of types of houses and can be used directly without gathering data from measurements.

The output of SIMDEUM is a flow pattern during the day (a flow in l/s on every second of the day) on all taps in a house. By addition of several flow patterns of taps the flow pattern from a bathroom, kitchen or a house arises. With the composed flow pattern it is possible to determine the MMF and the hot water use (HWU2) during two hours. Figure 1 shows the results.

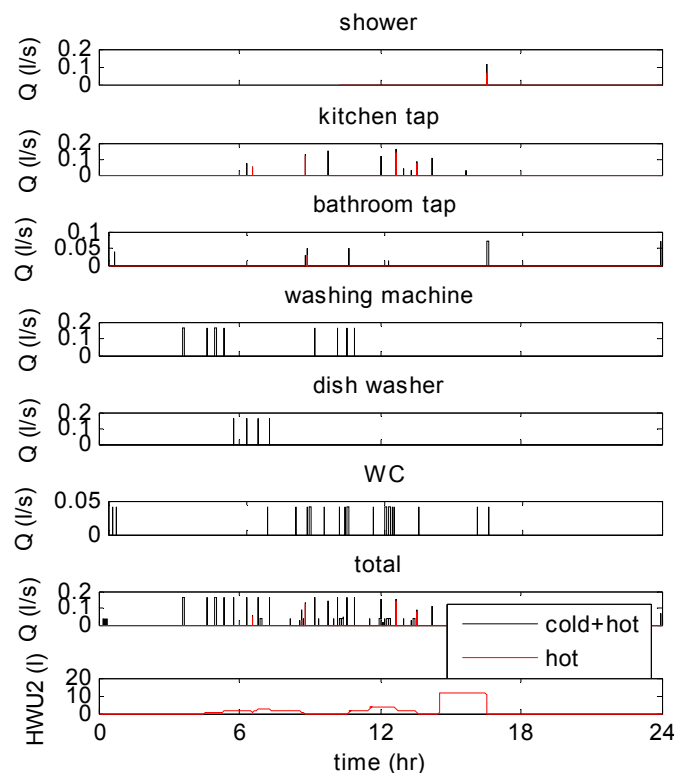


Figure 1 Flow pattern on the taps and hot water use in a simulated house

When a next set of flow patterns is generated by SIMDEUM the results differs from the first set like it does in real use. In a house two day patterns are never exactly the same. By simulation of one hundred-day patterns we get insight in the average and the spread of the MMF and the HWU2. The output of a simulation of MMF for hot and cold water in a house is shown in figure 2. Figure 3 shows the histogram of the simulated HWU2 in a house.

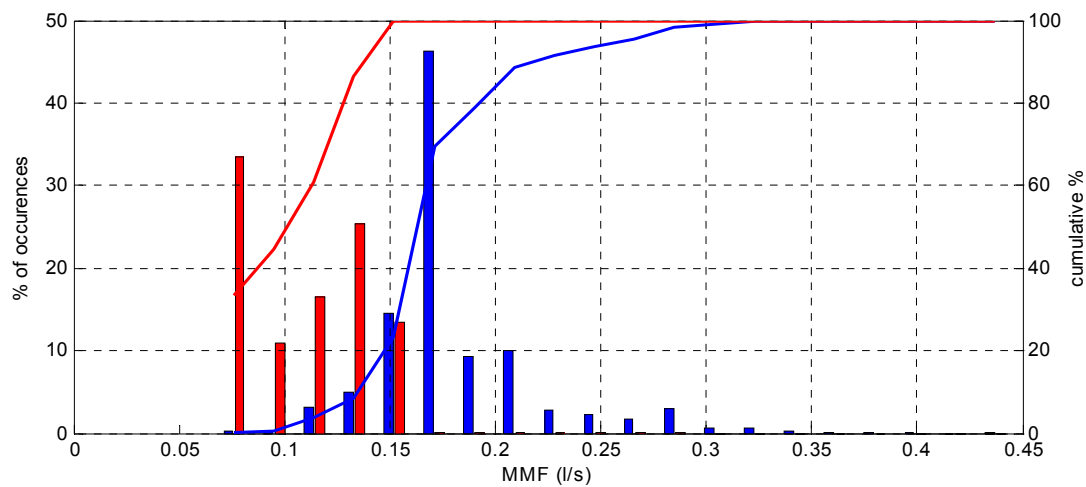


Figure 2 Histogram of the MMF for cold and hot water in a simulated house.

The red and blue bars in figure 2 represent the distribution of the MMF for cold and hot water. Ca. 34% of the MMF of hot water is equal to 0.07 l/s and ca. 46% of the MMF of cold water is equal to 0.17 l/s. The blue and red lines show the cumulative distribution on the right axis: ca. 99% of the MWD is less then 0.31 l/s.

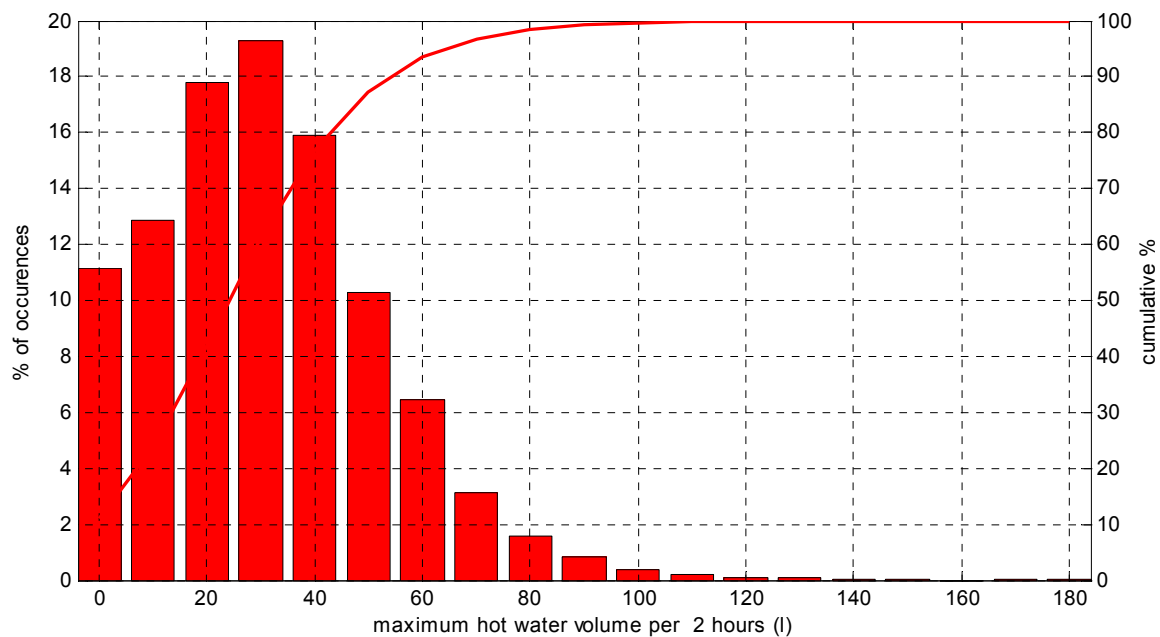


Figure 3 Histogram of HWU2 in a simulated house.

The red bars in figure 3 show the distribution of the maximum hot water use over 2 hours (HWU2) and the red line expresses the cumulative distribution; ca. 90% of the maximum hot water flow over two hours is less then 55 litres.

3 Measurements of the water flow in individual houses

Measurements of the water flow were executed in four houses in Amersfoort over a period of 9 to 35 days. The occupants filled in a questionnaire to get information about the composition of the people, age, sex, type of employment and the taps in the house. The information gathered by the questionnaire is used to simulate one hundred-day patterns with SIMDEUM.

Figure 4 shows a so called box-whisker-plot with the maximum measured and simulated flow per house per day. The box indicate the 25 and 75 percentile and the 'whiskers' indicates the limit of the normal distribution, the crosses indicates the maximum and minimum values. The red line indicates the maximum calculated by the $q\sqrt{n}$ -method for each house.

Firstly figure 4 shows that the results of the simulation and the measurements show a good resemblance for the MMF and secondly that both the results of the simulation and measurements exceeds the result of the $q\sqrt{n}$ -method. So we can conclude that the simulation model SIMDEUM is a useful tool to predict the flow and there is a necessity to check the $q\sqrt{n}$ -method.

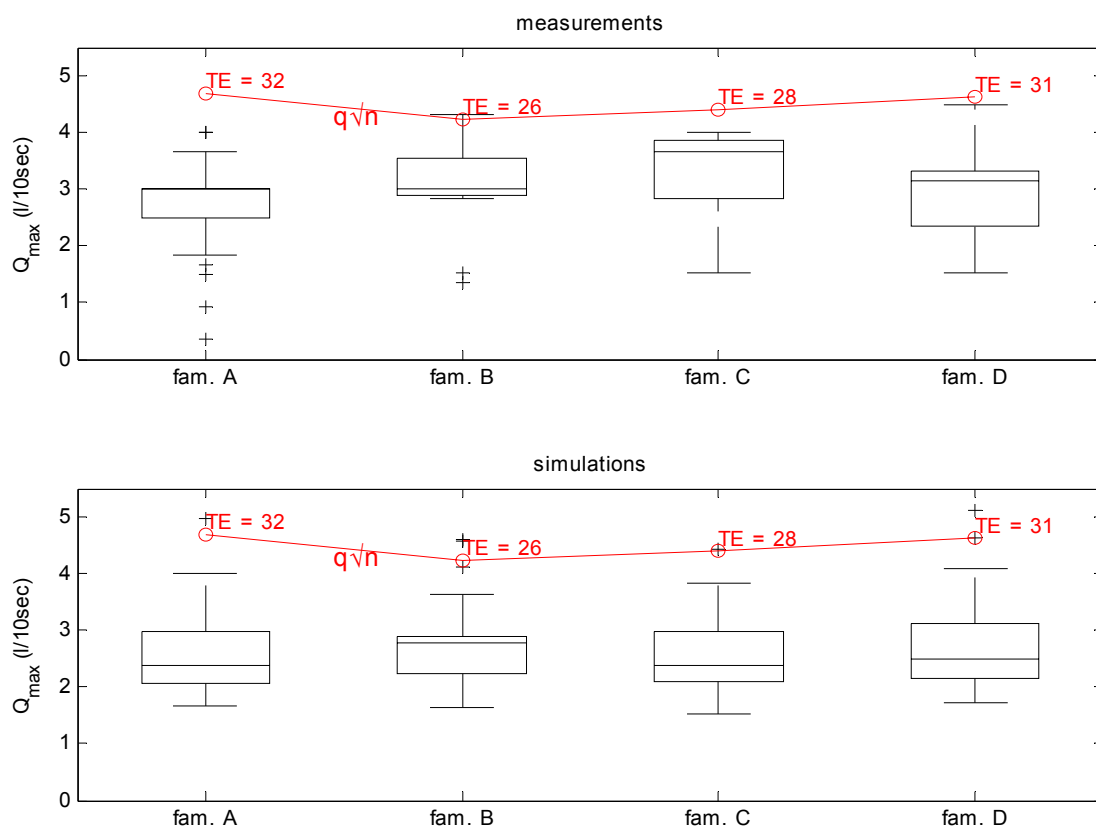


Figure 4 Results of the MMF by measurements and simulations

4 Example with SIMDEUM

The model SIMDEUM is used to define the flow in an apartment for old aged people. This apartment is defined as follows:

- Occupants:

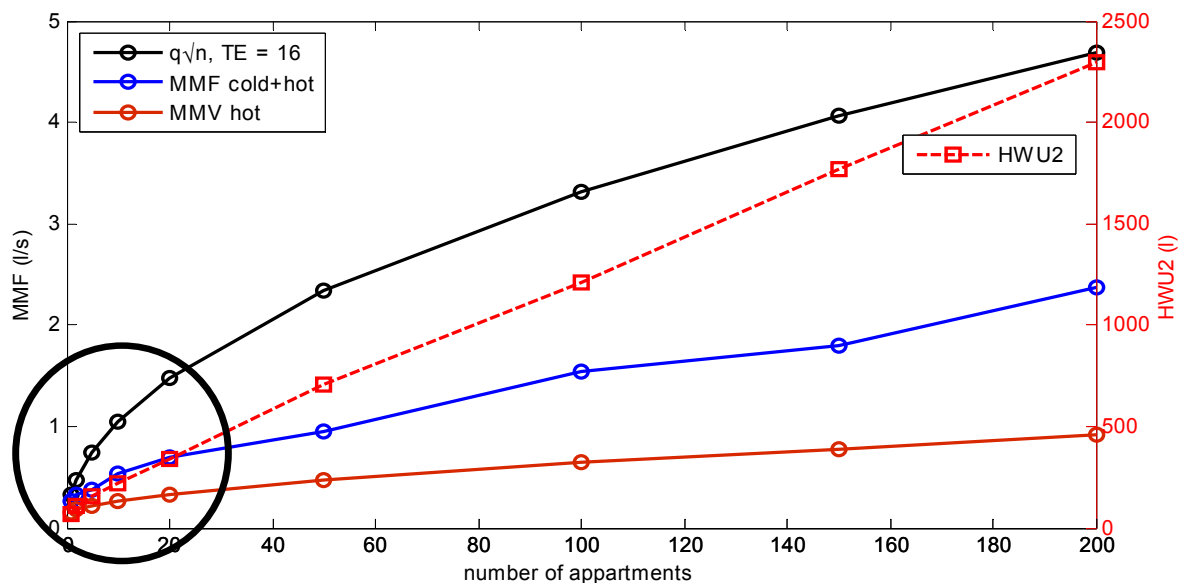
- 80% occupied by two persons, 20% by one person
- 80% of the occupants is aged 65+, 20% is aged 55+ without work
- Water system:
 - toilet: a 6 litre cistern (flow 0.042 l/s) and flush interruption, a cold water wash basin (flow 0.042 l/s);
 - Bathroom: one shower (water saving, flow 0.12 l/s), no bath, no second toilet, a wash basin (flow 0.083 l/s), a washing machine;
 - Kitchen: one tap (flow 0.167 l/s), 40% equipped with a dish washer;
 - No outside tap;

Figure 2 and 3 shows the results of MMF en HWU2. Table 1 shows the results of SIMDEUM (99 percentile of MMF and HWU2) and the calculated results with the $q\sqrt{n}$ -method. The apartment has 8 tap-units in the kitchen and 8 tap-units in the bathroom.

Table 1 MMF en HWU2 of the house predicted by SIMDEUM and $q\sqrt{n}$ -method

	MMF (l/s) - cold		MMF (l/s) - hot		HWU2 (l)	
	SIMDEUM	$q\sqrt{n}$ -method	SIMDEUM	$q\sqrt{n}$ -method	SIMDEUM	$q\sqrt{n}$ -method
total	0.31	0.33	0.15	0.28	93	-
kitchen	0.20	0.23	0.15	0.15	N.A.	-
bathroom	0.29	0.23	0.07	0.12	N.A.	-

Figure 5a and 5b shows the relation between a building with 200 apartments and the 95-percentiles of MMF for cold and warm water and the HWU2. The $q\sqrt{n}$ -line in figure 5 represents 16 tap-units for each apartment.



**Figure 5a MMF for cold and hot water and HWU2.
Simulation of a building with 200 apartments**

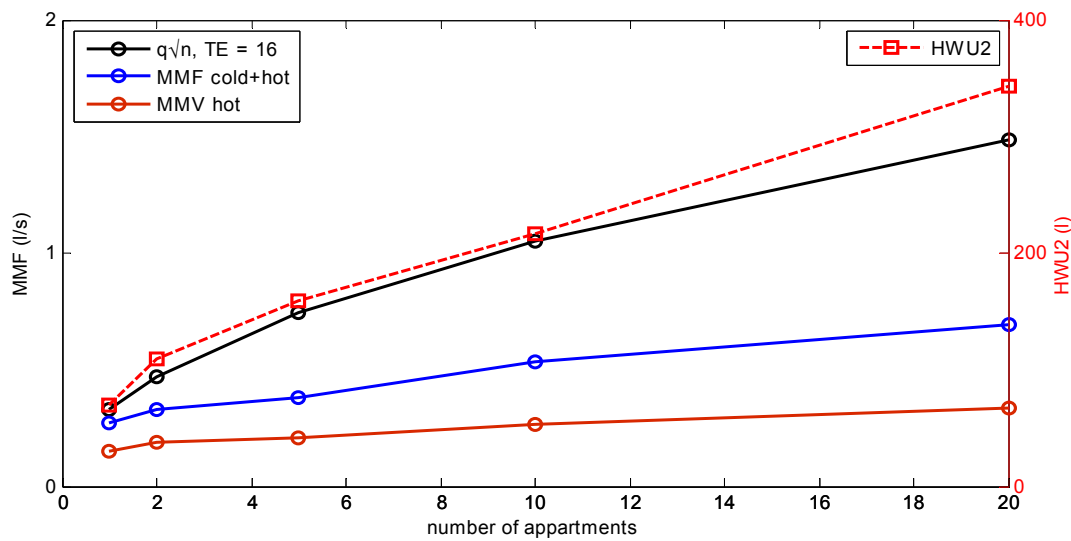


Figure 5b Detail for 1 to 20 apartments

The lines in figure 5 could be approached with equations:

$$\begin{aligned}
 \text{MMF}_{\text{total}} &= 0.01 \cdot n + 0.4 \\
 \text{MMF}_{\text{warm water}} &= 0.11 \cdot n^{0.4} \\
 \text{HWU2} &= 11.2 \cdot n + 100
 \end{aligned}$$

The flow for one apartment with 16 tap-units calculated by the $q\sqrt{n}$ -method approach rather accurately the flow modelled with SIMDEUM. Yet from two apartments the flow calculated with the $q\sqrt{n}$ -method exceeds the simulated maximum by a factor 2. Measurements of MMF on buildings are not available. But measurements in the network the street for 2 until 45 houses were analysed. These measurements show that the $q\sqrt{n}$ -method with 19 tap-units for each house overrates the real flow with a factor 1.5 until 2 [3].

5 Conclusion

The $q\sqrt{n}$ -method leads to a good prediction for the MMF for one apartment or house. but it seems that this method overrates the MMF for a collective of apartments and houses.

SIMDEUM offers the possibility to simulate not only the MMF of cold water. but also to simulate the MMF of hot water and HWU2. Also SIMDEUM has the possibility to define the above mentioned parameters. which lead to a better prediction of the expected demand of the hot water consumption and a better design of the hot water production.

There is no big difference in the results of SIMDEUM and the $q\sqrt{n}$ -method for an individual house. So it is not necessary to change the method to design an installation for one house. For residential buildings there is a big difference between the results of SIMDEUM and the $q\sqrt{n}$ -method. The design method for distribution systems in those kind of residential buildings can be improved.

The next step will be to extend SIMDEUM to simulate the water demand in buildings like hospitals, hotels and prisons.

6 References

1. Kanne, P. Water use at home 2004. TNS NIPO. Amsterdam (2005). in Dutch
2. Broek, A. van der en K. Breedveld. Time budget survey 1995 - TBO'95 [computer file]. Sociaal en Cultureel planbureau. SCP. Den Haag. Amsterdam. Steinmetz-archief (P1383). in Dutch.
3. Blokker, M. (2006). "Modelling the domestic water consumption". H2O. #6-2006. 48-51. in Dutch.
4. Blokker, E. J. M. en Vreeburg, J. H. G. "Monte Carlo Simulation of Residential Water Demand: A Stochastic End-Use Model " (2005). Impacts of Global Climate Change; 2005 World water and environmental resources congress. (American Society of Civil Engineers. Reston, VA. USA. 2005). 34.

7 Presentation of authors(s)

E.J.M. Blokker¹ MSc. KIWA Water Research. P.O. Box 1072. 3430 BB. Nieuwegein. the Netherlands; +31 (0)30 6069 533; fax +31 (0)30 6061 165; email: mirjam.blokker@kiwa.nl
Her speciality field is developing models to simulate the water demand in networks and huge water systems.
For further information see www.kiwa.nl



Walter van der Schee is a representative of the Netherlands Technical Association for Building Installations (TVVL). He is a member of the board of the department Sanitary Technologies (ST). The objective of the association is to promote research and technology in the field of building services. This is done by networking; giving courses; lectures; organising symposia; subcontracting research and co-financing university-chairs.
For further information see www.tvvl.nl



Walter van der Schee is working at Wolter & Dros where he is responsible for the engineering of installations in buildings.
For further information see www.wolterendros.nl

Artificial Neural Network Analysis for Reliability Prediction of Regional Runoff Utilization

S.C. Lee (1), H.T. Lin (2)

(1) Hylaman@itri.org.tw

(2) Siraya01@mail.ncku.edu.tw

(1) Energy and Environment Laboratories, Industrial Technology Research Institute, Taiwan

(2) National Cheng-Kung University, Department of Architecture, Taiwan

Abstract

Many factors in the reliability analysis of planning the regional rainwater utilization tanks capacity need to be considered. Based on the historical daily rainfall data, the following four analyzing procedures will be conducted, which include: 1.the regional daily rainfall frequency, 2.the amount of runoff, 3.the water continuity, 4.reliability, thereafter, the suggested designed storage capacity can be obtained. Accommodating to the conditions with the demand and supply reliability. By using the output data, two different types of ANN models are used to build up small area rainfall runoff supply systems for the simulation of reliability and the prediction model. They are also used for the testing of stability and learning speed assessment. Based on the result of this research, the RBFNN model using the Gaussian function that has the similar trend as the nature as basic function has better stability than using the BPNN model. This should have significant benefit in the future application of the instantaneous prediction or the development of related intelligent instantaneous control equipment.

Keywords

Back-propagation Neural Network; Radial Basis Function Network

1 Introduction

As the rainfall process contains uncertainty in addition to the random chance, these factors are the source of lower reliability in utilizing rainwater. Therefore, in designing the storage capacity of rainwater, the reliability of supplying water after the completion of system installation in future has become an important parameter of the design.

As there are many factors affecting the reliability of water supply, there is also the feature of interaction between factors. For example, rainfall has very close relationship with factors including area of collection, runoff coefficient, water volume required, and

capacity of rainwater storage, etc. Therefore, this study adopts the artificial neural network model having strong nonlinear learning ability and suitable for complicated system. The structure recommended by this research proves reasonable prediction accuracy can be obtained through the actual calculation of case study. At the same time the structure has significant expandability and will be discussed in this paper.

2 Theory and Application of Model

2.1 Water balance formula

The so-called water balance refers to the simulation of continuous changes of storage system by making use of the flow recorded in the history. The formula can be expressed as shown below:

$$Z_{t+1} = Z_t + Q_t - D_t - E_t - L_t \quad 0 \leq Z_t, Z_{t+1} \leq S \quad (1) \quad \text{where}$$

Z_{t+1} : The storage at time $t+1$; Z_t : The storage at time t ;
 Q_t : The inflow at time t ; D_t : The outflow at time t ;
 E_t : The evaporation at time t ; L_t : Other loss at time t ;
 S : Capacity of storage system.

As the rainfall storage area to be installed in future is used as closed space, this research will ignore evaporation and other losses. Also, this study is using day time as the space for investigation and usually the daily changes in water needed is not easy to obtain, this research therefore assumes the daily water required each day is the same throughout the year. Hence formula (1) can be written as:

$$Z_{t+1} = Z_t + Q_t - D \quad (2) \quad \text{where}$$

D : discharged (water required)

The inflow rainfall Q_t is calculated using rational formula.

As the method of water balance formula is easy to understand and also takes seasonal and sequential relations into consideration, each related variables such as time difference, and water required, etc could be changed according to the actual situation and the status and behavior of the system operation could be clearly seen. Therefore, this is widely used in the engineering field.

2.2 Artificial Neural Network Model

2.2.1 BPNN network structure and Learning Algorithm

Assume a forward three-layer neural network as shown in Figure 1. The network contains an input layer, a hidden layer, and an output layer. Also, the input layer contains a single node, the hidden layer contains J nodes, and the output layer contains K nodes. Therefore, the output Z_k can be expressed as:

$$z_k = f\left(b_{0k} + \sum_{j=1}^J b_{jk} \cdot f\left(a_{0j} + \sum_{i=1}^I a_{ij} \cdot x_i\right)\right) \quad (3)$$

where $f(\cdot)$ is the transfer function or activation function and will be described later, x_j is the input quantity, a_{ij} and b_{jk} ($i=1,2,\dots,I; j=1,2,\dots,J; k=1,2,\dots,K$) are the weighted values, and a_{0k} and b_{0k} are the deviations. The transfer function is defined as below:

$$f(x) = \frac{1}{1 + e^{-x}} \quad (4)$$

where the range of the value is (0, 1). And if a linear function is selected for this transfer function, such as $f(x)=x$, the whole ANN structure will become the linear influence from input layer to output layer.

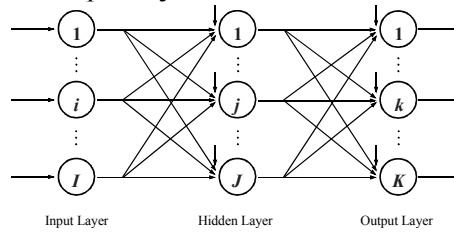


Figure 1 Illustration showing a three-layer network as an example.

As BPNN belongs to a supervisory learning, the optimum parameter is obtained through adjusting the weighted values in the network, and optimum means the squared deviations between the network outputs z_k 's and the actual values or target values t_k 's achieve a minimum, i.e.,

$$E = \frac{1}{2} \sum_{k=1}^K (z_k - t_k)^2 \quad (5)$$

In order to match the range values of transfer function, it is necessary to process the data through normalization or scaling. Assume the minimum value of transfer function is $f_{\min}$, the maximum value is $f_{\max}$, and the minimum value of the data itself is $x_{\min}$, and the maximum value is $x_{\max}$. Now, let $x^{(s)}$ represents the value of certain data x after normalization. Then,

$$x^{(s)} = f_{\min} + \frac{x - x_{\min}}{x_{\max} - x_{\min}} \times (f_{\max} - f_{\min}) \quad (6)$$

However, in order to compare the difference with the actual values (target values) after calculating the output value, we will process them with back propagation. And the calculation equation of the back propagation can be easily obtained through equ. (6).

2.2.2 RBFNN Network Structure and Learning Algorithm

RBF is a three-layer neural network as shown in Figure 2. Layer 1 is input layer for inputting data and is the node for connecting to the network. It does not have the ability of calculation. Layer 2 is a singular hidden layer that different from the hidden layer of

BPNN, which has multiple layers. Hidden layer is input space for non-linear mapping to hidden space. Layer 3 is output layer for linear mapping to obtain output value.

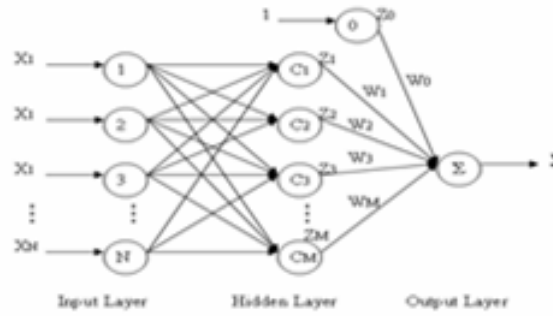


Figure 2 Illustration showing an RBFNN Network.

When inputting data into the network, the input vector enters input layer and transfer to each radial basic function in the hidden layer as expressed in the formula below:

$$z_j(x) = R(\|x - c_j\|) \quad j=1,2,\dots,M \quad (7)$$

where c_j is the j th neuron center point, $\|x - c_j\|$ is the Euclidean distance between x and c_j , and $R(\cdot)$ is the radial basis function. The radial basis function selected for this research is Gaussian function. Then, after calculation of input vector and the distance between the center points of the neurons, the output of each neuron is obtain through transfer function. The output value of the hidden layer times the weight is propagated to output layer for linear combination to obtain the network output value. Below is the expression:

$$y = \sum_{j=0}^M w_j \cdot z_j(x) \quad (8)$$

where y is the network output value, w_i is the weight from the j th neuron to the output layer, and z_j is the output of the j th neuron. This study makes use of the composite learning method in that the feed-forward stage is to select the neuron center point through non-supervisory learning. During the selection process, the number of neurons and the locations of the center points in the hidden layer (Chang, 2003). This research makes use of the orthogonal least square (OLS) (Chen, 1991) to select the number of hidden neurons and location of center points in the front stage. The back stage is to make use of stochastic gradient approach (SGA) (Ham, 2001) to modify the RBFNN parameters, i.e. neuron center location, shape of radial basis function (sigma), and the weight of output layer, in order to improve the network performance.

2.3 Analysis Procedure and Input of Preset Parameters

The procedure of designing storage tank capacity (capacity design procedure flow is as shown in Figure 3), parameter input, and algorithm can be summarized as below:

1. Determination of runoff coefficient: Runoff coefficient is dependent on the material and type of the collection surface. This study is to analyze the simulation by setting runoff coefficient to between 0.2 and 0.4 after considering the conditions of the area under investigation.
2. Setting the range of water supply reliability: This research sets the future system water supply reliability (water supply rate) to between 70% and 90% and uses this to calculate the capacity of the storage tank.
3. Determination of volume of water required: The volume of water required is related to the usage of water supply. Currently the rainwater utilization system without reprocessing of water quality could be supplied for the use of toilet, air conditioning, watering, and irrigation, etc. Here the usage is set for general secondary use (not in contact with human body). Based on the need of the case, the daily water supply varies between 50 and 100 CMD after analysis.
4. Calculation based on water balance formula: The day rainfall data are inserted into the continuous equation for calculation. The rainfall supply volume and total water required are calculated during the simulation period. The ratio between the two is the ratio of supplement.

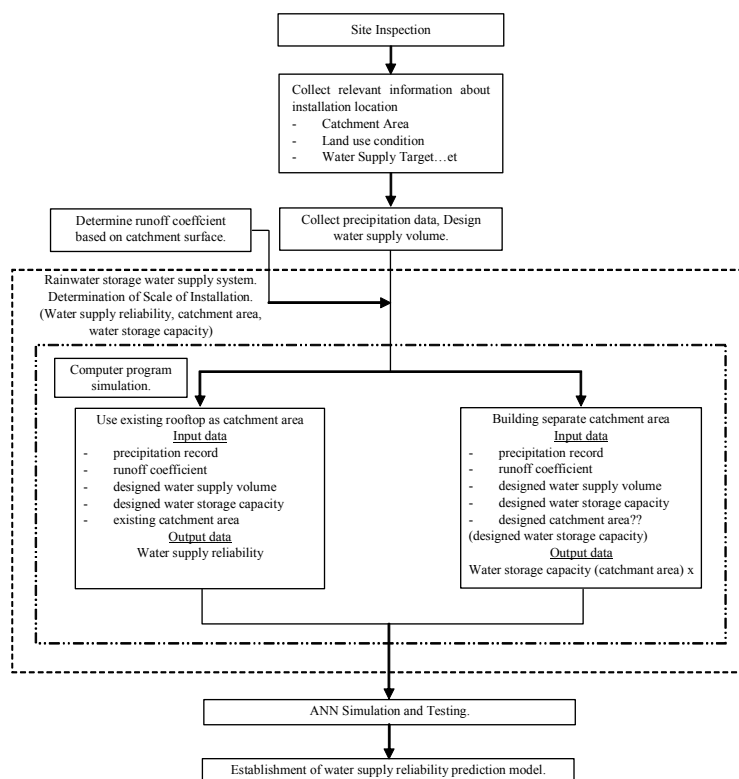


Figure 3 Flow of the Research.

5. Plotting of supplement – storage tank capacity relationship curve: Through this curve it is possible to understand under the limited catchments area the interacting relationship between the storage tank installation capacity and the supplement. In other words, the

setting of designed supplement could obtain the storage capacity required to install or given the installed capacity of the storage tank the supplement achievable could be obtained.

6. On obtaining the different water requirement conditions and the recommendation of rainfall storage designed capacity under the requirement of water supply reliability, the artificial neural network is used to build up the simulation and prediction model for the future system water supply reliability based on the various factors (catchment area, runoff coefficient, day water requirement, rainfall storage capacity and water supply reliability) generated through setting and simulation.

3 Description of Model Analysis Result

3.1 Regional Rainfall Analysis

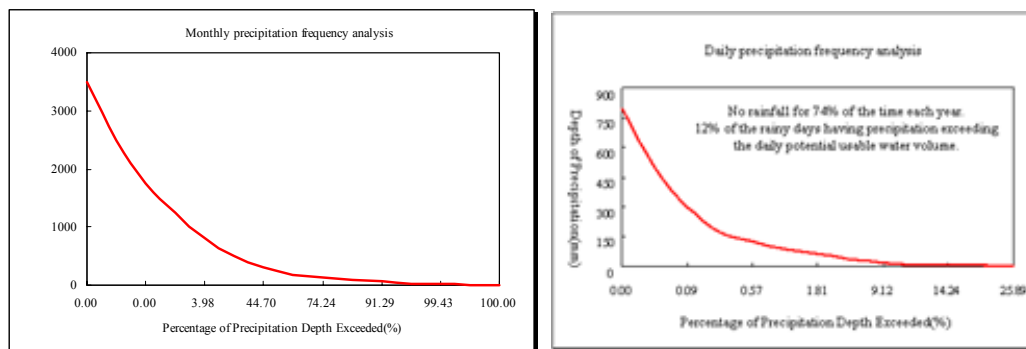


Figure 4 Diagram showing the frequency of regional precipitation.

Studying the historical area rainfall record and analyzing the frequency shows that for the area around 74% of the time does not have precipitation. And 12% of the rainy days are having precipitation exceeding the daily potential usable water volume. However, the distribution of monthly rainfall appears to be smoother.

Table 1 - Analysis of Record of monthly precipitation for the region

Unit:(mm/mth)	X	$\sigma(n)$	$\sigma(n-1)$
Jan.	128.97	77.85	78.75
Feb.	168.78	137.83	139.42
Mar.	182.96	116.86	118.21
Apr.	161.02	112.65	113.95
May	265.26	133.94	135.49
Jun.	375.86	185.55	187.70
Jul.	273.40	134.41	135.97
Aug.	348.35	237.37	240.11
Sept.	370.88	236.23	238.96
Oct.	186.60	141.38	143.02
Nov.	146.49	84.56	85.54
Dec.	118.00	59.46	60.15
Annual Rainfall Depth (mm)	2,726.58	549.63	555.98

data type : monthly ; station : 1140P055 [Tsu-Keng]

recorded period : 43 years ; potential maximum water utilization : 7.470 mm/day

3.2 Calculation of Supply Water Reliability

Based on the procedure of Section 2.3 and inserting parametric value into water, the relationship of catchment area, capacity of storage tank, and supplement can be obtained. We can know that the design of the size of storage tank for utilizing regional rainwater has quite a lot of affecting parameters. However, the size of the storage capacity of ordinary storage tank mostly depends on the amount of water volume required and rainwater supplement. The analysis of relationship between the supplement and the capacity of storage tank is as shown below:

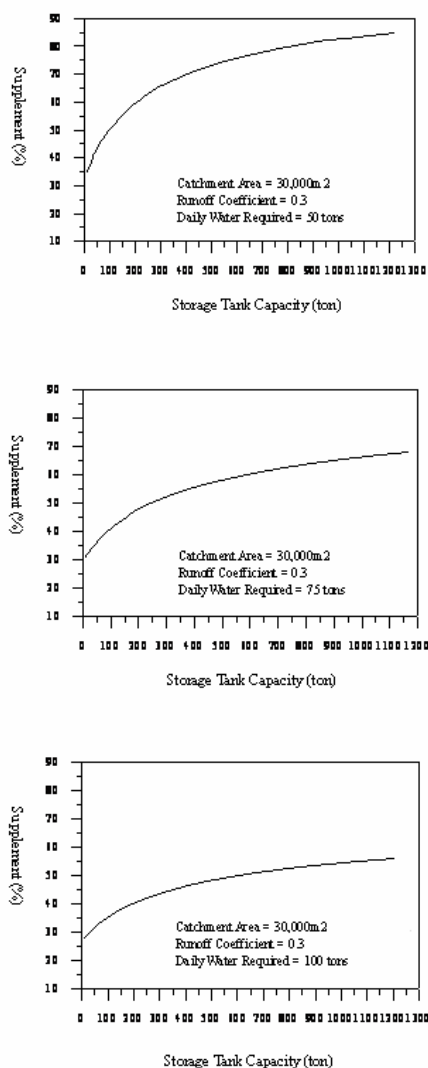


Figure 5 Relationship between the supplement and the capacity of storage tank.

1. When the catchment area, runoff coefficient, and the volume of water required are fixed, the supplement is proportional to the capacity of storage tank. And when the capacity of the storage tank reaches certain fixed value, the increase of supplement will

be reduced. Usually, under the restriction of environment and economic condition, the optimum capacity occurs in this section.

2. In addition, from Figure 4 we can discover that under the condition of catchment area is 30,000 m², runoff coefficient is 0.3, daily water required is 50 tons, installation of storage tank of 500 tons could also have supplement close to 75%. The rainwater runoff replacement ratio could almost reach 3/4.

3. As shown in Figure 5, as the catchment area is 30,000 m², runoff coefficient is 0.3, water volume required is 1000CMD, and the capacity of storage tank is 100 tons, the supplement reaches around 40%. However, when the capacity of the storage tank is increased to 500 tons, the supplement increases to about 56%. When the capacity increases by 400 tons, the supplement increases by 16%. And when the capacity of the storage tank increases to 1,000 tons, although the supplement could reach as high as 66% and as the capacity increases by 500 tons the supplement only increases 10%. From here we know that the rate of increase in the capacity of storage tank may not have linear relationship with the supplement.

In summary, replacing the tap water with rainwater runoff in this area is expected to have good result. And further due to the good water quality, slight plan in the design to use rainwater runoff to replace the supply of tap water will make the most effective use of water resources possible.

3.3 Analysis of Artificial Neural Network

The runoff coefficient – catchment area – storage tank capacity – daily water volume required and supply water reliability (supplement) relationship obtained in Section 3.2 are used to substitute into back propagation neural network (BPNN) and radial basis function neural network (RBFNN), the simulation and forecast model is built up.

In the hidden layer of BPNN, the selection of the number of units in this layer is based on the following principle, i.e. number of units in the hidden layer = (number of units in input layer + number of units in output layer)/2, or number of units in the hidden layer = (number of units in input layer x number of units in output layer)^{1/2} (Yeah, 1997). Therefore, the number of units in the hidden layer obtained is (4+1)/2 or (4×1)^{1/2}, the larger integer is chosen to be 3. And in the whole network learning process, the largest number of iteration of 15,000 is used as standard and the learning rate and inertia factor are taken to be 0.4 and 0.6, respectively. Observing from the above results, the artificial neural network structure adopted in this research is the type of 4×3×1.

On the RBFNN side, after choosing location of each center in hidden layer using OLS method, a total of 112 suitable center location and a set of initial weight values are obtained. Then, the above initial values are inserted into RBFNN and the SGA method is used to modify each parameter of the network. During the modification process of the whole network, the maximum iteration of 15,000 is also used as standard and the learning ratio is 0.7. The result of analysis for BPNN and RBFNN are as shown below:

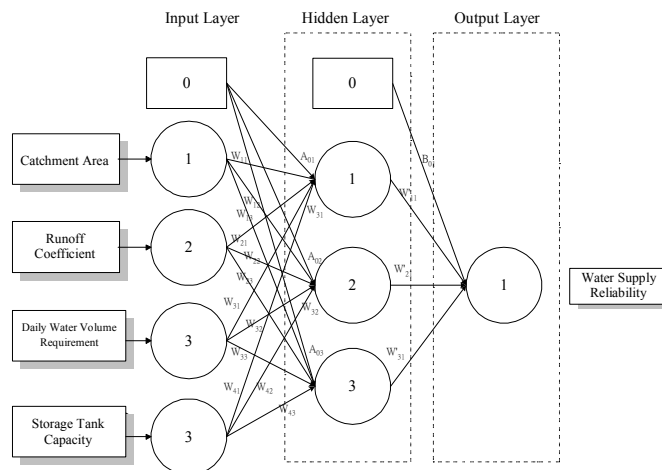


Figure 6 Diagram of BPNN structure constructed in this research.

3.3.1 Analysis Results of Case Study

After 15,000 times of iterative learning, Figure 7 shows the changes of 540 sets of samples used for prediction (where 80% of the sample points are selected randomly to conduct model training and learning, 10% of sample points are used for testing, and 10% of sample points are used for prediction).

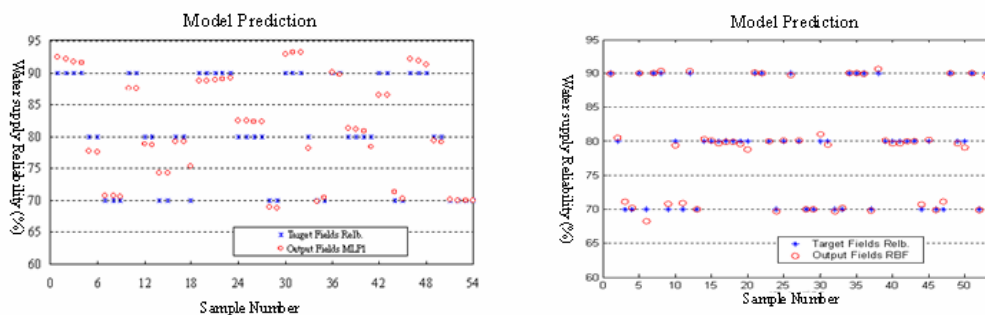


Figure 7 Prediction result of BPNN and RBFNN system

3.3.2 Analysis of Results

Table 2 and Table 3 show the statistics of the impact variances between the results used in training, testing, and prediction and the actual results. In these tables, in terms of the success rate of prediction as a whole, the results are about 83% (BPNN) and 98.6% (RBFNN). Such result is similar to the training or testing results, indicating the model itself has good stability.

Table 2 Overview of statistics of impact variances of BPNN in the results of training, testing, and prediction and the actual results.

Item	Over-estimated			Coincide Completely	Under-estimated		
	Grade 3	Grade 2	Grade 1		Grade 3	Grade 2	Grade 1
Training	0	0	44	350	38	0	0
Percentage (%)	0.00	0.00	10.18	81.02	8.80	0.00	0.00
Testing	0	0	10	40	4	0	0
Percentage (%)	0.00	0.00	18.52	74.07	7.41	0.00	0.00
Prediction	0	0	7	45	2	0	0
Percentage (%)	0.00	0.00	12.96	83.33	3.71	0.00	0.00

Inspecting the misses or failures of 19% (BPNN) and 6% (RBFNN) during the artificial neural network training process of this research, it shows the percentage of over estimation by one grade is 10.18% (BPNN) and 0.93% (RBFNN), while for under estimation by one grade is 8.80% (BPNN) and 0.46% (RBFNN). In other words, even there are mistakes in the estimation of this model, the variance in the affect is just one grade and the sample points of over estimation by one grade is similar to the under estimation by one grade. This also indicates based on the current model the variance of prediction result tends to be “optimistic” but the prediction result tend to be “pessimistic” is only around 9% (BPNN) and 0.5% (RBFNN), further indicating the stability of the model itself.

Table 3 Overview of statistics of impact variances of RBFNN in the results of training, testing, and prediction and the actual results.

Item	Over-estimated			Coincide Completely	Under-estimated		
	Grade 3	Grade 2	Grade 1		Grade 3	Grade 2	Grade 1
Training	0	0	4	426	2	0	0
Percentage (%)	0.00	0.00	0.93	98.61	0.46	0.00	0.00
Testing	0	0	0	54	0	0	0
Percentage (%)	0.00	0.00	0.00	100	0.00	0.00	0.00
Prediction	0	0	0	54	0	0	0
Percentage (%)	0.00	0.00	0.00	100	0.00	0.00	0.00

4 Conclusion and Recommendation

4.1 Key points to the planning of rainwater storage tank capacity

On the influence of increasing water volume required to the system, when the water volume is increased, theoretically the volume of the storage tank has to be increased if the system supplement is to remain unchanged. However, if the volume of the storage tank is already fixed, what is the relationship among the water volume needed, system supplement, and rainwater runoff utilization rate? Based on the case study of this research, if the water required increases, the reliability of the system supply will be reduced but the overflow rate accompanying could be reduced. In other words, if the water demand increases, the utilization rate of runoff during rainfall will increase.

This is similar to the case when the water level of the reservoir is close to full, but due to typhoon, large runoff flowing into the reservoir. At this time, though the water volume required downstream the reservoir remains unchanged, large amount of water must be released. The efficiency will be increased through discharging or increasing electricity generation and maintaining the safety of the reservoir. However, if the water volume needed downstream of the reservoir, though the system supplement of the

rainwater storage water supply system is not increased relatively the utilization rate of the rainwater is increased.

4.2 Performance Analysis of Artificial Neural Network

Summarizing above analysis, the performance of model constructed by RBFNN is better than that of BPNN. After the fixed 15,000 times of iterative learning, it is obvious that BPNN has not learned to suitable degree. If better network performance were to be received, more learning time has to be spent. However, RBFNN uses OLS center selection method for the processing. After 15000 times of iterative learning (SGA algorithm for the modification of parameters) the 98.61% accuracy is achieved. Therefore, RBFNN has quite good prediction ability in the non-linear characteristic of this research. Also, comparing to BPNN, the learning speed of RBPNN will be significantly beneficial to the online or instantaneous application in future.

4.3 Model Assessment

In addition to incorporate the traditional hydrological analysis results into the range of learning, the application of ANN concept to make use of the reliability of simulation and prediction of regional rainwater runoff could include other influencing factors at any time. And through the suitable adjustment in the hidden layer in order to adapt to the complexity of the model, adding suitable learning it could be applied directly and no additional study is required. This is indeed very convenient application tool.

This research is to calculate the regional rainwater runoff utilizing water supply reliability factors including rainfall frequency distribution, changes of runoff coefficient, catchment area and daily water required. From the above discussion it is not difficult to see the factors affecting rainwater runoff utilizing water supply reliability including weather, hydrology, geographical, and requirement aspects. The first two items could be considered as natural factors, i.e. its major cause is due to the law of nature itself, whereas the last two items could be considered as human factors, i.e. mainly caused by the situation of human development and water supply requirement. Therefore, during the process of utilizing regional rainwater runoff capacity planning and the design of water supply reliability, these factors bound to be incorporated and adopt consolidated indices to manifest. In this way, the objective result can be anticipated. As to how to form the overall index, traditionally the method often employed is through linear combination. However, there could be interactions among the indices and adding the use of linear approach to represent the cause and effect relationship might not be pertinent, therefore this research adopts the neural network analysis that is gradually gaining importance. Through this kind of non-linear combinatorial process, a new structure is established for the simulation and ideal results could be achieved.

Based on the result of this research, by applying the RBFNN model, which is using the Gaussian function as basis function that has similar trend as in the nature, it has significantly better stability and converging speed than the general BPNN model. This should have significant benefit in the future application of the instantaneous prediction or the development of related intelligent instantaneous control equipment. In future, changing different transfer function (e.g. binary logistic sigmoid, etc.) for the simulation

or adopting different series of artificial neural network structure for model construction analysis and comparison, it is believed to provide different reference as basis for the research in the related field or in the implementation of design.

5 References

Ruby L. Kennedy et al – *Solving data mining problems through pattern recognition*, Unica Technologies, INC, New Jersey, USA, 1998.

Adya M., Collopy F. – How effective are neural networks at forecasting and prediction?, Jr. Forecasting, 1998, 17(516):481~495.

Micheline Kamber et al – *Data mining – Concepts and techniques*, Morgan Kaufmann publishers, INC, San Francisco, USA, 2000.

S.C. Lee, M.C. Lin, W.H. Chou, *Rainwater Catchments System Planning and Design in Hope Engineering Project*, East Asia 2000 Regional Symposium on Rainwater utilization, Taiwan, 2000.

6 Presentation of Author(s)

Shih-Chi Lee is the researcher at Energy and Environment Laboratories, Industrial Technology Research Institute. He published widely on rainwater catchment system and grey water system in building. He was the plan leader of water-saving system of the Hope Engineering Project (initiated by the Buddhist Tzu-Chi Compassion Relief Foundation) to reconstruct schools damaged after the 921 earthquake in 1999 at Taiwan.



Positive Pressure Prediction Method for Drainage Systems with Special Fittings with Consideration of Combined Drainage Loads inside the House Drain

Takahiko Suzuki (1), Masayuki Otsuka (2)

(1) m0543010@kanto-gakuin.ac.jp

Graduate Student, Graduate School of Engineering, Kanto Gakuin University

(2) dmotsuka@kanto-gakuin.ac.jp

Department of Architecture College of Engineering, Kanto Gakuin University, Dr. Eng

Abstract

At the International Symposium of CIBW062, which was held in Paris, France in 2004, the authors proposed a method to predict the drainage performance of drainage stack systems in the light of combined drainage in the house drain. At that time the method was examined and confirmed using a single stack system drainage stack system with conventional fittings (JIS-DT fittings), which is designed for high-rise apartment housing. This paper examines the abovementioned drainage performance prediction method further with the intention of achieving two objectives.

1. Discussing the effectiveness of the method when it is applied to a drainage system with special fittings, which is of a type favorably employed recently for high-rise apartment housing
2. Identifying and discussing the influence of combined drainage characteristics and the relieving effect to the positive pressure created by combined drainage in the house drain by comparison of when the prediction method is used on the single stack drainage system with conventional fittings and when the method is used on the drainage system with special fittings.

Key words

Drainage system with special fittings, Combined drainage system, Single stack system, Prediction of pipe pressure, Allowable flow rate for the house drain

1. Introduction

The approved testing method of the drainage performance of drainage systems in Japan is the “Testing Method of Flow Capacity for Drainage System in Apartment Houses, SHASE-S 218-1999”¹⁾. This method is applied to drainage systems each typically comprising, as shown in **Fig.1**, a drainage stack and an approx. 5m-long straight house drain (“primary house drain”). However, drainage systems installed to the existing housing complexes each comprise several drainage stack systems, as illustrated in **Fig.2**, which are connected to a large-aperture house drain (“secondary house drain”) in header formation. That is to say, the abovementioned testing method is inadequate for evaluating the drainage performance of the existing multi-stack drainage systems with combined drainage carried into the house drain.

This study proposes a method for predicting drainage performance with consideration of combined drainage, which is created by a multi-stack drainage system and which is then carried into the house drain, while evaluating the allowable flow rate for the house drain.

At the 30th International Symposium of CIBW062 held in Paris, France in 2004, the authors proposed a drainage performance prediction method using a single stack system with JIS-DT fittings. The results acquired by the method were discussed and the effectiveness of the method was examined.

This study examines the same method applied to a drainage system with special fittings instead of JIS-DT fittings to make a comparison.

- ① Discussion of airflow resistance characteristics when using JIS-DT fittings and when using special fittings
- ② Discussion of the prediction of pipe pressure (max. and min. values)
- ③ Discussion of the allowable flow rate for the house drain

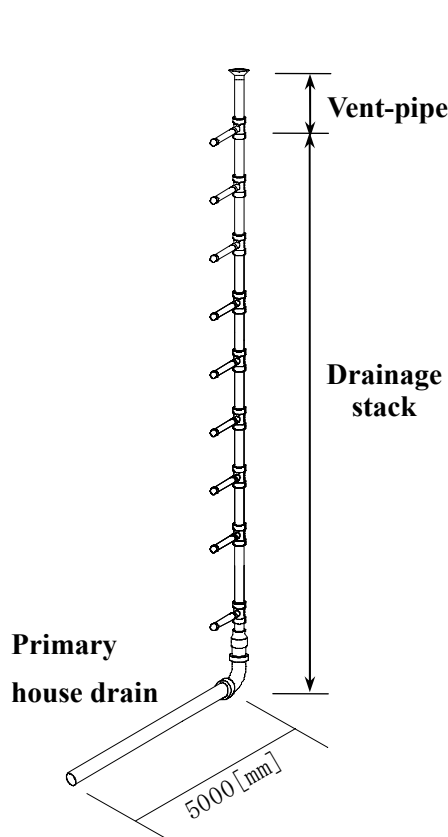


Fig.1 SHASE-S218-1999

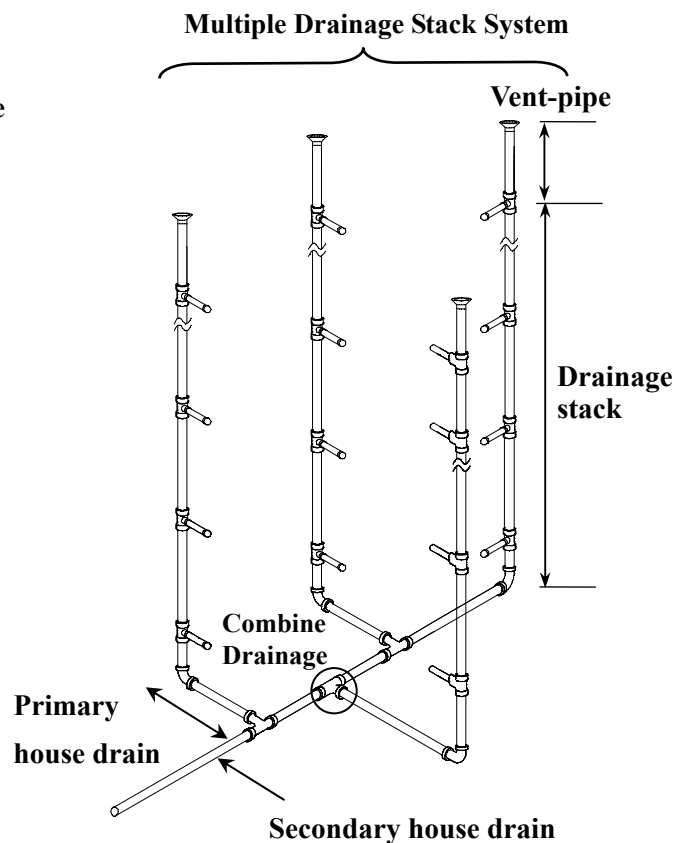


Fig.2 Typical drainage system for the existing housing complexes

2. Experiment overview

Photo 1 shows the exterior of the experimental tower. Its configuration is shown in **Fig.3**. The drainage stack system for the experiment comprises stacks 1, 2 and 3. For the experiment, the first drainage load was applied from stack 1 followed by the second load from stack 2 and the third load from stack 3 respectively to create a combined drainage load. **Table 1** summarizes the drainage load pattern of each stack. **Fig. 4** compares the formation of the special fitting (swirl type) and the JIS-DT fitting. For the experiment, two drainage systems; one with JIS-DT fittings and the other with special fittings were installed side by side. In terms of influence to the drainage performance, the drainage system with special fittings provides more severe conditions than the drainage system with JIS-DT fittings, as the point where combined drainage is created is closer to the core of each stack. **Table 2** lists the specifications of the pipe work and the trap used for the experiment.



Photo 1 Experimental system (exterior)

P : Pipe pressure [Pa]
W : Hot-wire anemometer [m/s]
H : Pipe water level [mm]

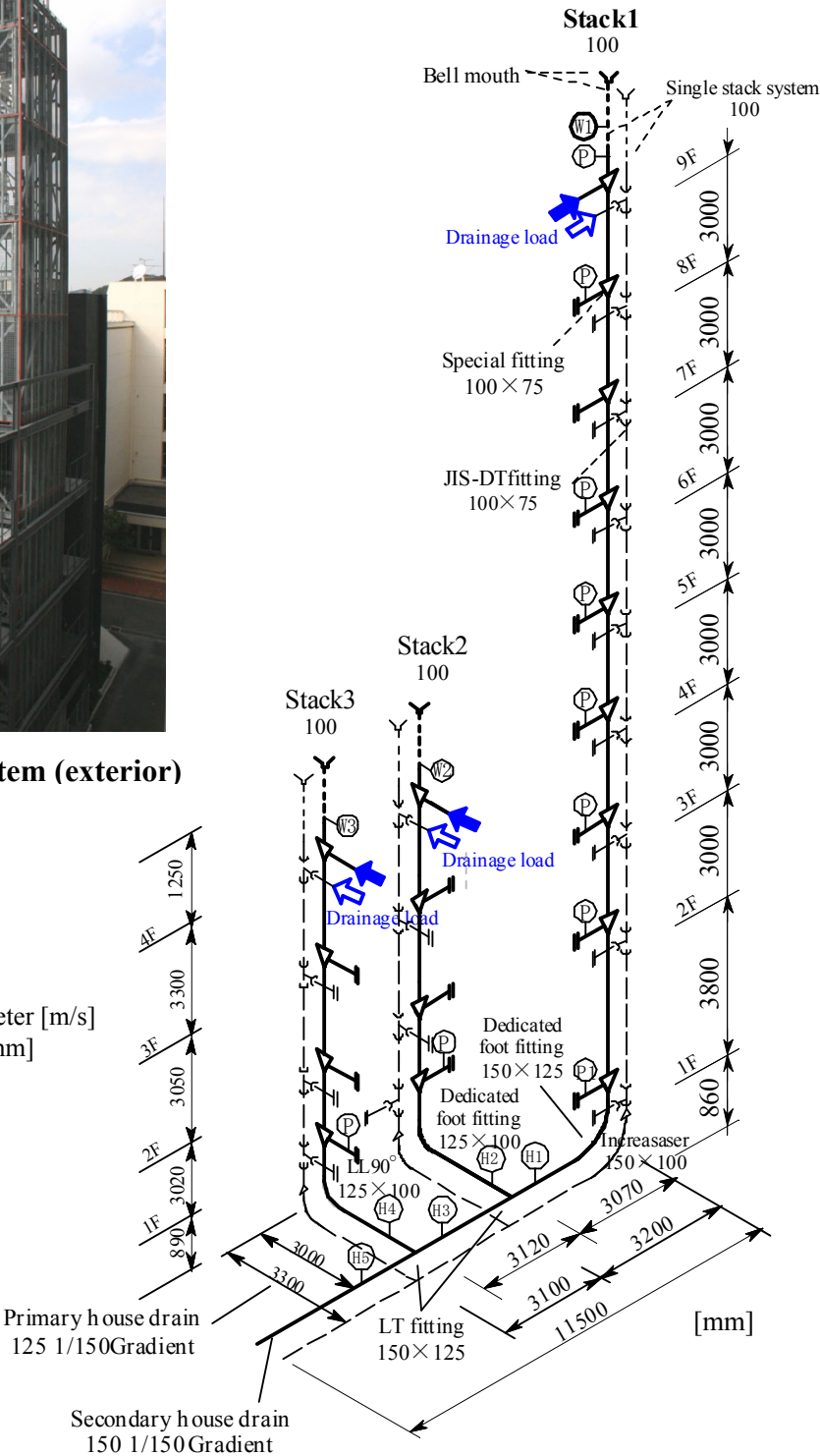


Fig.3 Experimental system (configuration)

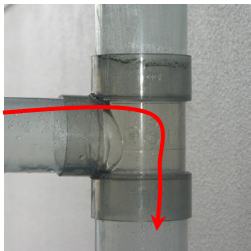
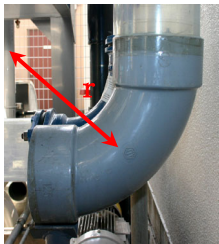
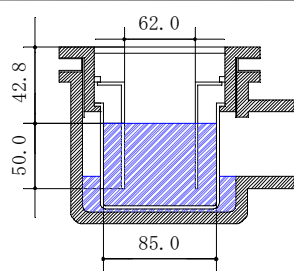
	Conventional fitting	Special fitting
Stack fitting		
	JIS-DT fitting 100×75	Swirl-type special fitting
Foot fitting		
	150×150 90° long elbow Curvature radius $r = 234$ [mm]	150×100 dedicated foot fitting Curvature radius $r = 187$ [mm]

Fig.4 Fittings (stack fittings and foot fittings)

Table 1 Drainage load pattern of each stack

	Drainage load flow[L/s]			
	1.0	1.5	2.0	2.5
Stack 1	1.0	1.5	2.0	2.5
Stack 2	1.0	1.5	2.0	2.5
Stack 3	1.0	1.5	2.0	2.5
Total flow rate [L/s] of combined drainage(1+2+3)	3.0	4.5	6.0	7.5

Table 2 Experimental pipe and trap

Drainage Stack	Diameter 100[mm] (VP)	
Primary House Draine	Diameter125[mm] (VP)	
Secondary House Drain	Diameter150[mm] (VP)	
Standard Floor Level	3000[mm]	
1F- 2F Level	3800[mm]	
Draining Floor 9F	9F	
House drain pipe gradient	1/150	
Allowable flow rate by SHASE-S206	6.8[L/s]	
		Water machine floor drain trap Ratio of cross-section area=0.82

3. Items to measure

The items to be measured are the pipe pressure fluctuation, the centreline velocity in the pipe and the water level of the house drain. The measurement points are indicated in Fig.3, and Table 3 describes how each item should be measured.

Table 3 Items to measure

	Item	Unit	Symbol	How to Measure
A	Pipe centerline velocity	m/s	W1,W2,W3	Install a hot-wire anemometer to the single stack section of stack 1,2 and 3
B	Pipe pressure fluctuations	Pa	P1-1F~P1-9F P2-1F,P3-1F	Install a small-size pressure sensor to the house drain 500mm away from the stack
C	House drain water level	mm	H1~H5	Install an ultrasonic water level sensor to the house drain with measuring points H1-H5

Centerline velocity in the pipe is calculated using formula (1):

$$Q_a = A_s \times 0.82 \times V_c \times 10^{-3} \quad \cdot \cdot \cdot \text{Formula (1)}$$

V_c : centerline velocity [m/s] Q_a : air flow [L/s]

A_s : cross-sectional area of the stack [m^2]

4. Evaluation criteria

Pipe pressure fluctuation: evaluate combined drainage drainable within a pipe pressure range of $\pm 400\text{Pa}$, which complies with SHASE-S218.

5. Analysing method

Fig.5 illustrates a pipe work model that comprises three drainage stack systems creating combined drainage. P_4 indicates “suction force” whereas regions 1, 2, 3 and 5 indicate different resistance levels. Region 5 also indicates a resistance level when combined drainage is created. Airflow resistance coefficients are indicated with ζ_{5-1} , ζ_{5-2} , and ζ_{5-3} .

The airflow rate of stacks 1, 2 and 3 is indicated with Q_{a1} , Q_{a2} , or Q_{a3} and a total airflow is indicated with Q_a , calculated using formula (2), (3), (4), (5), (6) and (7).

Table 4 lists the analysis formula used for the pipe work model evaluation. Assuming that the total suction pressure is equal to the total resistance, formula (8), (9) and (10) are applied to stack system No.1, No.2 and No.3 to acquire Q_{a1} , Q_{a2} and Q_{a3} by successive approximation.

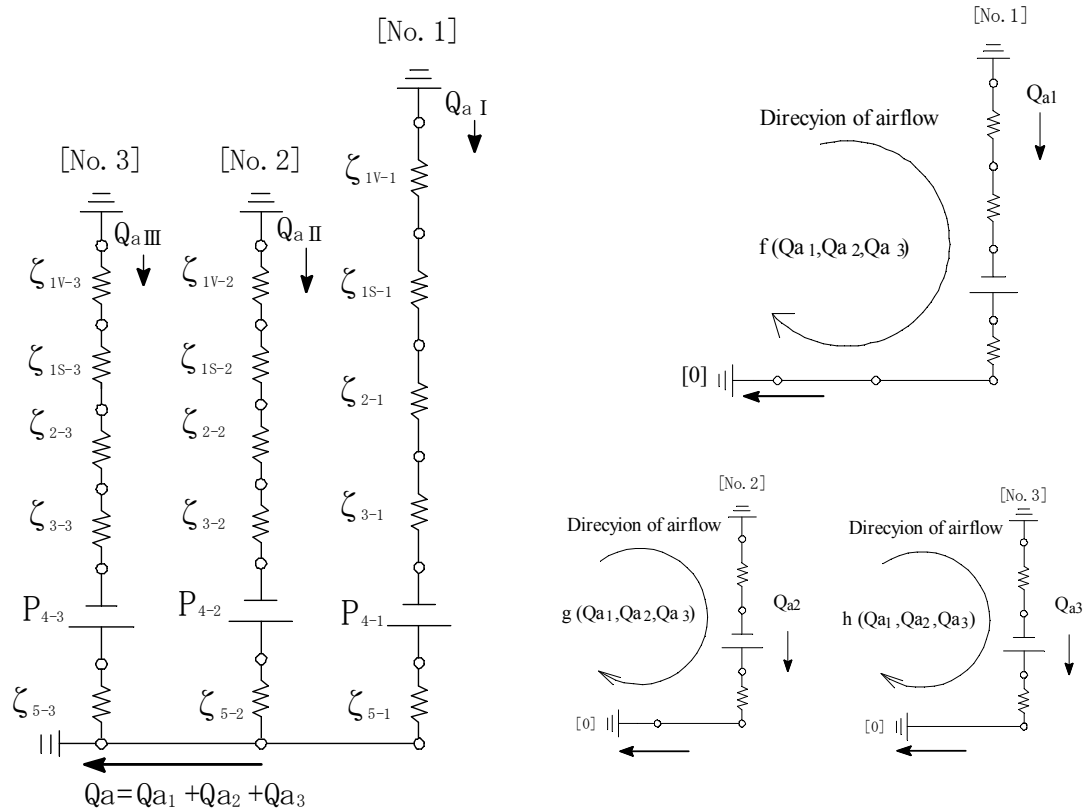


Fig.5 Pipe work model comprising 3 drainage system creating combined drainage

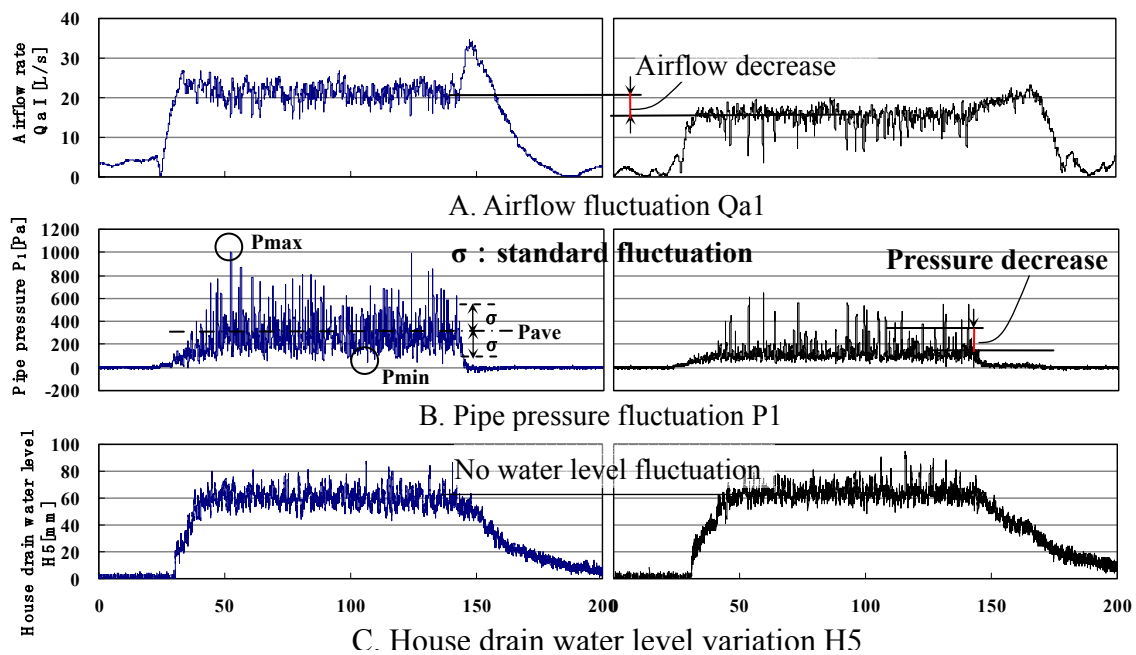
Table 4 Formulas used for the pipe model evaluation

$P_{n-i} = \zeta_{n-i} \cdot \frac{\rho}{2} \times \left(\frac{Q_{ai}}{A_s} \right)^2 \cdot (2)$	$P_{1V-i} = \zeta_{1V-i} \cdot \frac{\rho}{2} \times \left(\frac{Q_{ai}}{A_s} \right)^2 \cdots (3)$	$P_{1S-i} = \zeta_{1S-i} \cdot \frac{\rho}{2} \times \left(\frac{Q_{ai}}{A_s} \right)^2 \cdots (4)$
$P_{5-1} = \zeta_{5-1} \cdot \frac{\rho}{2} \times \left(\frac{Qa_1 + Qa_2 + Qa_3}{A_H} \right)^2 \cdots (5)$		
$P_{5-2} = \zeta_{5-2} \cdot \frac{\rho}{2} \times \left(\frac{Qa_1 + Qa_2 + Qa_3}{A_H} \right)^2 \cdots (6)$		
$P_{5-3} = \zeta_{5-3} \cdot \frac{\rho}{2} \times \left(\frac{Qa_1 + Qa_2 + Qa_3}{A_H} \right)^2 \cdots (7)$		
$f(Qa_1, Qa_2, Qa_3) = \left(\frac{P}{L} \right)_{\text{勝}_1} - (P_{1-1} + P_{2-1} + P_{3-1} + P_{5-1}) \cdots (8)$		
$g(Qa_1, Qa_2, Qa_3) = \left(\frac{P}{L} \right)_{\text{勝}_2} - (P_{1-2} + P_{2-2} + P_{3-2} + P_{5-2}) \cdots (9)$		
$h(Qa_1, Qa_2, Qa_3) = \left(\frac{P}{L} \right)_{\text{勝}_3} - (P_{1-3} + P_{2-3} + P_{3-3} + P_{5-3}) \cdots (10)$		
i : Drainage stack No.1, No.2, No.3 P/L : Suction per 1m [Pa/m] ρ : Air-tightness [kg/m³] A_s : Drainage stack cross-section[m²] P_{n-i} : Pressure loss per region [Pa] P_{1V-i} : Vent end pressure loss [Pa] P_{1S-i} : Vent linear section pressure loss [Pa] P_{5-i} : Total suction pressure[Pa] n : Region No.(1,2,3,5) Q_{ai} : Vent airflow rate[m³/s] L_i : Stack length to the balance point [m] A_H : House drain cross-section [m²] ζ_{n-i} : Airflow-resistance coefficient per region ζ_{1V-i} : Vent resistance coefficient ζ_{1S-i} : Vent end resistance coefficient ζ_{5-i} : Total suction resistance coefficient		

5. Results and speculation

5.1 Characteristics of the fluctuations of airflow rates, pipe pressure and house drain water levels

Shown in **Fig.7 (1)** and **(2)** are waveforms indicating the fluctuation of airflow rates, pipe pressure and house drain water levels when JIS-DT fittings are used and when special fittings are adopted. The airflow rate Q_{a1} of stack 1, the pipe pressure fluctuation P_1 measured on the first (ground) floor and the water level fluctuation measured at point H5 in the house drain, as in **Fig.3**, are exemplified here. For the experiment 2.5[L/s] of drainage load was applied from stacks 1, 2 and 3.



(1) JIS-DT fittings (2) Special fittings
Fig.7 Waveform comparison between JIS-DT fittings and special fittings
 (Stack 1, 2 and 3 with 2.5[L/s] of drainage load)

Table 4 Measurement value comparison between JIS-DT fittings and special fittings

	Item	Symbol	JIS-DT fitting		Special fitting	Decrease ratio
A	Airflow rate	Q_{a1}	27[L/s]	→	20[L/s]	25[%] approx.
B	Pipe pressure fluctuation	P_{smax}	1000[Pa]	→	642[Pa]	35[%] approx.
		$P_{ave(max)}$	253[Pa]	→	120[Pa]	53[%] approx.
C	Pipe water level fluctuation	H5	53[mm]	→	55[mm]	Unshanged

Table.4 compares each item that was measured. Airflow rate Q_{a1} decreased by the use of special fittings, and compared to when JIS-DT fittings were used, the rate of suctioned airflow was successfully reduced by approx. 25[%] from 27[L/s] to 20[L/s]. As for the pressure fluctuation P_1 measured on the first floor, compared to when JIS-DT

fittings were used, the use of special fittings reduced the maximum pressure P_{max} by approx. 35[%] from 1000[Pa] to 642[Pa], thus reducing the average maximum pressure $P_{\text{ave(max)}}$ by approx. 53[%] from 253[Pa] to 120[Pa]. The water level of the secondary house drain indicated no significant change regardless of the type of fittings, even at measuring point H located at the bottom of the drainage flow where the maximum water level H_{max} becomes highest, 53[mm] with JIS-DT fittings and 55[mm] with special fittings.

Based on the above results, it is speculated that the use of different types of fittings, JIS-DT fittings and special fittings, does not affect the water level fluctuation of the house drain, thus not affecting the airflow cross-section greatly. However, the airflow rate decreases by approx. 25[%], so does the airflow resistance, relieving the pipe pressure.

5.2 Pipe pressure prediction and performance evaluation

(1) Airflow characteristics of the regions

Using the pipe work model in **Fig.5**, the airflow resistance of region 2, which is located in the inlet section of the drainage stack, the pressure gradient $\left(\frac{P}{L}\right)$ of region 4, and the airflow resistance of region 5, where combined drainage is created, Can be acquired.

Region 2 is where the minimum system pressure P_{min} is created within the drainage system. When using JIS-DT fittings, the airflow resistance coefficient varies between approx. 50 and 600, as indicated in **Fig.8**, affected by the airflow fluctuation. When special fittings are used, the airflow coefficient remains 20 or below regardless of the change of the airflow and the combined drainage load flow, confirming that the airflow resistance of region 2 is constantly low. This suggests that the input resistance in the inlet section becomes moderated by the use of special fittings. **Fig.9** illustrates

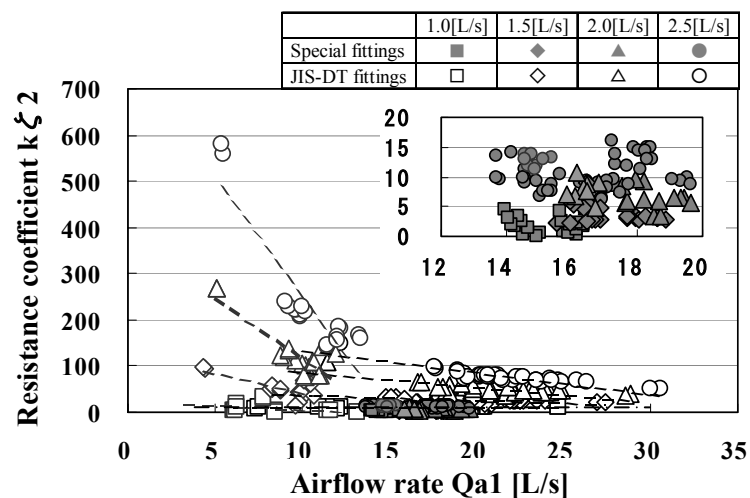


Fig.8 Comparison of airflow resistance coefficients in region 2

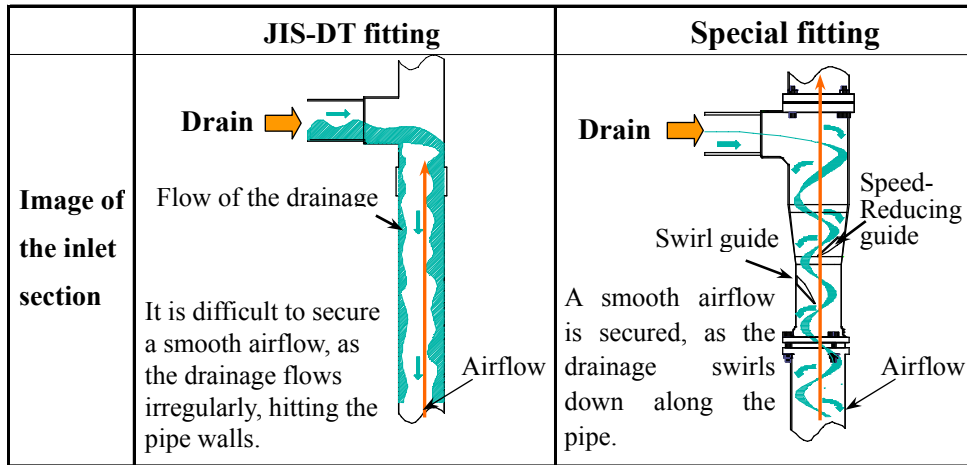


Fig.9 Different fitting configurations in the inlet section

configuration differences between the JIS-DT fittings and the special fittings.

Fig.10 shows different pressure gradients of region 4 in comparison between when JIS-DT fittings are used when special fittings are used. The pressure gradient $\left(\frac{P}{L}\right)$ is the suction force by the air inside the drainage system pipe. The airflow ranges rather significantly between 6 and 30[L/s] approx. when JIS-DT fittings are used, whereas it is suppressed to a range of 10 - 20[L/s] approx. when special fittings are used, indicating a speed-reducing effect on the drainage flow. Furthermore, $\left(\frac{P}{L}\right)$ remains low when the airflow rate is the same, suggesting that the influence to the pipe pressure is also small.

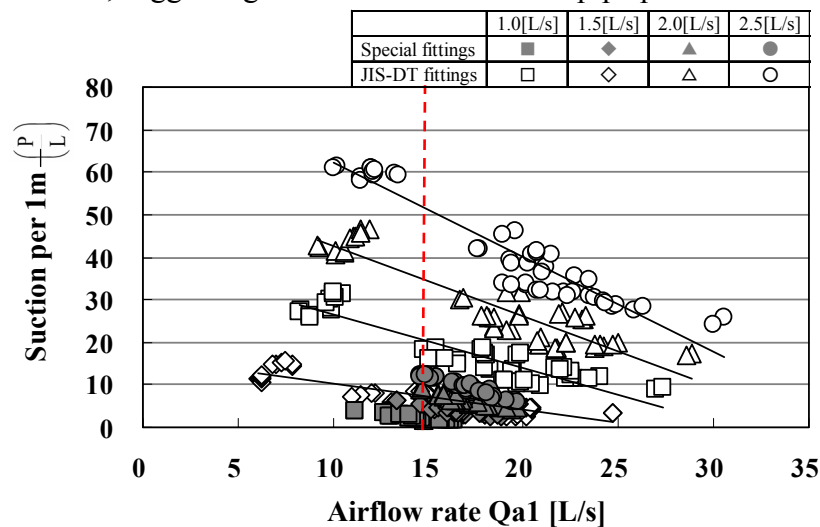


Fig.10 Pressure gradient $\left(\frac{P}{L}\right)$ in comparison

Fig.11-(1), (2) and (3) show the comparison of the airflow resistance coefficients ζ_{5-1} , ζ_{5-2} and ζ_{5-3} of region 5 where combined drainage from the three drainage stack systems is drained. With both special fittings and JIS-DT fittings there is a tendency that the increase of drainage load raises the airflow resistance. With regards to the airflow resistance, with both special fittings and JIS-DT fittings, since the water level fluctuation remains more or less unchanged, as shown in **Fig.7 C House drain water**

level fluctuation H5, the airflow is also thought to indicate little change, although it decreases slightly when special fittings are used.

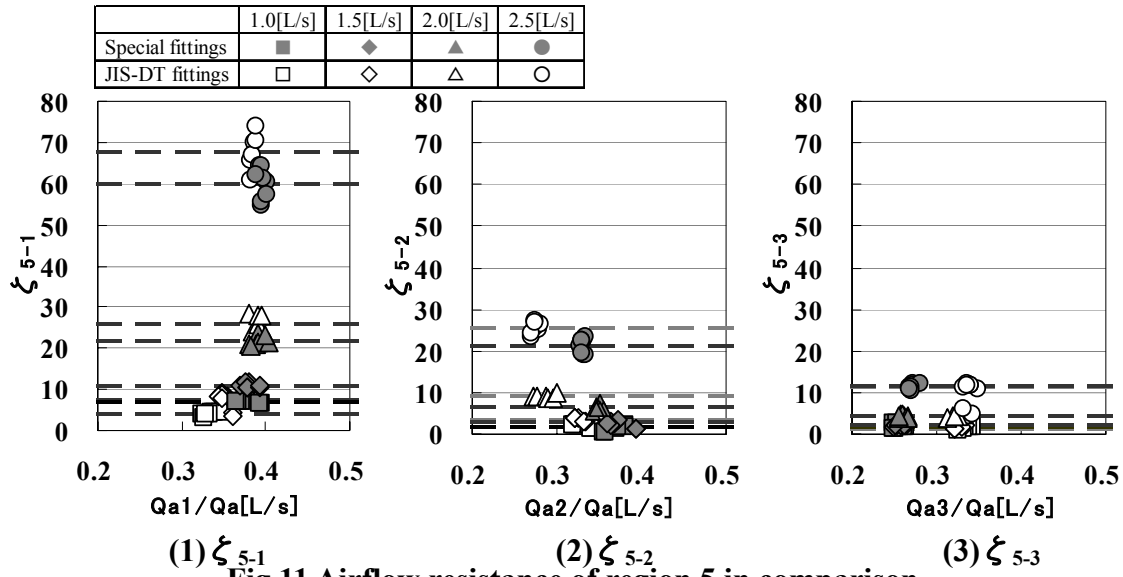


Fig.11 Airflow resistance of region 5 in comparison

5.3 Predicted average maximum and minimum pipe pressure, $P_{ave}(\max)$ and $P_{ave}(\min)$

Using the airflow resistance and the suction force explained in 5-2, the rates of suctioned airflow rates Q_{a1} , Q_{a2} , and Q_{a3} were calculated according to formulas (2) - (7) so as to acquire the average maximum and minimum pipe pressure, $P_{ave}(\max)$ and $P_{ave}(\min)$. These calculated values are compared with the actually measured values in **Fig.12 (1) and (2)** where the $\pm 10\%$ error is indicated by the dotted lines in each graph. There are slight differences of 2 - 15[Pa] between the predicted and actually measured values with both $P_{ave}(\min)$ and $P_{ave}(\max)$, but the values still fall within the practical use range.

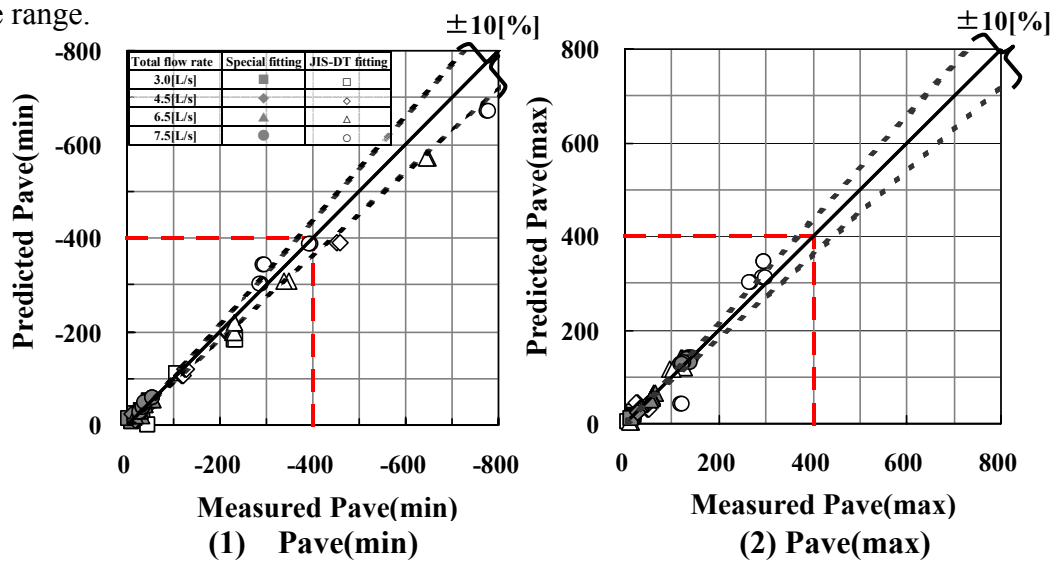


Fig.12 Average pipe pressure values

5.4 Predicted maximum and minimum system pressure, P_{max} and P_{min}

The predicted Pave(max) and Pave(min) were placed in formula (11) and (12) to calculate P_{max} and P_{min}, which are compared with the actually measured values in **Fig.13 (1) and (2)**. In order to clarify the accuracy of value prediction, the $\pm 10\%$ error is indicated by dotted lines in each graph. There are slight differences between the predicted and actually measured values with both P_{min} and P_{max}, but the accuracy of value prediction is justified in practical terms in reference with the SHASE-S218 threshold $\pm 400[\text{Pa}]$. As for P_{max} around $+650[\text{Pa}]$, where the waterproof pan trap would be flung completely by pressure, the value prediction becomes less accurate beyond $+400[\text{Pa}]$ especially when there is a fluctuation with flow rate.

$$\begin{aligned} P_{\max} &= P_{\text{ave}}(\max) + \sigma_1 \times N_1 & \dots (11) \\ P_{\min} &= P_{\text{ave}}(\min) + \sigma_2 \times N_2 & \dots (12) \end{aligned} \quad \left(\begin{array}{l} \sigma_1, \sigma_2: \text{standard fluctuation} \\ N_1, N_2: \text{constants} \end{array} \right)$$

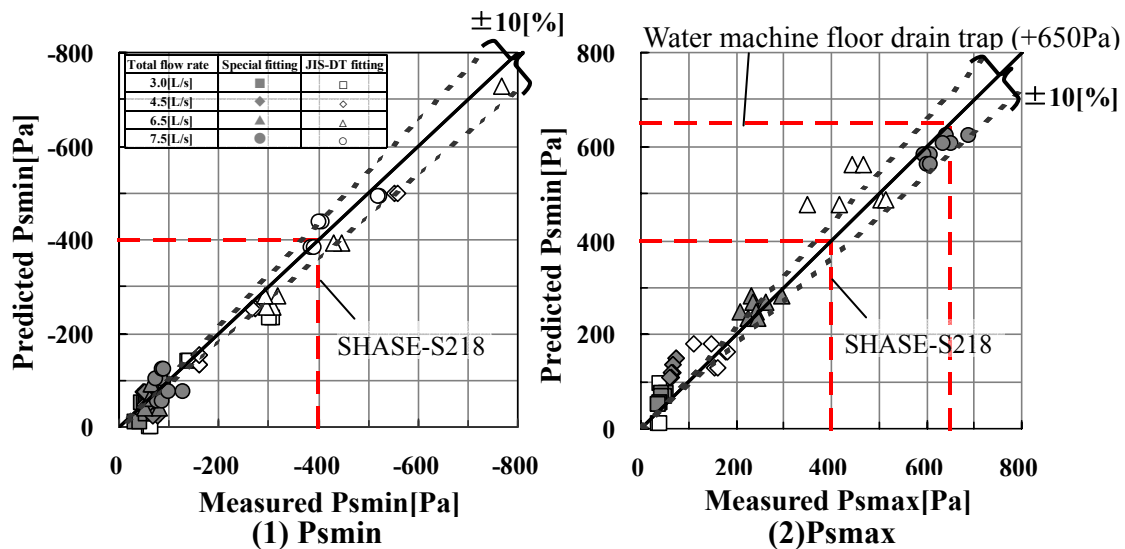


Fig.13 Predicted system pressure

5.5 Maximum system pressure P_{max} and the allowable flow rate for the secondary house drain

Fig.14 shows the relationship between the total flow rate Q_w and the maximum system pressure P_{max} when combined drainage from the three drainage stack systems is drained. When Q_w is $7.5[\text{L/s}]$, P_{max} is $1000[\text{Pa}]$ with JIS-DT fittings and $642[\text{Pa}]$ with special fittings, moderated by approx. 35% by the adoption of special fittings. With reference to the SHASE-S218 threshold $+400[\text{Pa}]$, the allowable flow rate increases to $5.8[\text{L/s}]$ with JIS-DT fittings and to $6.5[\text{L/s}]$ with special fittings. When using special fittings, the drainage performance almost reaches $6.8[\text{L/s}]$, the SHASE-S206 allowable flow rate for house drains.

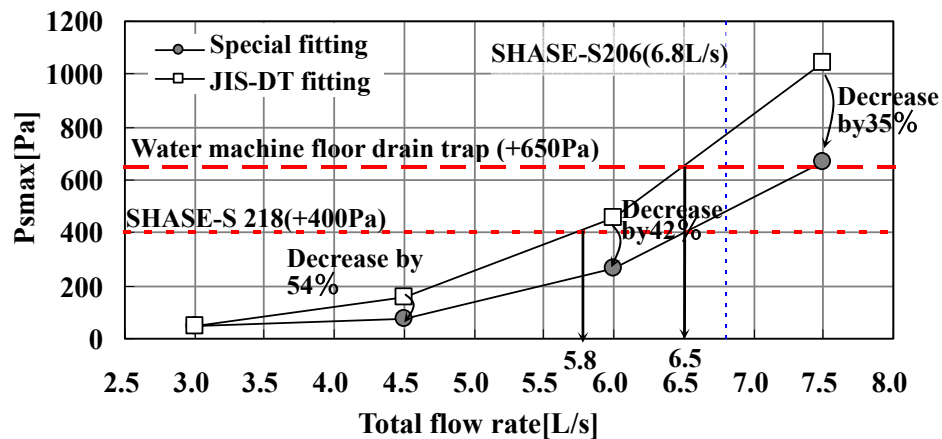


Fig.14 Total flow rate Q_w and maximum system pressure P_{smax}

6 Summary

The drainage performance prediction method with consideration of combined drainage in the house drain was discussed in the previous report. The effectiveness of the method was discussed and verified further in this report by applying it to the drainage system with special fittings. The results are as follows:

- (1) Airflow resistance values were acquired in different regions and compared both when JIS-DT fittings were applied and when special fittings were used. In region2 the input resistance in the inlet section became moderated by the adoption of special fittings and the airflow resistance was reduced. As for the pressure gradient (suction force) in region 4, the airflow rate remained low when special fittings were applied. (suction force) also remained small with special fittings when the same airflow rate was applied, thus anticipated to create a minor influence to the pipe pressure. In region 5 there was no significant fluctuation identified with the airflow resistance, as with the house drain water level.
- (2) The value prediction of the maximum and minimum system pressure P_{smax} and P_{smin} was verified to be fairly accurate especially with reference to the SHASE-S218 threshold of $\pm 400\text{Pa}$ and below.
- (3) The allowable flow rate for house drains is 5.8[L/s] with JIS-DT fittings and 6.5[L/s] with special fittings. The allowable flow rate is 6.8[L/s] when a diameter of 150A and a pipe gradient of 1/150 are applied according to the SHASE-S206 specifications. Hence, the adoption of special fittings improves drainage performance, almost reaching this value.

7. Acknowledgements

The research study was conducted as part of the “Strategic Development Studies of Symbiosis Technologies with the Aim of Urban Construction Stock Reproduction”, the academic frontiers promotion program 2004 by the Ministry of Education, Culture, Sports, Science and Technology.

8. References

- 1) Testing Method of Flow Capacity for Drainage System in Apartment Houses, SHASE-S-218-1999
- 2) Masayuki OTSUKA, Masahide NANYO; Proposal of the Flow Capacity Prediction Method for Drainage Systems Considering the Influence of Combined Drainage Loads inside House Drains, 32nd International Symposium CIB W62 2004
- 3) SHASE-206 “Standards for Plumbing and Sanitary System(2000)
- 4) Takahiko SUZUKI et al.; Experiment Research on Drainage Performance Evaluation of Combined House Drain (Part 1 A Method of Estimating the Combined Drainage Performance), Technical Paper of Annual Meeting The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, II pp.769-772 (2003.9)
- 5) Masahide NANYO et al.; Experiment Research on Drainage Performance Evaluation of Combined House Drain (Part 2 Prediction of Air Pressure Distribution of Drainage Stack Systems and Drainage Performance Evaluation), Technical Paper of Annual Meeting The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan , II pp.773-776(2003.9)
- 6) Masayuki OTSUKA et al. ; Experiment Research on Influence Prediction of Drainage Capability of Drainage Stack System (Part3 Influence of Combined Drain of House Drainage Stack System with Special Fitting) , SUMMARIES OF TECHNICAL PAPERS OF ANNUAL MEETING ARCHITECTURAL INSTITUTE OF JAPAN (2006.9)

9. Presentation of Author

Takahiko Suzuki is currently on a Masters course at the Graduate School of Engineering, Kanto-Gakuin University. He has been conducting research on the drainage performance of drainage stack systems with consideration of combined drainage in the house drain. Suzuki is also interested in symbiosis housing.



Simulation of multi-physics flow patterns in a single-drainpipe of gravity drainage systems -A preliminary CFD study

W.R. Chang (1) , C.L. Cheng (2), J.T. Wang (3)

(1) ruby@chu.edu.tw

(2) CCL@mail.ntust.edu.tw

(3) M9413201@mail.ntust.edu.tw

(1)(2)(3)National Taiwan University of Science and Technology, Department of Architecture, Taiwan

Abstract

Empirical research using full-scale models on the flow patterns of building sewerage systems usually requires the expenditure of time and effort, which places restrictions on the option of the experimental parameters to be investigated to a certain extent. Against the limitation of empirical research, computational fluid dynamics (CFD) has emerged as one of the powerful methods to be used to study flow related problems in sanitary application. However, the application for the multi-physics simulation inside a drainpipe system is rather complicated and challenging. This paper presents a preliminary CFD study on water and air flow patterns in gravity drainage systems of the single-drainpipe type. A general-purpose CFD code is employed to predict the multi-physics flow fields in the modeled drainpipe. The theory and implementation of the computational simulation are carefully examined in order to find out the feasibility and the limitation of CFD method. The computational outputs are visualized in the form of animation. It is showed that the utilization of CFD method is not only helpful to provide extensive flow data for better study on draining systems but also effective to display complex patterns of the drainage flow visually. The preliminary simulation shows quite satisfactory results. The numerical model employed in the study should be as a foundation for the follow-up extensive and systematic study on related problems and a supplement to traditional empirical research to provide better design of building drainage systems.

Keywords

Building sewerage system; Gravity drainage system; Computational fluid dynamics.

1 Introduction

The basic requisite of a ventilated gravity drainage system is to carry away any appliance discharge while at the same time preventing any foul odour ingress into the habitable space from the drainage network. Explicitly understanding and well control the nature of flow patterns including pressure transient propagation and velocity variations is vital to the successful performance of building drainage and vent systems. Quite a few of studies on flow patterns of ventilated gravity drainage systems are implemented through empirical researches on full-scale models or real cases and the deduction of mathematical models[1-4], which usually requires the expenditure of time and effort, and, therefore, places restrictions on the option of the experimental parameters to be investigated to a certain extent.

As computers become more and more powerful and popular, computational fluid dynamics (CFD) has emerged as one of the effective methods to be used to study flow related problems in sanitary application in order to surmount the limitation of empirical research[5]. However, the application of CFD for multi-physics simulation inside a drainpipe system is rather challenging. Discharge from sanitary appliances to ventilated drainage systems is usually multi-physics, i.e., mixed with air, water and solid materials, which constitutes a rather complex fluid system.

This paper presents a preliminary CFD analysis using a general-purpose CFD code on air-water fluid patterns while discharging at a steady water flow rate in a ventilated gravity drainage system of the single-drainpipe type. As our initiation of CFD study, the whole large and complicated drainage system is simplified as showed in Fig. 1 for main discussion in this study. The four key focus parts are including stack vent, vertical stack, lateral drain and main horizontal drain. The theory and implementation of the computational simulation are carefully examined in order to find out the feasibility and the limitation of CFD method. The numerical model developed in the study is expected as a foundation for the follow-up extensive and systematic study on related problems and a supplement to traditional empirical research to provide better design of building ventilated gravity drainage systems.

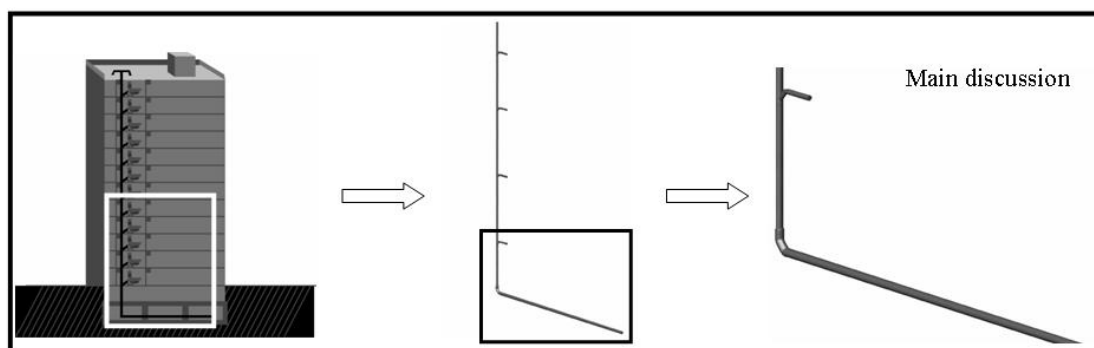


Figure 1 –Schematic representation of simplified drainage system for main discussion

2 The CFD approach

CFD is the use of computers to analyze problems in fluid dynamics and to provide detailed information about the flow field. The developed equations governing fluid physics are partial differential equations which can be solved numerically rather than analytically. The most fundamental consideration in CFD is how to treat a continuous fluid in a discretized fashion on a computer.

To start a typical CFD research process, the major works in the pre-processing stage involve the definition of the computational domain of the problem, the construction of geometric models, and the creation of the discrete cell system within the whole computational domain. Secondly, the decisions of governing equations and the numerical methods adaptable to the attribute of the fluid flow studied need to be made for performing the subsequent simulation. At last, after the equations are solved iteratively, the attention is then focused on the large data sets generating from the simulation in order to extract useful information and to visualize the solution output about the flow field.

A general-purpose CFD code, CFD-ACE+, is employed to predict the flow fields in the modeled drainage system. CFD-ACE+ is a set of computer programs including CFD-GEOM: an integrated geometry and grid generation module, CFD-ACE-GUI: a graphical user interface for preparing the model, CFD-ACE-Solver: a computational solver for performing the simulation, and CFD-VIEW: an interactive visualization program for examining and analyzing the simulation results. The interactive relationship between these applications is illustrated as Fig. 2. The application of CFD-ACE+ in the author's previous work on the air flow patterns behind a porous hedge[6] has obtained quite successful results. However, the application for the multi-physics simulation inside a drainpipe system is quite different and should be more complicated and challenging.

2.1 The geometric model

A schematic drawing illustrating the three-dimensional modeled drainage system of the single-drainpipe type is shown in Fig. 3. The origin of the coordinate system is set at the bottom of the vertical stack. Z-direction is along the vertical stack and opposed to the direction of gravity forces. The diameters of drainage pipes are all set to be 10cm. The lengths of the vertical stack, the stack vent, the main horizontal drain and the lateral drain are 100cm, 25cm, 300cm and 60cm, respectively. The main horizontal drain and the lateral drain both have a 45° junction with the stack and a 1/50 slope declined from the junction.

The ends of the stack vent and the main horizontal drain are both open to the air; meanwhile, the water is supplied to the stack from the lower half part of the lateral drain at a steady flow rate of 4l/s. The reference pressure is set to be 100000 N/m² and gravity forces are considered in this simulation.

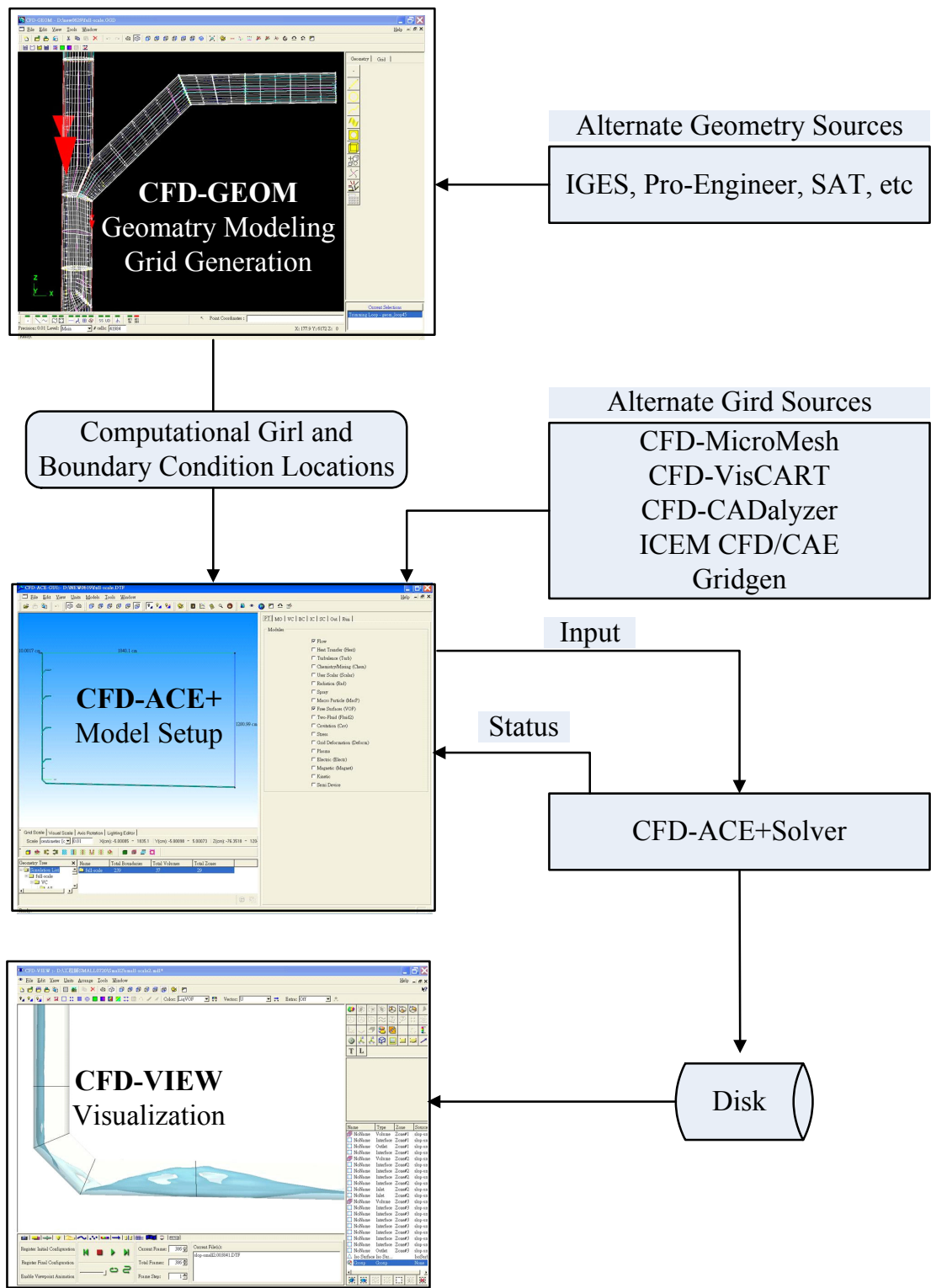


Figure 2 –Interactive relationship of standard CFD-ACE+ package

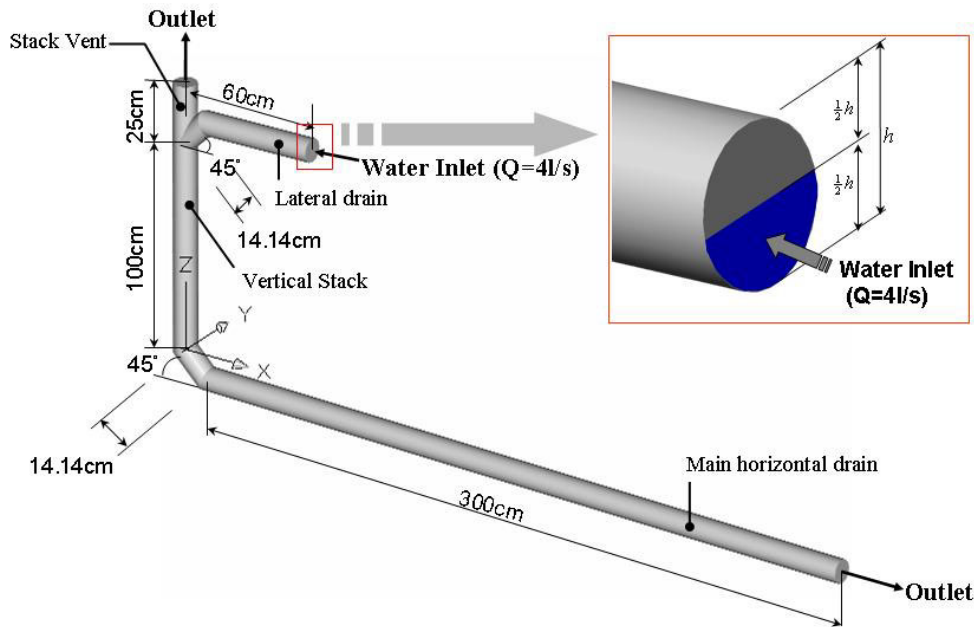


Figure 3 –Schematic drawing of the three-dimensional modeled drainage system

2.2 Grid creation

The discretization of the spatial domain into small cells is critical for the discrete solution of the partial differential equations governing fluid physics. The most important elements concerning grid quality are smoothness, packing and skewness. For a more accurate and robust grid, the grid is slightly modified to improve the quality after creating the grid. In general, the fluid flow around the junction is expected to change significantly. Therefore, a fine mesh of high spatial resolution is created around these regions so that an accuracy prediction may be obtained.

Both structure and unstructured grids are created and tested in this study as shown in Fig. 4 and 5 in order to verify the applicability and effectiveness. The amounts of control cells generated in the whole computational domain for the structured and unstructured grid system are 15,424 and 15,198 respectively. Comparing these two grid systems, the distinguishing characteristic of the unstructured grids is that each cell must be stored separately in memory and that divergence of the solution procedure is hard to prevent. However, the hexagonal structured grid in three dimensions is shown to be suitable for use with the Free Surface Module in spite of the labour in creating the grid system.

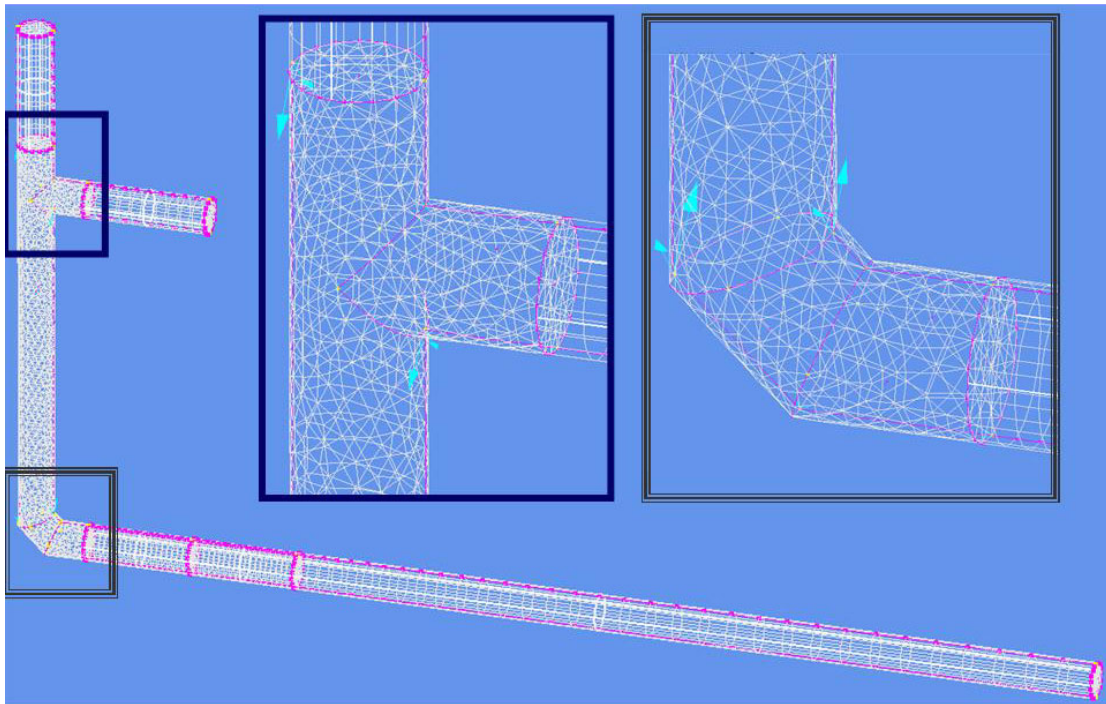


Figure 4- Unstructured Mesh distributions in the computational domain

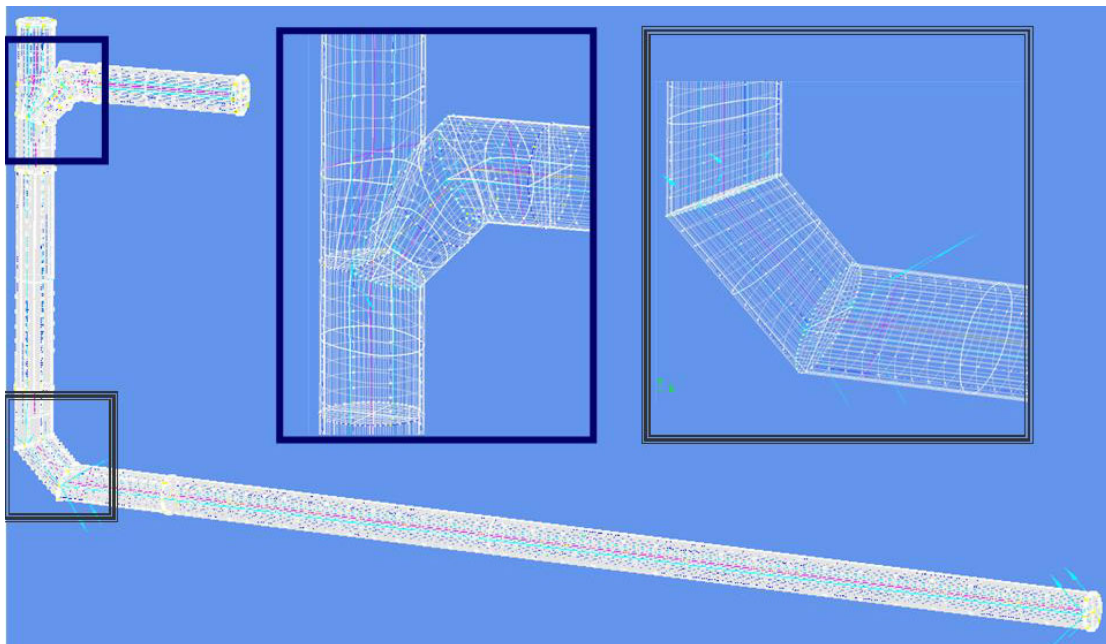


Figure 5- Structured Mesh distributions in the computational domain

2.3 Governing equations

In this study, the water and air flows are considered as three-dimensional, steady, isothermal, incompressible and turbulent. They are immiscible and where localized slip between the two is negligible. The Flow Module and Free Surface Module of CFD-ACE+ are used in the simulation for the air-water flows to provide a multi-physics based solution.

The Flow Module enables CFD-ACE+ to simulate almost any fluid flow problem to determine the pressure field within a given geometry and the mass flow characteristics of an internal flow system. The fundamental equations for the Flow Module to govern the motion of the flows are developed from the conservation laws of physics for flow. They are the continuity equation and the averaged Navier-Stokes equations, which can be expressed as:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \bar{\mathbf{V}}) = 0 \quad (1)$$

$$\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho \bar{\mathbf{V}} u) = -\frac{\partial p}{\partial x} + \nabla \cdot (\mu \nabla u) + S_{Mx} \quad (2)$$

$$\frac{\partial (\rho v)}{\partial t} + \nabla \cdot (\rho \bar{\mathbf{V}} v) = -\frac{\partial p}{\partial y} + \nabla \cdot (\mu \nabla v) + S_{My} \quad (3)$$

$$\frac{\partial (\rho w)}{\partial t} + \nabla \cdot (\rho \bar{\mathbf{V}} w) = -\frac{\partial p}{\partial z} + \nabla \cdot (\mu \nabla w) + S_{Mz} \quad (4)$$

The Free Surface Module allows the simulation of the fluid dynamics of two fluids with arbitrary immiscible fluid-fluid interfaces. The basis of the approach used in the Free Surface Module is Volume-Of-Fluid (VOF) [7,8]. The relative mixture of the two fluids within the computational domain is tracked in terms of the volume fraction, F , of each computational cell in the grid occupied by the second fluid (e.g. water). That is, the F value of a cell is 1 when it contains only water, and 0 when contains only air.

Given a flow field and an initial distribution of F on a grid, the equation governing the volume fraction distribution F is shown as followed:

$$\frac{\partial F}{\partial t} + \nabla \cdot (\bar{\mathbf{V}} F) = 0 \quad (5)$$

Where F is the liquid volume fraction, t is time, ∇ is standard spatial grad operator, and $\mathbf{v}$ is the velocity vector. This equation must be solved together with the above fundamental equations (1)-(4) to fulfill computational coupling between the velocity field solution and the liquid distribution.

The average value of any volume-specific quantity, ϕ , is determined by the proportions of air and water in the mixed flow and the properties of these two, which can be expressed as:

$$\tilde{\phi} = [F \rho_2 \phi_2 + (1 - F) \rho_1 \phi_1] / \rho_{mix} \quad (6)$$

Where ϕ is the volume-averaged quantity, ϕ_2 is the value of the property for water, ϕ_1 is the value of the quantity for air.

To extend the flexibility of VOF module to handle different cell types and different materials, auto scheme control model is set to employ three surface reconstruction methods based on cell type, type of material and the scheme user entered from GUI. The three surface reconstruction methods including 0th order upwind (FOAM)scheme, upwind scheme with the Single Line Interface Construction(SLIC) Method and upwind scheme with the Piecewise Linear Interface Construction(PLIC) method.

Back projection approach is used to determine the flux of water for a given velocity. The allowable timestep magnitude for the stability limit is given by the so-called Courant Condition:

$$\Delta t_c = \frac{d_c}{|\bar{v}_c|} \quad (7)$$

Where Δt_c is the maximum timestep that can be taken in cell c, $\bar{v}_c$ is the local velocity vector, and d_c is the local cell dimension. The CFL Number is then defined by:

$$\frac{|\bar{v}_c| \Delta t_c}{d_c} \quad (8)$$

For stability of the solution algorithm used to integrate equation (5), the CFL Number is set as 0.2 to allow the fluid or the interface to cross 20% of the width a cell during each time-step.

2.4 Numerical methods

The method used to solve the partial differential equations governing the water-air physics is to produce a discrete solution on a computation grid. For the discretization of the differential equations to yield a set of algebraic equations, the finite-volume approach is applied because of its capability of conserving solution quantities. In the volume approach, the governing equations are numerically integrated over each of these computation grids. The discrete solutions represent the values of the variables at the geometric center of each cell and the cell-face values are interpolated using the first-order upwind Scheme.

The continuity equation (1) can be expressed as:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \bar{V}) = \dot{m} \quad (9)$$

To discretize the above equation we have:

$$\frac{\rho \mathcal{G} - \rho^o \mathcal{G}^o}{\Delta t} + \sum_e \rho_e V_e^n A_e = \dot{m} \mathcal{G} \quad (10)$$

$$V_e^n = u_e n_x + v_e n_y + w_e n_z \quad (11)$$

Where the subscripts o denote an order time, V_e^n is the face-normal component of the velocity at fence e , n is the face-normal unit vector.

Employing the finite-volume method to integrate the governing equations 2,3 and 4, we have the discrete equivalent of the continuous flow transport equation as follows:

$$(a_p - S_p) u_p = \sum_{nb} a_{nb} u_{nb} + S_U \quad (12)$$

Where the subscripts nb denote values at neighboring cells, and a_{nb} are the link coefficients which are functions of u_p , u_{nb} , etc. The equation (12) is nonlinear. The formulation for each computation cell results in a set of coupled nonlinear algebraic equations. Because there is no direct matrix inversion method available to solve a set of nonlinear algebraic equations, an iterative, segregated solution method is adopted to solve the equation sets for each variable sequentially and repeatedly until a converged solution is acquired.

To prevent divergence of the solution procedure, under relaxation of dependent and auxiliary variables is applied. Equation (12) is adjusted as follows:

$$a_p (1 + I) u_p = \sum_{nb} a_{nb} u_{nb} + S_U + a_p I u_p^* \quad (13)$$

$$I = \frac{\rho \mathcal{G}}{\Delta \xi a_p} \quad (14)$$

3 Results and discussion

The large data sets generating from the simulation are preliminarily analyzed. The results are presented in the form of animation to visualize the solution output about the flow field in general. The approximate interface shape between the two fluids is reconstructed based on an interpolation to determine the isosurface corresponding to a volume fraction of 0.55.

Fig. 6 shows the flow phenomenon of the whole computational drainage system at a key frame, and Fig. 7 and 8 present the flow phenomenon at two junctions respectively. It is found that the simulation is quite near the real water movement. The discharged water runs along the declined drain. After hitting the opposite side of the vertical pipe wall near the junction, it then descends in the stack along the pipe wall. When arriving the bottom junction, the sloshing phenomenon is observed due to the dash against the horizontal pipe wall.

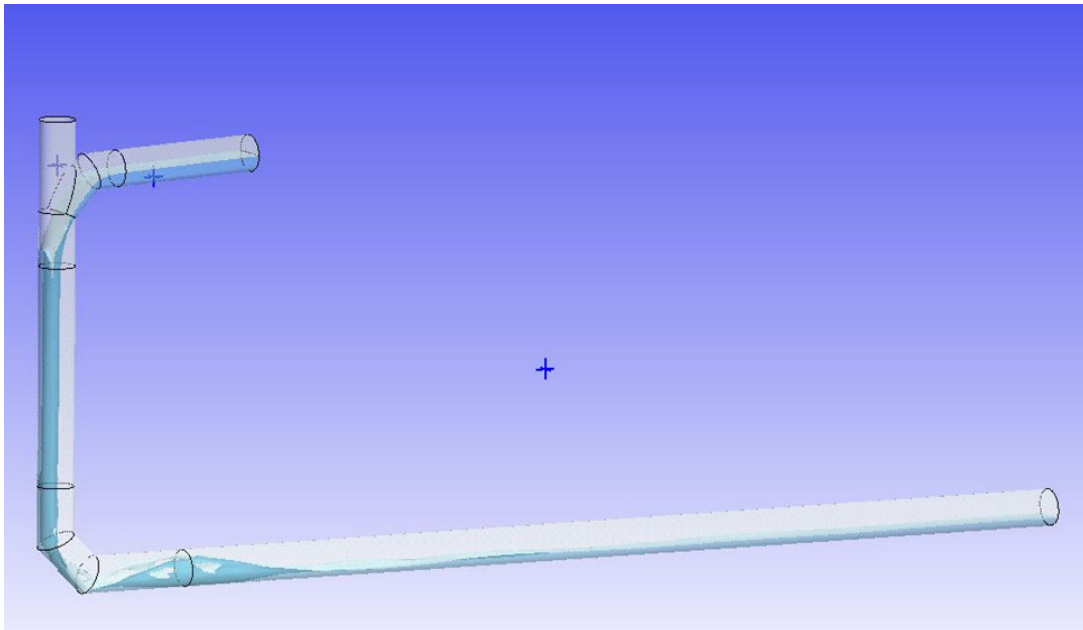


Figure 6- Flow phenomenon of the whole computational drain at a key frame

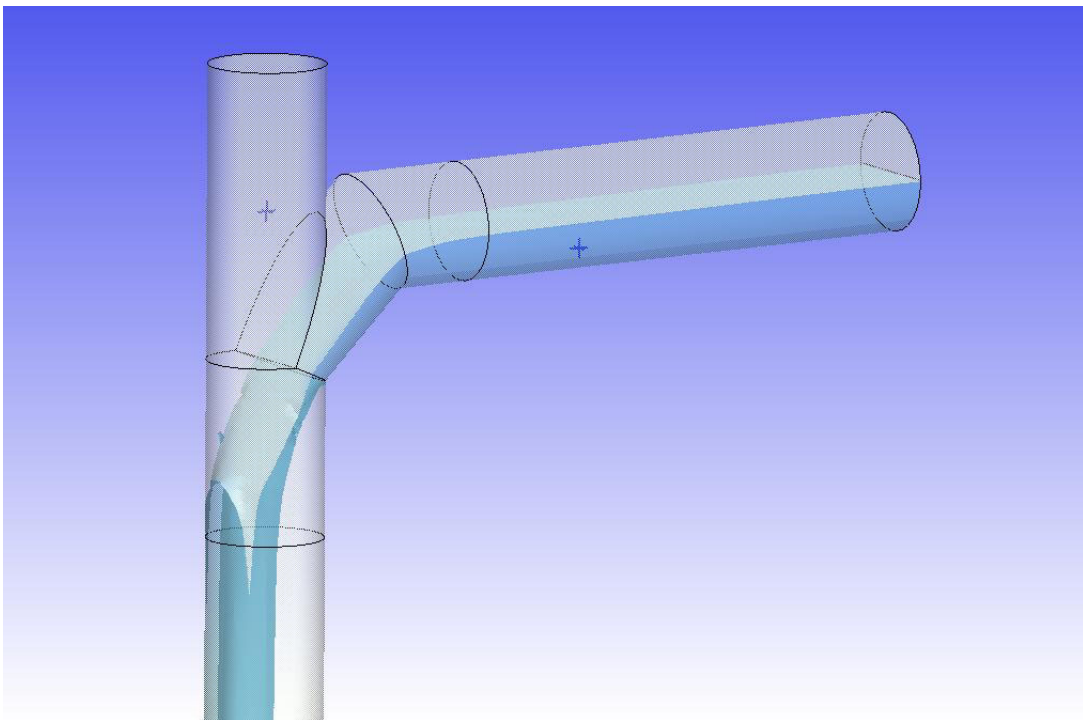


Figure7- Flow phenomenon at the upper junction

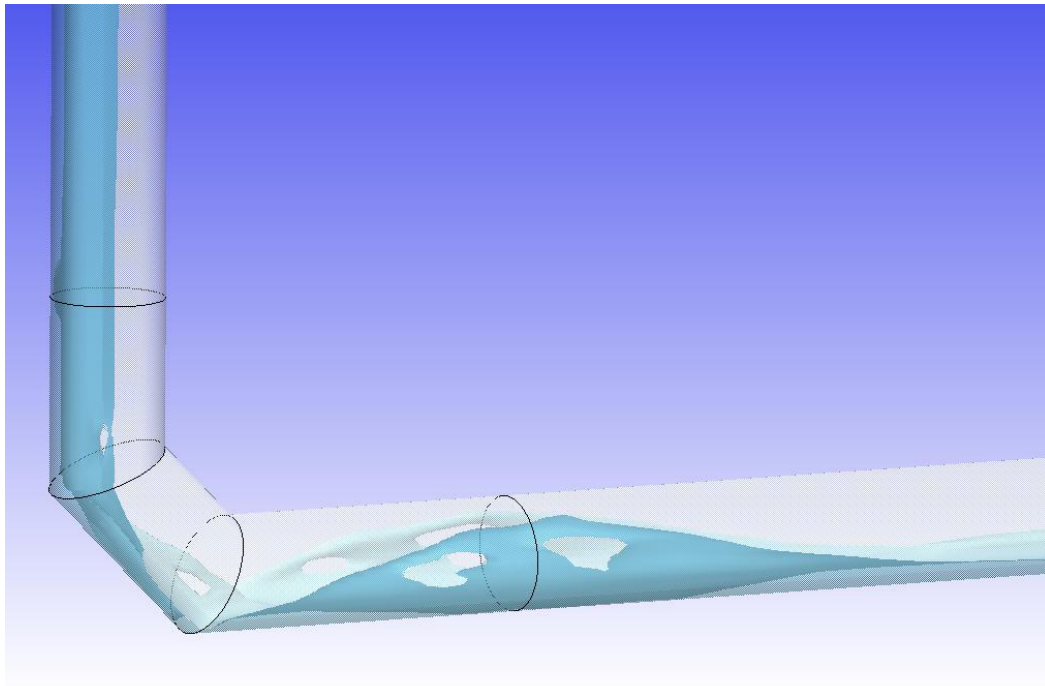


Figure8- Flow phenomenon at the upper junction

4 Conclusion

This paper demonstrates the CFD approach to analysis and visualize the air-water fluid patterns in a ventilated gravity drainage system of the single-drainpipe type. It is shown that the animation is a rather effective tool to present the transient phenomena in a drainage pipe. However, the validation of the present numerical procedure and the present solution outputs by comparing with those in previous works is necessary, before further utilization of the numerical model developed in the study for the follow-up extensive and systematic study on related problems.

5 References

1. Swaffield, J.A., Jack, L.B., Campbell D.P., Control and suppression of air pressure transients in building frairage and vent systems, Building and Environment 39(2004) 783-794.
2. Campbell, D.P., Macleod, K.D., Detergents in drainage systems for buildings, Wat. Res. Vol.35, No. 4, pp. 1086-1092, 2001.
3. Swaffield, J.A., Campbell, D.P., The simulation of air pressure propagation in building drainage and vent systems, Building and Environment Vol.30, No. 1, pp. 115-127, 1995.
4. Lu, W.H., Cheng, C.L., Shen, M.D., An empirical approach to peak air pressure on 2-pipes vertical drainage stack, Symposium CIB W62 2005 CSTB, France.
5. Ongoren, A., Materna, R., Investigation of the effect of swept entry configuration on the air entrainment and self-siphoning behaviour in gravity drainage systems, Symposium CIB W62 2005 CSTB, France.

6. Chang, W.R., Effect of porous hedge on cross ventilation of a residential building, *Building and Environment* 41(2006) 549-556.
7. Hirt, C.W., Nichols, B.D., Volume of fluid(VOF) method for the dynamics of free boundaries, *Journal of Computational Physics*, Vol.39, pp.201-225,1981.
8. Kothe, D.B., Rider, W.J., Mosso, S.J., Brock, J.S. Volume tracking of interfaces having surface tension in two and three dimensions, *AIAA Paper*, 96-0859, 1996.

6 Presentation of Author(s)

W.R Chang is a Ph.D. student majoring in CFD –aided architecture design. She is also an associate professor at Chung Hua University, Department of Landscape Architecture.



Cheng-Li Cheng is the Professor at National Taiwan University of Science and Technology, Department of Architecture. He is a researcher and published widely on a range of water supply and drainage in building. Currently he also acts as referee of Taiwan Green Building Evaluation Committee and Nation Building Code Review Committee.



Study on the Carrying Performance of the House Drain Using a Food Waste Disposer

YUSUKE MINAMI (1), MASAYUKI OTSUKA (2)

(1) minami014@sekisuihouse.co.jp

(2) dmotsuka@kanto-gakuin.ac.jp

(1) Sekisui House, Ltd, Dr. Eng.

(2) Prof., Dept. of Architecture, College of Engineering Kanto-Gakuin Univ., Dr. Eng.

Abstract

This research focuses on the plumbing of the drainage system with a disposer with the intention of collecting essential data regarding the evaluation of the system's performance and its design method.

The important point to bear in mind is to identify the appropriate range of supply water flow volumes. In the practical application of the drainage stack system, the flow volume of supply water is recorded to be rather low and the operating time of the disposer is reported to be short. These facts cast negative anticipation that the horizontal pipe's performance to carry waste water may be degraded.

With the background stated above, with the focus on the following two points, this research intends to acquire knowledge essential for the proposal of a method to evaluate the water-carrying performance of the house drain, which forms part of the drainage stack system with a disposer, as well as a method that enables efficient pipe cleaning and management.

1. Evaluate the house drain's performance to carry waste water by classifying types of remnants of food waste, and examine effects to the pipe flow and pipe performance by the flow volume of supply water, the amount of food waste disposed of and different floor levels in relation to load variation, from which identify supply water volumes and pipe flow rates appropriate for carrying waste water.
2. Remnants of ground food waste can be accumulated within a pipe, causing serious trouble by blocking the pipe. Simulate this condition using a simplified system model and identify load-carrying strength required in practical application.

Keywords : drainage system with food waste grinder, carrying performance, house drain

1. Introduction

This study focuses on the pipework of a drainage system in order to collect data, which will make basis for proposing a reliable method for the evaluation of carrying performance and a sound design technique. In the previous reports the authors conducted studies on how the carrying performance of the horizontal fixture drain branch and instantaneous positive pressure created at lower building floors affected the drainage stack system¹⁾²⁾. The next challenge is to discuss the carrying performance of the house drain and a design technique.

Firstly, an important factor to consider for good carrying performance of wide-aperture house drains is to acquire an adequate flow volume range of water to be applied to drainage systems. The flow volume range of water actually applied to the subject drainage system for this study is less than 8 – 9L/min, the flow volume range specified by the drainage performance standards and the guidelines in Japan³⁾⁴⁾. The operating time of a disposer used with the drainage system is also reported to be insufficient to create a good effect. These facts lead to concern about hindering the carrying performance of the house drain. Furthermore, a typical drainage system in Japan discharges drainwater into sewerage via a drainage treatment tank. In addition, the Ministry of Land, Infrastructure and Transport has recently begun the implementation of a pilot program where drainwater is discharged directly into sewerage. Hence, the sound use of wide-aperture drainage pipes and the ensuring of good carrying performance of sewerage pipes are more important than ever.

Some research was carried out in the past on the carrying performance of drainage pipes with the main focus on the carrying performance of toilet bowls⁵⁾. However, there are very few reports on the quantitative evaluation of waste-containing drainwater.

Under these circumstances, the purpose of this study is to examine the following two aspects: (1) further evaluation and study consolidation of sediment of waste-containing drainwater in the house drain using the same testing method as in the previous study on the horizontal fixture drain branch¹⁾; (2) experimentation using pipework models, where sediment of waste-containing drainwater is created causing a “damming effect”, to acquire the degree of force necessary to carry waste without creating sediment. Through the above evaluation and experimentation this study intends to collect basic knowledge to develop a sound evaluation method of the carrying performance of the house drain and a good technique to schedule pipe cleaning and maintenance.

2. Experimentation

2.1 Outline of the experiment and method

The experiment concentrates on the following two points as outlined below:

(1) Understanding the carrying performance of the house drain

Firstly, the carrying performance of the house drain was classified into five types according to the condition of sediment in the pipe, as identified in the previous report¹⁾. As well as the carrying performance of the pipe, effects of the flow volume of water and the amount of kitchen waste that were applied to the drainage system and effects of the floor level to the flow rate were examined.

The experiment was carried out on the simulation tower set up on the premises of Kanto Gakuin University. The simulation tower represents a high-rise apartment building with a disposer drainage stack system using conventional fittings installed. Table 1 shows the pipe diameters used for the experiment. The disposer used for the experiment is of just one kind, which grinds to particles of a standard size. The specifications of the disposer are stated in Table 2. The disposer was operated for 30 seconds five seconds after the start of applying water to the drainage system. Water was applied in two different flow volumes; 4L/min and 8L/min, for 40 consecutive seconds respectively. Different floor levels were also used for applying drainage load; the 2nd, 4th, 6th and 8th floor for the single drainage testing and the 8th + 7th + 6th floor, the 6th + 5th + 4th floor and the 4th + 3rd + 2nd floor for the 3-point drainage testing. Kitchen waste typically produced in Japan was used for the experiment in different amounts; 250g and 500g.

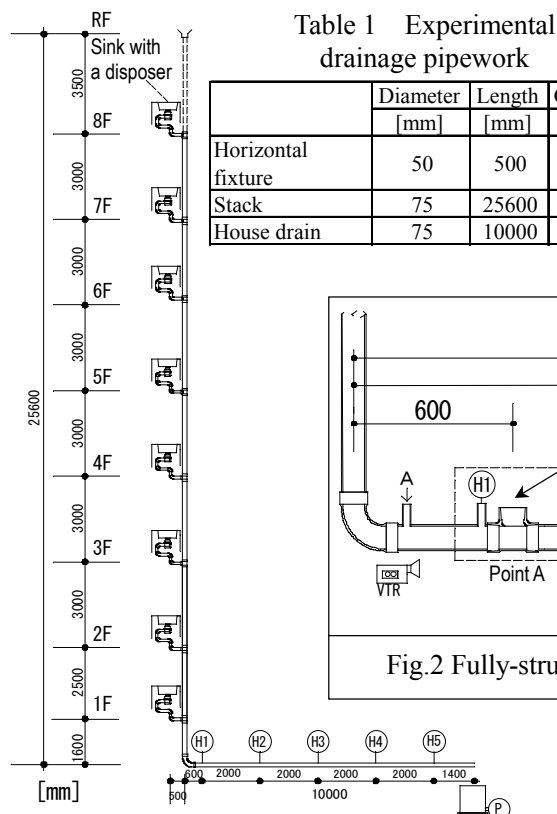


Fig.1 Experimental drainage stack system

Table 1 Experimental drainage pipework

	Diameter [mm]	Length [mm]	Gradient
Horizontal fixture	50	500	1/100
Stack	75	25600	-
House drain	75	10000	1/100

Table 2 Experimental disposer

Applying method	Batch method
Crushing method	Hammer mill method
Crushed volume	1.2L (in the crushing room)
Crushed particle size	1.0mm
Output voltage	250W
Drain trap	38mm

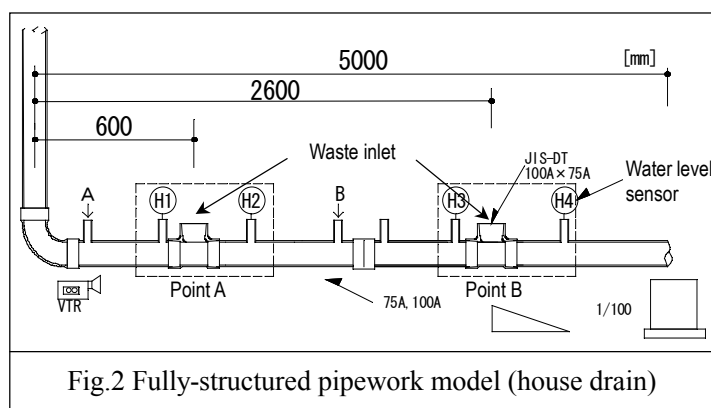


Fig.2 Fully-structured pipework model (house drain)

(2) Understanding carrying performance using piepwork models

By the above experiment (1) if waste accumulates in the house drain creating a damming effect, it is necessary to identify a force sufficient to make waste flow, and for this purpose a fully-structured pipework model ① and a simplified model ② were constructed. In this paper, carrying force F_c was defined as a force sufficient to make waste flow and it was calculated using formula (1).

$$F_c = \rho g h_g A + mg \sin \theta + f_p \quad \cdot \cdot \cdot \text{Formula (1)}$$

F_c : force [N] to make waste begin to flow, ρ : water density [kg/m^3], g : gravity acceleration [m/s^2], h_g : barycentric position of drainage cross section [m], A : cross-sectional area of flow [m^2], m : mass of kitchen waste applied [kg], θ : pipe gradient, f_p : drainage collision force [N]

Item 1 is the force created by the hydrostatic pressure of drainwater retained on the upstream side of waste sediment. Item 2 is the force by gravity, and item 3 is the force created by the impact of colliding drainwater flowing down into the house drain from the drainage stack. It should be noted, however, that since the quantitative estimation of f_p is difficult, f_p values are excluded from F_c calculation with the exception of the evaluation of the impact of drainwater in 3.2.2 (2).

① Fully-structured house drain model

Fig.1 illustrates the experimental drainage stack system including Fig.2 showing a fully-structured house drain model with water level sensors and a waste inlet in place. During the experiment, ground kitchen waste was accumulated in the house drain and then a constant flow of clean water was applied in order to calculate an F_c value. Two locations; point A and point B (600mm and 2600mm respectively from the drainage stack) were determined within the house drain to create waste sediment. Two types of waste were also specified for creating sediment; kitchen waste typically produced in Japan and cabbage waste. They were both ground by the disposer first and were immediately inserted into the house drain to create sediment, which was of three different amounts; 250g, 500g and 750g.

② Simplified model

For simple F_c verification a 950mm-long and 600mm-high model was constructed, as illustrated in Fig.3. Sediment of waste was created in (1), as for the experiment on the fully-structured house drain model (①), and water was gradually applied before drainwater became retained. The force by hydrostatic pressure against the sediment was then calculated from the water level.

In (2), drainwater was drained from the drainage stack in order to understand the impact of the colliding drainwater on the waste sediment. Water was applied after the drainwater was retained on the upstream side of the waste sediment and the water level

was acquired as the waste sediment began to flow. Also in (3), an electronic cell (push-pull gauge) was used for measuring the force as the waste sediment began to flow.

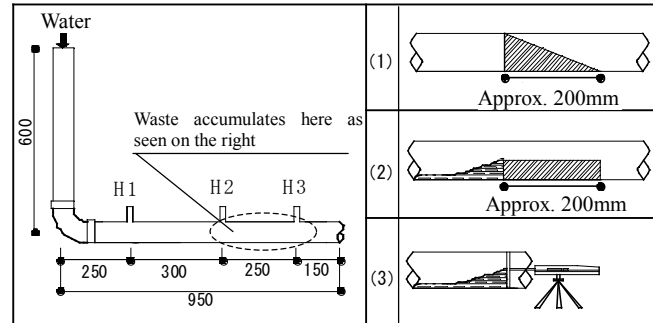


Fig.3 Simplified model (pipe diameter: 75A, 100A)

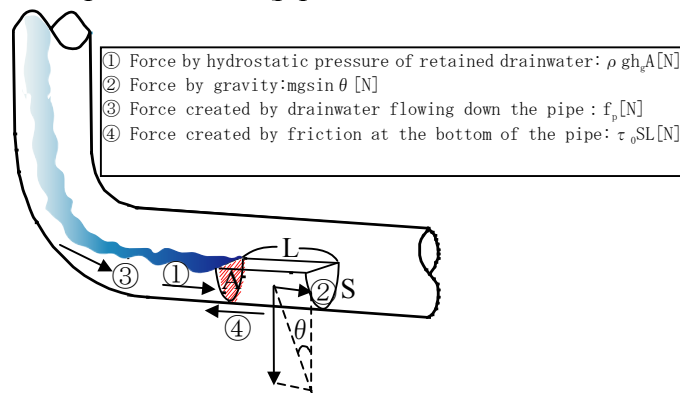


Fig.4 Factors considered in F_c calculation

2.2 Items to measure and record

- ① Pipe water level fluctuation: Water level sensors were set at points H1 to H5 to measure water fluctuation. The recorded results were then used for acquiring the tip flow rate of waste-containing drainwater.
- ② Carrying condition: How waste was discharged was visually observed and recorded by a camcorder. The condition of waste remnant was classified into five types; class I to class V. Class I indicates a condition where the pipe cross section is completely blocked by drained ground waste with drainwater being retained behind the waste. Class II shows a condition where about half of the pipe cross section is blocked by drained ground waste with drainwater retained behind the waste. Class III represents a condition where a large amount of drained waste forms a trail of sediment along the pipe. Class IV is a condition where waste sediment occurs in an intermittent manner, and class V signifies a condition where ground waste is entirely drained out.
- ③ Drainage load [N]: A push-pull gauge was attached to the downstream side of the simplified model to measure drainage load. The force was measured with consideration of the water level at the exact moment when the waste sediment began to flow.

3. Results and speculation

3.1 Carrying performance of the house drain

1) Remnant distribution

The experiment was carried out on the drainage stack system in Fig.1 by applying different conditions (1) to (3) in Fig.5. A typical example of how waste remnant occurred in the house drain is also shown corresponding to each condition. In (1), a 3-point drainage technique was implemented. When drainage load was applied from the 8th, 7th and 6th floor respectively, the class IV remnant condition was identified where there was a good flow of drainwater mixed well with ground kitchen waste. When drainage load was applied from the 6th, 5th and 4th floor respectively as well as from the 4th, 3rd and 2nd floor respectively, the drainwater was drained out completely. These results therefore suggest that the 3-point drainage technique ensures good carrying performance without creating waste sediment along the pipework.

In (2) and (3), a single drainage method was implemented and evaluated. When applying 8L/min of water, the class III remnant condition was created approximately 1m from the basal part of the drainage stack. When applying 4L/min of water in (3), however, the class II remnant condition was identified. This condition is shown in Photo 1. With reference to the waveforms of various water levels in Fig.6, waste sediment creating a damming effect becomes stationary after passing water level sensor point H1. The water level of the drainwater, which eventually became retained still, was approximately 30mm. The analysis of this water level will be explained later in 3.2 through further experimentation.

The previous study reports that the average flow volume of water used with a food waste disposer is approximately 4L/min. This leaves some concern that the single drainage technique can create the class II remnant condition, or even worse, in the house drain. In addition, low drainwater flow creates instantaneous positive pressure in the drainage stack and can hinder the carrying performance of the house drain. It is therefore important to identify the appropriate flow volume of water for good drainage. The following sections focus on the relationship between the flow volume of applied water and the pipe flow rate in search of how to secure good carrying performance.

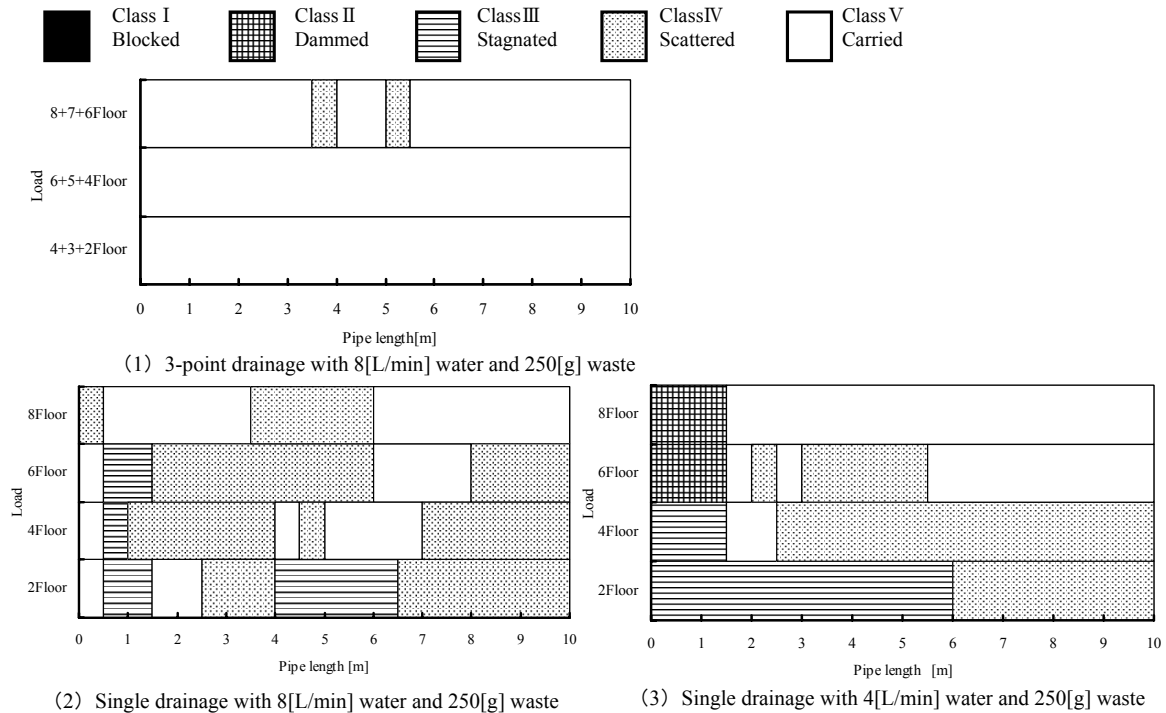


Fig.5 Accumulation in the house drain (house drain: 75A 1/100)

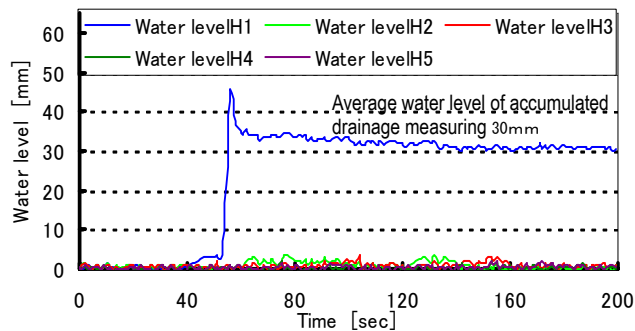


Fig.6 Various water levels in the house drain

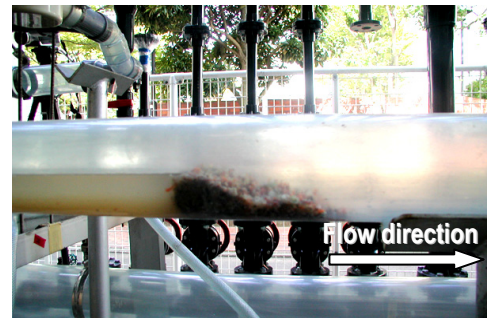


Photo 1 Sediment creating a "damming effect" in the house drain

2) Tip flow rate of drainwater and remnant distribution

Fig.7 shows the flow volume of applied water in relation to the tip flow rate of drainwater. Two drainage methods were used; (1) single drainage and (2) 3-point drainage. Fig.7 also shows a flow rate range, where the abovementioned remnant conditions (classes I to V) occur, based on the results acquired in 3.1 (1). Table 3 clarifies the knowledge acquired about the horizontal fixture drain branch in comparison with the range of remnant distribution (by class) within the house drain. The flow rate, which encouraged the class II condition where waste formed a dam, was 0.10m/s in the horizontal fixture drain branch and 0.12m/s in the house drain, showing an almost identical value. Incidentally, the flow volume of water applied was 4L/min. and this finding implies a high possibility of pipe blockage caused by waste sediment when the

single drainage technique is actually used. Moreover, the flow rate ranges with the other class conditions shown in Table 3 are very similar on the horizontal fixture drain branch and this can also be said about the house drain.

The flow rate required for the perfect drainage of waste-containing drainwater was identified to be 0.42m/s in the horizontal fixture drain branch and 0.44m/s in the house drain when applying the 3-point drainage technique with a water flow volume of 8L/min or greater. This suggests from a quantitative point of view that 8L/min of water applied under normal drainage operation for approximately 40 seconds would ensure good carrying performance.

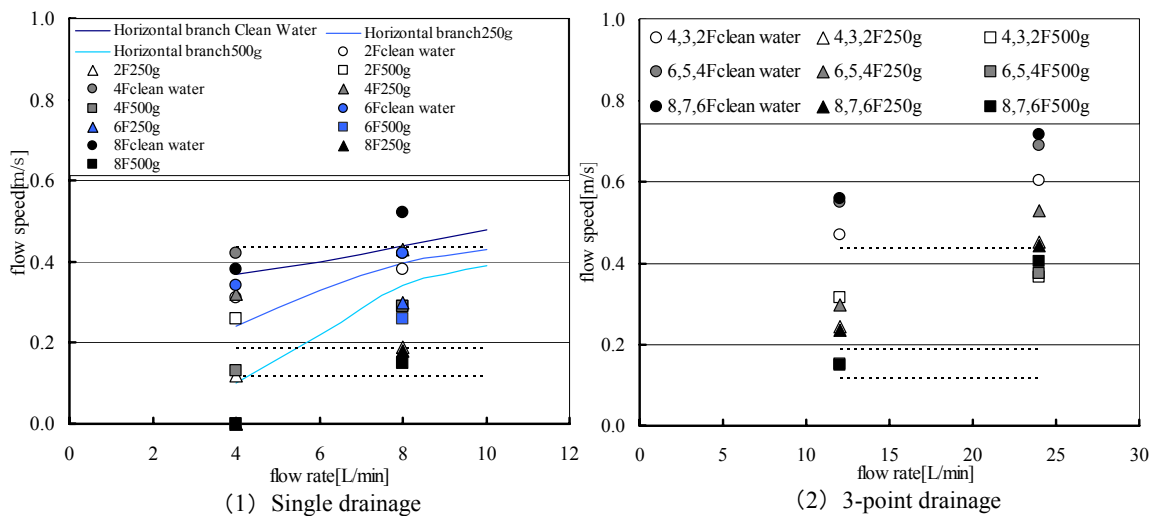


Fig.7 Flow volume of applied water and tip flow rate

Table 3 Pipe flow rates by remnant classification [m/s] (*V_n : n indicates class)

Class II	Horizontal branch	$V_{II} \leq 0.10$
	House drain	$V_{II} \leq 0.12$
Class III	Horizontal branch	$0.10 < V_{III} \leq 0.22$
	House drain	$0.12 < V_{III} \leq 0.19$
Class IV	Horizontal branch	$0.22 < V_{IV} \leq 0.42$
	House drain	$0.19 < V_{IV} \leq 0.44$
Class V	Horizontal branch	$0.42 < V_V$
	House drain	$0.44 < V_V$

3.2 Model conditions for carrying waste sediment

Based on the results acquired in 3.1, F_c , the force required to make class II waste sediment flow was evaluated.

3.2.1 Evaluation of the fully-structured house drain model

1) Effects of sediment areas

Drainwater that flows down along the drainage stack continues to flow into the house drain and accelerates its flow rate for 1 to 2m along the pipework. Whether or not F_c would vary by hydraulic jumps was examined.

Fig.8 shows an example of how the water level is related to F_c when 250g of cabbage waste is drained. With the average flow volume of applied water F_c was measured to be 0.81N at point A and 0.66N at point B, showing only a small discrepancy. It is therefore suggested that effects of hydraulic jumps are insignificant when a small flow volume of water is drained, for instance, from the kitchen sink.

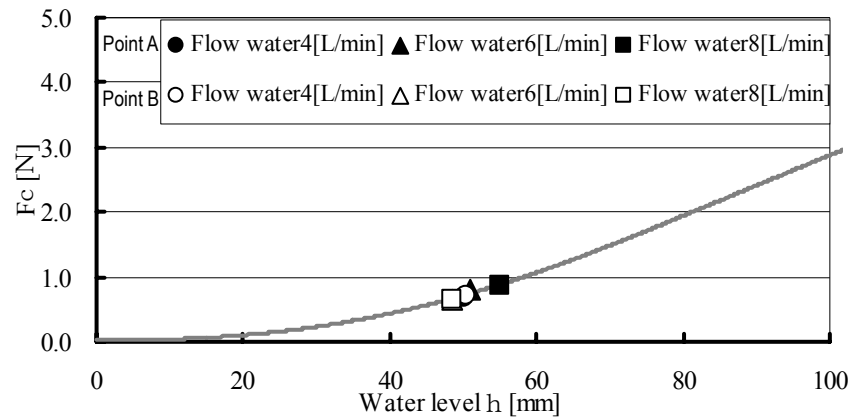


Fig.8 F_c in relation to the points where sediment is created

2) Effects of different pipe diameters

Fig.9 shows how different diameters of the house drain; 75A and 100A may affect F_c and effects of the pipe diameters in comparison. When 250g of kitchen waste typically produced in Japan was accumulated F_c was 0.81N with the 75A diameter and 0.89N with the 100A diameter - almost identical despite the diameter variation. This finding implies that the water level when waste sediment begins to flow is affected by the pipe diameter but the force required for carrying the waste sediment remains unchanged.

Also, based on the results of the carrying performance experiment in 3.1, the certain factors that contributed to causing the class II remnant condition are plotted in the graph. When 250g of typical kitchen waste accumulated as in Fig.5 (2), the final water level of the retained drainwater was approximately 30mm and F_c was approximately 0.23N. It is suspected that because the F_c value was 0.58N less than the F_c value required for carrying waste sediment, the class II remnant condition was created.

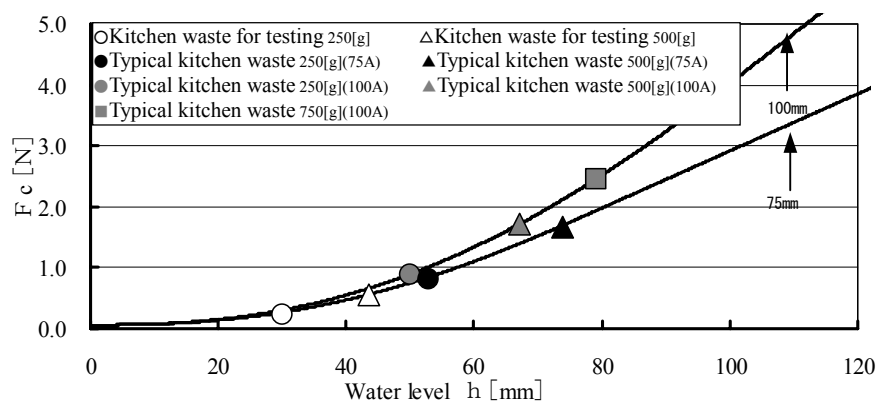


Fig.9 F_c and the diameter of the house drain

3.2.2 Simplified model

1) Effects of hydrostatic pressure

Effects of hydrostatic pressure were examined using the simplified model (Fig.3 (1)). Fig.10 shows the ratio of the water level when damming waste sediment is smoothly drained out and the pipe diameter (water depth ratio) in relation to F_c' which is calculated using formula (1). The average F_c' value calculated for both pipework models is 0.86N with 250g waste, 1.70N with 500g waste and 2.89N with 750g. This confirms that there needs to be a force greater than the above F_c' values created by the increase of hydrostatic pressure to make waste sediment begin to flow along the pipework when a low flow volume of water is drained, as it would be from the kitchen sink.

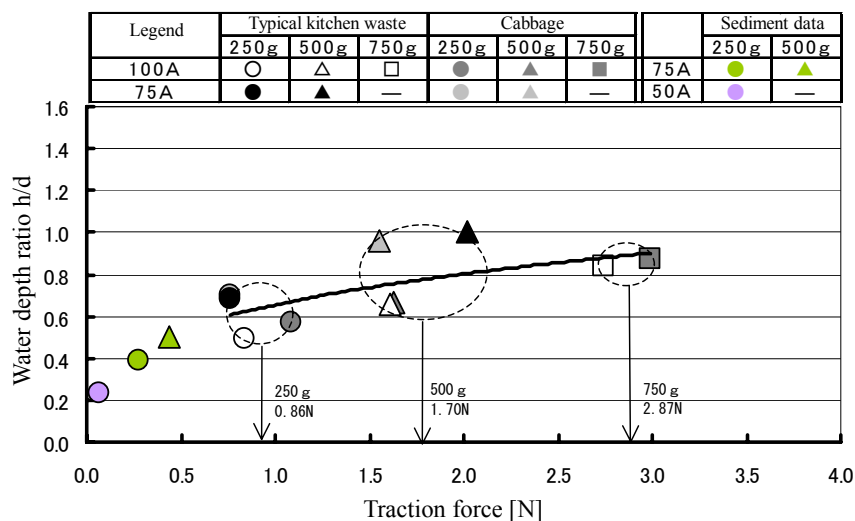


Fig.10 F_c' and water depth ratio

2) Impact of drainwater

The experimentation has so far focused mainly on the examination of F_c which is created by hydrostatic pressure. The next factor to evaluate is the force created by additional water, which is applied to the condition where waste-containing drainwater is retained still in the pipe, to make the waste sediment begin to flow (Fig.3 (2)). Fig.11 shows the typical waveform of water level fluctuation when additional water was applied to the condition where waste-containing drainwater was retained at a water level of 50mm. The additional drainwater collided with the retained drainwater momentarily, increasing the water level, and then began to push the retained drainwater to flow.

The water level when the retained drainwater began to flow is compared to the results of 3.2.2 (1) in Fig.12. where the same examination was carried out without retaining drainwater. There is $\pm 9\%$ discrepancy in the average values acquired in 3.2.2 (1) and through this examination, yet it is clearly indicated that the very similar water level was identified when waste sediment begins to flow in both cases.

It should be noted that the mathematical estimation of f_p , the spreading impact to the waste sediment created by drainwater flowing down the drainage stack, is difficult. Hence, a push-pull gauge was used to measure F_c' values that include f_p values. Although there was a case where colliding drainwater bypassed the waste sediment, it had to be disregarded, as the quantitative estimation of the force of drainwater affecting waste sediment in such a case is very difficult.

Fig.13 summarises the relationship between the water levels measured in Fig.3 (10) and the F_c' values. The F_c' values with consideration of the force created by hydrostatic pressure acquired in (1) and the impact identified in (2) show little discrepancy, giving a fairly good idea what F_c' value is required for carrying waste according to the weight of the sediment. That is to say, when the F_c' value is 0.92N with 205g waste, 1.61N with 500g waste or 2.74N with 750g, it is sufficient to carry waste efficiently.

An example would be when approximately 250g of waste accumulates to cause blockage in the pipe with a diameter of 100A, the temporary application of additional drainwater to create a 52mm water level (water depth ratio: 0.52) will enable the waste sediment to flow.

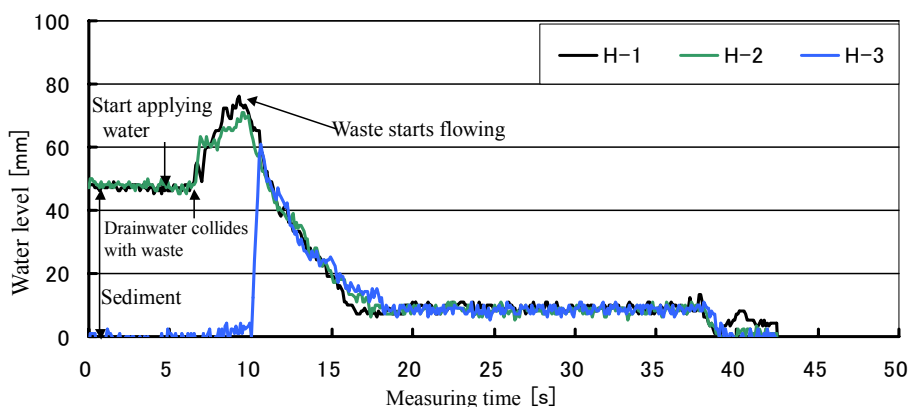


Fig.11 Water level variation
(pipe diameter: 100A, waste: cabbage 500[g], water applied: 20[L/min])

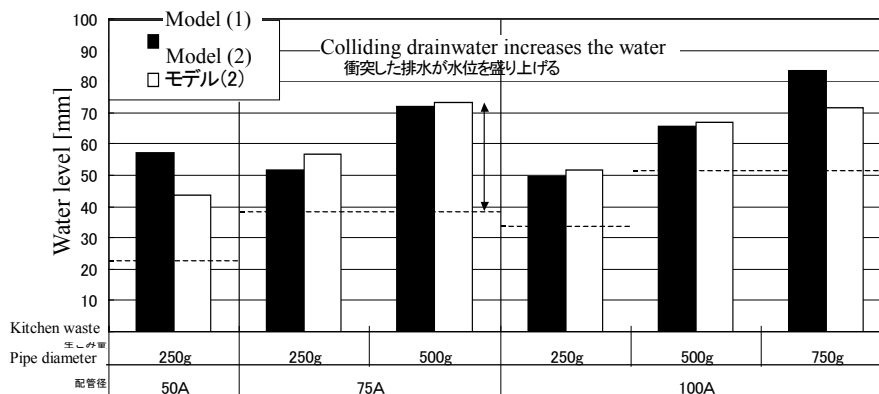


Fig.12 Different water levels between Model (1) and Model (2)

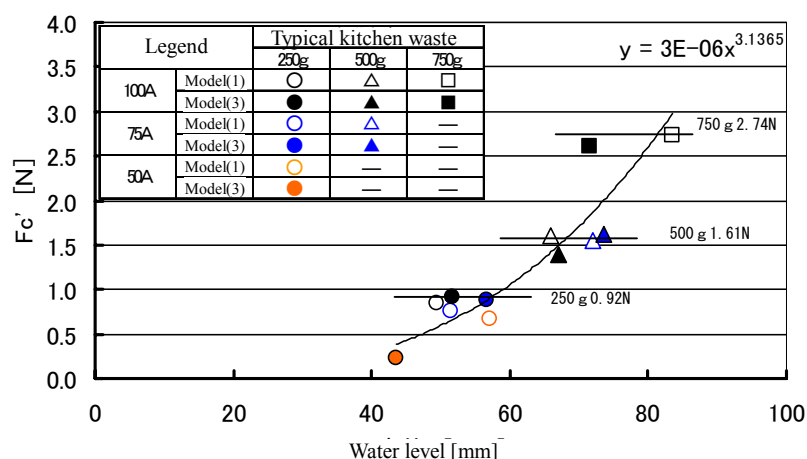


Fig.13 F_c' in relation to the water level per sediment volume

4. Summary

This study has evaluated the carrying performance of the house drain, which is part of a disposer drainage system intended for high-rise apartment buildings, and has discussed the force required to carry ground kitchen waste by constructing pipework models in which waste sediment was created for experimentation. The following is the knowledge acquired through this study:

- 1) The condition of waste remnant in the house drain was identified by classifying it into five types, as in the previous study for the evaluation method of the horizontal fixture drain branch. The relationship between each categorized remnant condition and a corresponding tip flow rate range has been clarified. In comparison to the knowledge acquired about the horizontal fixture drain branch, almost identical carrying performance was identified in both the house drain and the horizontal fixture drain branch.
- 2) Providing that 8L/min of water is applied under normal drainage operation, good carrying performance is more or less ensured by the condition of waste remnant and the flow rate of drainwater. Quantitative data was acquired to demonstrate that the flow volume of 8L/min is adequate.
- 3) A house drain model was constructed to form waste sediment, creating a “damming effect”. The force sufficient to push and carry such waste sediment was estimated according to the volume of sediment. It was confirmed that the impact of downward flowing drainwater is insignificant, which is very similar to the effect by hydrostatic pressure.

References

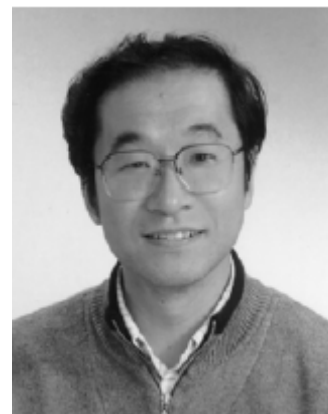
- 1) Yusuke Minami, Masayuki Otsuka: Evaluation of the Horizontal Fixture Branch's Performance to Carry Waste Water Containing Food Waste Disposed of Using a Food Waste Grinder,CIB-W62 Symposium 28th (Iasi, Romania)2002.9
- 2) Yusuke Minami, Masayuki Otsuka ; Study of the Flow Pattern of Ground Food Waste in the Drainage Stack CIB-W62 Symposium 30th(Pails, France) 2004.9
- 3) The Building Center of Japan : Development of recycling kitchen waste using a disposer, 1999
- 4) Japan Sewage Works Association: Performance Criteria for Disposer Sewerage Treatment systems (draft), March 2004
- 5) J A Swaffield & L S Galowin: The Engineered Design of Building Drainage Systems,pp.271~319

Personal data of authors

(1) Yusuke Minami was the graduate student (doctor course) at Graduate School of Architectural department Engineering Kanto Gakuin University. (Until Mar. 2005). He is conducts research on the drainage performance evaluation of the drainage system with food waste disposer grinder (food waste grinder). He works for Sekisui house. Ltd, a hosing maker in Japan, as an engineer in Tokyo.



(2) Masayuki Otsuka is the Professor at Kanto Gakuin University, Department of Architectural Environmental Engineering. He is a members of AIJ (Architectural Institute of Japan) and SHASE (Society of Heating, Air-Conditioning and Sanitary Engineers of Japan) .Current Research interests are performance of plumbing systems, drainage systems with food waste disposers in high-rise apartment houses and drainage piping system for SI (support and infill) housing.



A comparison of modelling techniques and supporting data for the prediction of air pressure changes in building drainage and ventilation systems

Dr L.B. Jack¹, Professor C. Cheng², Dr W.H. Lu³

1. l.b.jack@hw.ac.uk

2. CCL@mail.ntust.edu.tw

3. sammy@abri.gov.tw

1. Drainage Research Group, Heriot-Watt University, Edinburgh, Scotland.

2. National Taiwan University of Science and Technology, Taipei, Taiwan

3. Architecture and Building Research Institute, Ministry of the Interior, Taiwan

Abstract

The need to understand both the steady-state and transient-derived pressure regime established within the building drainage and ventilation system during and subsequent to appliance discharge is a fundamental pre-requisite for good design practice. The local pressure established at the appliance-trap interface will ultimately determine trap (water) retention and is thus influential in determining the overall integrity offered by the system in protecting against cross contamination or the ingress of infection. The network response cast in terms of steady-state pressures currently underpins many of the codes and regulatory documents used to establish design specification and operational limits. However, in order to better reflect system response, transient pressures and their impact need to be better understood. Accurately reflecting the flow mechanisms that determine the generation of air pressure transients and their associated propagation and interaction with system components demands the application of a numerical simulation technique that, in turn, requires a definition of the range of factors that influence pressure and flow throughout the network. Internationally however, there are few research groups for whom a major theme within their work is the characterisation of such parameters. With the aim of establishing the extent of congruency of, and the potential for synergy between, existing bodies of research, this paper presents an extensive comparison of experimental data and simulation predictions that have previously been established independently in Taiwan and in Scotland. In doing so, the paper identifies the degree of validation facilitated, and identifies how descriptive algorithms might be enhanced to yield best benefit for system designers.

Keywords: building drainage and ventilation systems, numerical modelling, research

1. Introduction

Ensuring effective waste removal whilst maintaining appliance trap seal retention is a fundamental pre-requisite underpinning the operation of any building drainage system. However, designing systems that meet with this apparently simple concept can often be difficult given the complexity of the user- and system-driven operating conditions that give rise to an inherently unsteady pressure and airflow regime throughout the network. It is clear that since the first use in the UK of formal piped drainage systems, there has been recognition of the potential impact of airflow-induced pressure excursions from atmospheric. This recognition is evidenced by the heavily vented design solutions adopted from around 1880. Importantly however, by the 1950s, the role of research and the application of fluid mechanics theory to system flow analysis had become well-established. For example, the move from the cumbersome two-pipe system through to, in the 1960s, the widespread use of the single stack, was facilitated primarily by work undertaken at the UK Building Research Establishment^[1,2] that detailed pressure limits based on load and capacity predictions earlier defined in the US by Hunter^[3] and Wyly and Eaton^[4]. Similarly, in Taiwan, there has been recognition of work undertaken in the UK and in Japan^[5,6] that, using loading figures from the US National Plumbing Code (NPC) has also facilitated the widespread use, in buildings of up to around 30 storeys, of the single stack design. Further, a review of systems installed internationally readily yields an indication of the range of new pipework and appliance solutions now commonly adopted, and thus reiterates how subsequent research has underpinned design and technological advancement.

There remain, however, many challenges that result in the need for ongoing research. These include: the continuing and increasingly important need to conserve water; the design of ultra high-rise buildings; the requirement for systems to incorporate components designed to alleviate the detrimental impacts of pressure excursions; and the requirement for systems to accommodate changing sanitary appliances, user needs and user products. In addition, trap seal retention under a range of operational parameters that not only encompasses expected flow loading conditions but that also introduces wider user-induced aspects, has been shown to be a vital design precept to prevent odour ingress and infection spread. Many of the codes of practice and regulations that are used internationally to specify systems are essentially based upon a theoretical responsive pressure regime that may be described as steady-state. It is now well-recognised however, that relatively rapid changes in operating conditions introduce air pressure transients that propagate throughout the network. These transients affect the local system-trap interface pressure, and, ultimately, determine trap seal retention. The ability to simulate this propagation has not only led to a better understanding of the overall system response, but has also facilitated the development, design, installation and successful use of distributed pressure control devices.

Given the well-established role of research in enhancing the prediction of system response and integrity, and ultimately therefore also design and efficacy, the importance of leading-edge research, collaboration and dissemination is clear.

2. Background for collaborative research

Of the limited number of research groups worldwide that have the resources to develop system pressure prediction techniques, only a small proportion demonstrate a degree of compatibility in approach that might allow model enhancement through the identification of methodological synergies. Since early 2004, the authors have endeavored to align and develop datasets and research findings that could potentially offer advancement in the simulation and prediction of the pressure response of building drainage and ventilation systems. This paper presents an overview of the collaborative work undertaken by the Drainage Research Group at Heriot-Watt University (HWU), the National Taiwan University of Science and Technology (NTUST) and the Architecture and Building Research Institute (ABRI) in Taiwan, and presents a comparison of data with the dual aim of validating the accuracy of the numerical models developed to date, and, importantly, identifying model simulation and prediction components that require further refinement.

The research groups with which the authors are, or have been, affiliated, have, over the past 15-20 years, addressed a number of issues with specific relevance to the prediction of the pressure response of building drainage and ventilation systems. From Heriot-Watt, these may be summarised, chronologically, as follows -

- The initial development of the numerical simulation model, AIRNET, that is based on the application of the Method of Characteristics (MoC) finite difference technique to the underpinning equations of flow continuity and momentum, and that facilitates the prediction of the transient airflow and pressure response of building drainage and ventilation systems^[7]. (AIRNET is discussed in more detail below.)
- The inclusion within the numerical model, AIRNET, of an airflow ‘driver’. This initial approach induced air movement through the network by a mechanism analogous to that of a fan located at the base of the stack^[8]. Additionally, the definition of boundary condition equations, as necessary to drive any MoC-based simulation, and that describe the fundamental components of the drainage network were introduced to the simulation.
- The definition of both positive and negative pressure excursions from atmospheric when influenced by changes in water downflow, entrained airflow and pipe roughness, all for varying wet stack heights. Additionally, these findings facilitated the development of a pseudo friction factor term that operates across the wet stack height and using the air-water velocity differential present at the air-core annular water flow interface, introduces a distributed traction force that negates the need for the use of the ‘single point’ fan analogy. Importantly, defining this traction as the system ‘driver’ not only allows entrained airflow and corresponding pressures to be modelled, but also enables the simulation of both single and combined downflows in different sections of the wet stack^[9].

- Recognition of the effect of detergent dosed discharge on the pressure response of the system. Laboratory results confirm that the use of anionic surfactants (and in particular those detergents that contain foaming agents, for example, shampoos and washing-up liquid) tend to *increase* suction pressure, and that the use of cationic surfactants (for example, fabric softener and hair conditioner) *decrease* suction pressure. Investigations indicate that these changes arise as a direct result of a variation in surface tension acting at the water/air core boundary^[10]. Importantly, site investigations have also confirmed that foaming agents subject to a turbulent mixing effect induced at the base of the stack, result in the generation of a large volume of suds that, through time, form a rising column of foam that restricts entrained airflow and that therefore significantly alters the overall system pressure response.

From a Taiwanese perspective, research developments may be summarised as:

- Experimental work on a 30m high tower at Meiji University, Japan, that established an early prediction model for air pressure distribution within a drainage stack.
- The definition of four zones comprising the overall pressure response of the system subject to steady water inflow. These four zones identify: pressure loss in the dry stack; the concentrated pressure loss generated at an active branch connection; pressure regain in the constant (water downflow) velocity section of the wet stack; and positive pressure as the entrained airflow is impeded at the stack base before recovering to atmospheric in the sewer connection pipework^[5,6].
- The determination, using regression functions operating on stack height and discharge flow rate, of 'reduction ratios' in peak pressure predictions. These ratios are based upon a comparison of maximum pressure levels within vented networks with those measured when the rig is curtailed to represent a single stack system^[11]. It was found that reduction ratios were more readily identified for peak negative pressures, whereas those for positive pressure demonstrated a significant degree of variability.

Although the focus of this paper lies with research undertaken at Heriot-Watt and at NTUST, it is worth noting at this point, the system performance indicators established throughout the 1990s by the UK Building Research Establishment and the empirical investigations jointly undertaken by the University of Passo Fundo and the Escola Politécnica of the University of São Paulo^[12]. Output from these research groups has clearly advanced knowledge and understanding in the characterisation of the performance of building drainage and ventilation systems, and has contributed to the development of the prediction techniques discussed herein.

3. Basis for Comparative Study

Although a fundamental component of the collaborative research initiated between Heriot-Watt University and NTUST was the comparison of an extensive range of datasets

established independently following monitoring of both laboratory-based and site-installed systems, the differences in test and network parameters ie roughness, diameter, water downflow rate and entrained air flow rate, meant that a *direct* comparison was not possible. However, comparisons *are* made possible through the use of the AIRNET simulation model, when set to run with the system and operating parameters descriptive of the experimental tower used at NTUST.

As noted above, AIRNET is based on the analysis of the full equations of continuity and momentum. For the simulation of air pressure transients in building drainage systems, these equations are cast in terms of airflow velocity and wave propagation speed, and are transformed, via the Method of Characteristics, to give a pair of total differential equations (C^+ and C^- ‘characteristics’) solvable by finite difference methods that link the conditions adjacent to any given node to those one time step in the future, Figure 1. Figure 1 also illustrates how compliance with the Courant Criterion is embedded within the approach to define time step stability by linking the nodal separation distance to the local flow and acoustic velocity variables. The need for boundary condition equations to supplement the appropriate ‘Characteristic’ to yield solvable simultaneous equations is also apparent. Such boundaries may be described as either passive or active. Passive boundary conditions are defined by equations independent of time, for example, branch connections or pipe terminations, whereas active boundary conditions are time dependent, for example, appliance discharge.

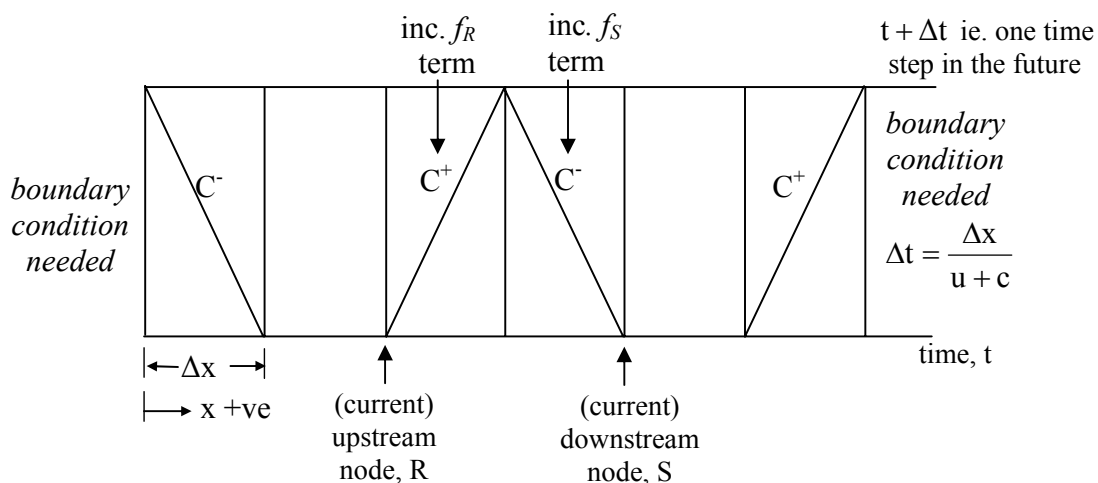


Figure 1 Finite difference grid used within AIRNET, illustrating the use of the friction factor term and the need the definition of for boundary conditions equations

Worth noting at this point is the inclusion of the friction factor term, f , that operates within each of the C^+ and C^- characteristic equations. In the dry stack, the friction term is based upon the use of the Colebrook White formula, whereas in the wet stack, it acts at the annular downflow/central air core interface as the air flow driver or ‘traction force’, mentioned in Section 2 above.

When set to run with descriptors representative of the NTUST experimental tower, AIRNET will hence yield output data that can be compared with that measured using pressure sensors located as shown in Figure 2. Figure 2 also shows how the NTUST tower is approximately 38 metres high and comprises two vertical stacks – one a main drainage stack of 100mm diameter, connected to a second 75mm diameter ventilation stack using 50mm loop vents. Pipework is acrylic and is served by a re-circulatory water supply, with airflow measured in the upper region of the stack using a hot wire anemometer. Although the equipment facilitates water inflow control across 11 floors, measurements were restricted, in this study, to discharge from levels 6 to 12.

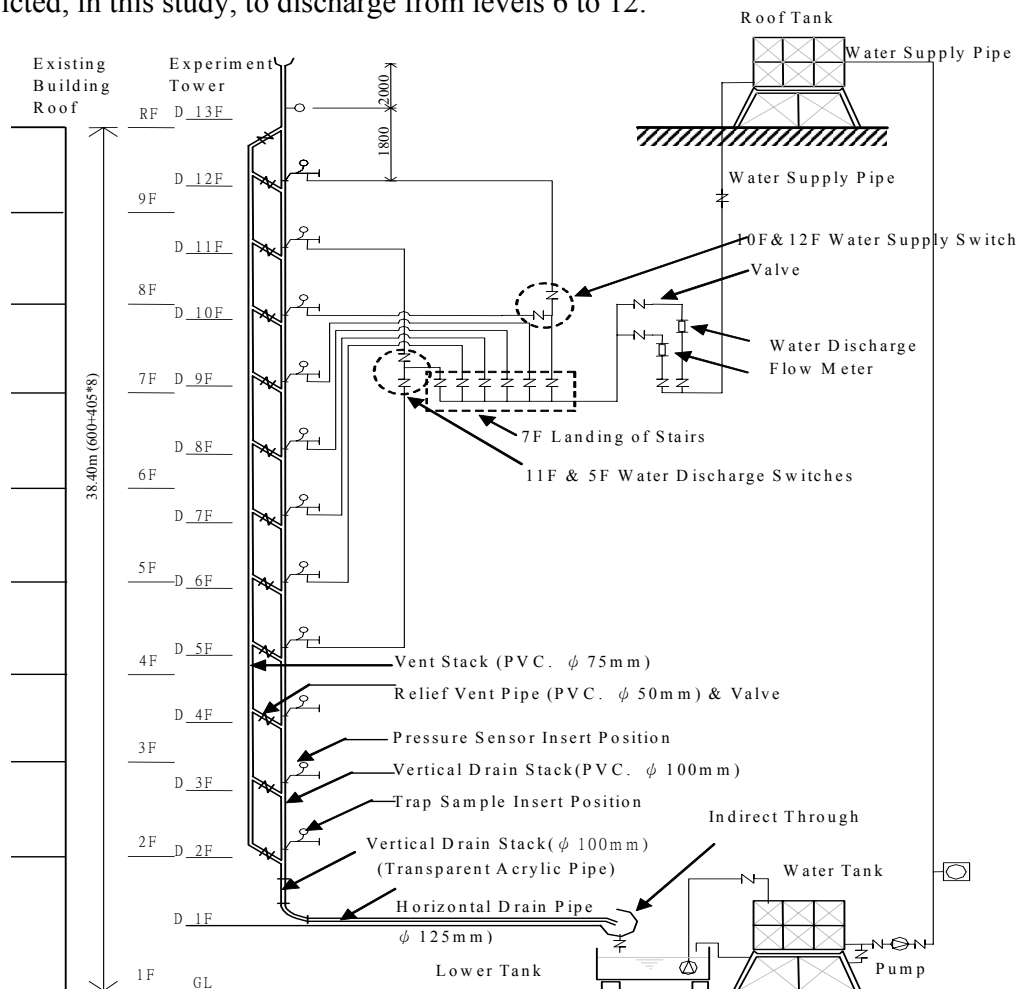


Figure 2 Schematic diagram of the experimental tower used at NTUST

Importantly, the inclusion of ball valves on all ventilation cross-connections allows the rig to be adapted to yield network designs with varying degrees of ventilation provision. The configurations monitored to establish peak pressure regression coefficients, discussed in section 2 above, are shown in Figure 3. In addition to the dimensions presented in Figure 2, these arrangements yield the descriptive parameters required as input data by the AIRNET simulation model.

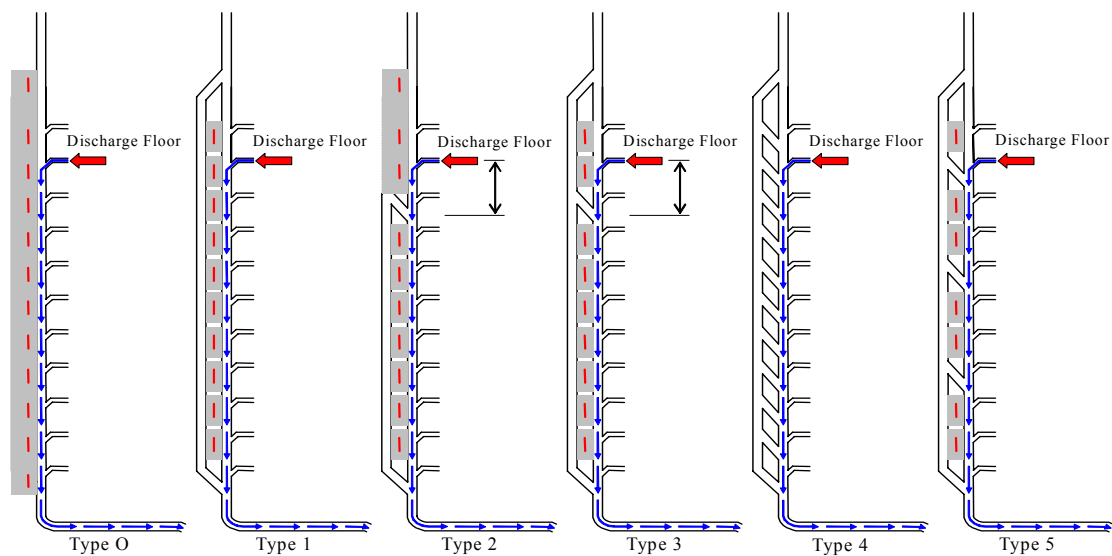


Figure 3 Ventilation configurations yielding Design Types ‘0-5’, for comparative purposes

4. Results

Comparisons between the output from the AIRNET simulation model and NTUST measured data were undertaken across the range of six vent configurations (possible through adaptation of the experimental rig and referred to as Types 0-5), four discharge flow rates (1-4 litres/second) and seven input levels (Floors 6-12). Pressure profile information and peak negative pressure levels were selected as indicators of simulation model/measured data congruency, and results revealed that output generally demonstrated a high degree of correlation. Additionally, the extensive datasets generated readily facilitated disaggregation to yield important information regarding specific model components that directly influence the prediction of network pressure response.

Figure 4 presents two examples of profile comparisons, where Figure 4a shows that for Type 0 (ie single stack) with a 4l/sec inflow from Floor 8, and Figure 4b that for Type 1 with a 4l/sec inflow from Floor 9. The degree of congruency is clear, as is the correlation between specific profile components.

Both Figures 4a and 4b reveal how the AIRNET representation of the concentrated increase in negative pressure that occurs at the ‘active’ branch connection incorporates a localised effect, whereas the NTUST measured data demonstrates a junction loss that has an associated (vertical) application distance. It will be appreciated, intuitively, that junctions will exhibit a ‘development’ length prior to the stabilisation of water and airflow velocity within the wet stack. When viewed as a determinant in establishing the gradient of the pressure regain in the wet stack, the importance of the accurate simulation of flow from a

discharge branch becomes clear, and this comparison thus identifies an area for the future model enhancement.

Within AIRNET, the pressure regain in the wet stack is determined using the pseudo friction factor term discussed in section 2 and illustrated in Figure 1, above. The almost parallel traces exhibited within the relevant stack sections, as shown in both Figures 4a and 4b, corroborate the accuracy of this approach in which the water-air velocity differential term allows the simulation of both single and multiple discharge flows.

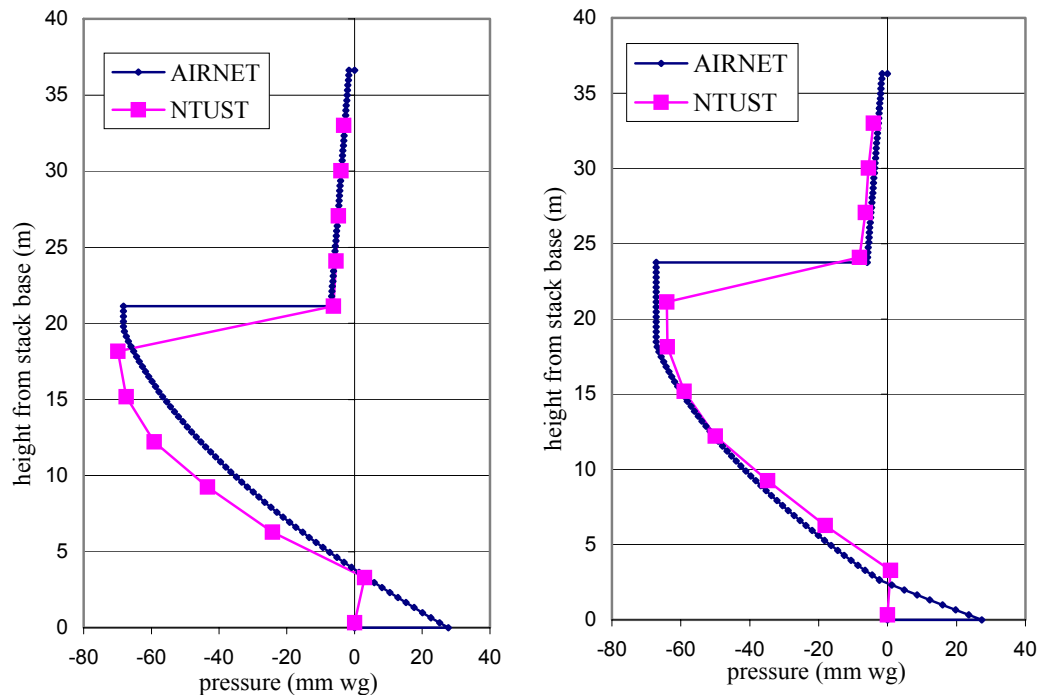


Figure 4 (a and b) Pressure profile comparison for Type 0, 4l/s, Fl 8 and Type 1, 4l/s, Fl 9

Although at first glance, it would appear that the AIRNET simulation overestimates the positive pressure induced in the lower stack region, it should be remembered that the NTUST data is representative of steady-state conditions for a specified water downflow and single point discharge. Recent research at Heriot-Watt has shown that the intermittent behaviour of the water curtain formed at the stack base results in an impediment to entrained airflow such that positive air pressure *transients* are propagated upwards through the network. These short-duration peak pressure levels are often difficult to monitor and are often obscured by lower magnitude steady-state measurements^[13].

With the exception of Type 0 (the single stack system) and Type 4 (the heavily vented design), all profiles predicted by the AIRNET model demonstrated a slightly higher degree of pressure reduction in response to the inclusion of vent pipes. This is thought to occur as a result of the simulation of unobstructed vent provision, whereas, in practice, water curtain effects, generated by the annular flow in the stack, at 'inactive' branch connections will

introduce an airflow loss coefficient. This comparison thus also identifies an area for future model enhancement.

Direct comparisons of peak negative pressures also correlate well – a finding that is important, given that limits of excursions from atmospheric pressure provide a key indicator of the efficacy of system design. When the data is categorised by ‘Type’ ie by vent arrangement, the correlation between measured and predicted data is clear, Figure 5.

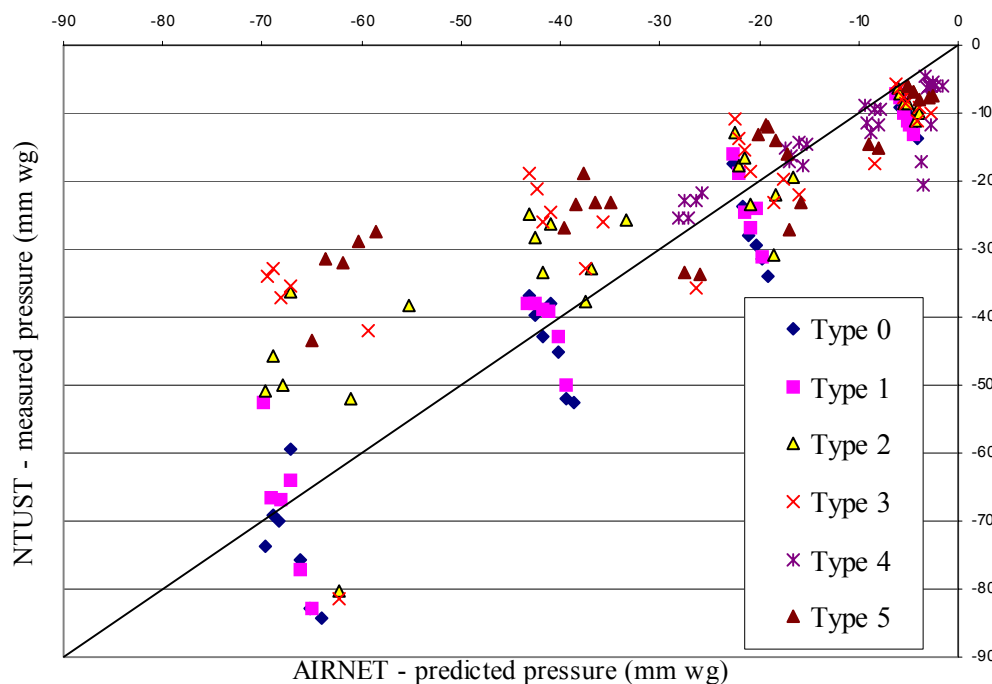


Figure 5 Direct comparison of AIRNET output data & NTUST measured data – by ‘Type’

Closer inspection shows that the degree of congruency for Types 1 and 4 are excellent. For Types 2, 3 and 5, the AIRNET model slightly overestimates peak pressure values, whereas for Type 0, pressures are marginally underestimated. Interestingly, the inclusion of the 75mm diameter ventilation pipe in Type 1 has an almost negligible impact upon the peak negative pressure and only a small impact upon the stack-base positive pressure when compared to those values for Type 0. Conversely, the significant reduction in peak pressure values for the heavily vented Type 4 is clear.

When categorised by ‘input level’ - essentially a representation of wet stack height - it can be observed that correlation for input at floors 8 to 12 are all excellent, Figure 6. When inflow is introduced at levels 6 and 7, the AIRNET simulation model slightly overestimates peak pressure levels. Interestingly, the difference in scale between the pressures arising from the extremes of level 6 and level 12 input are not significantly different. This suggests that the impact of any increase in traction, and in turn entrained airflow, due to the increased length of the water column is not necessarily directly reflected in a corresponding increase in peak negative pressure.

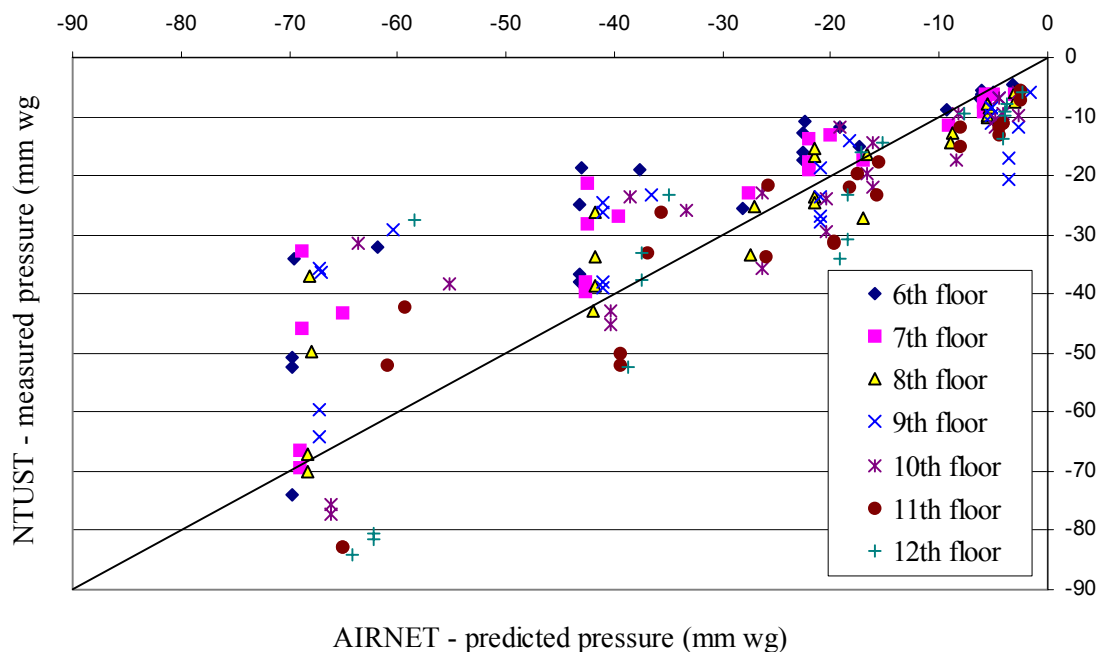


Figure 6 Direct comparison of AIRNET output data & NTUST measured data – by ‘Floor’

The separation of peak pressure ‘groups’ is clearest when data is categorised by input flow rate, Figure 7. The impact of increasing the water inflow to the system, and of the ventilation relief provided by different system configurations, is clear. As noted above, at the lowest control water flow rate of 1 l/s, AIRNET clearly underestimates peak pressure – although these values all fall within the limited and ‘low-end’ range 0-15 mm wg.

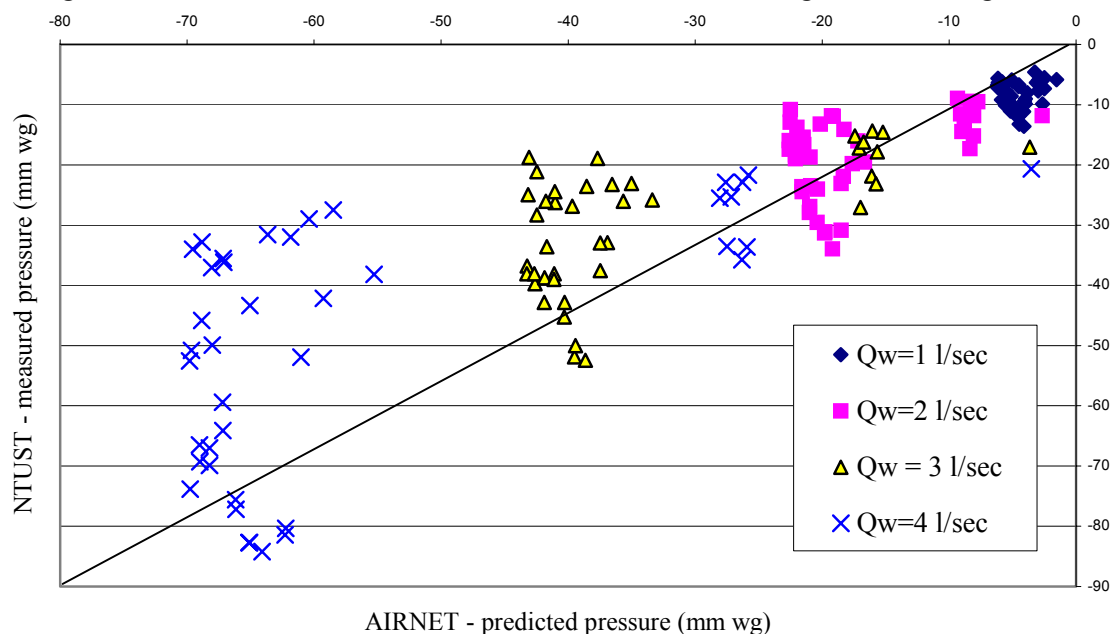


Figure 7 Direct comparison of AIRNET output data & NTUST measured data – by ‘Flow rate’

The correlation at 2l/s is excellent, although at 3 and 4 l/sec, AIRNET slightly overestimates peak pressures. This is thought to occur as a function of the way in which the water curtain formed at the 'active' branch junction is defined. It has been found that the representation of this concentrated loss is exceptionally sensitive to minor (and often otherwise seemingly negligible) changes in pipe and flow parameters, thus re-iterating the importance of the ability to accurately model flow at branch-stack junctions.

5. Conclusion

The extensive comparison of data presented above has clearly provided validation of the pressure response predictions facilitated through the use of the AIRNET model and the robust nature of the data gathered using the experimental tower located at NTUST. Examining the results of the study by 'type', 'wet stack height' and 'water flow rate' categories, has provided important information on simulation aspects that are both robust and accurate as well as those that require further refinement. By disaggregating datasets, this examination also begins to reveal the numerical modelling components that are not only fundamental to the accurate prediction of system pressures but that may also be sensitive to small changes in dimension or operational descriptors. More generally, this collaborative study has been important in establishing how empirical data supporting two prediction techniques established independently in the UK and in Taiwan have been shown to be compatible and robust, and how this clearly establishes the potential for significant future development.

6. Acknowledgements

The authors acknowledge the support for this collaborative work, kindly awarded by the Royal Society of Edinburgh and National Science Council of Taiwan.

7. References

1. Wise A.F.E., 'One Pipe Plumbing – Some Recent Experiments at the Building Research station', Journal IPHE, London, No. 51, 1952.
2. Wise A.F.E and Croft J., 'Investigations of single stack drainage for multi-storey flats', Paper presented to the Royal Sanitary Institute, London, 1954.
3. Hunter, R.B., 'Minimum requirements for plumbing', US Department of Commerce 1924 Plumbing Code Report, 1924.
4. Wyly R.S., and Eaton H.N., 'Capacity of stacks in sanitary drainage systems for buildings', US Department of Commerce, National Bureau of Standards, Monograph 3, July 1961.
5. Ohtsuka M. and Saito H., 'Basic study on performance test and theoretical calculation system of drainage pipe network', Part 2, Journal of SHASE, No 38, pp115-133, Japan, 1988.
6. Cheng-Li C., Kamata M., Kurabuchi T. and Sakaue K., 'Study on pressure distribution of drainage stack in high-rise apartment houses', CIBW62 International Symposium on Water Supply and Drainage for Buildings, Switzerland, September 1996.
7. Swaffield J.A. and McDougall J.A., Designing drainage and associated ventilation networks for buildings, Research Focus, No 27, November, 1996.
8. Swaffield J. A. & Campbell D. P., 'The simulation of air pressure propagation in building drainage and vent systems', Building & Environment 30, 115-127, 1995.

9. Jack L.B. 'Developments in the Definition of Fluid Traction Forces within Building Drainage Vent Systems', Building Services Engineering Research & Technology, Volume 20, Number 4, pp266-273, 2000.
10. Campbell D.P. and MacLeod K.D., 'Detergency in soil and vent pipe (SVP) systems', Building Services Engineering Research and Technology, Volume 21(1), 2000.
11. Lu W.H., Cheng C.L., Shen M.D., 'An empirical approach to peak air pressure on 2-pipes vertical drainage stack', CIBW62 International Symposium on Water Supply and Drainage for Buildings, Paris, September 2004.
12. Fernandes V.M.C and Gonçalves O.M., 'limits for use of vent elements in building drainage systems considering the risks of infection spread by means of water-seal behavior and integrity: the case of Brazilian systems', Building Services Engineering Research and Technology, Volume 27 (2), 2006.
13. Jack L.B., Swaffield J.A. and Filsell S. 'Identification of potential contamination routes and associated prediction of cross flows in building drainage and ventilation systems', CIBW62 Symposium, Paris, September 2004.

8. Presentation of Authors

Dr Lynne Jack is a Senior Lecturer in the School of the Built Environment and has been a member of the Drainage Research Group at Heriot-Watt University since 1993. Her research interests include the measurement and simulation of air pressure transient propagation in building drainage ventilation systems.



Cheng-Li Cheng is the Professor at National Taiwan University of Science and Technology, Department of Architecture. He is a researcher and published widely on a range of water supply and drainage in building. Currently he also acts as referee of Taiwan Green Building Evaluation Committee and Nation Building Code Review Committee.



Lu Wen-Hung is an associate researcher of the Architecture & Building Research Institute, Ministry of the Interior, R.O.C. Dr Lu graduated with a PhD from the National Taiwan University of Science and Technology, and his research focuses on drainage systems for buildings, and energy conservation in the specification of building materials.



The transport of deformable solids at low flush volumes within building drainage networks.

J.A. Swaffield (1) and J.A. McDougall, (2)

(1) j.a.swaffield@hw.ac.uk

(2) j.a.mcdougall@sbe.hw.ac.uk

(1, 2) School of the Built Environment, Heriot Watt University, Edinburgh, Scotland.

Abstract.

Water conservation will become a design requirement in the provision of new build in response to both demographics and climate change. Measures to reduce per capita water usage in both domestic and commercial buildings will reduce disproportionately the flow available to remove waste solids flushed into branch drains within or close to the building. There is a need to fully understand the mechanisms of solid transport close to the head of the network where solid transport takes place within an attenuating discharge flow and to provide design guidance.

Extensive laboratory research, including recent dual flush tissue transport results are presented to identify a suitable model for deformable solid transport. The results of these programmes have been confirmed by simulation models developed independently that in turn provide the basis for predicting the capability of low flush volume and dual flush w.c.s to transport deformable solids over acceptable lengths of drain within or close to the building. These simulations are available as assessment tools to aid system design and the development of codes and regulations recognising the importance of waste removal within a water conservation conscious environment.

Keywords

Water conservation, solid transport, attenuating flows.

1. The impact of water conservation on building drainage design.

The 1996 report of the House of Commons Environment Committee¹ identified the w.c. as the major cause of water consumption and recommended that '*reducing w.c. flush volume is a priority (that) could save 10% of water usage*'. Such savings would be a valuable contribution to offsetting the predicted effects of climate change. The committee recommended the re-introduction of a dual flush w.c. operation to provide a lower flush volume to remove urine and tissue waste, replicating Australian

experience. The committee's views were supported by water use data^{2,3,4} indicating that w.c. flushing in domestic applications absorbed 23 to 32% of domestic potable water; in commercial applications some 60% was used for w.c. and urinal flushing.

Following the Environment Committee's report the 1999 Water Regulations⁵ for England and Wales reduced w.c. flush volume to a maximum of 6 litres with dual flush at a volume not to exceed 2/3rds of the full flush – this flexibility to allow lower w.c. flush volumes to be used. Current concerns as to water availability to support major UK housing projects imply that the Environment Committee's views remain relevant as shown by the formation of a Water Saving Group chaired by a government minister to deliver the government's commitment *'to create a water saving body with the remit to cut water usage and encourage householders to use water more wisely'*⁶.

While water conservation remains a prime objective in the design and provision of both domestic and commercial building infrastructures, it is also necessary to ensure that reduced water usage does not exacerbate other drainage system issues, such as satisfactory drain cleansing in the smaller bore branches within the building envelope. While water conservation aims to reduce usage, new build proposals and changes in demography imply that overall sewer flows will not fall as steeply as the local flows within the building envelope. The governmental review of the Affordability and Supply of Housing⁷ confirms that demographic changes will impact the occupation norms for the UK *'...there will be a major increase in single person households which are projected to make up 39% of all households by 2026 compared to only 27% in 2001'* – a 50% increase. In-dwelling water use may decrease but as the overall number of dwellings is set to increase by 4.8 million by 2026, sewer flows may not decrease. Thus the impact of appliance re-design to reduce water usage will have a disproportionate effect close to the building where the flow conditions are also at their most complex as the appliance discharge wave attenuates. This reduction in peak flow conditions, accompanied by a 'spreading' of the wave is well known⁸ and reduces the transport capability of the flush wave. Further downstream the sewer flows tend to be quasi-steady so that the flow conditions are simplified and do not require unsteady free surface flow analysis. Satisfactory waste transport in the unsteady flow regime in the upper reaches of the system remains a concern, particularly as w.c. flush volumes are progressively reduced and the use of dual flush w.c.s increases. These considerations are further exacerbated by changes in hygiene, in particular a movement towards increased usage of disposable products such as surface wipes that are often flushed.

2. Waste transport mechanisms in attenuating discharge flows.

The successful transport of faecal and other sanitary waste from the discharging appliance to the sewer, or the first junction of joining flows, remains a pre-requisite of w.c. and drainage system design. Reductions in flush volume, brought about by the increasing importance of water conservation, and an increase in the usage of convenient sanitary items, such as chemically impregnated surface wipes and other personal products, has ensured that solid transport has remained an important system criterion. By definition hygiene products discharged to the building drainage system are deformable and will change shape in response to the fluid forces acting and the dimensions of the carrying drain or branch. Faecal solids will also be deformable to some degree, breaking up of stools being normally encountered.

The mechanism of deformable solid transport was identified during studies of hospital interfloor drainage networks in the 1970s⁹. Solid transport downstream of a discharging w.c. displays three distinct zones; Zone 1 where the high initial solid velocity depends on its position in the w.c. discharge; Zone 2, typically from 2-4 m onwards, where frictional forces lead to a sustained deceleration and finally a tranquil Zone 3 where continued solid movement is controlled by hydrostatic forces emanating from dammed water behind the solid and leakage past the solid. This final zone may extend for some distance, however immediate solid deposition may occur due to passage over a coupling or junction that interrupts the sliding action characterising this zone. Increased use of disposable sanitary products in domestic and commercial buildings led the Association of Sanitary Protection Manufacturers to develop a test criterion for flushable products in the early 1980s¹⁰. This standard, still in use, recognises the need to ensure both w.c. discharge and subsequent drain transport for a distance sufficient to reach junctions with other appliance flows.

Modelling solid transport also requires simulation techniques to represent both the attenuation of an appliance discharge during its passage along a branch drain and the interaction between solids in transport and the surrounding flow. These models are at their most challenging in dealing with the attenuating free surface flow generated by appliance discharge and only found in the upper reaches of the drainage network. Models dealing with the transport of solids in the quasi-steady flow encountered in sewer systems are somewhat simplistic by comparison as the rate of change of accompanying flow will be low and the flow depth surrounding the solid will be greater than in the building network. The method of characteristics represents a suitable simulation for wave attenuation in free surface unsteady flow and allows solids in transport to be treated as moving boundaries within the branch drain^{11,12}.

3. Dependency of deformable solid transport on both appliance, waste solid and drain parameters.

The transport of deformable solids in free surface unsteady flow within small bore building drainage networks, diameters from 80 – 150 mm, is characterised by the solid taking up the cross sectional shape of the drain, resulting in a damming of discharge water behind the solid and a leakage flow past it. As the solid decelerates, the depth behind the solid and the leakage flow increase. **Figure 1** illustrates this sequence of events for a solid travelling at close to the velocity of the accompanying water and displaying minimal depth differential, and a solid close to deposition where the solid to water velocity decrement is a maximum, as is the depth differential.

The increased usage of flushable sanitary products in the late 1970s led the Association of Sanitary Protection Manufacturers (ASPM) to develop an industry standard for flushability, still in current use. In order to ensure statistically valid results the standard defines a 100 flush test series. A sanitary product placed in the w.c. must leave the w.c. on the first flush and travel 10 m along a 100 mm diameter branch drain, set at a slope of 1/80, 94 times out of 100. A test sample failing to leave the w.c. on the first flush must be discharged on a second flush to avoid failure. This was the first test to introduce the concept of both appliance and drainline carry performance.

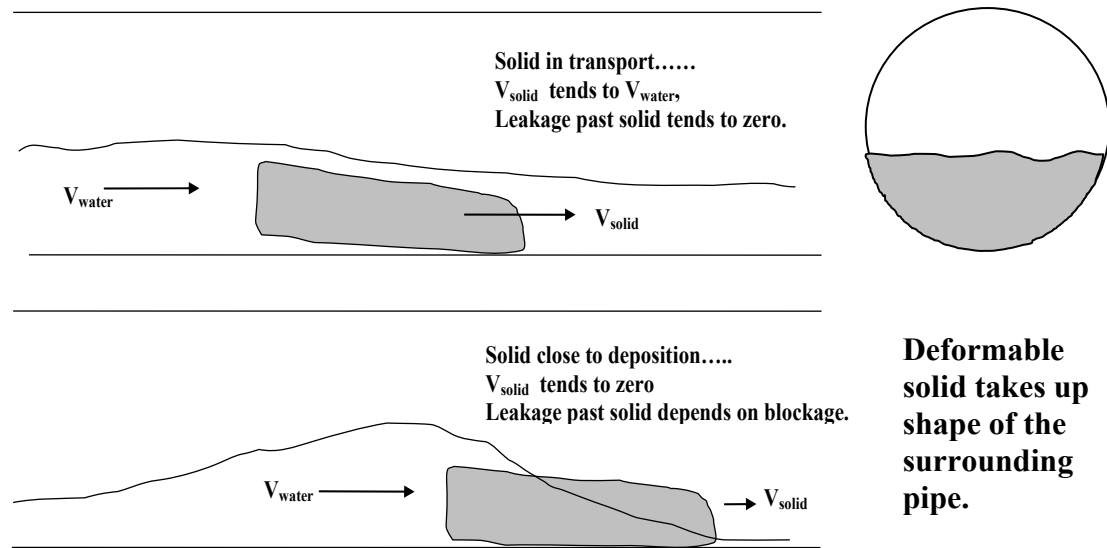


Figure 1. Deformable solid transport in branch drain free surface flow, illustrating the effect of the surrounding flow conditions on solid transport velocity.

The extensive testing of commercially available sanitary products provided a source of data to define the transport model. Recent developments in data analysis have allowed this data to be re-assessed to identify the impact on solid transport of variations in system and solid parameters. Work by Wakelin^{9,13} proposed a relationship linking solid velocity to both pipe slope and distance travelled,

$$V_{\text{SOL}} = C_1 - C_2 \sqrt{\frac{L}{G}} \quad (1)$$

and at deposition, as the solid velocity goes to zero,

$$\sqrt{\frac{L_{\text{deposition}}}{G}} = \frac{C_1}{C_2} = C_3 \quad (2)$$

The $C_{1,2}$ coefficients were dependent upon product dimensions - length, width and thickness, l, w, t , and mass, m , wet and dry, and branch diameter, d , and gradient, S . Water density, ρ_w , the actual flush volume, F , and the volume discharged behind the solid, F_B , are also relevant. Reducing flush volume, analogous to a lower dual flush capability, introduces the w.c. design flush volume, F_{wc} as a variable. Gravitational acceleration g is required as the flow is free surface. The transport coefficients $C_{1,2}$, may thus be expected to be functions of

$$C_{1 \text{ or } 2} = \phi(l, w, t, m_{\text{dry}}, m_{\text{saturated}}, d, S, F, F_B, F_{w.c.}, g, \rho_{\text{water}}) \quad (3)$$

Buckingham's π Theorem suggests that as these variables display dimensions of Mass, Length and Time, the 13 variables may be transformed into 10 dimensionless groups. The repeating variables are ρ_{water} , g , and d .

$$\begin{aligned}\pi_1 &= F/F_B, & \pi_2 &= l/d, & \pi_3 &= wt/d^2, & \pi_4 &= t/d, \\ \pi_5 &= F/d^3, & \pi_6 &= m_{\text{saturated}}/m_{\text{dry}}, & \pi_7 &= m_{\text{saturated}}/(\rho_{\text{water}} ltw) = sg, \\ \pi_8 &= F/F_{wc}, \quad \pi_9 = S, & \pi_{10} &= C_1/(\sqrt{g^6 F_B}) \quad \text{or} \quad \pi_{10} = C_2/\sqrt{g}\end{aligned}$$

$$\pi_{10} = \frac{C_1}{\sqrt{g^6 F_B}} = 0.755 + 0.00205 \left(\frac{\pi_1^{0.622} \pi_4^{2.866} \pi_5^{0.886} \pi_6^{1.084}}{\pi_2^{0.677} \pi_3^{2.297} \pi_7^{1.62} \pi_8^{2.53}} \right) \quad (4)$$

$$\pi_{10} = \frac{C_2}{\sqrt{g}} = 0.00442 + 0.0377 \left(\frac{\pi_1^{0.74} \pi_2^{0.996} \pi_3^{0.051} \pi_4^{1.013}}{\pi_5^{0.616} \pi_7^{0.55} \pi_8^{0.69}} \right) \quad (5)$$

$$C_3 = \frac{C_1}{C_2} \quad (6)$$

As the results analysed were all at a single gradient, the slope term is omitted.

Figures 2a and b illustrates these dependencies for a range of commercially available products with width and thickness from 45 to 70 mm and 3 to 20 mm and lengths from 133 to 300mm. Dry and saturated weights varied from 2 to 19 gms and 22 to 250 gms. Data for flush volumes from 9 to 4 litres was available.

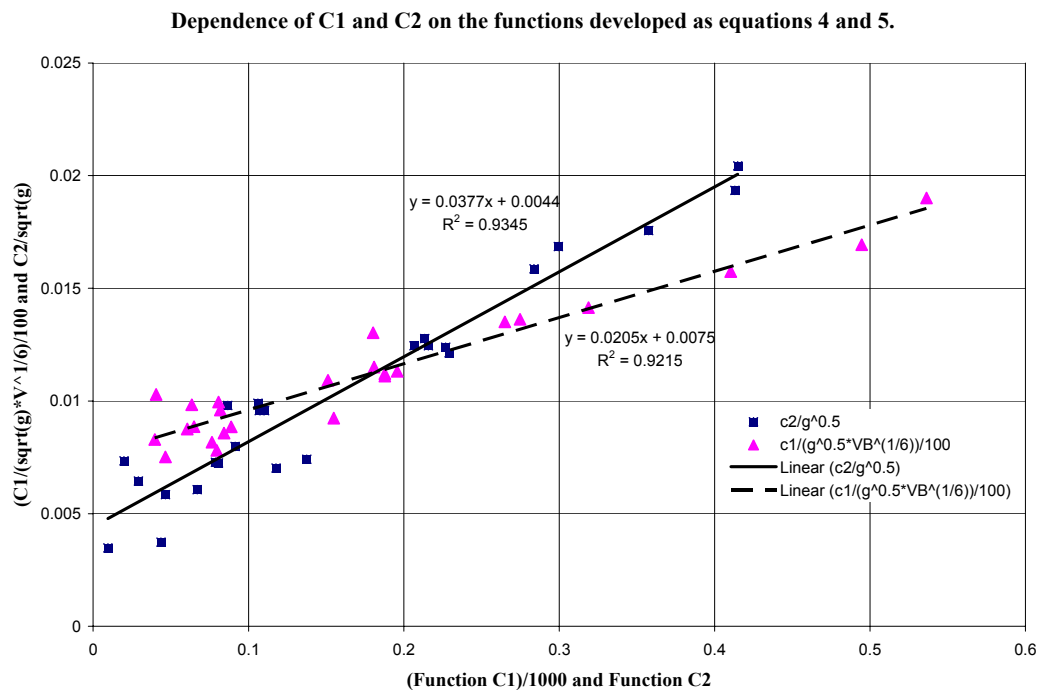


Figure 2a. C1 and C2 defined in terms of the solid and drain parameters as identified in equations 4 and 5.

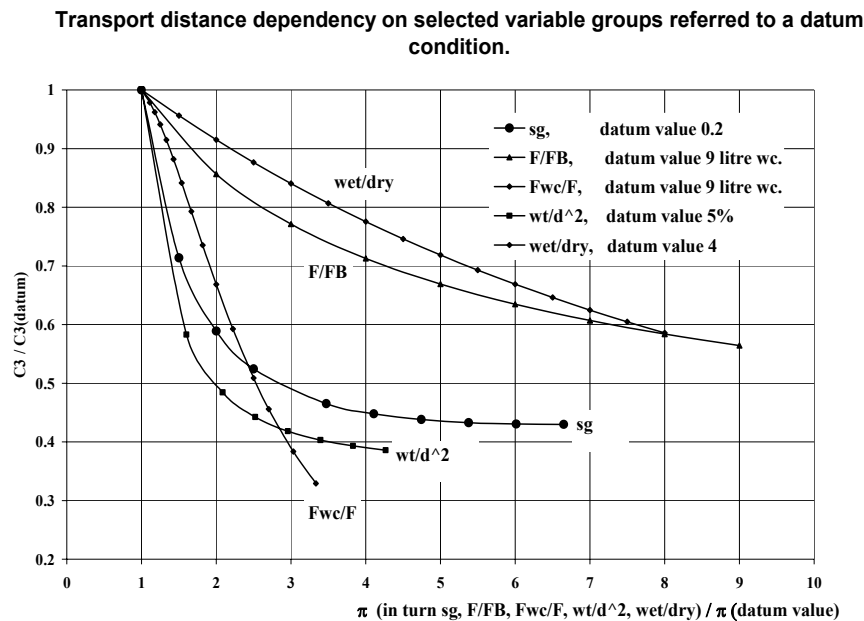


Figure 2b. Dependency of deformable solid transport on a range of solid, appliance discharge and branch drain dimensionless groups.

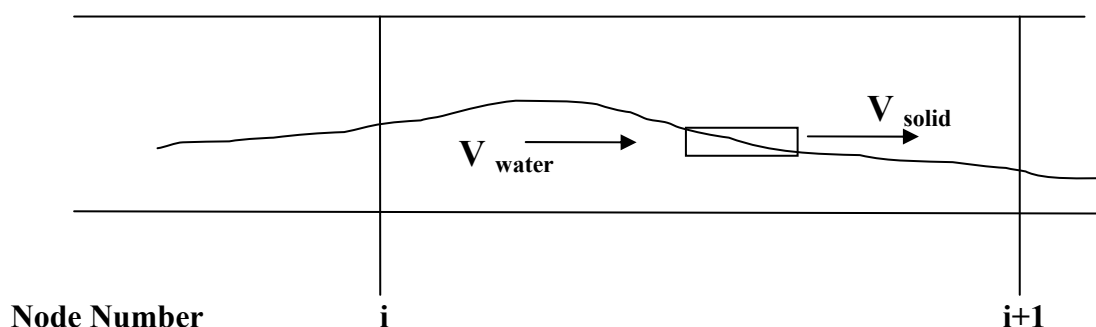
Figure 2b illustrates the relative performance in terms of likely transport distance, the C_3 parameter, as the various parameter values are changed relative to a chosen datum, e.g. as the specific gravity group, π_7 , is increased relative to a chosen datum of 0.2 or a cross section blockage, π_3 , is increased relative to a datum of 5%. For all other parameters constant, increasing solid specific gravity, solid cross sectional area or saturated mass all result in a reduced transport at any flush volume. The design of the w.c. has a fundamental effect on solid transport as a poor design will discharge solids late in the flush resulting in a severely curtailed transport. Reducing w.c. flush volume reduces transport if the volume is decreased with no change to the w.c. design, significant for dual flush installations and retro-fit flush volume reducers, from the ‘urban myth’ brick to drop valve installation discharge dams.

4. Simulation modelling

The laboratory based identification of the mechanism of solid transport provided an explanation of observed transport and deposition and the basis for the flushability criterion. However it was limited in application; modelling solid transport requires the simulation of wave attenuation due to the scale and location of the drain. Attenuating flow provides a transient traction and transport capability that may result in waste being ‘left behind’ and deposited. Downstream in the quasi-steady sewer flow this is less probable and such modelling would be excessive. The negative consequences of solid deposition justifies the simulation effort.

The method of characteristics (MoC) solution of the St Venant equations predicts flow velocity and depth along a channel during and following an appliance discharge.

Wave attenuation is modelled and if coupled with a relationship linking solid velocity to surrounding flow allows solid transport to be predicted. McDougall developed the first velocity decrement model by experimentally relating solid velocity in a steady flow to solid and drain parameters, i.e. drain diameter and slope and solid specific gravity and cross section^{8,11}. **Figure 3** illustrates the technique necessary to predict the track of a solid through an x-t plane. The MoC solution provides the flow depth and velocity at any node. Reference to the solid and drain parameters allows the resulting local instantaneous solid velocity to be determined. Stationary solids remain deposited until the surrounding flow conditions are sufficient to induce movement while flow conditions close to deposition set the solid velocity to zero.



Solid position calculated as $x_{t+\Delta t} = x_t + V_{\text{solid}} * \Delta t$

Solid velocity based on $V_{\text{solid}} / V_{\text{water}} = \text{decrement factor (S, sg, } d_{\text{solid}} / d_{\text{pipe}})$

Figure 3. Calculation technique for solid velocity based on surrounding water flow and solid/drain parameters.

The model described is ‘virtual’ as the solid does not affect the local flow velocity. Close to deposition this might underestimate travel distance due to the damming of water behind a slowly moving solid, however, this effect is automatically included in the decrement factor appropriate to the surrounding water flowrate.

The experimental determination of the velocity decrement factor relationships was undertaken with a range of geometrically similar hollow cylindrical solids, first developed at the US National Bureau of Standards¹⁴, ranging from 20 to 50 mm diameter. Specific gravity variation was by appropriate filling. Following publication of McDougall’s model¹⁵, these solids were also used in sewer solid transport¹⁶ studies. The $\sqrt{L/G}$ model indicated the form of solid transport in attenuating flows. **Figure 4** illustrates the simulated transport of a 38 mm diameter NBS solid of sg 1.05 following a known appliance discharge. The simulation output corroborates Wakelin’s $\sqrt{L/G}$ model. An improvement on the model introduced the ‘y-axis’ $V_{\text{solid}} G^{0.1667}$ modification to improve the degree of fit is shown. Thus a simulation of waste solid transport in attenuating flows is available to aid an assessment of solid deposition under flow conditions subject to water conservation and to provide a suitable linkage between deformable solid / cylinder specific gravity and cross section area.

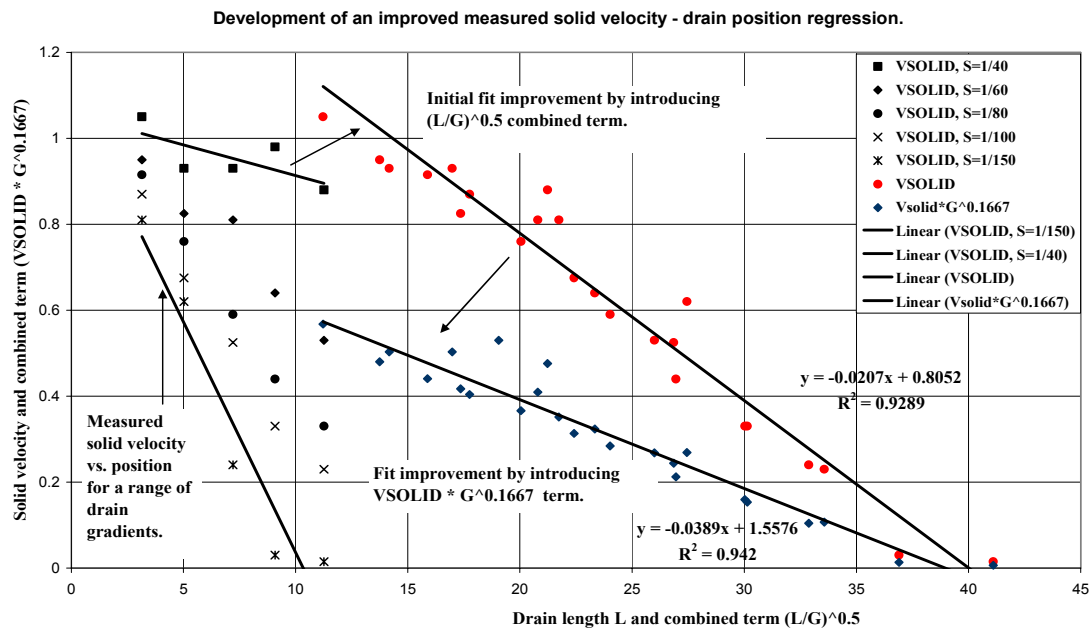


Figure 4. Method of characteristics simulation of the transport of a 38mm diameter, 1.05 sg NBS solid in an attenuating w.c. discharge.

5. Modelling sanitary tissue transport in dual flush systems.

Figures 5 and 6 illustrate the transport of toilet tissue from three commercially available dual flush w.c.s. The analysis may be based on the historical understanding of solid transport - Wakelin's model - and the more recent simulation techniques - McDougall's use of MoC and a velocity decrement factor. The figures present both the overall transport distance - labelled Zone 3, and the end of the intermediate Zone 2. Observation identified the onset of the final transport zone, characterised by dammed water behind the solid and a low leakage rate. In all cases a 6 litre full flush was sufficient to remove the tissue from a 16 m branch drain at a slope of 1 in 50.

The lower dual flush volume outcome was dependent upon the toilet tissue length. Lengths of 4 to 32 sheets, folded so maximum length was equivalent to four sheets, were flushed into the test drain. It was still possible to identify the onset of Zone 3. A second flush was required to remove all lengths above 4 sheets from the drain.

Deformable solids take up the shape of the surrounding pipe, **Figure 1**, allowing the tissue block cross sectional area to be estimated, yielding an equivalent cylindrical diameter from 15 to 25 mm for these tests. Tissue absorption and total surface area provided an equivalent cylinder specific gravity from 0.2 to 0.96. Combination of the equivalent diameter and specific gravity allowed the use of the velocity decrement model. The discharge characteristic of each w.c. type drove simulations of both a full flush and repeated dual flush operation that generally replicated the experimental results, **Figures 5 and 6**. A full flush was always sufficient to clear the 16 m branch.

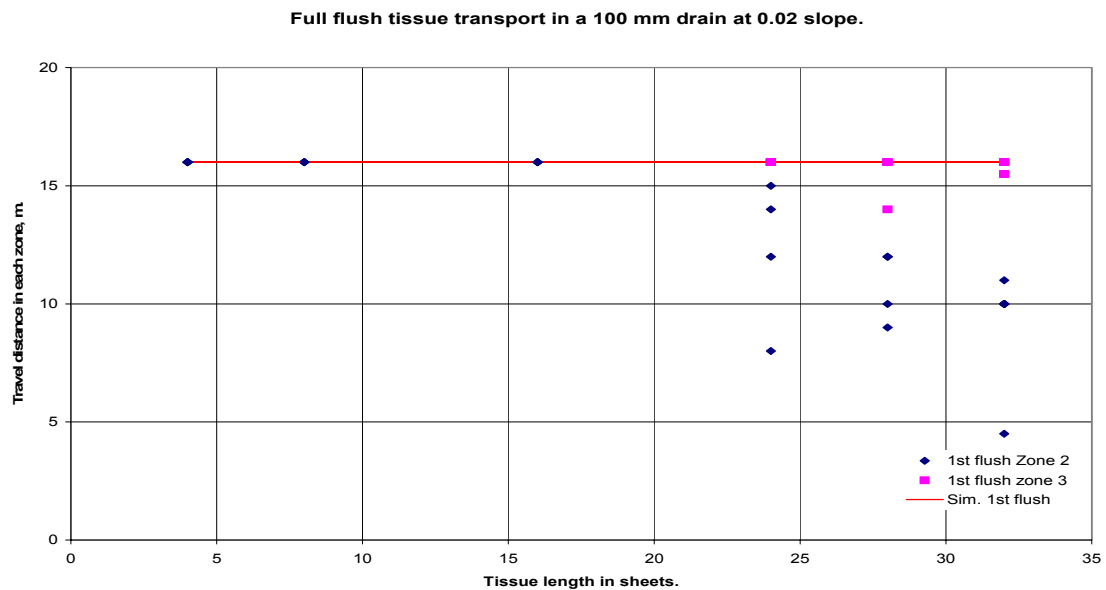


Figure 5. Predicted tissue transport in a 1/50 gradient branch drain subject to a 6 litre discharge from each of three commercially available dual flush w.c.s. Both experimental and simulated solid transport indicate first flush clearance of a 16 m drain.

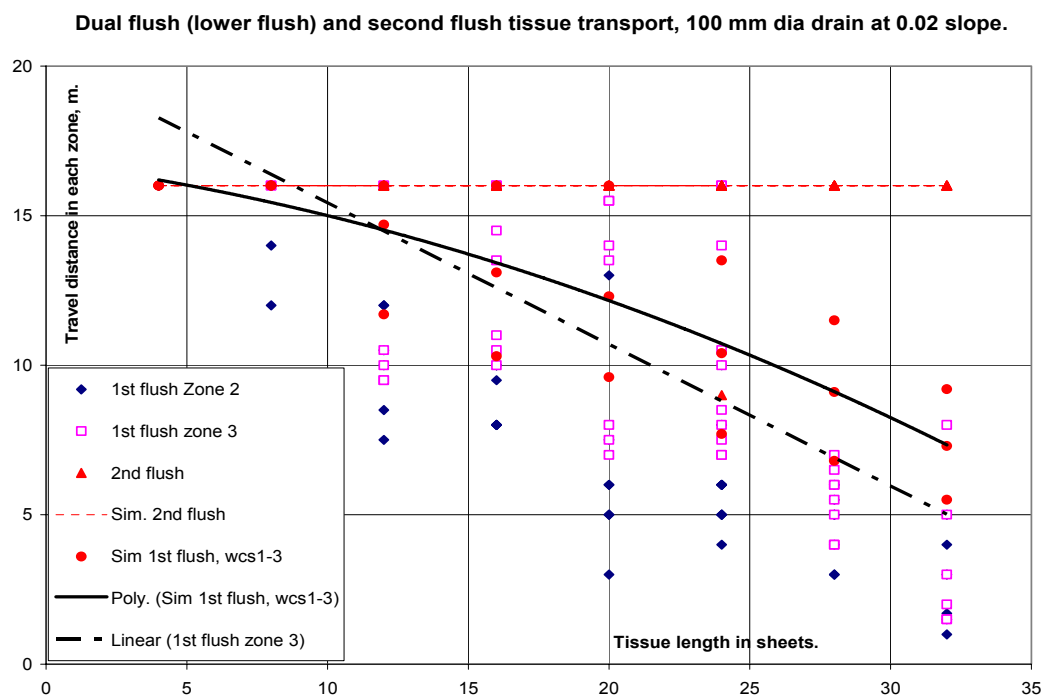


Figure 6. Predicted tissue transport in a 1/50 gradient branch drain subject to the lower setting dual flush discharge from each of three commercially available dual flush w.c.s. Both simulation and experiment indicate that a second lower setting dual flush clears a 16 m drain.

The lower dual flush volume provided clearance for the 4 tissue sheets, all other lengths required a second dual flush to clear the branch, both results confirming the experimental data. The efficiency of the second flush is expected from the dependencies illustrated in **Figure 2b** as the full flush is effectively 'behind' the solid and the transport should therefore be a maximum.

The transport of deformable toilet tissue is random, confirmed by the spread of deposition distances for each tissue length.. The solid also deforms during transport; Bokor¹⁷ observed a shortening of the tissue due to the impact of a following flush or under higher flow conditions and a 'spreading out' in Zone 3 and commented that tissue transport dominated solid deposition, a conclusion later corroborated by laboratory studies¹⁸. Deposited faecal solids were moved on by any following tissue block so that tissue transport defined the efficiency of the system. While acknowledging the random nature of tissue transport and the initial state of the model proposed it is clear that the use of dual flush to remove toilet tissue following urination is acceptable as transport distances in excess of 8 m were achieved for reasonable tissue lengths and a second flush cleared the system on each occasion. In practice the efficiency of the second flush may be reduced if the drain is allowed a 'drying out' period, exacerbated by a heated environment.

6. Implications of water conservation on drain waste transport.

This paper has demonstrated that deformable solids dominate the waste transport expected in building drainage systems under design conditions that introduce water conservation measures. This is supported by extensive laboratory research and a long term study of faecal and other waste product disposal via conventional w.c. flushing and transport to a sewer connection. It has been shown that in the upper reaches of the drainage network in, or adjacent to, the building, the effects of wave attenuation predominate, necessitating unsteady free surface simulation techniques based on the method of characteristics to provide a velocity decrement methodology to link solid transport to the surrounding free surface flow. This introduces a higher level of simulation complexity compared to similar later models applicable to larger bore drains within the sewer infrastructure where carrying flows tend to the quasi-steady.

Water conservation will become a prerequisite of new build as demographic pressures, combined with the effects of climate change, become more apparent. Changes in domestic and commercial building cleansing and hygiene standards will also impact upon the assessment of waste transport via w.c. flushing. While reduced flush volume w.c. design is an imperative, and dual flush is a necessary and acceptable response to reducing water usage in commercial buildings, particularly those with a high female to male population ratio, it remains necessary to provide a methodology that will allow design solutions to be assessed. While the transport of deformable solids - tissue or similar hygienic wipe products - is random, acceptable models do exist that would provide guidance as to likely transport distances at design gradients. The simulations presented for dual flush operation clearly indicate that transport distances of acceptable magnitudes – 8 m or above – are achievable by dual flush operation. This is a highly encouraging result however as pressure mounts for even lower full

and dual flush volumes it will be necessary to revisit this model application to ascertain a confidence level in new appliances and installations.

Finally the paper has demonstrated that the prediction of drainage system operation is an assessment tool that may be applied to support both system design and the formulation of design standards that will require water conservation measures to be fully integrated into new build and refurbishment proposals.

7. References.

1. Environment Committee. 'Water Conservation and Supply', First Report, Session 1996-97, The Stationary Office, London.
2. Griggs J. and Shouler M. 'An examination of water conservation measures. Proceedings CIBW62 Symposium, Brighton 26-30th, 1994.
3. American Water Works Association Research Foundation 'Water efficiency making cents in the next century' AWWA Proceedings, 'Conserv 99' Monterey, California, 31 January – 3 February 1999.
4. Cox D. 'Designing with water', The Society for Responsible Design Newsletter, 1997; 48. 4.16
5. Department of the Environment, Food and Rural Affairs, 'Water Supply (Water Fittings) Regulations 1999'. HMSO London, July, 1999.
6. The Environment Agency. 'Water Savings Group promises action', Water Demand Management Bulletin, Issue 74, December 2005.
7. ODPM (DCLG) 'Affordability and the Supply of Housing', House of Commons ODPM: Housing, Planning, Local Government and the Regions Committee, Third report of Session 2005-06, HC703-1, May 2006.
8. McDougall J.A. and Swaffield J.A. 'Simulation of building drainage system operation under water conservation design criteria'. BSER&T, Vol 21, No 1, pp41-52, 2000.
9. Wakelin R.H.M. 'A study of the transport of solids in hospital above ground drainage systems'. PhD thesis, Brunel University, Uxbridge, 1977.
10. Howarth G., Swaffield J.A. and Wakelin R.H.M. 'Development of a flushability criterion for sanitary products'. Conseil International du Batiment CIBW62 Symposium, Brunel University July 1980.
11. McDougall J.A. 'Mathematical modelling of solid transport in defective building drainage systems'. PhD thesis, Heriot Watt University, Edinburgh, 1995.
12. McDougall J.A. and Swaffield J.A. 'The influence of water conservation on drain sizing for building drainage systems'. Building Services Engineering Research and Technology, Volume 24, Number 4 2003, pp 229-244.
13. Swaffield J.A. and Wakelin R.H.M. 'Observation and analysis of the parameters affecting the transport of waste in internal drainage systems'. Proc. IPHE., 1976; 4:165-170.
14. Galowin L.S. 'Review of HUD/NBS Residential Water Conservation Conseil International du Batiment CIBW62 Symposium CSTB Paris November 1979.
15. Swaffield J.A. and McDougall J.A. 'Modelling solid transport in building drainage systems'. Water Science and Technology, 33(9) July 1996.
16. Butler D., Davies J.W., Jeffries C. and Schutze M. 'Gross solid transport in sewers'. Procs. ICE, 156, June 2003, Issue WM2, pp175-193.

17. Bokor S.D. 'Correlation of laboratory and installed drainage system solid transport'. PhD thesis, Brunel University, Uxbridge, 1982.
18. Littlewood K. and Butler D. 'Movement mechanisms of gross solids in intermittent flow'. Water Science and technology, Vol 47, pp45-50, 2003.

8. Notation.

A	Flow cross sectional area, m ² .	C _{1,2,3}	Empirical constants
d	Branch drain diameter, mm.	F	Reduced w.c. flush, litres.
F _B	Flush volume behind a solid, litres.	F _{wc}	Design w.c. flush volume, litres
G	Branch drain slope.	g	Acceleration due to gravity, m/s ² .
h	Free surface flow depth, mm.	L	Distance along drain, m.
l	Deformable solid length, mm.	m	Deformable solid mass, gms.
S	Branch drain slope	V	Flow mean velocity, m/s
t	Deformable solid thickness, mm.	w	Deformable solid width, mm.
π	Dimensionless group.	ρ	Density, kg/m ³ .



Professor John Swaffield is Head of the School of the Built Environment and leads the Drainage Research Group at HWU, Edinburgh and is currently Vice-President of CIBSE. Research interests include water conservation, mathematical simulations of drainage and vent flows and the prediction of cross contamination routes. He has been a regular contributor to CIBW62 since 1975.

A Breathing Pipework System – Building Drainage Pipework System

Ir Lonnie S H Cheung MSc(Brunel), AP(HK), RPE(BS), CEng, FHKIPD, MCIBSE, MHKIE, MIHEEM, MIPHE
bslonnie@cityu.edu.hk

City University of Hong Kong, Division of Building Science and Technology

Abstract

Drainage pipework systems (one-pipe, two-pipe, single stack, modified one-pipe and SOVENT) can breathe. What does it imply? The air surges within the empty pipework sections and also when it is interlocked by sewage flow during intermittent flushing actions. Air is frequently breathed in or out reversibly. The most harmful effect is the resultant back-pressure causing health hazard due to sewage might be momentarily forced out.

By reviewing the drainage flow cycle, it re-called some basic principles: conservation of mass, displacement law and conservation of energy, which might have been over-looked. Different drainage cycles in those high-rise buildings, high densely population residential buildings and hotels are very complex. The breathing cycle when it is co-related to the sewage peak flow reveals critically those harmful health and hygiene effects.

Study for the peak flow inside a drainage pipework system has to examine the total pipe length simultaneously. The peak may re-occur more than once till the sewage reaches an “exit”. Accumulative effect does exist from the aboveground pipework to the underground sections. Analysis to the pipework circuit has never been worked out together with the below ground drainage circuit. The drainage cycle, peak flow determination and the breathing drainage pipework system have to be completely reviewed to establish firm grounds by research development. Firstly, the processes and problems appear initially. To tackle the problem and theory enhancement could be done by research projects finally.

Keywords

Drainage pipework systems; breathe; interlocked; drainage flow cycle; accumulative effect; peak flow determination.

1. Introduction

Drainage systems have been misinterpreted with their associated pipework systems. Sanitary wares sewage disposal system should be defined and termed as a sanitary drainage system. This system will engage a pipework which is selected basically from one-pipe, two-pipe, single stack, modified one-pipe and SOVENT pipework system to handle its sewage disposal. Those are the typical five pipework circuit arrangements or simply the pipework configuration for an effective sewage disposal without injury to the health of the occupants. Pipework systems are always misunderstood as drainage systems.

2. Pipework circuit and the breathing processes

Drainage pipeworks are empty sections occupied by the air when there is no sewage flow. When a sanitary ware is flushed, sewage will then be discharged. Releasing firstly the air, the pipe space will be displaced by sewage nearly simultaneously. If the air is not released, sewage will not flow. After the air is discharged and when the sewage is drained down, the empty space will have to claim the air back. This is very similar to breathing processes: breathing out and sucking in air lastly, in order to complete a cycle of sewage discharge. These cyclic actions are interlocked. Air breathing out and flow discharge whilst sucking air and refill empty drain reversibly re-appear.

To consider further, no air return will result a syphonage (vacuum pressure). Sewage disposal resulting compression force acting on air will form a positive pressure at the lower part of a drain to cause the backpressure (compression force). Lower floors water closet trap seal water and other sanitary wares trap seal have been experienced momentarily forced out during the peak hour of usage.

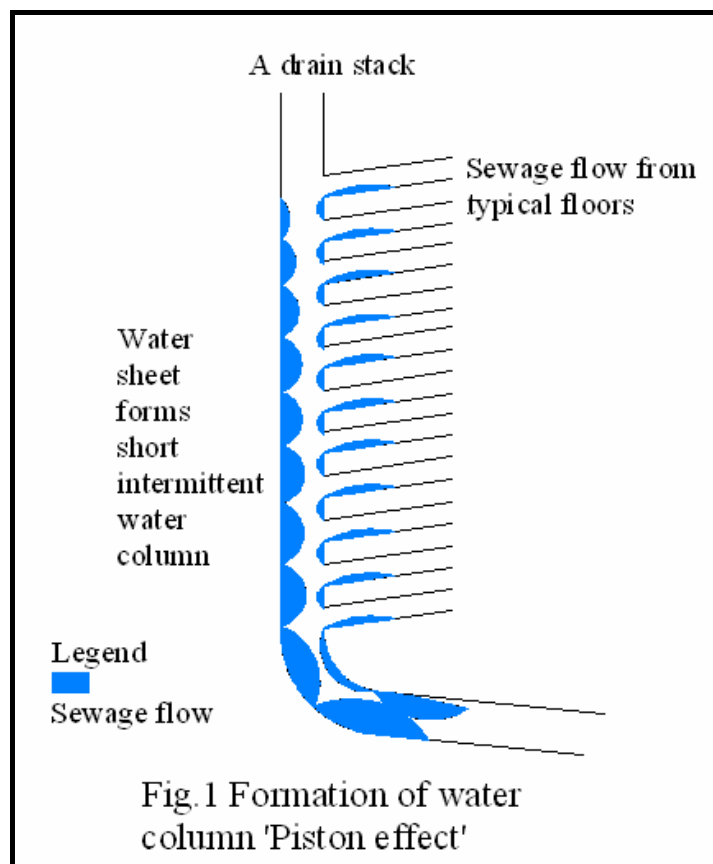
3. Understand air existence

In a drainage pipework, the existence of air is very important. All drainpipes let their upper open ends plus a vent pipe facing to atmosphere in balancing the air pressure either by relieving when it is under positive pressure or sucking air back when it is under a vacuum (negative pressure). Since the ends are open, the air will be circulated and subjected to the atmospheric pressure. Self-regulation of air pressure inside a drain

pipe can be maintained easily within a fully ventilated pipework. But it is difficult for partially vented or pipework system providing with vent assistance equipment. It may be due to their low effectiveness and early deterioration, and also lack of prompt action. However, when the air discharge and breathing in have to go through a long section, air pressure variation is unexpectedly complicated and cannot achieve a self-balance within a short period.

4. The cycle of drainage disposal

After using a sanitary ware or general ablution or washing with cold water, a flushing action follows naturally. The sewage discharge adhering to the drainpipe internal wall surface accumulates to form short water columns which continuously flows down a drain stack. Depending on the sewage quantity, the wall surface resistance will permit the sewage to form short water columns. They will form compression force to the air existed inside a drain. The author would like to term it 'Piston Effect' (Fig.1). You can always hear some bubbling noise or wind blowing inside a drain, which was formed by the compression of air. Air rushes back to the upstream (in escaping) in resulting the noise.



5. A breathing pipework system

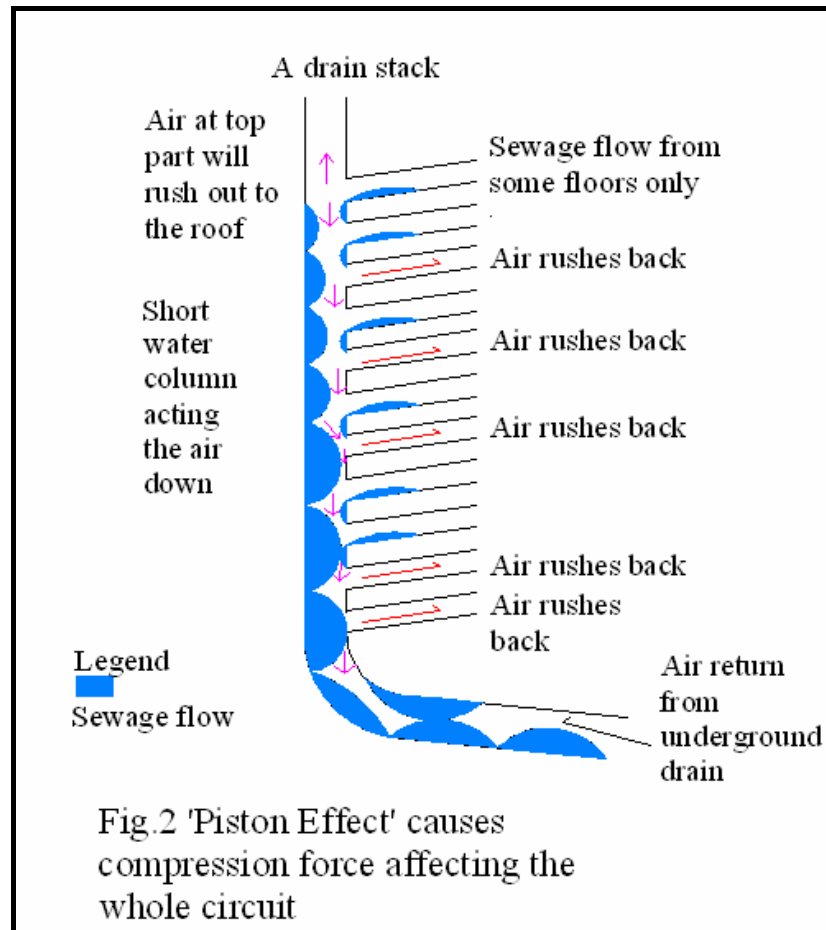
When a sanitary ware is flushed, the sewage or wastewater will be drained away. Small and short water columns will be formed intermittently inside a vertical drain stack. The compression force will result positive pressure acting on the air inside a drainpipe. Air evacuates first then wastewater or sewage will be drained down. After the air gone, the water leaves the drain (Within a long drain pipe, the air is bouncing inside the drain while sewage continuously or intermittently is flowing along. But, when air does not reach an “exit”, air balancing cannot be achieved.), air will be sucked back finally. The worst scenario is a short period of discharge followed by a long period of discharge and continuous intermittently. Air balancing is unachievable.

Normally, drains itself in balancing and self-regulating the internal air pressure variation, will claim the air back in every drainage disposal cycle. Therefore, the drain will create a suction force in evacuating the trap water seal of any sanitary ware (as if the shortest route or a prompt response within the shortest period) to balance with atmospheric pressure or the need for air replenishment from where there is a venting provision of the pipework circuit. Of course, ideally, it will suck air from the vent pipe. Unfortunately, when trap seal was empty, foul smell will leak out and afterwards, the second round compression force can transmit and forced out air-borne virus when the next flushing action rose by wares.

Furthermore, on the other side, the magnitude of compression force will never be the same due to differences in the building height, variation in time that the peak discharge appears. Designers may have neglected the sewage flow is still on their way before reaching an “exit”. This will form vacuum at different positions within a drain circuit.

No matter of semi-detached low-rise buildings or tall high-rise buildings, sewage discharge is either a continuous or an intermittent flow. From Conservation of Mass to Volume, equal volume of air and sewage will exchange nearly simultaneously. Displacement Law is the basic theory to explain the exchange processes. When the sewage flow does not reach an “exit”, the air inside a drain pipe will bombard by the intermittent sewage flow by the ‘Piston Effect’ formed as discussed in item 4 above. The compression force with transient suction force will affect the whole pipework

circuit and the connected branches to the appropriate sections are subjected to pressure fluctuating (Fig.2).



6. Consideration for peak period and its continuous impact

A drainage pipework system is normally connected and extended to an underground drainage pipework system which are either separate or combine underground drainage pipework and manholes system. Sewage flow from a high-rise building flows variously from several hundred meters aboveground pipework to another several hundred meters underground pipework system when it reaches the building last manhole (There are many thousands cases, but this may be the worst case). The complete circuit will have to continue till reaching the Government sewer to the sewage treatment plant in reaching an “exit”. The term “exit” is so important and must be explained because the “exit” is a point where air is free to circulate in balancing entry and exiting air pressure. An “exit” can be simply explained as an open outlet point to the atmospheric. The sewage flows along a complete seal circuit. Only are entrance points at top of a vent

stack and “exit” point permitting free air circulation and air balancing, unless free outlets in the form of open vent is allowed. The author insists to allow for.

When the sewage is still flowing without reaching an “exit”, the air pressure will be unstable and is hard to balance. The air pressure fluctuation will affect the stability of any drainage system.

In traditional calculation and theoretical application, designers and engineers always predict the flow by applying guidebook in the sense of one peak flow determination only for the selection of drain size. The select drain size is adequate for the peak flow only. Absolutely, the size in handling the sewage is quite adequate but for air purging simultaneously is incapable in resulting of virtually sized inadequately. They have not considered the complete circuit in the path and time required to completely discharge to an “exit”. After the first peak appeared, the peak sewage flows rush down the drain but have to flow through a long distance till an “exit”. While the peak flow is discharging, the time of flow along the drain is lengthy at the same time. Moreover, the air purging and air replenishment are incomplete. Then, there appears another follow-up second peak flow rushes down while the first peak is still within the far end downstream in the same circuit. Numerous ‘Piston Effect’ affects the flow and built-up air pressure pushing back or sucking out the trap seals inside pipework.

7. New concept

Let consider for the time lag of two peak flows. It may absolutely appear within a circuit. The factor of time lag occurrence also depends on the circuit. It varies from one circuit to another one. From the first peak to the occurrence of the second peak could be considered as a big leap from the traditional sizing theory. Under the “exit” consideration in achieving air pressure self-regulating and balancing conditions, the consideration of a complete drainpipe circuit will extend from aboveground to underground till the outlet to sewage treatment plant. Alternatively, an “exit” to balance the air pressure can be provided within a building and its boundaries, which is also admitted technically acceptable.

There appear two significant areas of consideration: flow path and the time required to reach an “exit” under the peak flow. The appearance of first peak sewage flow while it is flowing continuously without reaching an “exit”, a sufficient time is built-up for the formation of the second peak. This can explain why drainage problem was so difficult to be solved because the third peak may have been formed subsequently.

The accumulation time for peak flows and the timing of subsequent peak flows arriving later, the air release and air return (breathing and sucking effects), the practical analysis becomes very complex. From the past, the appearance of syphonage action and backpressure occurrence has drawn the attention of risk existence. The most important message is these complex situations (with mixed mode effects) cannot be assumed by simulation process to predict the anticipated working conditions due to the dependent cases. The permutation and combinations are quite complex.

For the consideration to a combination of various types of buildings of different peak flow pattern (from residential, commercial, hotel, institutional and industrial buildings), building height varying from 15 metres to 300 metres height difference, non-consistent users habits (European, American, Latin and Third-countries), celebration parties or Chinese cultural festival days (a big family dinner gathering at home) in producing abnormal and inconsistency peak flow, which are influencing factors. The target should be set out to collect data by carrying out operational research.

8. Major concerns

Engineers and designers do not normally concern about but it is difficult to master the total flow path where and when the sewage will reach an “exit”. However, this is the most significant concern in solving drainage problems in related to a breathing pipework system handling sewage and its overall routing after exiting from a building to an external Government sewer line. Moreover, air release and return points are provided or not within a self-contained pipe circuit for an independent building, sewage flowing excessive length in time accumulating and continuous subsequent sewage collections along the Government sewer towards a central sewage treatment plant, sewage from other buildings building up while air pressure was not released properly and total flow quantities accumulating at the same time from the contribution of the adjoining buildings on the flow path are co-related. These related discharges may affect to the

associated buildings connected to the same Government sewer due to the air relieving and back pressure effect, which is quite significant and serious.

9. Conclusion

The sewage quantity and air pressure built-up are directly proportional. Regarding the breathing pipework system, unless the air pressure is released and discharge air is replenished correctly and timely, the problem of backpressure causing flooding back and syphonage action sucking out the water seal in allowing the virus leakage path can be eliminated. It is warned the subsequent discharge will force out the virus naturally and automatically afterward.

The accumulating time and quantities are unpredictable and out of the control of a designer. It is not until the overall route is mastered. Mastering the theory of air exchange and sewage flow is not difficult. To progress to the overall control of drainage flow and cycles may be extremely hard. Designers cannot control the flow of other buildings on the main flow path. Other buildings along the main drain path can form side factors (in peak flow and peak time) causes backpressure and syphonage actions formation randomly. But, the accumulative effect undergoes tremendously and cannot be predicted accurately. To tackle this problem, operational research is in one goal and data collection from different buildings for analysis is in the second goal. Perhaps, the future intelligent building design with full monitoring on systems could help.

The only solution is to release the problem (air pressure) at the appropriate points without impacting to the other buildings. In Hong Kong, majority of the drain stacks and sewer from aboveground to underground are not vented adequately and effectively. The vent provision in all drainpipe sections for both the aboveground and underground is inadequate. In preliminary solving the basic problem, each building sewage disposal system must be vented independent. Impact formed by subsequent discharges and flow accumulation is unavoidably but must not link to air pressure building up along the main sewer till reaching an “exit”- the sewage treatment facilities. Then the problem due to air pressure is less troublesome.

10. Recommendations

After mastering the discharge process and the breathing pipework system concept, the author suggests:

10.1 Solve by releasing the air

Trapped air if under a continuous boosting will create hazardous situations. Air cannot escape, will render a high pressure in jetting wastewater to a tremendous height (It was recorded waste water jet up to the ceiling level from a water closet inlet at first office floor of Hong Kong Bank Headquarters in Central, Hong Kong, 1986).

In allowing automatic air vent, air admittance valve, Positive Air Pressure Attenuator (PAPA), it seems a temporary measure. If these were put in wrong locations, they cannot perform their function effectively (at possible bombard locations). The temporary allowance to absorb air built up and replenish to the system again later were not totally effectively. In Photo 1, there appears some draw back from a series of PAPA to absorb the air surge. It is queried why vent pipe was not considered to assist to resolve the problem.



Photo 1 - Placement of 3 to 2 to 1 PAPA on 2nd, 3rd & 4th floor to solve air transient problem. Can they be more effective than a vent pipe ?

10.2 Understand the effect of an underground drainage system

After mastering the impact of an underground drainage system will continue to receive the sewage from the above ground drainage system, the sewage will then flow through a long route to the sewage treatment facilities in Hong Kong. One example is drains gone through an internal underground drain of nearly two hundreds and the subsequent path to Government sewage treatment plant of several kilometres. The flow accumulations become larger and larger, and the greater the amount of air should be released back to the aboveground drainage system. If there is no provision of venting pipes, improper and in-effective release of air, sewage flow is interlocked by the air release and replacement by sewage. It may illustrate a typical very bad case.

Within a district sewage disposal system, various types of buildings, sewage accumulates from one to ten to even thousands of buildings are expected. Different building means for the different function usage, resulting different disposal peak flows and various peak times. However, the accumulation still occurs, which is a very complex situation.

To face the reality, the provision of vent pipes is recommended for the underground drainage system. In the past, vent is permitted at the first manhole and the last manhole for a group of underground manholes and drains system. The suggested additional vent pipes must be allowed to effectively vent the trapped air, release from boosting, let sewage discharge and replenish the air promptly.

The only draw back is the vent pipe may expose the virus transmission path to the surrounding which can be solved by dilution effect (reduce virus concentration). Vent pipe can be installed to face the wind direction at a height much higher than human beings. The aerosols have buoyancy force plus the wind effect serving for a dilution process so the risk can be reduced.

Let examine from the Law of Conservation of Mass. A drain of 300 mm diameter of a length of 300 metres has a volume of 21.026 m^3 . If it permits $1/3$ full flow of the drain capacity, the sewage handling capacity is 7.069 m^3 which will displace equal volume of

air. If the sewage flows at 1.0 metre per second, then the air will escape at 1.0 metre per second. Allowing vent pipe at first and last manhole is insufficient.

The requirement of vent pipes can be flexibly allowed to every 30 metres to allow for prompt release and replenishment.

From the Displacement Law and Conservation of Mass, air and sewage exchange their space instantly. The peak flow and occurred peak time cannot be predicted accurately and their re-occurrence was also difficult to be obtained. Hence, a simulation case is not accurate enough to preview the real situation. There are too many assumptions without really mastering the practical situation.

References

1. Drainage pipework system and SARS by Ir Lonnie Cheung, in March 2004 for the Symposium on Advance Technology for Health Care and Hygiene Control
2. Drainage pipework system and SARS Part II by Ir Lonnie Cheung, in May 2005 for the 2nd Symposium on Advance Technology for Health Care and Hygiene Control
3. Building Drainage Pipework System and Its Impact on a Healthy Building by Ir Lonnie Cheung in June 2006 for Health Building 2006 in Lisbon, Portugal

Presentation of Author

Cheung Siu Hung, Lonnie is a lecturer in City University of Hong Kong. He possessed over 27 years experience in piping systems design, research and studies. In his last twelve years, he taught his students about his expert area – plumbing and drainage. He has continuously served professional institutions for more than fourteen years.



Study on transportation performance of main drain with low flash water closet in buildings

(1) C.L. Cheng, Dr. (2) C.J. Yen, Ms. (3) K.C. Ho, Mr. (4) W.H. Lu Dr. (5) J.R. Ho Mr.

(1) CCL@mail.ntust.edu.tw

(2) D9313006@mail.ntust.edu.tw

(3) M9213211@mail.ntust.edu.tw

(4) sammy@abri.gov.tw

(1) (2) (3) National Taiwan University of Science and Technology, Department of Architecture, 43 Keelung Road Sec.4, Taipei, Taiwan, R.O.C.

(4) Architecture and Building Research Institute, Ministry of the Interior

Abstract

Due to the sustainable consciousness and green building policy, water conservation was seen as crucial strategy in Taiwan. Accordingly, low flash water closet was greatly encouraged to involve on the practical application in building facilities. However, people were beginning to worry about the performance of main drain in building couple years ago. This study mainly focuses on the transportation ability of main drain in ground level of buildings. According to the experimental observation of visual transportation phenomenon in building main drain, an empirical prediction method, which can at least reproduce the experiment data, is offered as one of the results of this research. The estimation of transportation performance had been verified and proved to be good for experiment reproduction. These results also approximately response to the public concern on the performance of main drain of buildings with low flash water closet.

Keywords : Main drain, lower flash water closet, transportation performance, water conservation

1 Introduction

We know that water reservation is a crucial item on current global sustainable activity. Due to the policy of green building and improving system recently in Taiwan, many types of water saving facilities are conducted in these periods for responding the water problem. However, the performance of drainage system must be ensured as the volume of flash water is reduced. Otherwise, it might cause sanitary problem to indoor environment and interrupt building function. People were beginning worry about the performance of main drain in building couple years ago. Our previous researches pay attention on the air pressure phenomenon on the stack and the influence to trap seal water. This study mainly focuses on the transportation ability of main drain in ground level of buildings. As technical review of related researches, 1986 Kamata studied the least necessary flow velocity in open channel and main drain performance. Afterward, we see L.Galowin presented several papers on CIB W62 annual symposium since 1990.

According to previous documents and technical reviews, this study would begin from investigation and experimental approach. The relevant standards and testing regulation are arranged as the reference of this research. Experiment plan was set up for visual transportation phenomenon in main drain of buildings and clarifying its feature. The testing rig is offered by ABRI (Architecture and Building Research Institute) and performed from 2003. Following the observation of visual transportation phenomenon in main drain of buildings, an empirical prediction method, which can at least reproduce the experiment data, is offered as one of the results of this research. The prediction results are verified at the end. It is seen that the obvious deferent transportation ability between low flash water closet and traditional articles. That is to say, low flash water closet might diminish the transportation performance of building main drain and this issue should not be ignored.

2 Experiment device and testing results

As simulation of building drainage system, we set up an experiment device with condition of 5 floor height and 18 meter main drain for the transportation ability test. Water closets with flash 6 liter of saving water type and flash 9 liter of traditional article are both adopted in this test rig. The main drain is set with two slope of 1/100 and 1/200 in the ground level. Figure 1 show the profile of experiment device. Figure 2 is the pictures of main drain testing rig in the ground level for the visual observation of transportation performance. As the objects of testing, the water closets included four types of articles which are three low flash types of T1~T3 with flash 6 liter and one traditional article W1 with flash 9 liter.

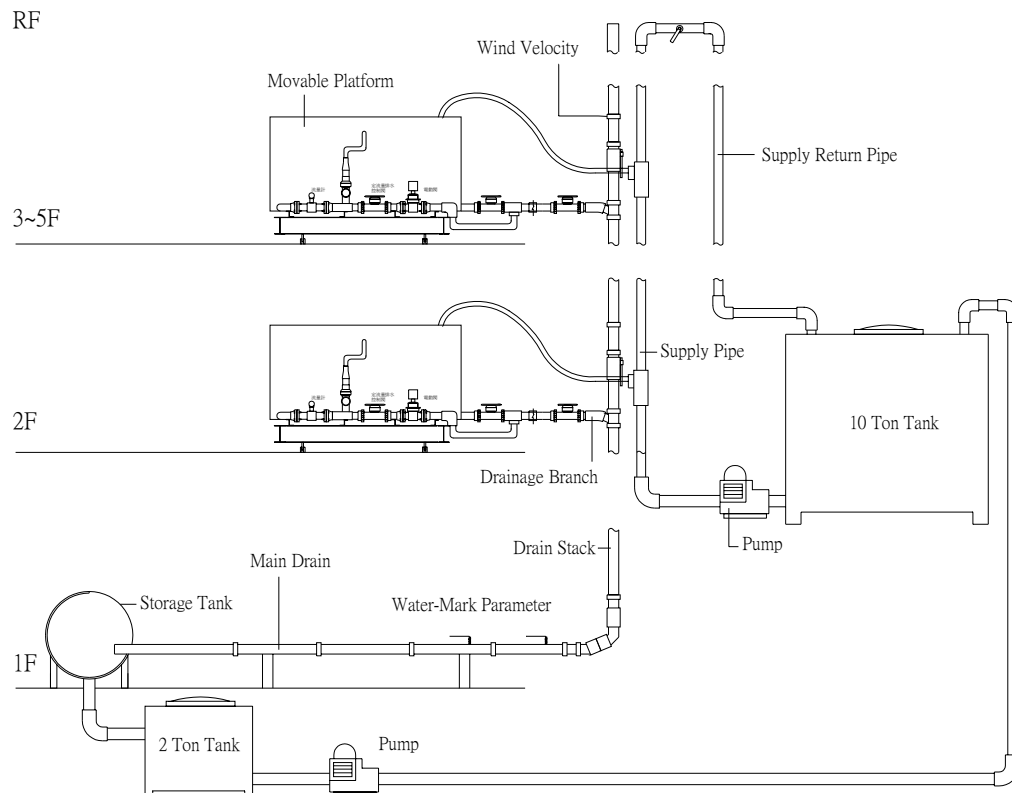


Figure 1 the profile of experiment device

The testing procedure referred from regulation of Japan Housing and Urban Development Corporation Research Institute with testing code WC-15 for main drain

transportation performance. According to the testing regulation, two imitate ordure pieces are made of long narrow strip sponge with density of 1.05. Figure 3 is the picture of imitate ordure and testing operation. Each testing operation is performed by 30 times' repeating throw. The result is recorded by statistic method with the average transportation distance and its standard deviation.



Figure 2 the pictures of main drain testing rig



Figure 3 pictures of imitate ordure and testing operation.

According to the previous researches and common judgment, the influence factors might include flash volume, slope of main drain, diameter of drain and height of discharge. As the initial observation of experiment, it is obviously revealed that the transportation distance of low flash water closet is far less than those of traditional article. Figure 4 shows the traditional non-saving water closet testing results of transportation distance and the distribution of imitate ordure pieces from discharge 5th floor height. Figure 5 shows the percentage of imitate ordure pieces movement due to the discharge floor height from 2nd ~5th.

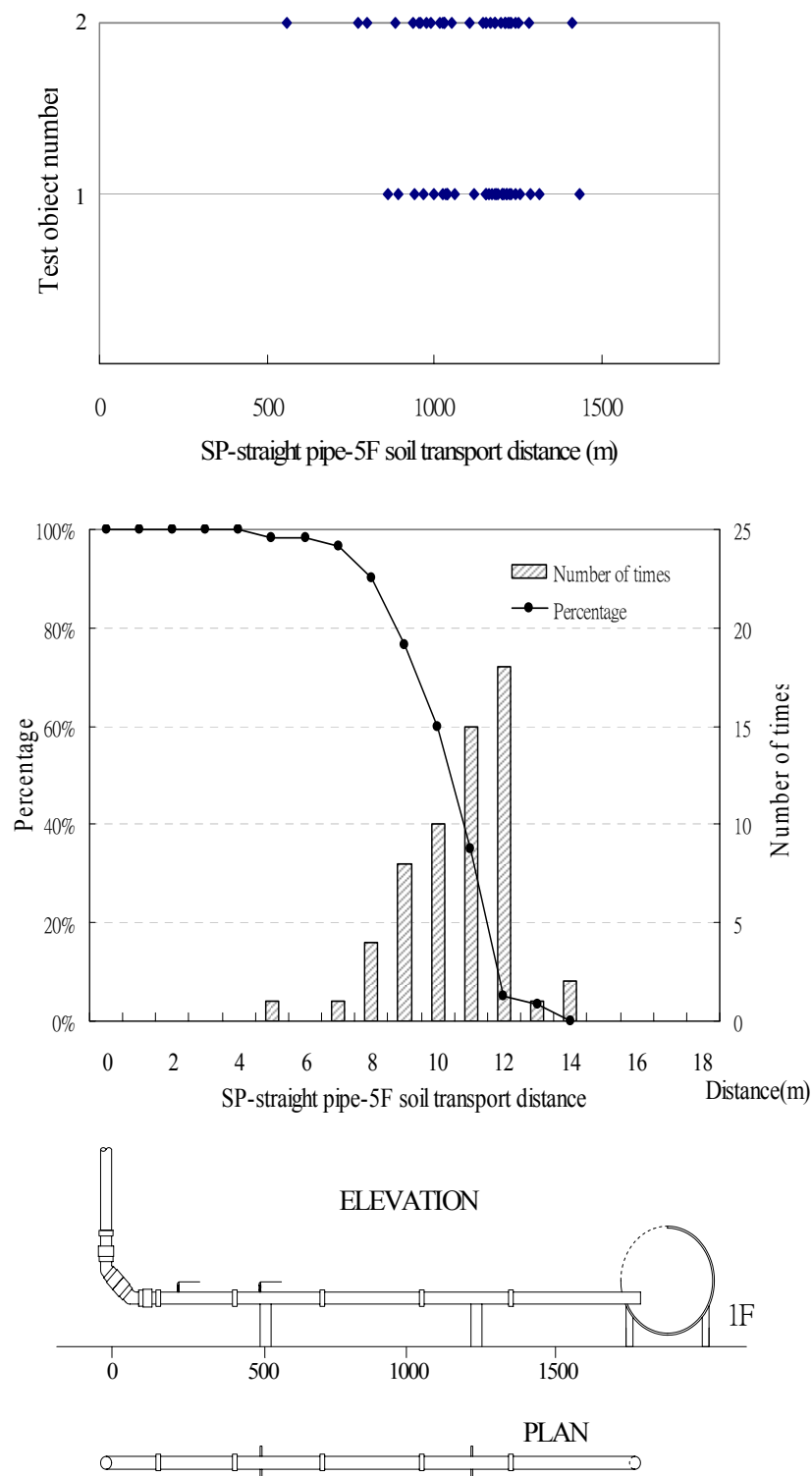


Figure 4 the traditional non-saving water closet testing results

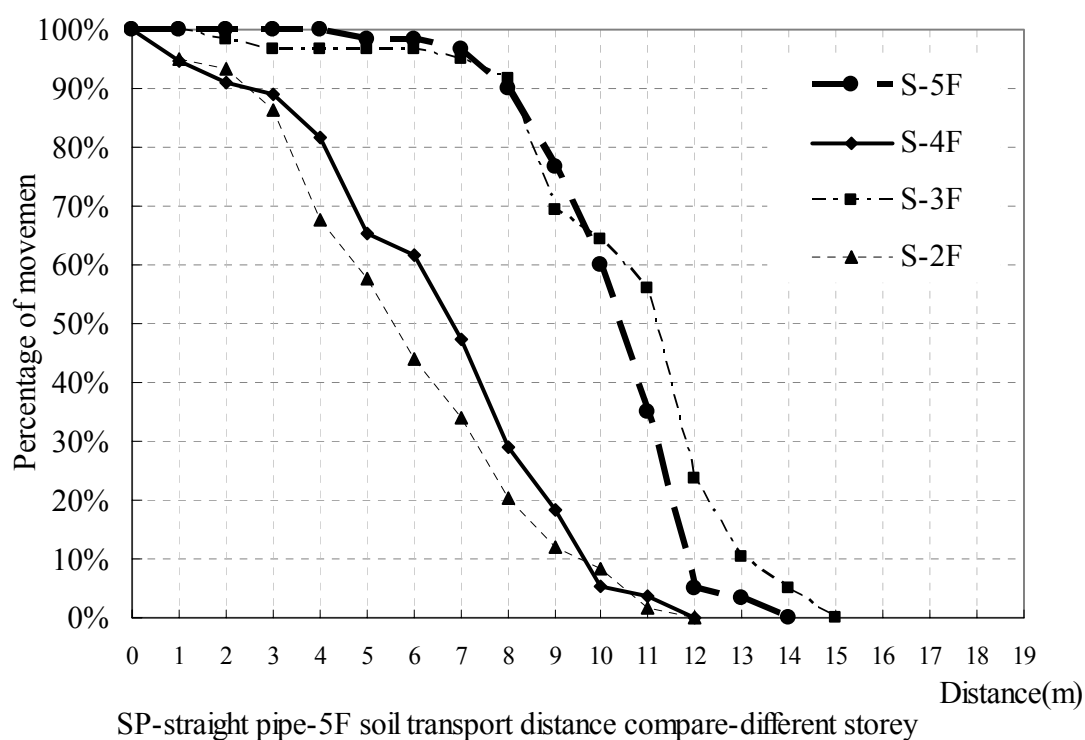


Figure 5 the percentage of imitate ordure pieces movement

On the other hand, Figure 6 shows the low flash water closet T1 testing results of transportation distance and the distribution of imitate ordure pieces from discharge 5th floor height. Also, Figure 7 shows the percentage of imitate ordure pieces movement due to the discharge floor height from 2nd ~5th. As a result, it is obviously seen that the flash volume dominated the transportation performance of main drain in building.

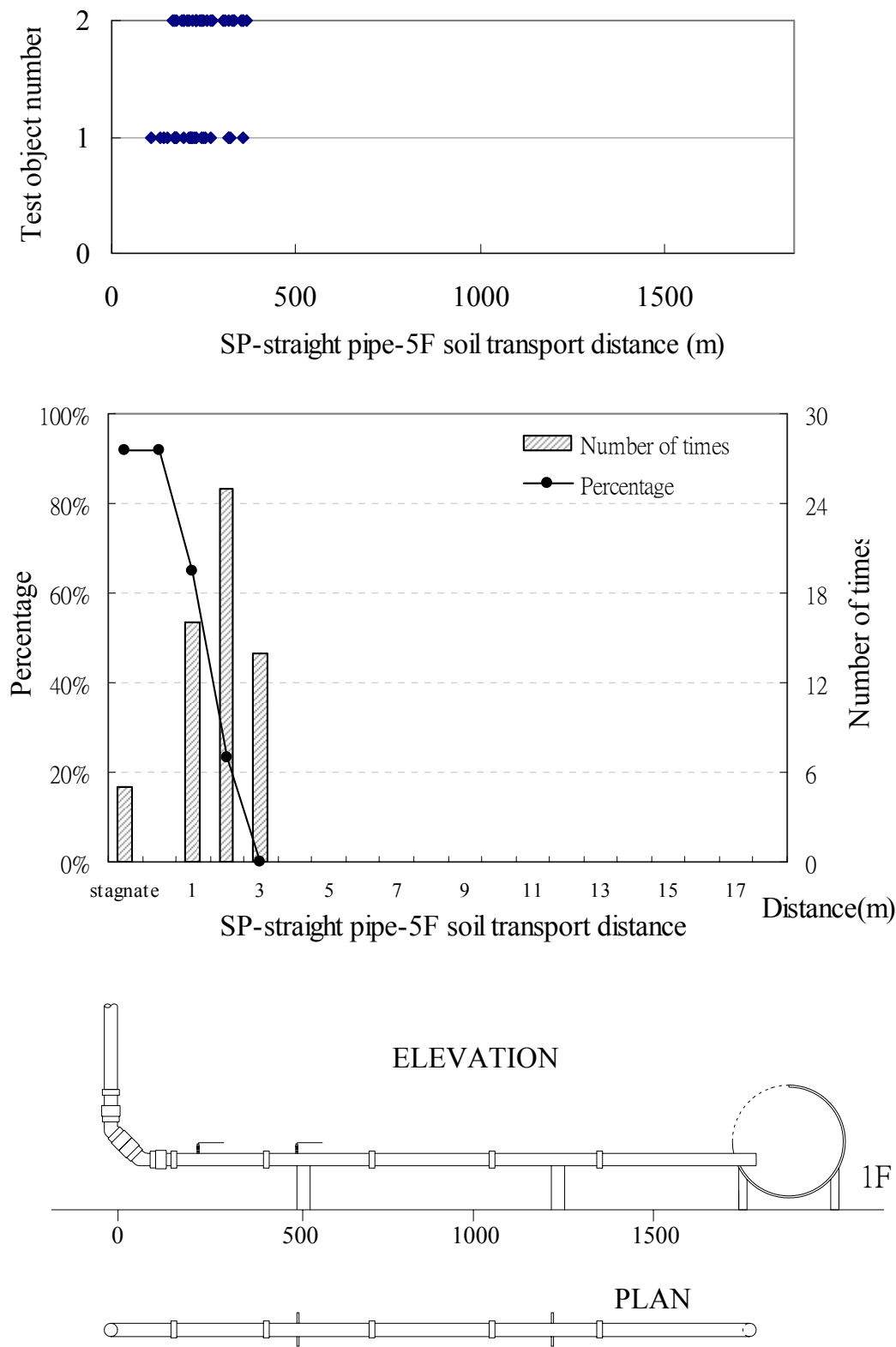
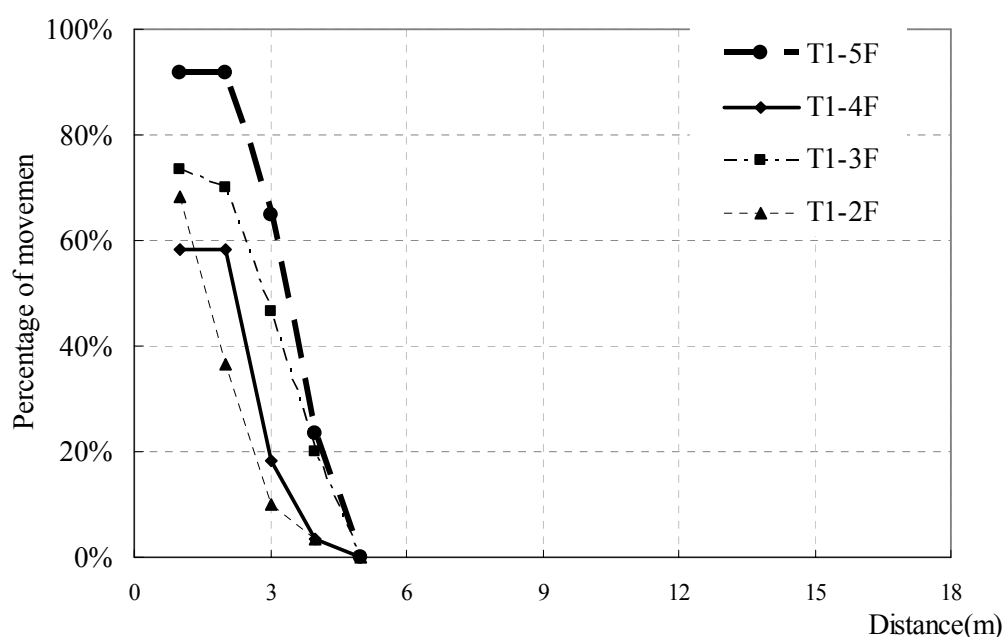


Figure 6 the saving water closet T1 testing results



T1-SP-straight pipe-5F soil transport distance compare-different storey

Figure 7 the percentage of imitate ordure pieces movement

Accordingly, the initial results also validate the public concern regarding the performance of drainage system after the adoption of low flash water closet. Table 1 shows the overall review on the testing results, which included four types of water closet and discharge from 2nd ~5th floor height. It reveals that the testing of low flash water closet move the imitate ordure pieces approximately 2~3 meter, and those of traditional article move 5~10 meter.

Table 1 the overall review on the testing results

Experimental Factor			Type of Toilet			
Diameter	Slope	Floor	T1 Siphon(6L)	T3 Siphon(6L)	T2 Gravity(6L)	9L
100 mm	1/100	2F	1.12 m	1.80 m	1.61 m	5.66 m
		3F	2.30 m	3.04 m	3.85 m	10.51 m
		4F	1.74 m	2.35 m	2.34 m	7.31 m
		5F	2.38. m	3.02 m	4.96 m	11.09 m

3 Empirical Prediction Method

In this chapter, we try to develop an empirical prediction method to reproduce the experiment data which were concluded in above section. As a general drainage in building, the gravity system without energy supply is the main current all over the world, and it is so popular for protecting indoor environment against bad smell and ill effect by a simple structure with trap. When drainage system is operating, a full flow in the stack of gravity drainage system is prohibitive. Actually, it is complex phenomenon with a mixing flow in pipe which mixed with water, solid and air. The definition of transportation distance is defined from the start of main drain and outlet of the drainage. Figure 8 shows the holistic view and profile of drainage process from the water closet to the end of the drainage system.

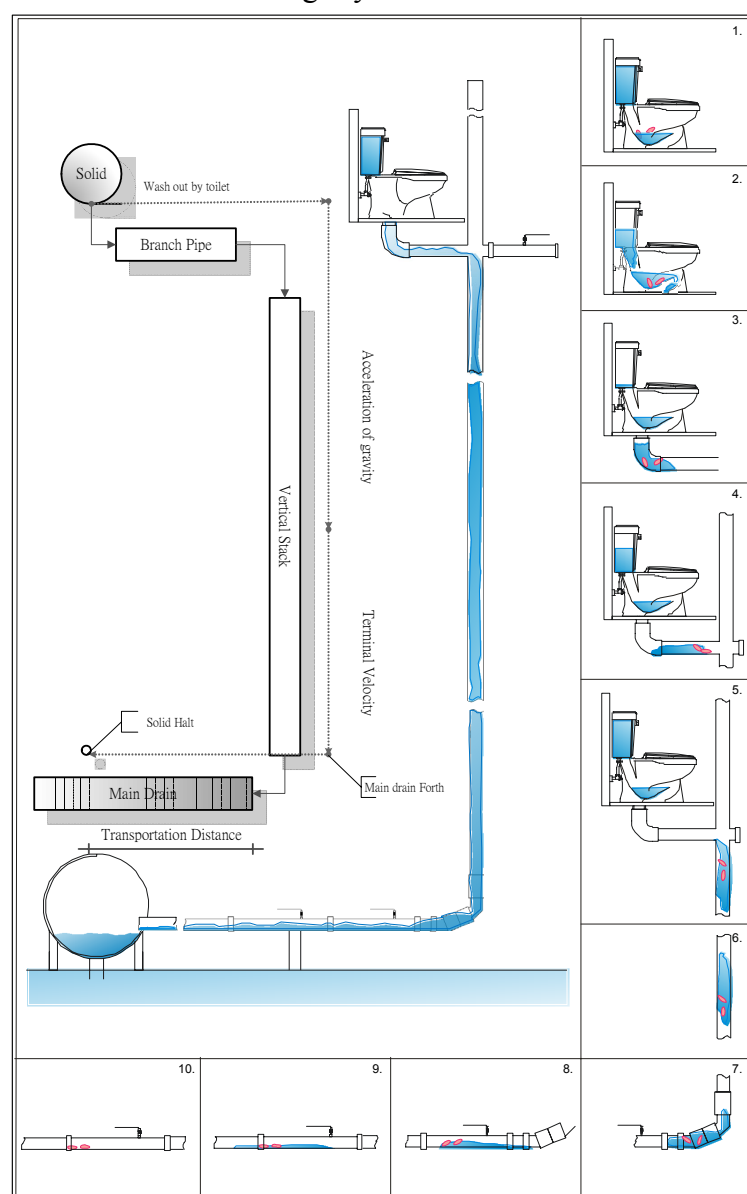


Figure 8 the holistic view and profile of drainage process

Figure 9 is the frame work and procedure which was conducted for estimating the transportation distance of imitate ordure pieces in building main drain. Firstly, four zonings are set up for parameters calculation including Branch Pipe (BP zone), Vertical Stack (VS zone), Main drain Forth (MF zone) and Main drain Back (MB zone).

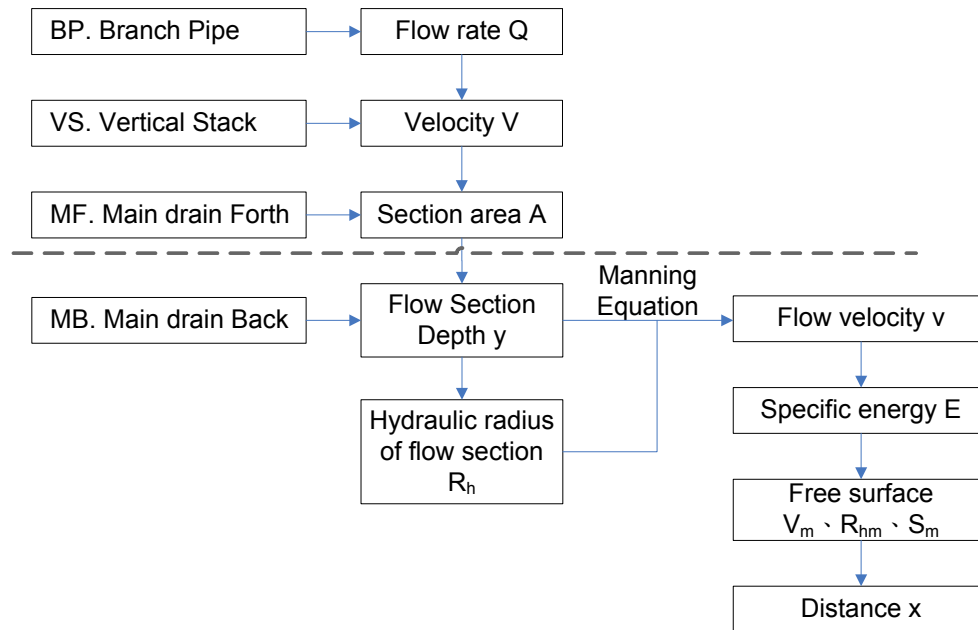


Figure 9 frame work diagram of calculation procedure

BP Zone—Branch Pipe

BP zone is branch piping zone connecting from water closet to drainage stack. The feature is ordure exiting from water closet to the piping system. Therefore, the first parameter need be ensured is the flash volume and the maxima flow rate $Q_{\max}$. Then, it can be standardized to be the average flow rate Q_w . The calculation equation is as the following.

$$Q_w = f'_{(f_{(Q_{\max})})} \dots\dots\dots (1)$$

$$f'_{(Q_w)} = 48.636Q_{\max} + 0.0461$$

$$f_{(Q_{\max})} = 5 * 10^{-5} v + 0.0007$$

Here v : flash volume (m^3)

$Q_{\max}$: maxima flow rate (m^3/sec)

Q_w : average flow rate (m^3/sec)

VS Zone-- Vertical Stack

VS zone is vertical stack piping area from branch joint to building main drain. The flow liquid is pulled by gravity and accelerated to the second parameter terminal velocity V_t with interaction between water and air and piping surface. According to the previous document, the following terminal velocity V_t is adopted in this study. Table 2 shows the data of terminal velocity V_t in different flow rate.

Table 2 shows the data of terminal velocity V_t

Flow rate Q(l/s)	Research Reference		Terminal velocity V_t
	Wyly	Dawson	
1.0 l/s	1.60	2.06	3.161
2.0 l/s	2.11	2.72	5.353
3.0 l/s	2.48	3.20	5.297
4.0 l/s	2.79	3.60	6.533

MF Zone—Main drain forth area

MF zone is the forth part of main drain in the position of stack change to horizontal piping. The crucial feature is hydraulic jump and air curtain which cause the first wave and move to the end of drain. The section area can be calculated by the continuity equation with parameters of flow rate and velocity.

MB Zone—Main drain back area

MB zone is the main drain back area after the hydraulic jump to the end of the drain. The flow depth is decreasing due to the distance of moving. Due to the assumption that flow depth is set as the critical parameter of transportation ability, thus the ordure would stop at the place where flow depth is lower than the diameter of the imitate ordure pieces. Herein, we set each variety of flow depth as 0.01cm, thus, the response of transportation distance to flow depth can be calculated. Consequently, as the flow depth decreases to 2.2 cm which is equal to the diameter of the imitate ordure pieces, then the sum of imitate ordure pieces moving would be the transportation distance. Figure 10 shows the assumption diagram of ordure transportation.

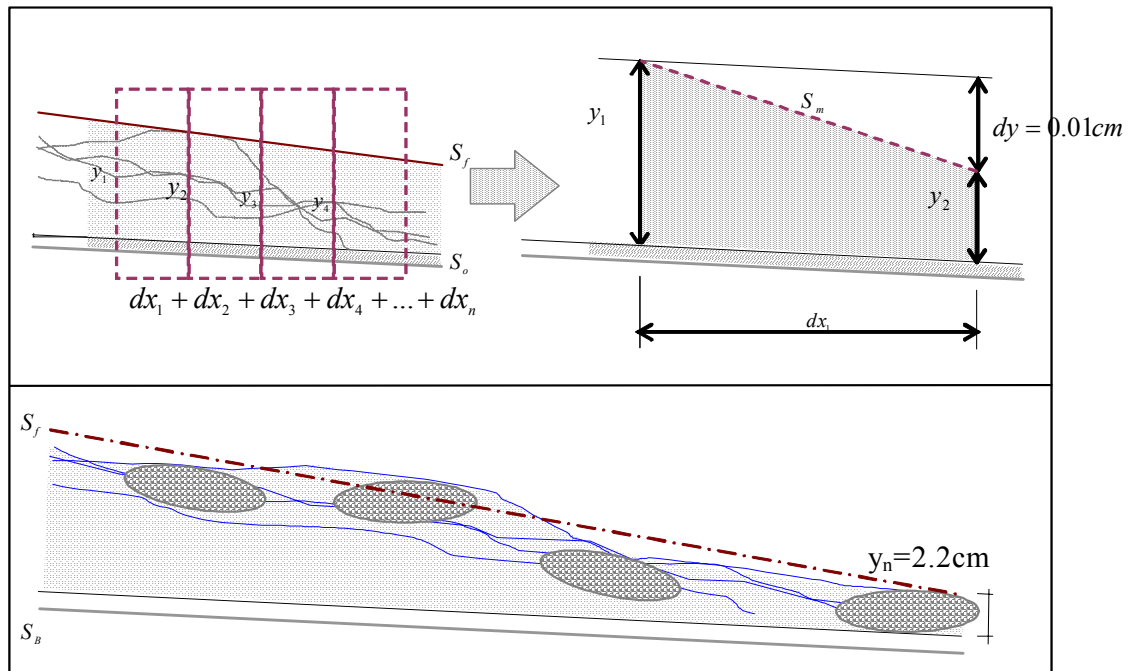


Figure 10 assumption diagram of ordure transportation

As the first step for calculation, initial flow depth and hydraulic diameter are necessary for the estimating flow velocity by Manning equation. Then we also need the main drain piping slope S_b and Manning coefficient n which is related to the resistance feature of piping material. The equations are as the following.

$$A = (\alpha - \sin \alpha) \frac{D^2}{8} \dots\dots\dots(2)$$

$$\alpha = 2 * \cos^{-1} \frac{(R - y_n)}{R} \dots\dots\dots(3)$$

$$R_h = \frac{A}{P} = \frac{D}{4} \left(1 - \frac{\sin \alpha}{\alpha}\right) \dots\dots\dots(4)$$

$$v = \frac{R_h^{2/3} S_o^{1/2}}{n} \dots\dots\dots(5)$$

Here α : Included angle between flow section and the free surface ($^\circ$)

R : Radius of flow channel (m)

D : Diameter of flow channel (m)

R_h : Hydraulic radius of flow section (m)

A : Area of flow section (m^2)

P : Perimeter of flow section (m)

v : flow velocity (m/sec)

S_b : Slope of channel

n : Manning coefficient

4 Discussion

According to the procedure of ordure transportation distance which was arranged as above section, we validate the calculation results and the testing data records. Table 2 shows the calculation parameters and validation data as the following.

Table 2 calculation parameters and validation data

Flash volume	Discharge height	Flow rate	Flow velocity	Flow section	Diameter	Slope	Manning coefficient	Initial depth	Transportation distance	
Vf (m ³)	H (m)	Qw (m ³ /sec)	V (m/sec)	A (m ²)	D (m)	Sb	n	Yo (m)	Calculation X(m)	Testing data X(m)
0.006	10.8	0.00343		0.004156				0.046	4.05	4.96
	8.3	0.00275	0.7644	0.003352	0.125	0.01	0.012	0.039	2.93	2.34
	2.3	0.00186		0.002383				0.031	1.63	1.61
0.009	10.8	0.01157		0.009548				0.09	10.3	11.09
	8.3	0.00979	1.1466	0.008045	0.125	0.01	0.012	0.077	8.65	7.31
	2.3	0.00624		0.005076				0.054	5.3	5.66

As the results, the comparison of calculation and testing data reveals that estimation is almost reproduce the results of experiment as shown in Figure 11. That is said the calculation method is approximately good to estimate ordure transportation distance of building main drain as the situation similar to experiment device.

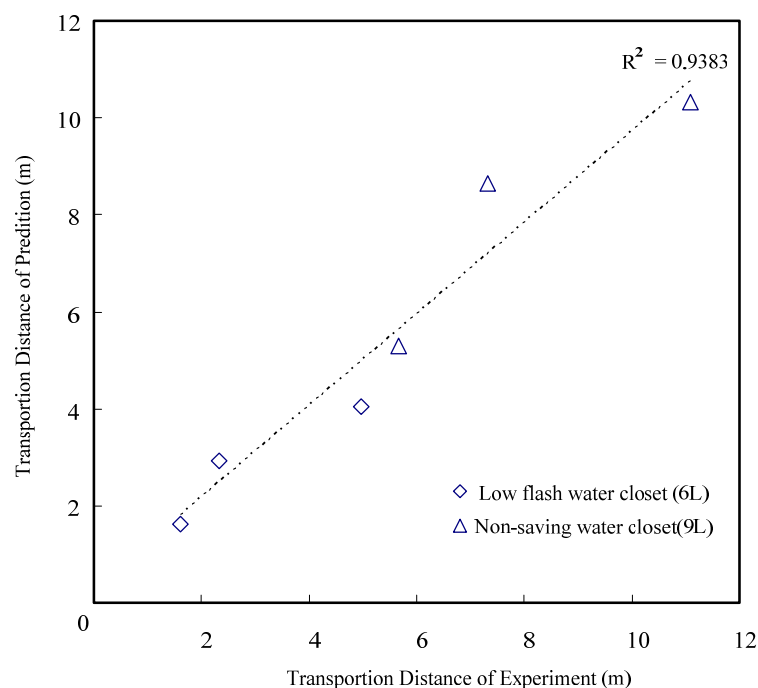


Figure 11 validation of calculation and experiment

Furthermore, it is obviously seen that flash volume of water closet dominates the transportation ability of building main drain. The transportation distance is increasing which follows up the flash volume of water closet. Reversely, the reduction of flash volume of water closet would shorten the ordure transportation distance in building main drain. Responding to the public concern, the low flash water closet is very probable to cause the problem of drainage system in buildings. On the other hand, it is also found that the diameter of main drain reveals the opposite relationship with the ordure transportation distance in building main drain. As we reduce the diameter of building main drain, the ordure transportation distance would be increased.

5 Conclusion

The performance of building main drain with low flash water closet has been identified as important issue from the observation of visual transportation phenomenon. The main purpose of the research is to explore the performance of main drain of buildings and validate the public concern. This research set up comparison experiment with low flash water closet and traditional article for visualizing the transportation ability of building main drain. The conditions of test rug included three types of water closets and several setting which may simulate some real situations of practical buildings. As the results, we concluded the transportation ability of traditional water closet with 9 liter per flash is far better than the water saving articles with 6 liter per flash. Furthermore, we try to develop an empirical prediction method for reproducing the experimental data in this research. The method had been verified and proved to be good for experiment results. These results approximately response to the public concern on the performance of main drain of buildings with low flash water closet. There are still many topics need to be clarified in this issue and more relevant researches should be conducted in the future.

ACKNOWLEDGEMENTS

The authors would like to thank the Architecture & Building Research Institute of the Ministry of the Interior of Taiwan (ABRI) and the National Science Council of the Republic of China for financially supporting this research.

REFERENCE

- 1) J.A.Swaffield and D.P.Campbell; *Numerical modelling of air pressure transient propagation in building drainage system, including the influence of mechanical boundary condition*. Building Envir. 27, (1992)
- 2) L.B.Jack and J.A.Swaffield, *Developments in the simulation of the air pressure*

transient regime within single stack building drainage system, CIB-W62 Symposium, 1999.9. (Edinburgh, Scotland)

- 3) Cheng, C. L., Lu, W. H., Shen, M.D., *An Empirical Approach: Prediction Method of Air Pressure Distribution on Building Vertical Drainage Stack*, Journal of the Chinese Institute of Engineers, Vol 28.
- 4) Masayuki Ohtsuka · Heizo Saito · 1988 · ”*Basic Study on Performance Test and Theoretical Calculation System of Drainage Pipe Network*”
- 5) R.S. Wyly and H.N. Eaton · 1961 · ”*Capacities of Stacks in Sanitary Drainage System for Building*”, N.B.S. Monograph 31 ◦
- 6) R.S.Wyly and H.N.Eaton · 1952 · ”*Capacities of Plumbing Stack in Building*”,BMS Repoet,132

Main author presentation

Cheng-Li Cheng is the Professor at National Taiwan University of Science and Technology, Department of Architecture. He is a researcher and published widely on a range of water supply and drainage in building. He has published extensively on a range of sustainable issues, including the water and energy conservation for green building. Currently he also acts as referee of Taiwan Green Building Evaluation Committee and Nation Building Code Review Committee.



Chia-Ju Yen is a Ph.D student majoring in drainage system at National Taiwan University of Science and Technology, Department of Architecture. She is also interested in sustainable building.



Kuen-Chi. Ho is a Ph.D student majoring in drainage system at National Taiwan University of Science and Technology, Department of Architecture.



Rainwater System in TAIPEI 101



Agenda

1. Building Climate Rainwater System Recycling System



TAIPEI IOI

Reported By:
Continental Engineering Consultants, Inc.



Agenda

- **Building
Climate
Rainwater System
Recycling System**

A map of Taiwan showing its administrative divisions. The map is color-coded: blue for major cities (Taipei, Keelung, Taichung, Tainan), green for most counties, yellow for mountainous areas, and pink for Kinmen and Matsu. Labels in Chinese identify various regions like Taipei City, Taichung City, and Tainan City.



Location – Taipei, Xin Yi District

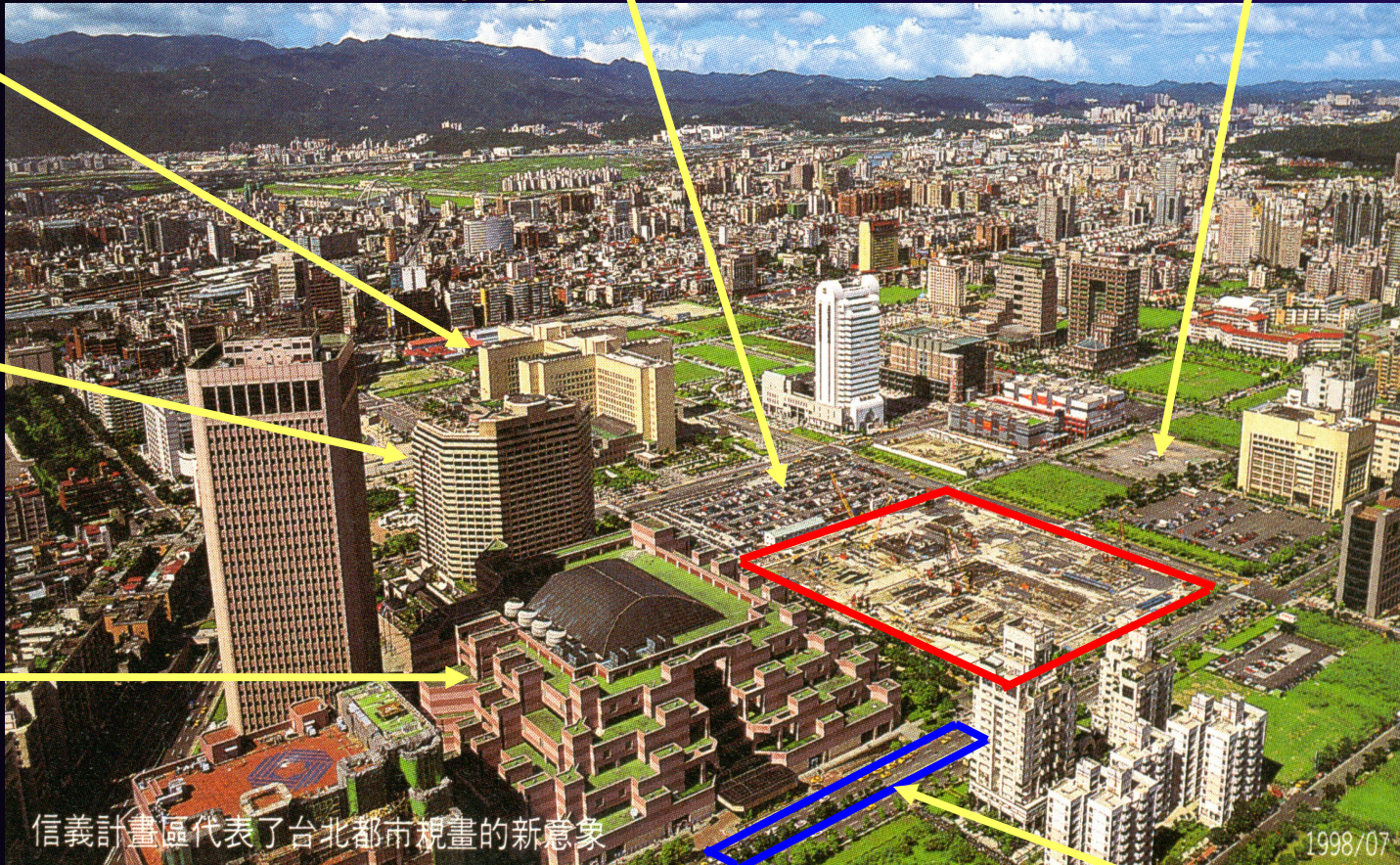
Taipei
City
Hall

Grand
Hyatt
Taipei

World
Trade
Center
Hall # 1

World Trade Center
Hall # 2

World Trade Center
Hall # 3



MRT Station

Basic Facts



Site.....30,277 sq. m

Construction.....15,138 sq. m

Total.....370,000 sq. m

Tower.....202,020 sq. m

Mall.....77,330 sq. m

Garage.....90,650 sq. m

Building Height 508 m

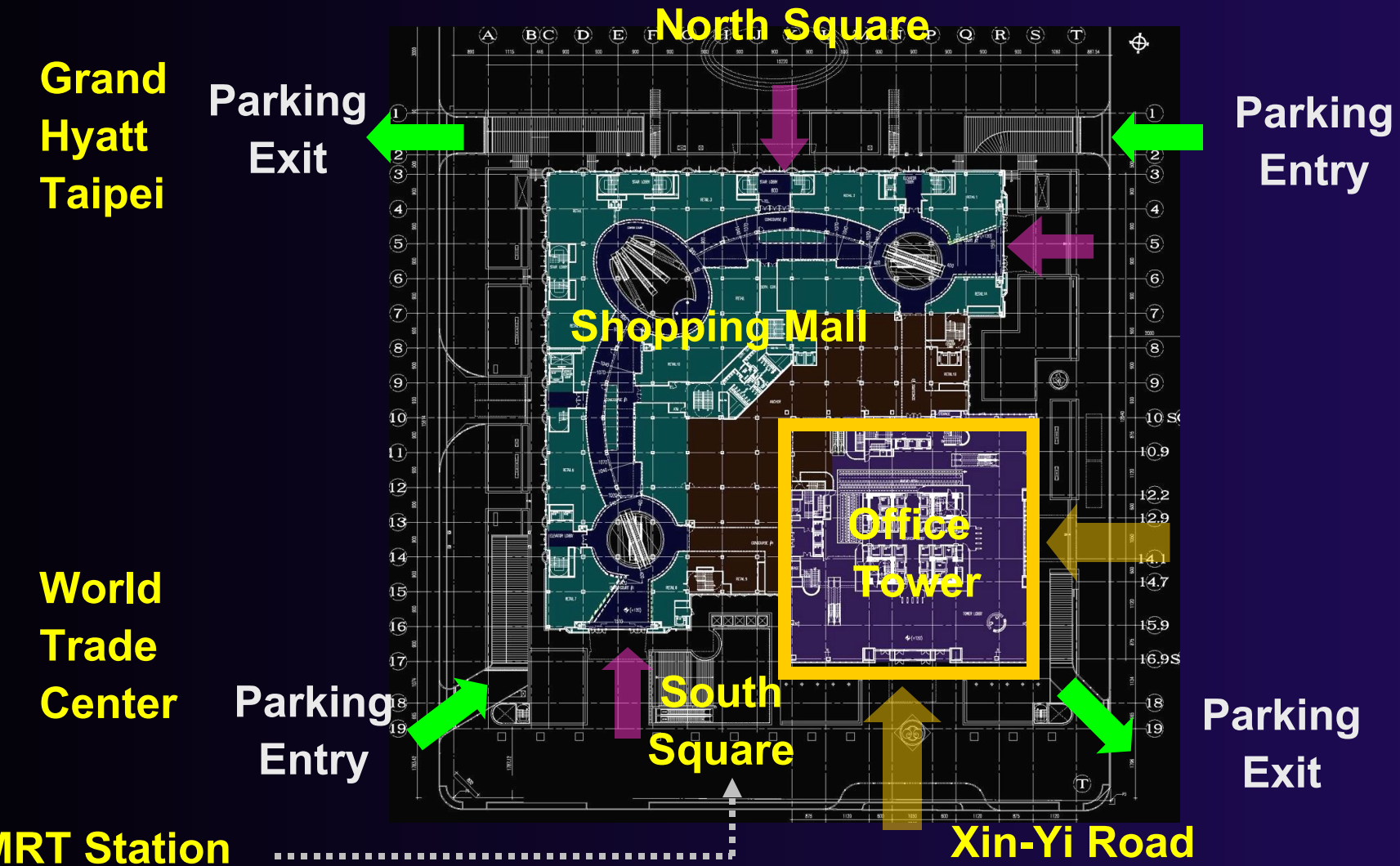
Floor No.....B5~B1 + 1F~101F

Occupants

Tower.....15,400 person

Mall.....24,000 person

Site Develop Plan



Space Utilization

Podium & Basement:

B5~B2 / Garage

B1~4F / Food Court, Shopping mall, Book Store

5F,6F / Health Club, Exhibition Room,
Banquet Room, Conference Room,
Financial Service

Tower:

1F~3F / Office Main Lobby

9F~84F / Office Floor (65 No.)

35F,36F,59F,60F / Sky Lobby

85F~88F / Restaurants

89F / Observation Floor

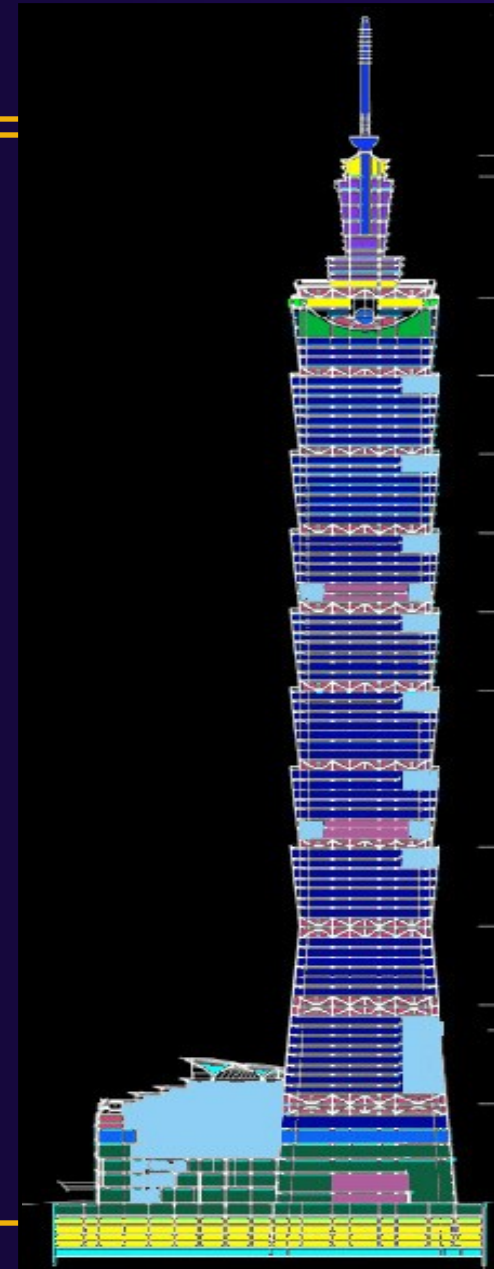
91F / (Outdoor) Observation Deck

92F~100F / Communication Service

101F / Summit 101

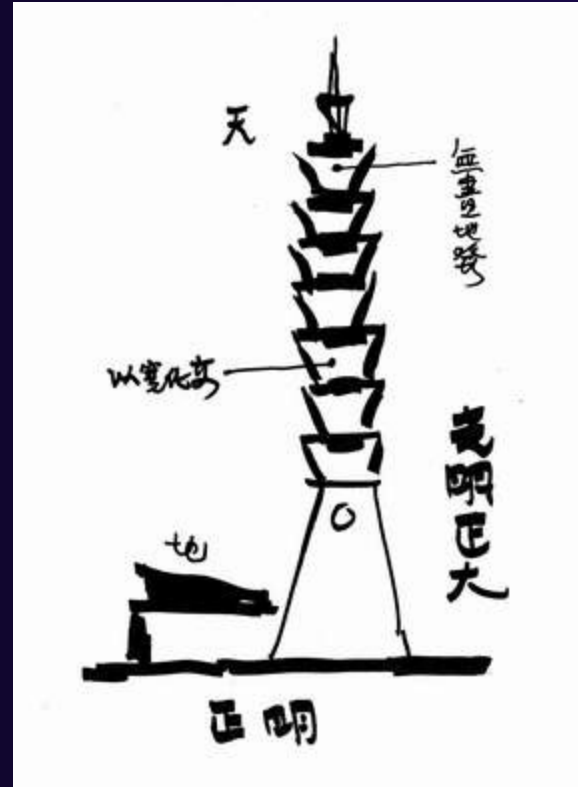
7F,8F,17F,18F,25F,26F,34F,42F,50F,58F,

66F,74F,82F,90F / Mechanical Floor



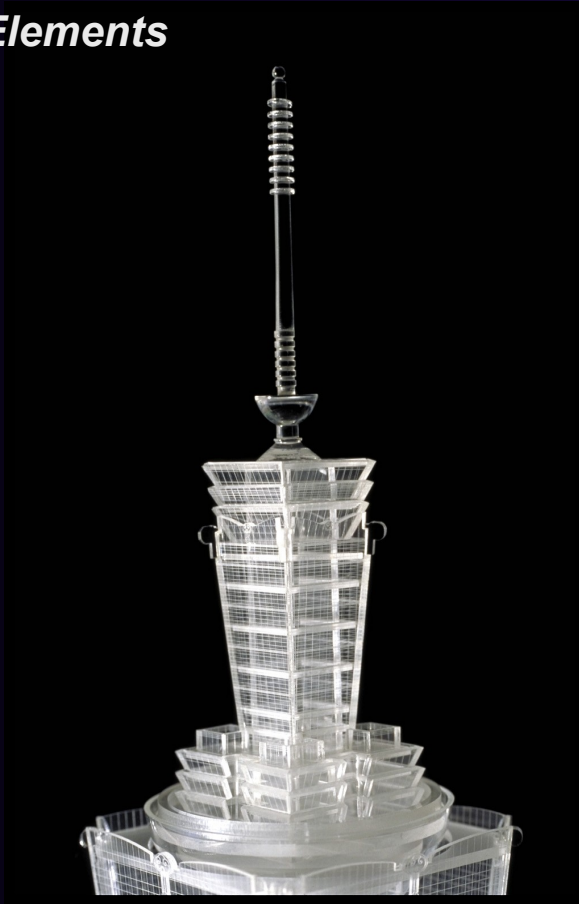
Design Concepts

Chinese Good Fortune



Design Concepts

Chinese Elements



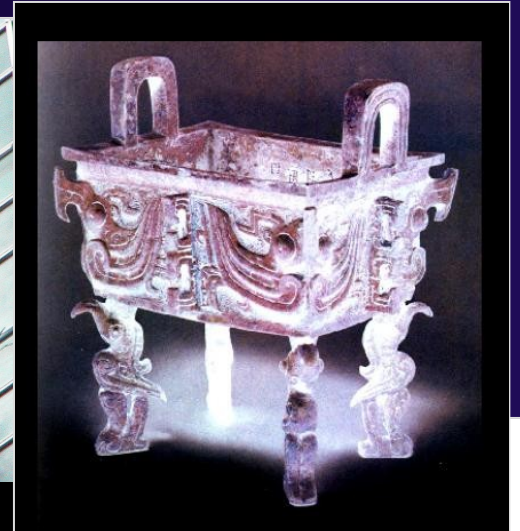
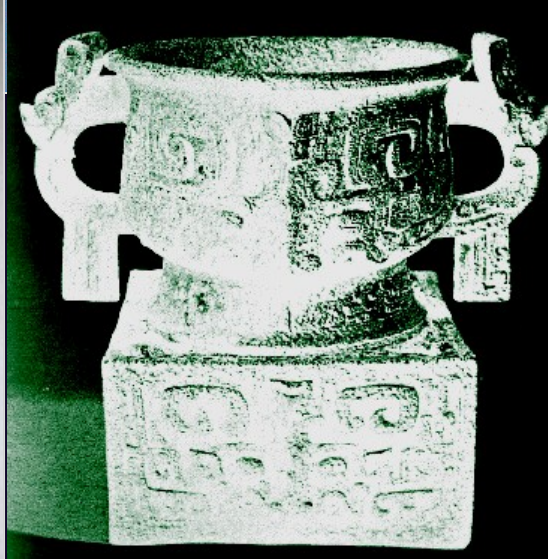
Design Concepts

Chinese Elements



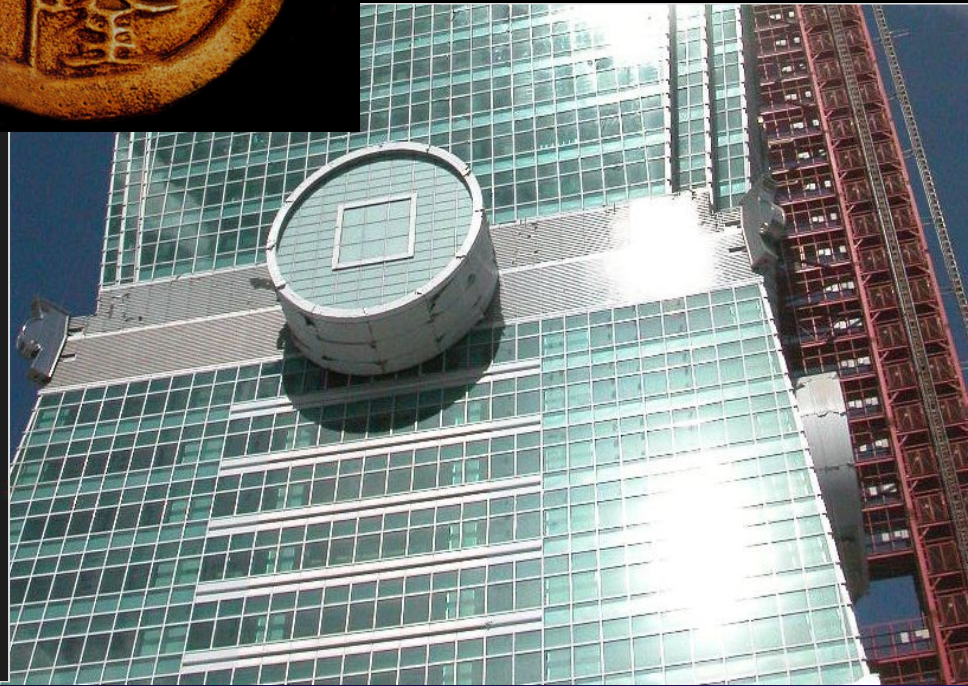
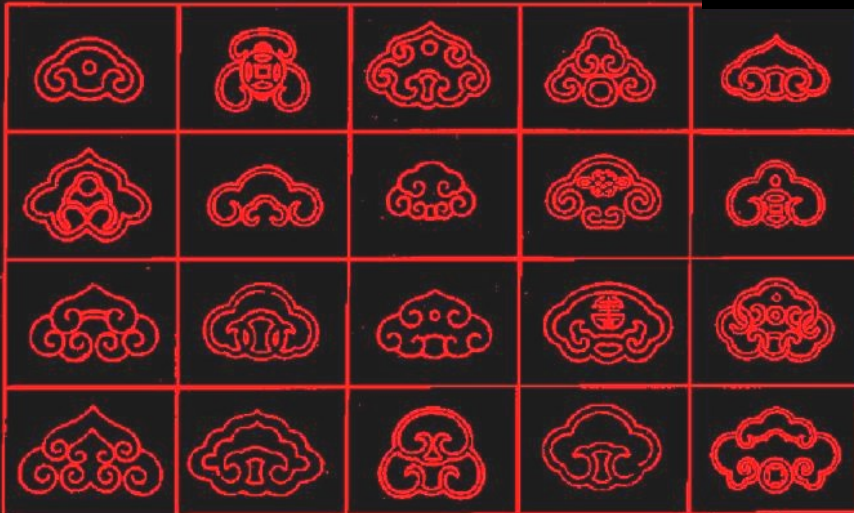
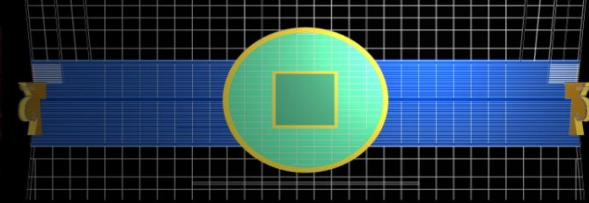
Design Concepts

Chinese Elements



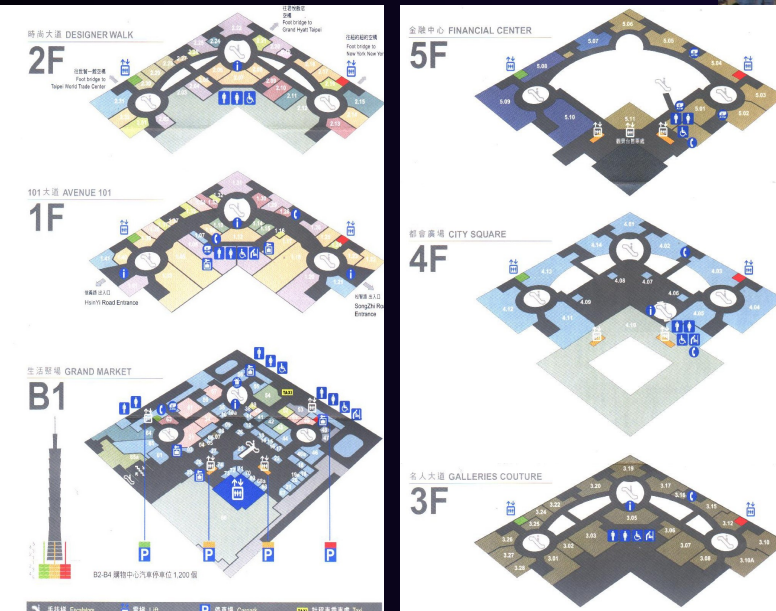
Design Concepts

Chinese Symbols



Floor Planning (Mall)

Urban Street with Vertical Transferring Knuckle



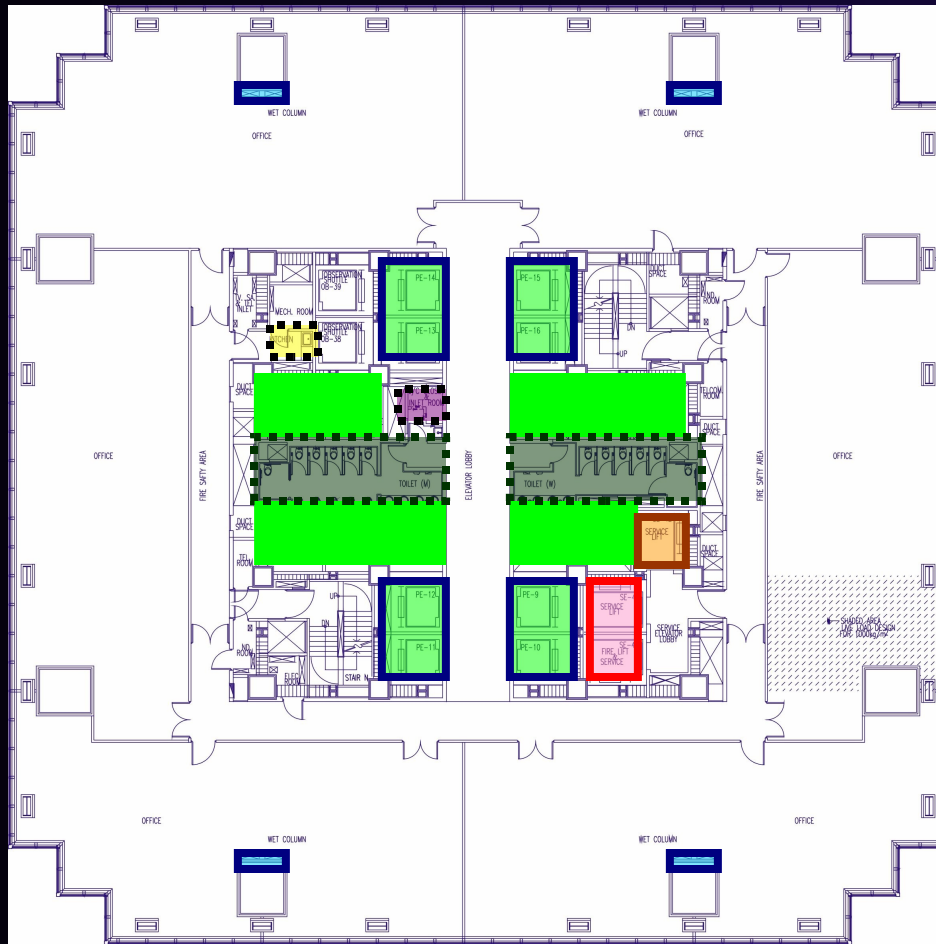
Floor Planning (Mall)

Social Plaza with Beautiful Structural Roof



Floor Planning (Office Floor)

Space introduction



Elevator (shuttle)



Elevator (Local)



Elevator (Service)



Elevator (Fire)



Toilet



Tea Room



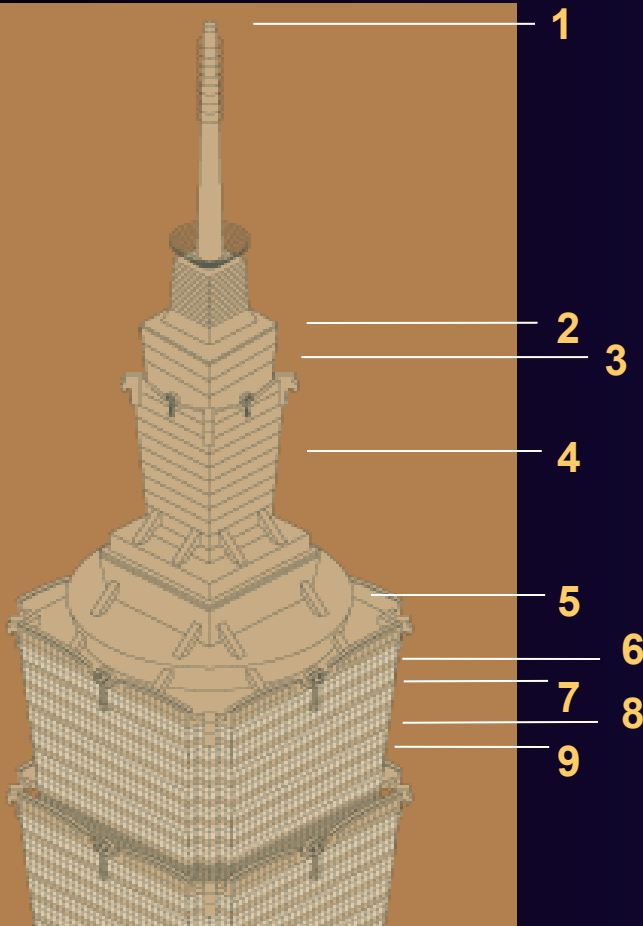
Garbage Disposal Room



Wet Column

Floor Planning (Tower Top)

3 Categories As World Tallest Building



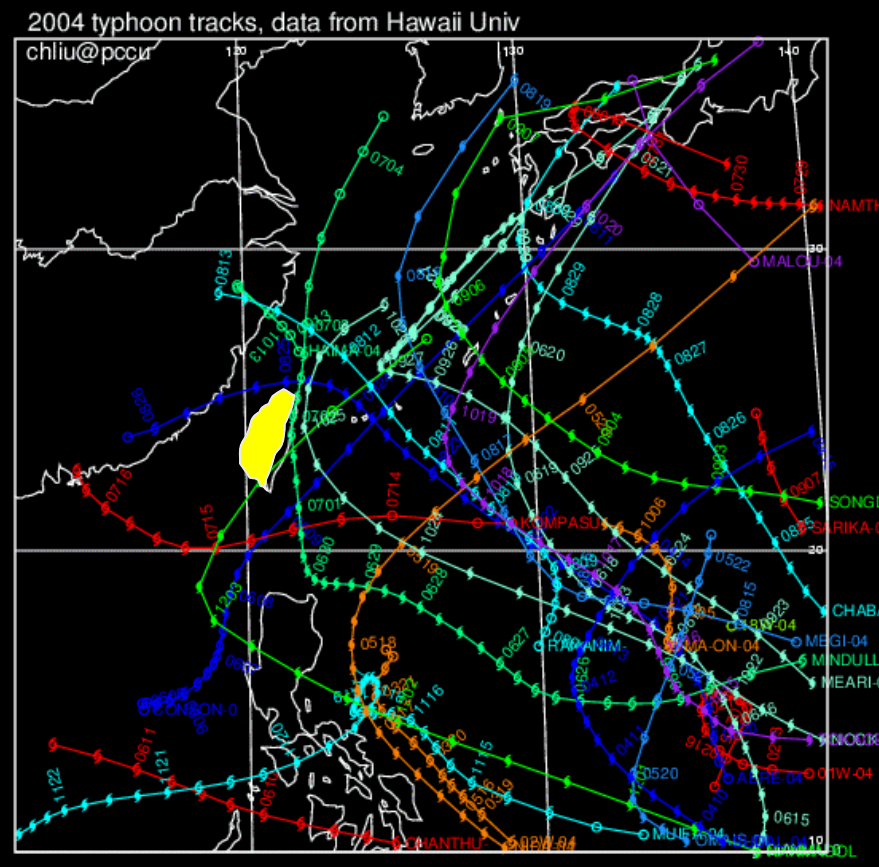
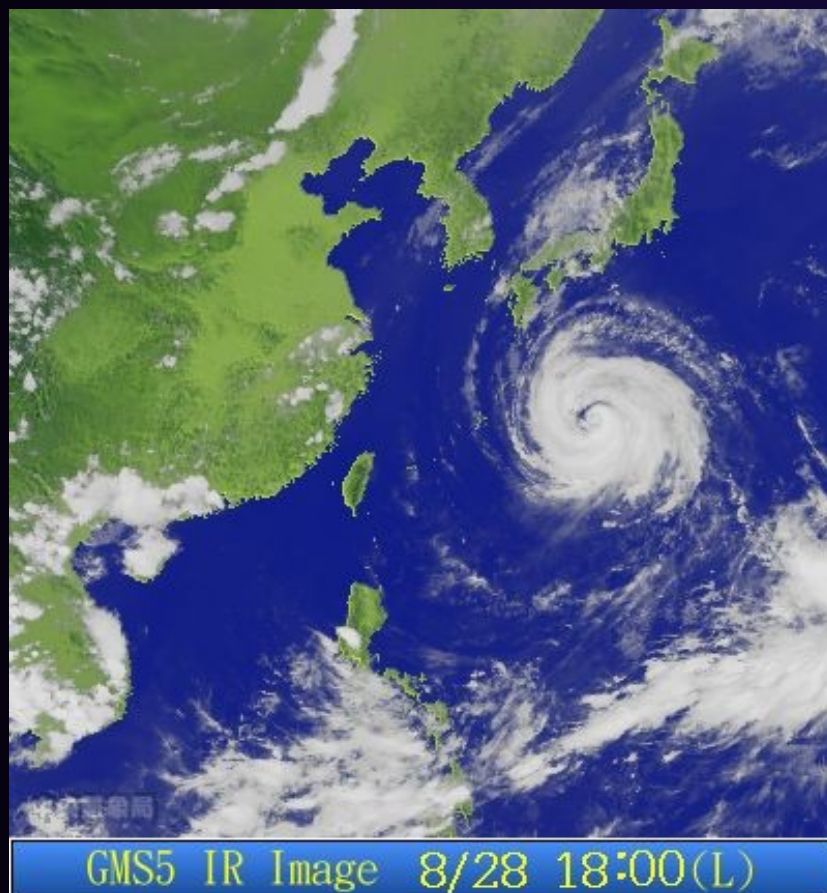
- ◆ **Pinnacle(508m)**
- ◆ **101R : 101 Rooftop(448m)**
- ◆ **101 : Summit 101(438m)**
- ◆ **92-100: Communication Floors**
- ◆ **91 : (Outdoor) Observation Deck**
- ◆ **89 : Observation Floor**
- ◆ **88 : Restaurants**
- ◆ **86+87 : Double High Restaurant**
- ◆ **85 : Restaurant**

Agenda

- **Building
Climate
Rainwater System
Recycling system**

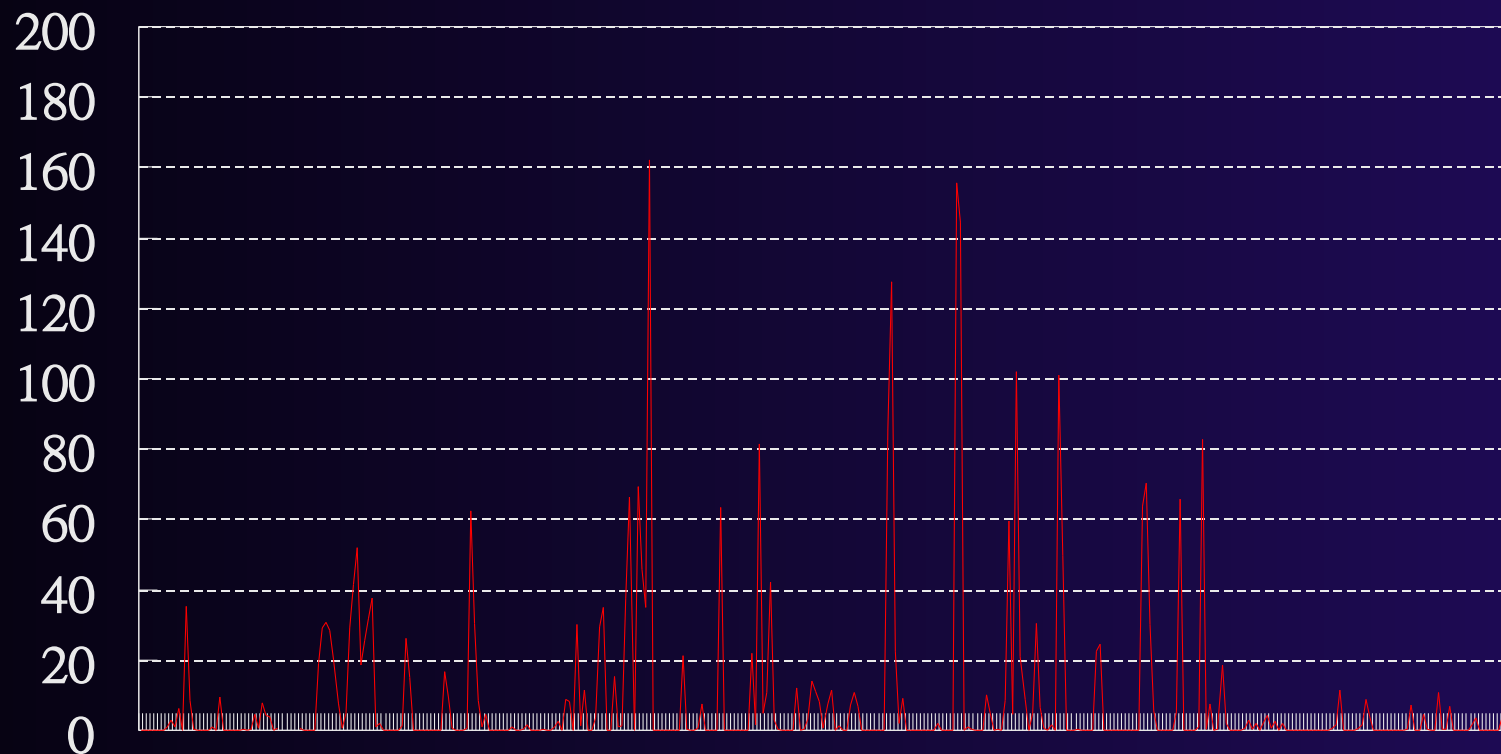
Regional Climate

Typhoon's Tracks 2004



Regional Climate

Daily Precipitation 2005 (mm/day)



Data from : Central weather Bureau

— Daily Precipitation(2005)

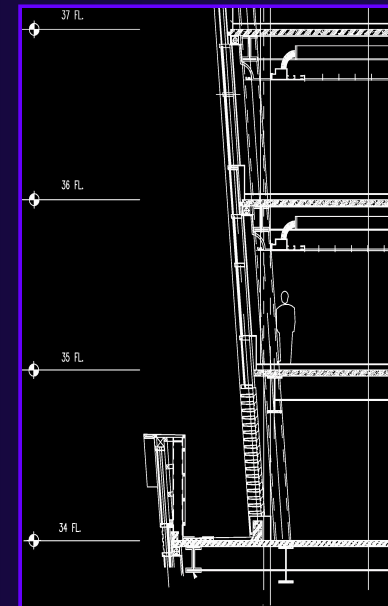
Agenda

- **Building
Climate
Rainwater System
Recycling system**

Hourly Precipitation

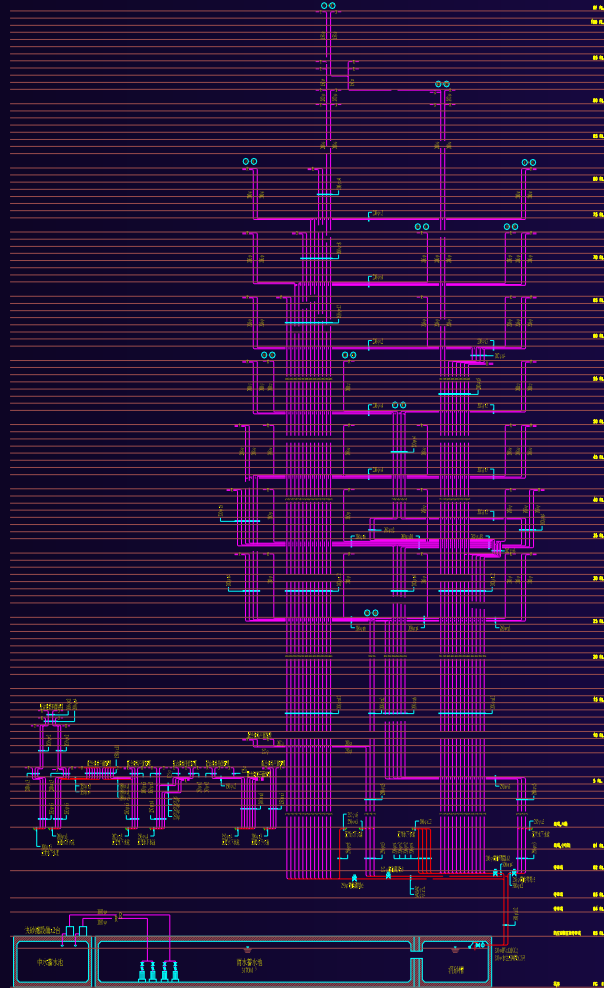


$$38,000\text{m}^2 * 87.5\text{mm/hr} = 3,300\text{m}^3/\text{hr}$$



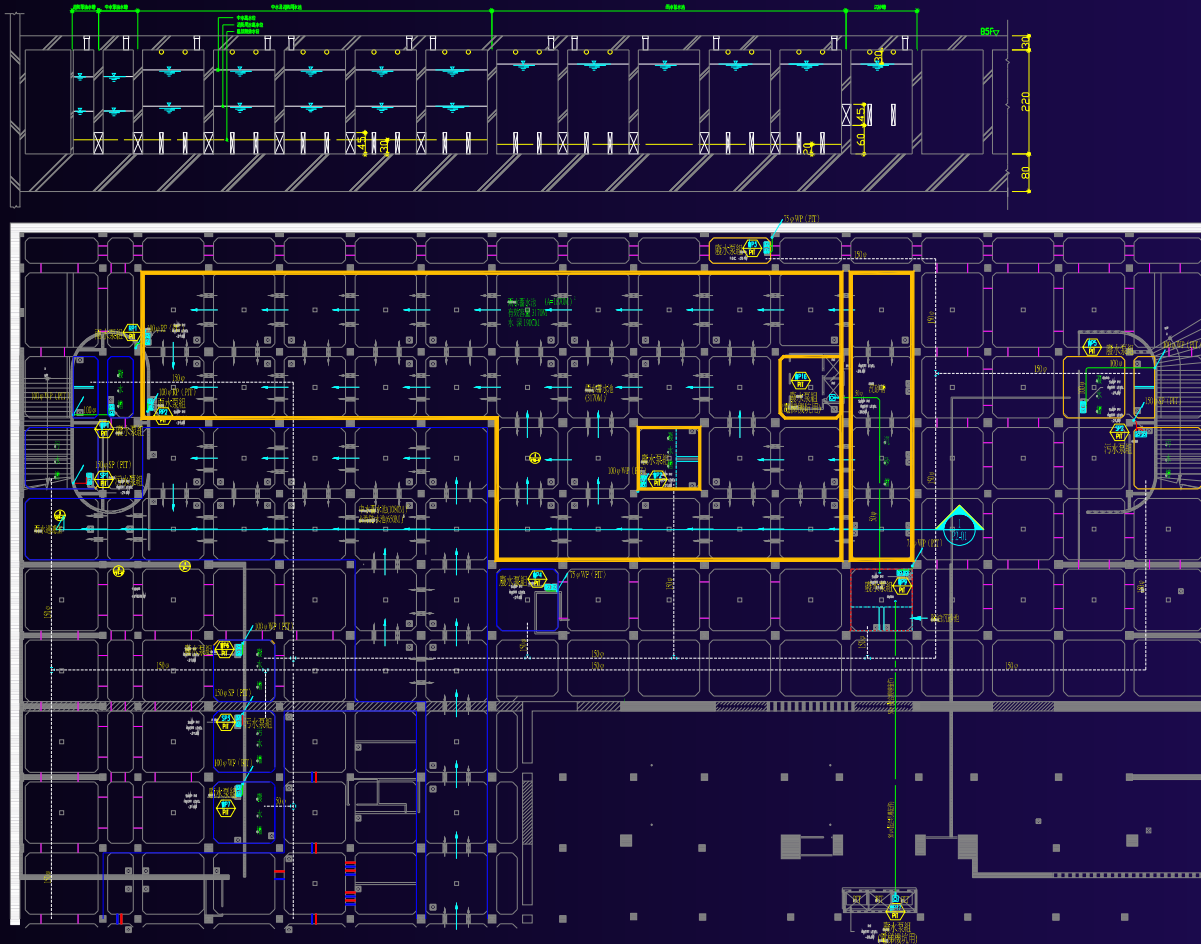
Rainwater System

System Riser Diagram



Rainwater System

Rainwater Storage Tank / Matt Level



TAIPEI IOI

Reported By:
Continental Engineering Consultants, Inc.

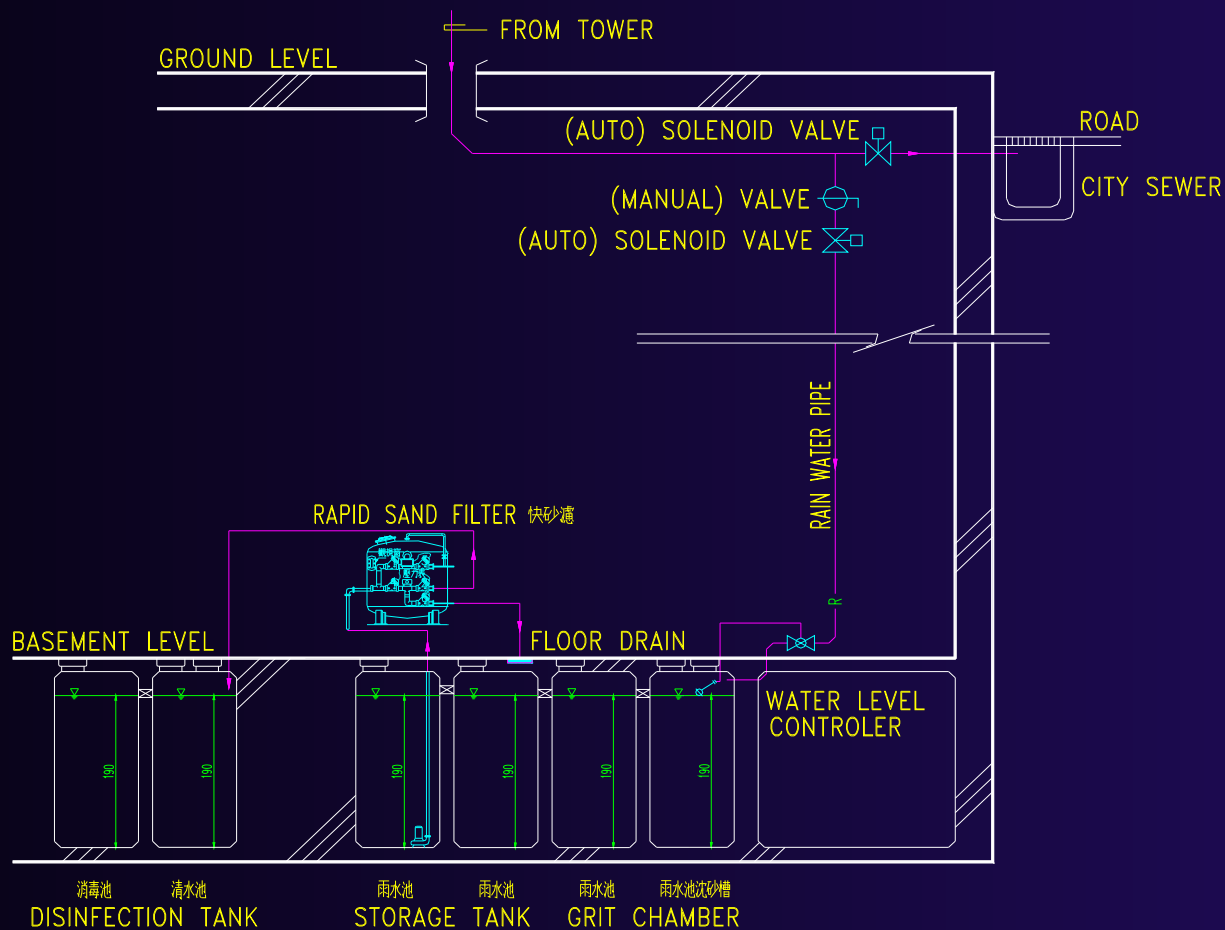


Agenda

- **Building
Climate
Rainwater System
Recycling system**

Recycling System

Collecting / Recycling Schematic diagram



Recycling System

Water quality for Recycling water

Item	Application
	Toilet
Coliform	< 10
BOD(mg/l)	< 10
pH value	6.0~8.5
Turbidity	< 5
Odor	Comfortable
Color	< 40
Residual Chlorine	Chlorineless

Suggested criterion from : Graduate Institute, Environmental Eng. NCU

The End

Design

Rainwater Piping System:
Continental Engineering Consultants, Inc. (CEC)
Rainwater Recycling System:
Rising Sun Engineering Consultant, Inc.

Presentation

Integrator: Y.T. Hsu / CEC
Reporter: I.M. Wang / CEC



Solids in building drainage stacks: A potential cause of air pressure transients?

Dr. M. Gormley¹

**1. Drainage Research Group
The School of the Built Environment
Heriot Watt University
Edinburgh EH14 4AS**

m.gormley@sbe.hw.ac.uk

+44 (0) 131 451 8262

Abstract

The consequences of air pressure transients in building drainage and vent systems (DVS) can be serious as they compromise the last line of defence between the potentially hazardous foul air in the drainage and sewer network and the habitable space within buildings. Pressure transients are caused by rapid changes in flow conditions in fluid systems. Much previous research has defined the nature and effects of air pressure transient generation and propagation within DVS. This paper confirms that solids have an effect on the pressure regime in a vertical stack; that transients are generated and that pressures are modified in a way hitherto undefined. Numerical models have been developed to predict the effects of different configurations and innovative techniques on the air pressure regime in DVS. These models have so far not included the effects of solids in the vertical stack and their influence on the flow and pressure regime within the system. A series of controlled experiments in a 16 storey building with a single stack system are described and a simulation of these events in the numerical model AIRNET confirms the minimal impact, on water trap seals of the short duration transients generated by solids falling in vertical drainage stacks.

1. Introduction

The flows found in DVS are inherently unsteady as a result of appliance discharges throughout a building and are difficult to define. The discharges from appliances generate surge waves and while these are subject to attenuation in the horizontal elements of the network, still emerge into the vertical stack as a rapidly varying flow. Appliance discharges transporting solids will naturally eject these solids into the stack where they will fall within the central air core. Much research has been carried out on the inflow to vertical stacks from branches^{1,2,3}. The mechanisms of air entrainment due to fluid to fluid traction forces⁴ has also been defined and numerical models have been developed which can accurately simulate the pressure regime in this two phase flow of air and water.

Of great concern to the public health engineer, and the researcher in this field, is the protection of water trap seals from unacceptable pressure fluctuations in the DVS. International codes recognise the importance of protecting water trap seals from undue pressure fluctuations by limiting the allowed variation to 38mm wg. Recent investigations in this area have attributed the spread of the deadly SARS virus in South-East Asia to a possible cross contamination from one housing unit to another in a high rise block as a result of dried-out water traps^{5,6}.

This paper considers whether solids falling in a vertical stack can cause the generation of low amplitude air pressure transients of sufficient magnitude and duration to compromise water trap seals in a single stack system. The data gathered for the analysis was obtained from a set of investigative experiments on a 16 storey building in Dundee, Scotland due for demolition. The value of the data lies in its acquisition from a recently used building still connected to the public sewer network and bearing all the marks of a system which had been used for thirty years and having sufficient height to ensure terminal conditions^{7,8}.

Little prior research has been carried out on this subject with the exception of a small but significant test series carried out in the 1950s⁹, when the operational parameters of the single stack system was investigated by the Building Research Station in the UK. These tests showed that flushing wads of newspaper down a WC did not induce siphonage in water trap seals lower in the building. While the outcome of these tests was conclusive, in that they proved that the single stack system was robust enough to deal with heavy flush loads without the need for additional venting arrangements, no pressures were recorded and the mechanisms of transient generation were not defined. It was also assumed that the excessive loads would generate only negative transients.

The series of tests described in this paper, and their subsequent analysis, will define the mechanisms of generation and propagation of potential sources of negative and positive air pressure transients in building drainage systems and provide a credible means to predict their effect on system performance via a method of characteristics based computer model.

2. DVS air pressure Transients: Mechanisms and models

Low amplitude air pressure transients in DVS are commonplace, generated by the changing nature of the unsteady water and entrained air flows associated with the random discharge of appliances. These generated transients are suited to the classical elastic analysis of pressure surges associated with waterhammer in bounded systems and are governed by the St. Venant equations of continuity and momentum^{7,8}.

Consider the simple frictionless system shown in Figure 1 consisting of a pipe length terminating in constant pressure reservoirs, with a partially closed valve midway. The pipes on either side of the valve are at different pressures due to the setting of the valve and the ΔP across it (Figure 1a). At some time in the future, as depicted in Figure 1b, the valve is rapidly opened and a positive pressure transient propagates downstream from the valve as the fluid rushes through the open valve. An opposite, negative pressure transient propagates upstream from the valve. These two pressure transients propagate along the two pipes at the local acoustic velocity for the fluid in a rigid bounded conduit. For the case considered in this paper – air in a rigid pipe - the velocity of propagation is approximately 320m/s.

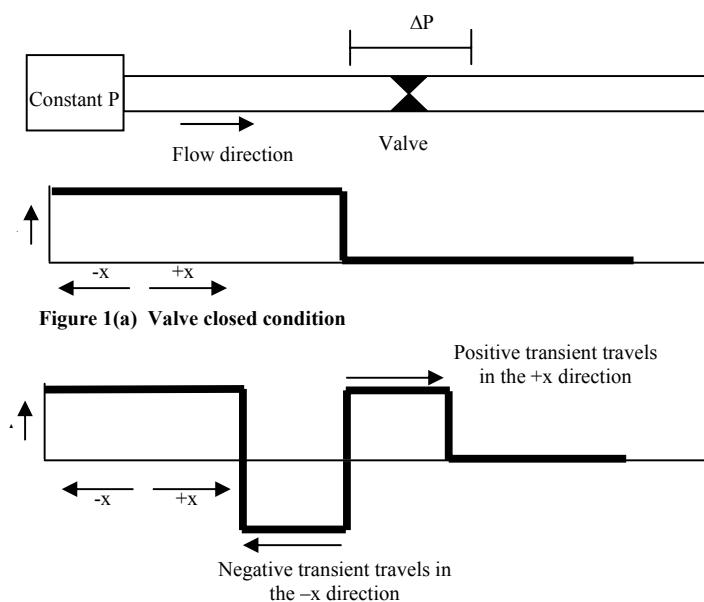


Figure 1(b) Transient generated following momentary opening of valve

Figure 1 Simple Transient Analysis

The above simple model of system operation can be applied to the flows associated with building drainage systems. Figure 2 shows the relevant components of the system. The air flow in the system is initiated as a result of the shear between the annular water film and the air core. In the case of Figure 2 the water at the branch/stack junction forms a partial occlusion to the air and is therefore equivalent to the valve in Figure 1 with a pressure difference across it, although it is not wholly closed. If the make up of the water curtain at the branch/stack junction is changed so that a momentary opening appears then a positive transient will be generated and propagate down towards the base of the stack and conversely, a negative transient will be generated and propagated upwards towards the top of the stack. Effectively an enlarged passage reduces the obstruction and results in an increased entrained airflow. This can only be maintained if the entrained airflow in the upper stack rises in response to the propagation of a negative transient.

This opening could be created by a solid falling in the centre of the stack pipe as depicted in Figure 2. The mechanisms described in this section can explain how falling solids could generate air pressure transients in a vertical building drainage stack. The task of proving whether this phenomenon would compromise water trap seals in practice will be evaluated by a combination of experimental investigation in a real building stack and simulation of their effect using numerical techniques described below.

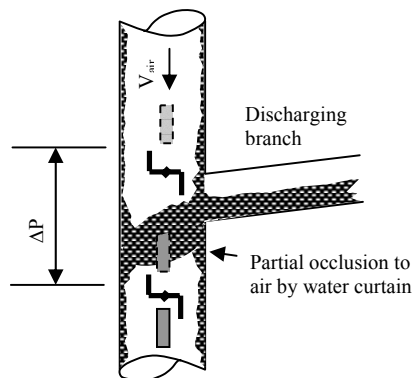


Figure 2 Solid piercing water curtain at a branch to stack junction

3. Numerical modelling of air pressures in DVS

The mechanisms of air pressure transient propagation in DVS described above are well understood. Modelling air pressure wave propagation in a bounded conduit is suited to numerical techniques applicable to full bore fluid flow. Previous research³ has developed the simulation techniques used extensively in this research to evaluate the risk associated with the generation and propagation of air pressure transients resulting from the presence of falling solids in drainage flows in vertical stacks.

The program simulates the propagation of low amplitude air pressure transients using the fundamental St. Venant equations of momentum and continuity and by the numerical solution

of these equations, via the method of characteristics. The method is used to yield air pressure and velocity within a bounded duct system subjected to air pressure transient propagation^{1,2,4,10}.

4. Experimental set up

4.1 General

The data upon which this paper is based was obtained from an extensive set of site investigations on a 16 storey local authority residential building in Dundee, Scotland which was due for demolition. The building contained 90 local authority housing units and the drainage system was sub-divided into 6 different sections, each one served by a 150mm cast iron vertical drainage stack which ran the height of the building. Each of the 6 single stack systems served a total of 15 housing units, and also served to drain the roof area of run-off rain water.

For modelling purposes, pressure and airflow measurements taken on the stack must be attributable to specific appliance discharges, which is an extremely difficult task in an inhabited building. Discharges from different appliances, WCs, baths, showers, washing appliances are difficult to control and predict, due to their random usage in reality. It was therefore necessary to control flows in the stack in order to cross reference discharges with pressure and airflow measurements.

The single stack system, shown in Figure 3, represents the test installation in the building. In order to ensure that all the air was entering the system through the roof termination, all water trap seals were disconnected from the system and the connecting pipes sealed. Metered water pumping stations were set up on 4 different floors, Figure 3 shows the arrangement. Airflow was measured using a pitot-static tube on the top floor of the building mounted in a 50mm connecting pipe. Pressure transducers were installed along the height of the stack.

4.2 Data Acquisition and possible error

The transducers were located just above the branch connections and were routed back to the Data Acquisition station on floor 10 of the building. The transducer outputs were connected to a data acquisition system based around a Keithley Instruments KPCMIA 3116 Analogue to digital converter (A/D) with 16 bit resolution. The scan rate of the system was set to 200Hz. The scan rate was chosen as a compromise between the need for high speed resolution and the file size on long test runs (typically 2 minutes). As the system was designed to record transient propagation, it was possible to miss a small amount of information using a scan rate of 200Hz. The error associated with the scan rate can be expressed either in time (seconds) or in distance (metres). A 200Hz sample rate will record a measurement every 0.005 seconds. This was considered appropriate for measuring pressure transients in this experimental scenario.

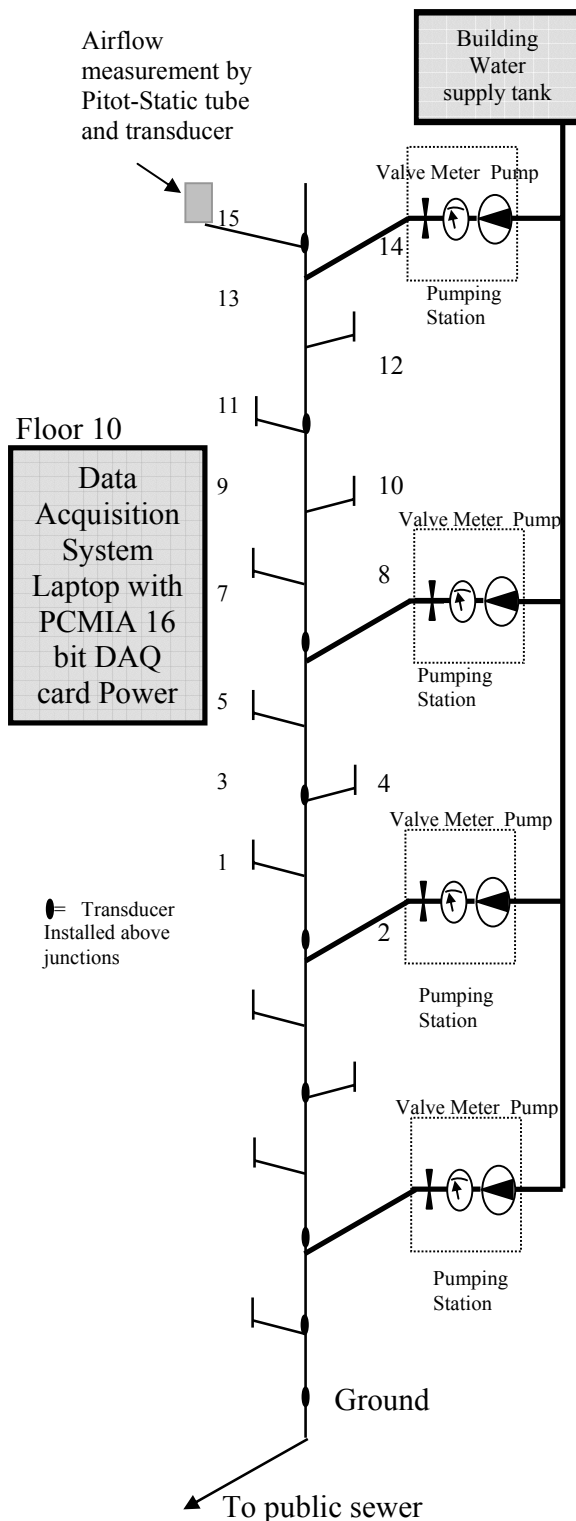


Figure 3. On-site Investigation schematic

4.3 Methodology

The hypothesis tested in this paper is that when solids are discharged from an appliance such as a WC, they fall in the centre of the pipe, driven by a combination of forces from the WC discharge and gravity. If such a solid were to strike the water from a discharging branch then the rapid change in airflow conditions as the water curtain opens would cause a pressure transient which would then propagate throughout the system.

In order to test this hypothesis it was necessary to simulate a WC flush containing a solid and to pump water into the stack at some point below to simulate a discharging branch, as shown in Figure 3. The WC discharge was simulated by pumping water into a WC containing a 250mm long maternity pad. The water pumping profile used represented a standard drop valve flow rate against time (Q/t) curve for a WC. The flow rate from floor 6 was set to 1.5 l/s steady flow.

Test number	Solid discharge	Steady flow discharge	Type of solid used	Termination
1	15	2	No solid	Open
2	15	2	200g pad	Open
3	15	6	No solid	Open
4	15	6	200g pad	Open
5	15	None	200g pad	Open
6	15	10	200g pad	Open
7	15	6	200g pad	Closed
8	15	6	2 x 200g pads	Open
9	15	10 & 6	2 x 200g pads	Open
10	15	None	2 x 200g pads	Open

Table 1. Test schedule

The test schedule given in Table 1 represented the range of investigations possible in the on-site part of this research. The tests formed a mixture of possible scenarios with different solids discharged from different heights and interacting with branch flows at various distances along the stack.

5. Results

In order to establish base conditions at the test site a series of experiments were executed to determine expected pressure levels when no solids were present. The methodology employed was to establish a steady flow from floor 10 of 1.5 l/s and then to simulate a WC flush from floor 15. The resultant pressure trace is shown in Figure 4. It can be seen that when the flow from floor 10 is turned on the pressure in the stack begins to go negative, eventually steadying when flow conditions steady. As expected there is a pressure regain towards the base of the stack and a slight positive pressure on the lower floors. Once this flow has been established the simulated flush flow was initiated. The pressure profile is modified by the unsteady flow from floor 15.

By introducing a solid into the discharge, it is possible to see the generated pressure transient (Figure 5b.). The pressure traces follow a similar pattern to those shown in Figure 4 until the solid pierces the water curtain formed at the branch to stack junction on floor 6. At this point a pressure surge can clearly be seen. Upon closer inspection (Figure 5a) it is clear that the sense of the transients generated are: positive down toward the stack base and negative up toward the roof termination. This is caused by the solid piercing the curtain, creating a momentary orifice in the water curtain allowing a pulse of air, in the form of an air pressure wave, down the stack. The negative air pressure transient propagating up the stack is a necessary consequence of the opening in the water curtain, as the system communicates its need for air to the open termination at the top of the stack. The

mechanism involved in this process is identical to that described above and illustrated in Figure 1. The water curtain formed at the junction is analogous to the partially closed valve in Figure 1, and the pressure surge is generated by the same mechanism as that described by the momentary opening of the valve which has a pressure difference across it.

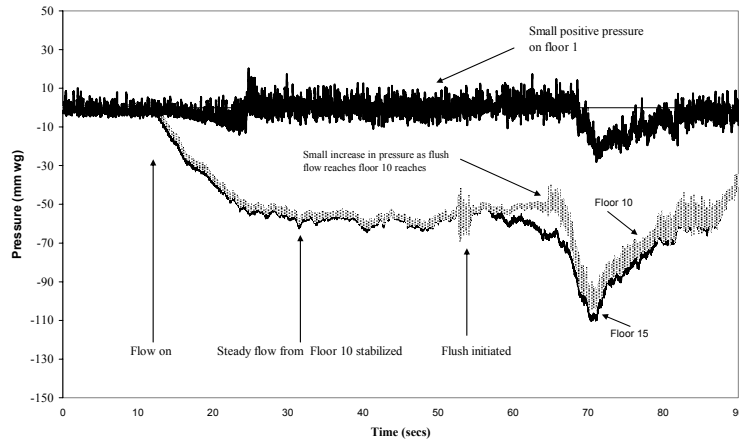


Figure 4. Baseline pressure trace – no solids discharged

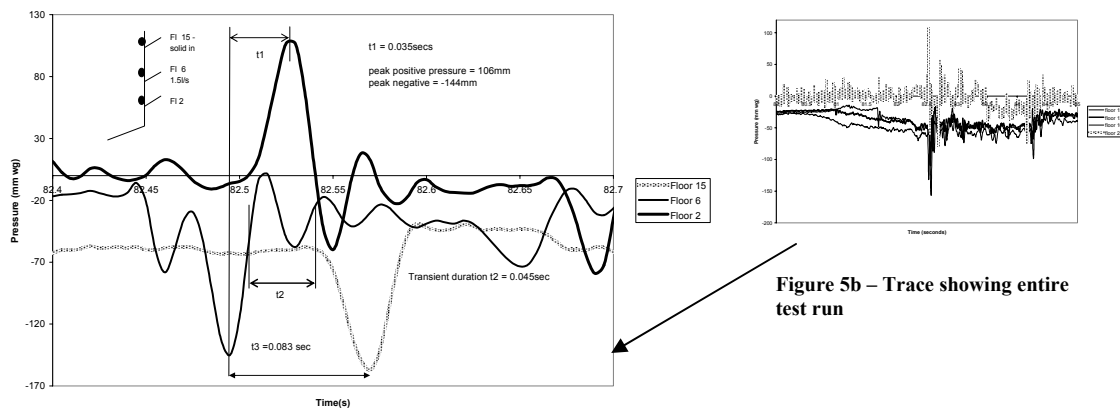


Figure 5a Definition of generated transients

Figure 5b – Trace showing entire test run

Figure 5. Trace showing positive and negative transients

Due to the predictable nature of transient propagation, it is possible to confirm that the pressure ‘spikes’ observed from the pressure traces are actually air pressure transients and not merely stray electro- magnetic forces (EMF) from pumps or other electrical noise. From Figure 5a the propagation time between floor 6 and floor 2 (t_1 at 0.035 s), floor 6 and floor

15 (t_3 at 0.075 s) can be measured. The distances between the transducers on floor 6 and floor 2 was approximately 12 m and between floor 6 and floor 15 was approximately 27 m - the velocity of propagation (VOP) is 320 m/s. It is therefore possible to confirm the distances travelled by multiplying the VOP by the travel time. The calculated distances between floor 6 and floor 2 was $320 \times 0.035 = 11.2$ m - and between floor 6 and floor 15 was $0.083 \times 320 = 26.5$ m – thus confirming the presence of air pressure transients as a result of falling solids in the stack.

The solid used in this experiment was a maternity pad 250mm x 65mm x 10mm with a wet weight of 200g. The experiment was repeated for the combination of solids and experimental configurations given in Table 1. From the analysis of the data recorded from these experiments Table 2 was produced and an assessment of a peak positive and negative pressure transient was obtained for use in the simulations. As can be seen from Table 2 the peak positive pressure recorded was 106mm wg and the peak negative pressure recorded was -195mm wg.

Solid weight	Solid discharge	Steady flow discharge	Peak pressure rise recorded (mm wg)	Peak positive pressure recorded (mm wg)	Peak negative pressure recorded (mm wg)	Transient duration (seconds)
200g	15	2	51	90	-90	0.060
400g	15	2	40	27	-80	0.055
200g	15	6	110	106	-150	0.045
400g	15	6	120	53	-130	0.040
200g	15	10	87	27	-100	0.050
400g	15	10	123	77	-140	0.065
200g	15	10 & 6	120	98	-195	0.050

Table 2 Test Results

7. Solid Velocity

The average velocity of a solid can be measured if the time a solid passes two known points along the stack can be logged. Since the distance is known then the solid velocity can be derived from $V = l/t$ where l is the distance between the points and t is the time taken to travel between the points.

In the experimental set-up described in this paper no special arrangements were adopted to measure a passing solid and it was therefore necessary to calculate solid velocity by using the principles of transient propagation. To do this, a steady flow was pumped into the stack at 2 locations – floor 10 and floor 6 and a solid was discharged from floor 15 in a flush volume as described above. As the solid pierces both water curtains, transients are

generated – it should therefore be possible to measure the time it takes the solid to travel between the water curtains by analysing the pressure traces.

Figure 6 shows such a pressure trace. By measuring the time between the 2 distinct peak pressure transients, a solid velocity of 4.27 m/s was established. This is an average velocity over the time taken to travel between the two transducers. Since the solid falls down the centre of a pipe there will be acceleration due to gravity and a significant drag factor. The solid also travels through the water curtain which inevitably causes some deceleration – the solid is therefore not in free fall. This investigation has established an average velocity for a solid in a vertical drainage stack, however more work is required in this area to establish the influence of parameters such as: solid characteristics, water and air flow rates and the pressure regime in the stack on solid velocity since these will all influence the terminal velocity and drag co-efficient of solids in practice.

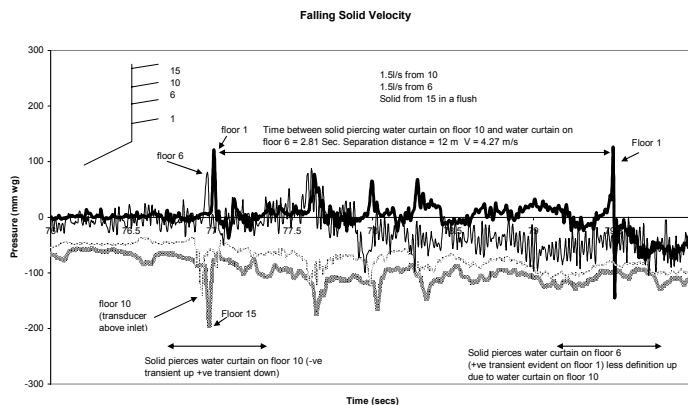


Figure 6. Assessing Solid Velocity

8. Numerical Simulation

The mechanism underlying the generation of pressure transients has been established as a modification to the pressure regime at a branch to stack junction by a solid piercing the water curtain, allowing a passage for air movement for a short time. The pressure regime at this junction can be modelled by introducing a concentrated loss on the entrained airflow – the result of a restriction to air movement caused by combining branch and stack water flows. The effect of the solid piercing the water curtain can therefore be achieved by reducing the concentrated loss to simulate an opening in the water curtain.

8.1 Effects on water trap seals

The simulation of the effects of solids falling in a vertical stack can be achieved by modelling the simple pipe configuration shown in Figure 7. By introducing a positive air pressure transient with the characteristics of those observed in the site investigations it is possible to establish whether such transients would be problematic in real installations.

The magnitude and duration of the positive air pressure transient to be simulated was based on the maximum figures obtained from Table 2.

The results of the simulations are shown in Figures 8 and 9. and shows the effect of the simulated positive and negative air pressure transients on the water trap at the end of the 2m branch. It can be seen that while the magnitude of the pressure transients were 106 mm wg (positive) and -195 (negative) they do not 'blow the trap' despite there only being a trap depth of 50mm. The reason for this is that there is insufficient energy in the pressure transient, due to its very short duration, to overcome the inertia of the water in the trap seal. This results in reduction in the effective pressure experienced by the water in the trap seal such that the water fluctuates by approximately 10mm, a phenomenon which will not compromise the integrity of the seal between the drainage system and the habitable space.

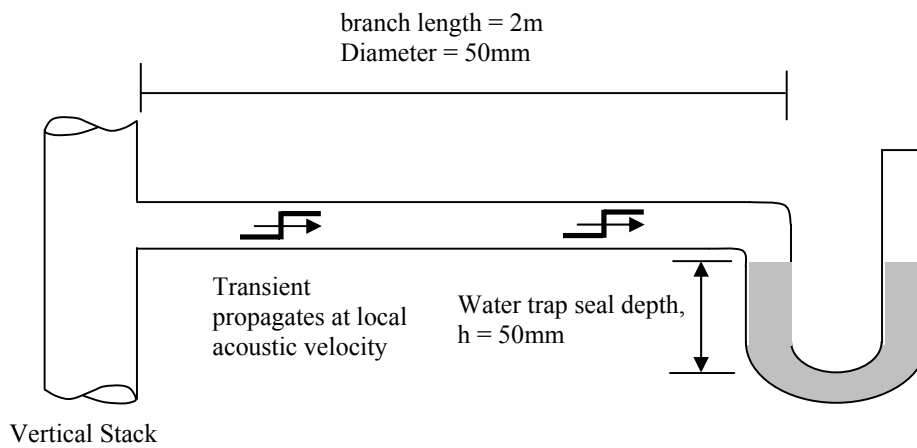


Figure 7. Simulated Configuration.

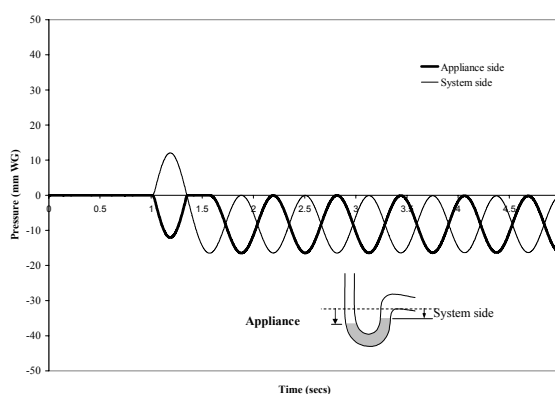


Figure 8. Effect of simulated positive transient on water trap seal.

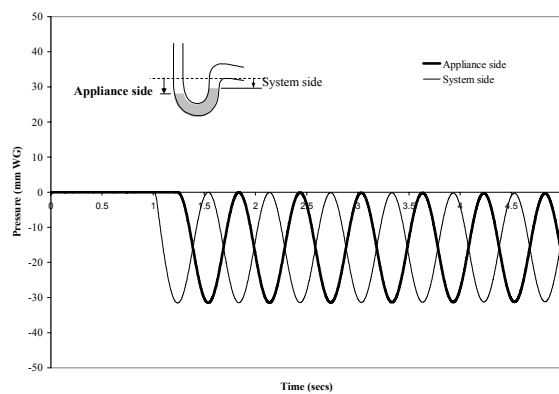


Figure 9. Effect of simulated negative transient on water trap seal.

9. Conclusions

This research has been undertaken in order to attempt to quantify a significant possible source of air pressure transients in building drainage systems. It has long been known that air pressure transients can cause problems with water trap seals. Anecdotal evidence and accepted mainstream thinking by professionals in the field, has often attributed the generation of such air pressure transients to solids falling down a vertical stack. This paper has shown that such pressure transients are generated by solids falling in a vertical drainage stack. This paper has identified the mechanisms of this transient generation and has confirmed that their effect on water trap seals can be assessed using a method of characteristics based numerical model. While it is clear from this paper that air pressure transients are generated in this manner it has also been shown that their duration is too short to have any real impact on the integrity of the water seal between the building drain/sewer network and the habitable spaces inside the building envelope.

10. References

- [1] Swaffield J. A. and Campbell D. P., 1992^a, "Air Pressure Transient Propagation in Building Drainage Vent Systems, an Application of Unsteady Flow Analysis", *Building and Environment*, Vol 27, n°. 3, pp 357-365
- [2] Swaffield J. A. and Campbell D. P., 1992^b, "Numerical modelling of air pressure transient propagation in building drainage vent systems, including the influence of mechanical boundary conditions", *Building and Environment*, Vol 27, n°. 4, pp 455-467
- [3] Swaffield, J.A., Jack, L.B. Campbell, D.P., & Gormley M. (2004) 'Positive air pressure propagation in building drainage and vent systems.' *Building Services Engineering Research and Technology*, 25(2) (2004) pp 77-88
- [4] Jack L.B., (2000). Developments in the definition of fluid traction forces within building drainage vent systems, *Building Services Engineering Research & Technology*, Vol 21, No 4, pp266-273, 2000.
- [5] World Health Organisation (WHO) (2003) 'Inadequate plumbing systems likely contributed to SARS transmission' WHO Press Release WHO/780 pp1-2, 26 Sept.
- [6] Hung, H *et al*, (2006) 'Industrial experience and research into the causes of SARS virus transmission in high-rise residential housing estate in Hong Kong' *Building Services Engineering Research & Technology*, Vol 27.2 pp 91-102, 2006.
- [7] Pink, B.J. (1973) 'A study of stack length on the air flow in drainage stacks' *Building Research Establishment, Current Paper 38/73*.
- [8] Fox, J.A. (1989) 'Transient Flow in Pipes, Open Channels and Sewers'. Ellis Horwood Ltd. Chichester UK.
- [9] Wise A.F.E, 1957 'Drainage pipework in buildings: Hydraulic design and performance' HMSO, London
- [10] Swaffield J. A. and Boldy A.P., 1993, 'Pressure surge in pipe and duct systems', Avebury Technical, England

11. Author



Dr. Michael Gormley is a Research Associate and has been a member of the Drainage Research Group since 2000. He specializes in air pressure transient analysis in building drainage systems, solid transport and flushability criteria for commercial products in horizontal drains and the effects of surfactants on drainage systems.

Transient defect identification in building drainage and vent systems – an application of pressure transient theory and practice.

D.A. Kelly (1), J.A. Swaffield (2), L.B. Jack (3), D.P.Campbell (4) and M. Gormley (5)

(1) d.a.kelly@hw.ac.uk (2) j.a.swaffield@hw.ac.uk

(3) l.b.jack@hw.ac.uk (4) d.p.campbell@hw.ac.uk

(5) m.gormley@hw.ac.uk

(1-5) School of the Built Environment, Heriot Watt University, Edinburgh, Scotland.

Abstract

Defective trap seals have been conclusively shown to be a public health hazard in complex building drainage and vent systems. Dry traps, either as a result of poor design, maintenance or system operation provide a cross contamination route for the ingress of infection into habitable space. The practicalities of system maintenance prevent the regular and routine checking of all system traps to prevent dry or semi-depleted traps remaining unidentified. A remote non-invasive technique to provide facilities management operatives with an indication of the areas most at risk and system designers with guidance as to the possible need for system modifications would ensure system compliance with performance standards.

Low amplitude air pressure transients are propagated within building drainage and vent systems in response to appliance discharge. Such transients are reflected and transmitted by each boundary encountered, whether branch to stack junctions or terminations formed by traps or any control device. This normal transient propagation may be employed to indicate depleted trap seals due to the dependence of the termination reflection coefficient on trap condition.

This paper will confirm the theoretical basis for a non-invasive monitoring system and will present laboratory and site test results confirming the application of the pressure transient theory. The paper will also identify the limits of the solution in terms of transient magnitude and the considerations necessary to determine the number and location of transient generators required for any complex network and the underlying theory determining suitable monitoring locations.

Keywords

Depleted traps, cross infection, pressure transient, remote defect identification.

1. Introduction

The prevention of appliance trap seal depletion has been a long term design concern and has dictated the development of venting systems and active control devices, including air admittance valves and variable volume containment devices. However the normal transient propagation that is an inherent part of the operation of any building drainage and vent system, taken together with other causes of depletion, including lack of maintenance, evaporation or system tampering, imply that trap seal depletion remains a major issue. Confirmation of this view was provided by the post event forensic analysis of the Amoy Gardens SARS outbreak in 2003, both by the Hong Kong investigators¹ and by remote simulation of the system operation². The combination of a shower room dry floor trap, the prevailing pressure regime in the shower cubicle and driving air pressure transients generated by drainage system operation allowed the ingress of the SARS virus from the system vertical stack, facilitating the faecal-oral transmission route for the infection.

In complex buildings it is effectively impossible for the facilities management team to undertake regular inspections to ensure that trap depletion does not provide a source of cross contamination. However many such buildings now feature a building management system (BMS) which includes remote sensing of comfort conditions and other parameters. The challenge therefore is to develop a remote sensing methodology that would provide a similar level of facilities management to the drainage network.

Low amplitude air pressure transients are continually propagated within building drainage networks by the normal operation of the system. Any appliance discharge to the system vertical stack results in an entrained airflow drawn from the open upper terminations of the network, any installed air admittance valves or any depleted trap seals or other defective fittings. The establishment of this entrained airflow must by definition be accompanied by the propagation of negative pressure transients. Similarly any interruption to this airflow, for example by local surcharge, generates positive air pressure transients. This mechanism is identical to the pressure surge generation normally expected in a whole range of systems carrying a flow that may be subject to time dependent change, including urban water supply, oil production and transmission, aircraft fuel systems and the hot/cold water services within buildings.

The mechanism of pressure surge propagation is well established, from the early and accurate studies undertaken by Joukowsky³ in St Petersburg in 1900 to the development of an industry standard analysis methodology, based on the use of the Method of Characteristics (MoC) to solve the St Venant equations of continuity and momentum that define transient propagation, in the 1960s by Streeter⁴, Fox⁵ and others up to the present⁶. Inherent to this understanding of transient propagation is the role of system termination as a reflector of transients traversing the network.

Figure 1 demonstrates the transient response of a single pipe length subjected to an imposed positive transient featuring either an open or closed downstream termination. It will be seen that the transient propagation is identical in each case – i.e. the terminal reflection arrives at the monitoring station at the same time for both cases, however the sign of the reflected wave is determined by the terminal condition, an open end yields a -1 reflection, a closed end generates a +1 reflection.

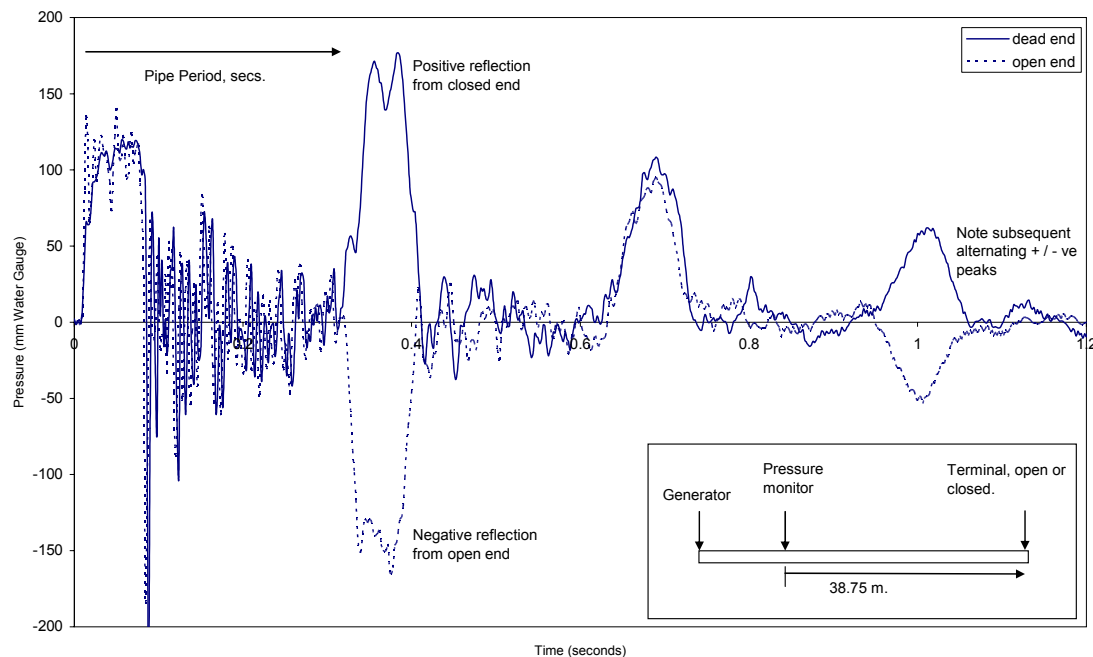


Figure 1. Laboratory demonstration of the +1 / -1 reflection coefficients encountered at a closed or open end termination on the transient response of a single pipe system subjected to a pressure surge.

Both results may be explained in terms of the discontinuity encountered by the transient at the termination. In the case of an open end, a wave arriving at the termination cannot retain its pressure due to the local imposition of the ambient surrounding pressure and hence a 'signal' to that effect is transmitted back along the duct, generating a -1 reflection coefficient. In the case of a closed end the fluid flow induced across the pressure wave as it traverses the duct cannot be sustained as the termination is closed. This flow is therefore destroyed and a signal is transmitted back along the duct, in this case this appears as a +1 reflection coefficient. Note that the reflection coefficient sign is independent of the sign of the incoming transient.

Figure 1 also introduces the concept of the pipe period, defined as the time taken for a transient to be propagated from its source to a selected termination and return to the source. The pipe period may be defined as $2L/c$ where L is the pipe length and c is the acoustic wave speed for air, around 320 m/s. A 20 storey building, overall height possibly 70m, will therefore have a pipe period from ground level to upper termination and back of 0.437 seconds which gives an indication of the time scales likely in this application of transient theory.

Thus a combination of the known terminal reflection coefficient, the known transient propagation velocity in air and the pipe period allows a methodology for identifying depleted trap seals to be postulated. The monitoring of the response of any network to a propagated transient will allow the identification of any change in terminal conditions when the relevant pressure traces are compared to a defect free standard.

An evaluation of the time of arrival of any reflections from an altered boundary will locate that boundary as the wave speed is known. Thus a pressure transient based remote and non invasive technique should be practical. This paper will draw on the earlier reported studies^{7,8} to provide ‘proof of concept’. It will detail parallel laboratory and site testing to confirm the practicality of the technique and will in addition demonstrate that the effect of changed boundary reflection coefficients is also confirmed by the application of the MoC modelling of the systems considered.

While the depleted trap is a clear analogue to an open system termination and will be represented by a -1 reflection coefficient, a full and unaffected trap will not be adequately described by a closed end +1 reflection coefficient. As discussed elsewhere⁷ the water seal will be displaced by an incoming transient. This movement of the air / water interface modifies the reflection coefficient as the flow across the transient wave will be able to continue while the water surface displaces. Thus full traps within a network will have little or no reflection during the short time periods necessary to evaluate the location of depleted traps.

In order to determine the divergence between the system response with and without a depleted trap it is necessary to compare the relevant pressure traces. Visual comparison is clearly helpful, examples will be provided below, however it is also necessary to postulate a numerical measure of divergence, similar in concept to that postulated for large scale water distribution network leak identification⁹. If the response of the network which contains N trap seal terminations is defined by a series of pressure trace recordings, taken at a location m, which in turn include a wholly defect free system and then sequentially the system response to each of the traps being depleted, a data set is constructed against which any future pressure recording may be compared. Let these traces be denoted as $mSp_{J=0 \rightarrow N}$, where 0 refers to a wholly defect free response and N is the number of traps in the network – this generates a dataset of N+1 traces. The divergence of any future trace, mSp_{actual} from the dataset may be determined by a least squares comparison, the degree of divergence being referred to as a Compliance Factor, C_J determined as

$$C_J = \sum_{i=1}^{npoint} (mSp_{J=1-N} - mSp_{actual})^2 \quad (1)$$

where npoint is the number of data points in the trace to be compared.

Figure 2 shows how the compliance factor would be applied by subtracting the test set pressure trace from that of the database. Equation 1 yields a matrix of “least square” compliance factors, the value approaches zero when the actual trace corresponds to the individual depleted trap dataset. The matrix thus provides the location of the depleted trap by virtue of a compliance factor that approaches zero.

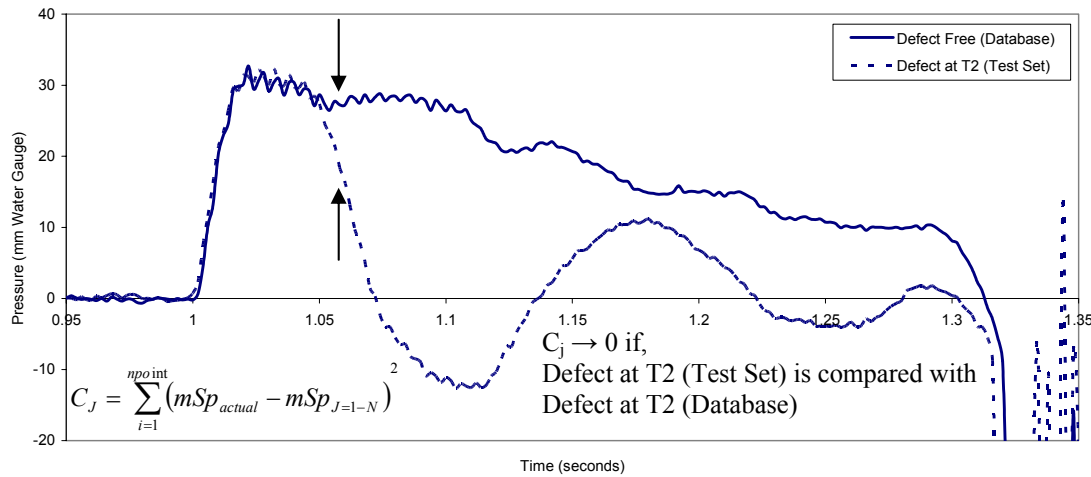


Figure 2. Basis of compliance factor calculation for Test Set 1 with PTG at ground floor with sewer closed. The compliance factor in each case indicates the relative divergence of the test set data from that of the database for any particular trap seal failure condition.

2. Laboratory evaluation of the pressure transient identification technique

To verify the proposed technique a laboratory evaluation was carried out using a simulated 77m high vertical drainage stack consisting of 75mm and 100mm diameter pipework, including connections to fourteen simulated appliance trap seals spaced at 3.2m centres to represent typical floor levels, **Figure 3**. Initially all traps were capped off to represent a full set of appliance trap seals (defect free system). To simulate an open trap, the cap was removed exposing the trap to atmosphere (defective system). The system response was monitored for each defective trap from trap 1 (T1) to trap 14 (T14) by removing the appropriate caps in turn.

In order to monitor the system response, a positive transient was imposed by activation of a pneumatically operated piston, or pressure transient generator (PTG), at the simulated stack base. Air pressure measurements were recorded using a pressure transducer located 1m from the PTG and connected to a high scan rate data logging system.

Figure 4 illustrates the system response to the applied pressure transient for the defect free system and sequential defective traps at T1, T3 and

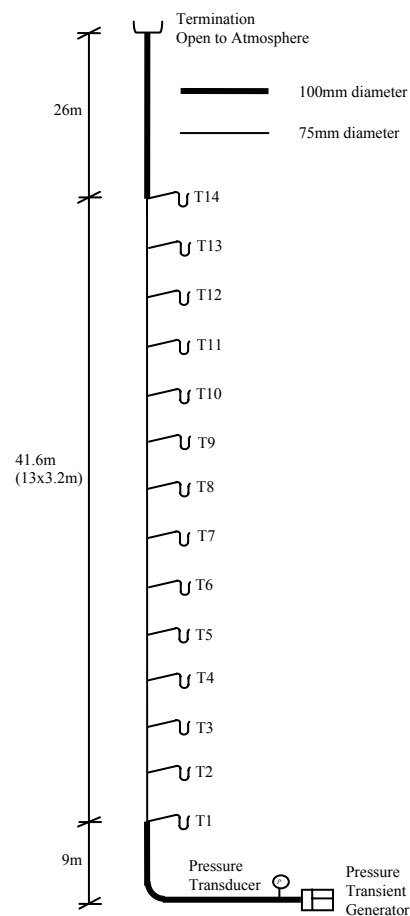


Figure 3. Laboratory test rig.

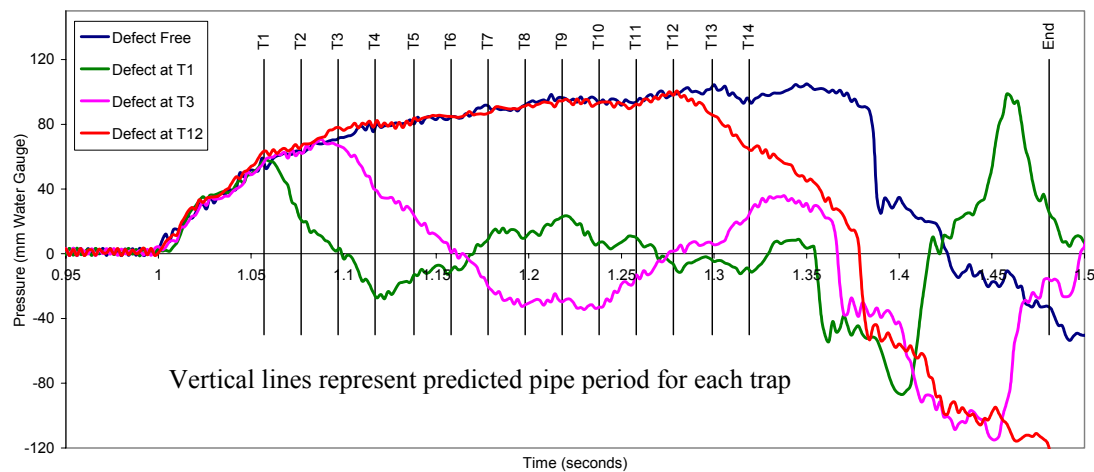


Figure 4. Laboratory comparison of system pressure response for defect free and selected defective open traps.

T12. The traces diverge, as shown, at the predicted time based on the return pipe period from source to trap, identified by the vertical lines on **Figure 4**.

In the defect free case, a negative reflection arrives at the transducer at 0.382 seconds after the first pressure rise, which is generated following the abrupt cessation of the piston. The trace shows no reflections back from any of the traps and, therefore, proves all traps to be full. However, the introduction of a dry trap at T1 generates a negative reflection that arrives at 0.057 seconds after the first pressure rise, consistent with a 320 m/s wave speed over a shorter travel distance of 9m. Similar results are shown for the other defective traps. This result validates this technique, both through the clear divergence illustrated between the defect free and open trap system response traces and the corroboration of the pipe period calculation with the defect location.

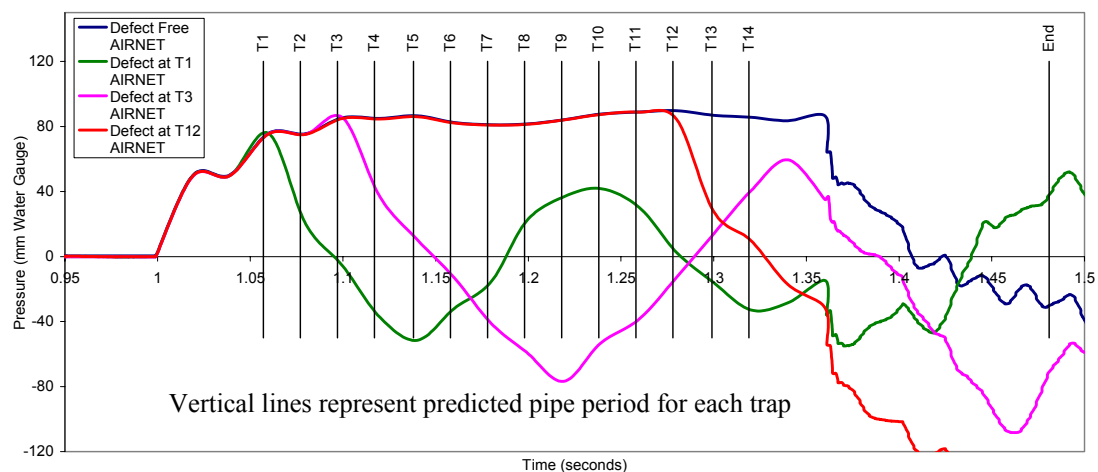


Figure 5. Simulated comparison of system pressure response using AIRNET for defect free and selected defective open traps.

Figure 5 shows the system response as modelled by the numerical model (AIRNET) developed at Heriot-Watt University, again for the defect free system and sequential defective traps at T1, T3 and T12. As with the experimental data, the simulated system response yields very similar return times for the negative reflection generated by the open traps. This high degree of agreement between the experimental and simulated results provides confidence in the method of characteristics simulation to the analysis of system operation and appraisal of this monitoring technique.

3. Site Test Validation

The validation of the proposed pressure transient identification technique was conducted under controlled site test conditions. The technique was tested on an unoccupied 17-storey residential apartment block in Dundee. The drainage network was of the standard one-pipe system and consisted of a 47.5m high cast iron vertical stack, 150mm in diameter, with 100mm, 35mm, 42mm and 54mm diameter copper branch connections serving the WC, WHB, bath, and kitchen sink respectively at each apartment, **Figure 6**. The applied pressure transient was generated by the PTG, having a 200mm stroke moving at a speed of 0.61m/s over a 0.33 second duration, which was connected into the stack via existing access panels. The air pressure measurements were recorded using a number of calibrated pressure transducers connected to a high scan rate data logging PC board, collected at a 500 Hz sampling frequency. The results presented in this paper are those recorded at the pressure transducer located on the connecting branch between the PTG and stack, VPT 1.

Three sets of tests were conducted. Test Set 1 was carried out with the PTG located at ground floor level, Test Set 2 with the PTG located at 9th floor, while the PTG was located at the 17th floor for Test Set 3. The system response for Test Set 3 is similar to that of Test Set 1 as both involve the pressure transient being applied to either end of the stack, whether it be from the bottom (trap 1 → trap 17) for Test Set 1, or from the top (trap 17 → trap 1) for Test Set 3. Therefore, only the result of Test Set 1 and Test Set 2 shall be discussed in this paper. In all three Test Sets, the defect free system pressure trace was recorded followed by the sequential introduction of a single open trap at each floor level by removing the water seal from each WC trap.

Figure 7 shows a sample of pressure traces recorded for Test Set 1. A large negative reflection can be seen returning 0.016 seconds after the first pressure rise which occurs at 1 second, which correlates to a reflection 2.61m from the transducer, with a wave speed of 320 m/s. This negative reflection returns before the predicted return times of any open traps and can, in fact, be attributed to the open sewer.

The resultant pressure trace does not continue with sufficient magnitude to allow defective traps to be easily identified, therefore, to remove this reflection the sewer was blocked off by placing a balloon within the lower section of the stack. **Figure 8** shows the system response for the defect free system and sequential defective traps at T2, T6 and T11 for Test Set 1 with the sewer closed off. For the defect free system, the pressure trace shows a more rapid natural damping than seen in the laboratory but this can be attributed to the greater pipe wall roughness of the older cast iron pipework compared with the relatively new uPVC pipework used in the laboratory. However, a negative reflection generated by the open termination can still be seen to

arrive at 0.3 seconds after the first pressure rise consistent with a 320 m/s wave speed and a pipe length of 47.5m. By applying an open trap at T2, the negative reflection arrives at 0.048 seconds after the first pressure rise, consistent with a 320 m/s wave speed and a reduced travel distance of 7.7m when taking account of the WC connecting branch length. Other cases shown in **Figure 8** confirm this mechanism.

This series of site tests have helped to confirm the practical usage of this technique to identify the location of open appliance trap seals. A good agreement between the predicted arrival time of the reflection from an open trap, with those recorded by the transducers, has been demonstrated. Additionally, comparison of the defect free and defective system response is shown to be sufficiently discriminatory to allow the identification of an open appliance trap seal.

A sample of the pressure traces recorded for Test Set 2 are illustrated in **Figure 9**. As the pressure transient is introduced into the stack at this mid-point location, the transient is transmitted to the upper and lower sections of the stack while a reflected transient is propagated back along the connecting branch towards the PTG. This reflection is characterised by the fall in pressure, occurring at the T9 pipe period vertical line, which limits the peak pressure trace, in this case 20mm water gauge, dropping to 10mm water gauge.

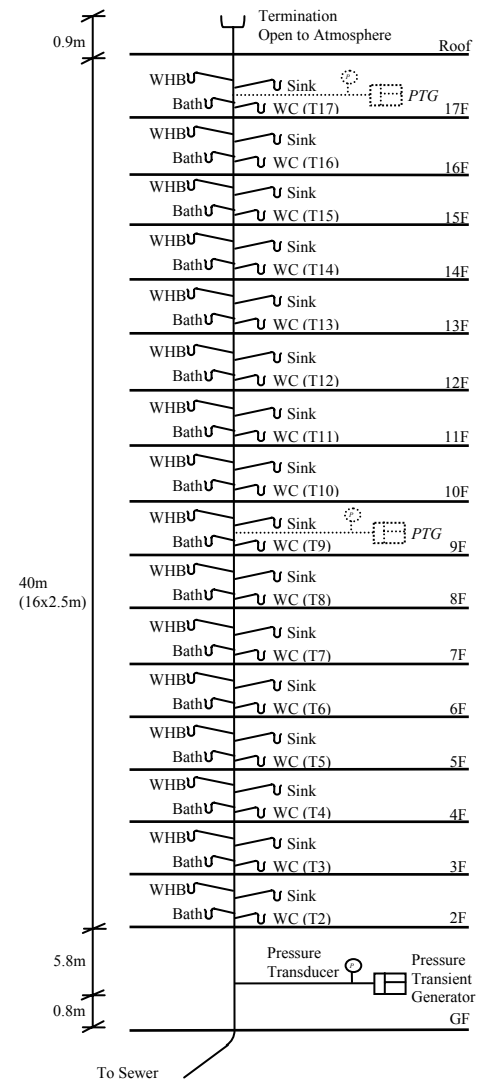


Figure 6. Drainage network used for site testing

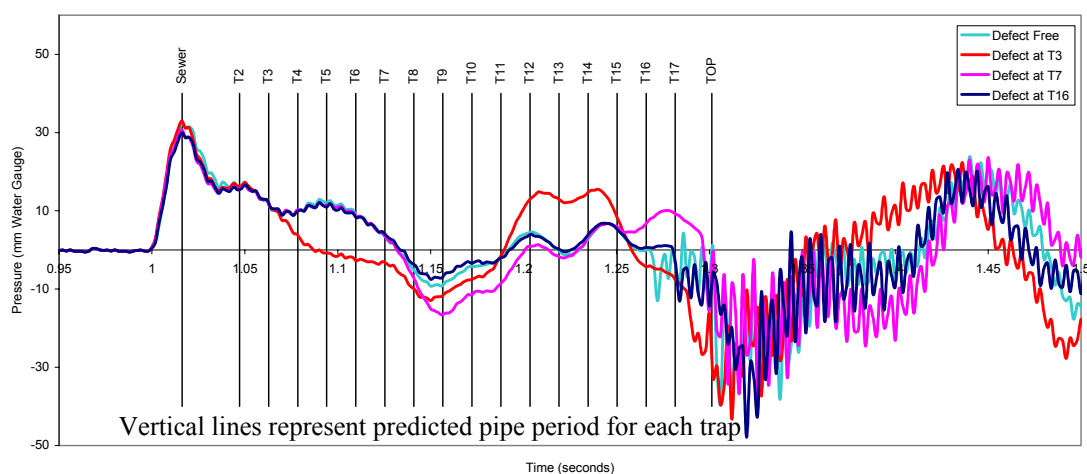


Figure 7. Site test comparison of system pressure response for defect free and selected defective open traps for Test Set 1 with PTG at ground floor with sewer open.

Another factor which is introduced by locating the PTG at the 9th floor is a possible problem of mirror image reflections due to the similar distance, and therefore pipe period, of adjacent upper and lower floor levels to this mid-point location. For example, the distance to T7 in the lower section of the stack is similar to that to T11 in the upper section of the stack and, therefore, produce similar pressure traces when either trap is defective. Hence, it is not possible to clearly identify which of the two similarly spaced traps are defective without first considering pressure traces recorded at a second or third location along the stack.

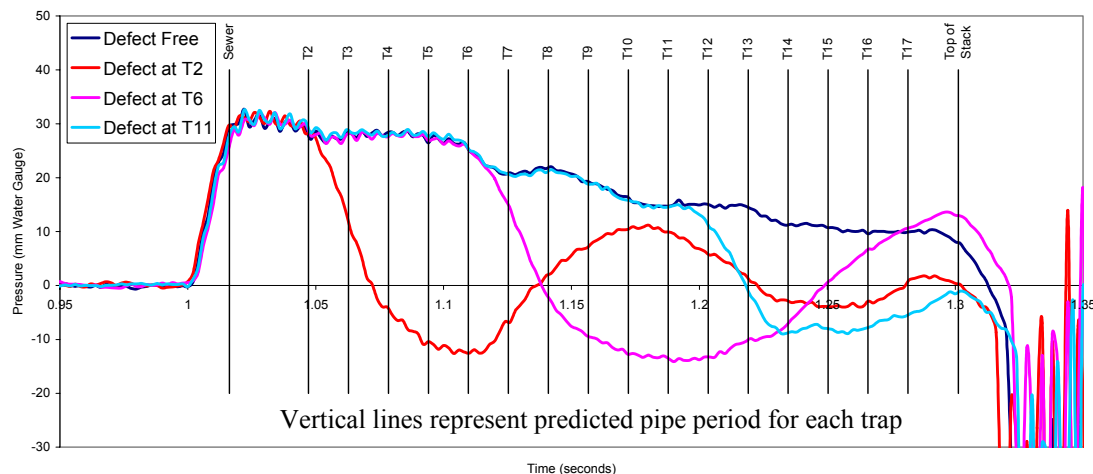


Figure 8. Site test comparison of system pressure response for defect free and selected defective open traps for Test Set 1 with PTG at ground floor with sewer closed. Note: Test Set 3 results generally replicated those shown here.

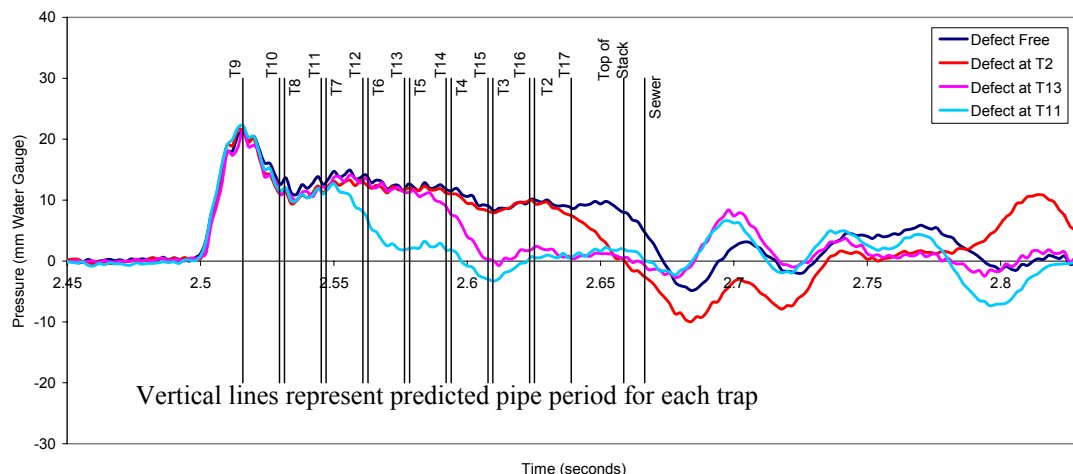


Figure 9. Site test comparison of system pressure response for defect free and selected defective open traps for Test Set 2 with PTG at 9th floor.

A numerical analysis has been carried out using the system response data recorded during the site investigations. Consider Test Set 1 with the sewer closed off. Two sets of system response data was recorded for the defect free system and then for each defective system by opening each WC trap, T2 through T17, one at a time. The first of each system response would be considered as the “true” transient response and

Table 1. Compliance factor matrix for Test Set 1 with sewer closed off. The highlighted diagonal indicates the event where the test set matches the database with $C_j \rightarrow 0$ and, therefore, identifies the correct system status.

Databank																		
		Testing																
		DF	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17
	DF	13																
	T2	45321	24															
	T3	43434	14781	33														
	T4	41413	39460	13354	69													
	T5	40262	53771	35197	11131	39												
	T6	41125	58996	49545	28549	6578	91											
	T7	38074	58393	57808	44735	19992	4873	218										
	T8	32263	56374	62118	56077	31658	13910	4246	59									
	T9	24559	49237	58791	62305	41079	23330	12867	3228	92								
	T10	24851	50448	61020	70317	51009	31556	19613	8439	52								
	T11	22926	49938	57757	70609	56793	38057	25641	13298	2268	224							
	T12	16179	47881	50574	65837	58675	44349	33193	19514	7832	2310							
	T13	16477	53312	51223	66275	62040	50002	38497	24521	12522	6459							
	T14	8592	53220	48248	58122	55989	48115	40575	27757	16188	10261							
	T15	1851	50669	47043	50880	47444	42969	40254	28881	19145	13674							
	T16	639	49740	46544	49012	45711	42892	41954	31076	23615	16071							
121																		
48085																		
43722																		
45630																		
43950																		
43203																		
44077																		
34075																		
26974																		
25929																		
19694																		
21523																		
17211																		
10895																		
2670																		
156																		
26																		

would be designated as the database. The second of each system response would be used as a test sample to be compared with the database. On calculation of the compliance factor matrix, it was found that identification of the correct system status occurred for only 50% of each trap defect, attributed to a variance in the measured transient generated by the PTG, possibly due to the piston sticking occasionally on activation which had the effect of increasing the travel speed and, therefore, the pressure generated by the piston. Therefore, to reduce this variation, five sets of system response data were recorded to calculate the average transient response for both the database and test sets for the defect free and each defective system.

Table 1 shows the compliance factor matrix calculated from the average transient response. In this case, all defective trap locations were successfully identified as represented by the compliance factor value approaching zero as the test set trace is compared with that of the corresponding database. There is a clear improvement in the compliance factor calculations by utilising an average value for each of the database and test set pressure traces. Using an average of five pressure traces for each, increased the successful identification of defective trap locations from 50% to 100%.

4. Conclusion

The SARS outbreak at Amoy Gardens in Hong Kong in 2003 has highlighted the vital role that the appliance trap seal plays as the primary defence in the prevention of cross-contamination and infection spread via the building drainage network into habitable space. This paper has presented results from extensive laboratory, field and simulation investigations demonstrating the use of pressure transient propagation as a potential technique for identifying the location of defective trap seals.

The proposed methodology relies on the measurement of system response to an applied transient and subsequent comparison with earlier simulated or measured system responses for the same applied transient. The proposed compliance factor matrix identifies the closeness of fit between average traces for the “database” and “test set” data and the location of the failure by matching the measured system response with that of a known system pressure signature.

The results presented indicate a measurable divergence between sequential defect free and defective system responses. High corroboration with predicted pipe period calculations and the defect location validate this technique as a remote non-invasive monitoring approach. The cases demonstrated for a 50m building height were within a 0.4 second testing duration which is clearly a practical time limit to occur during periods of system non-use (night-time operation). Development of the proposed technique may involve either integration into the building management system or the development of a stand-alone defective trap seal identification system that would highlight potential defects to building maintenance staff.

Further research will investigate the application of an applied pressure transient generated by the oscillatory movement of the piston to produce a sine wave motion. This will allow frequency analysis of the measured system response data and may prove a further method by which defective trap locations can be identified. Following

this, the technique shall be trialled within an occupied building and drainage ventilation system under full operational conditions.

4. References

1. Hung H.C.K., Chan D.W.T., Law L.K.C., Chan E.H.W. and Wong E.S.W. 'Industrial experience and research into the causes of SARS virus transmission in a high-rise residential housing estate in Hong Kong', CARDIS Special Edition BSER&T, Vol 27, No 2 2006 pp91-102.
2. Jack L.B. 'Drainage design: factors contributing to SARS transmission', Procs. ICE Municipal Engineer 159, March 2006 Issue ME1, pp43-48.
3. Joukowsky N.E. 'Über den hydraulischer Stoss in Wasserleitungsrohren', Memoires de l'Academie Imperiale des Sciences de St. Petersburg, SER 8, 9(5): Olga Simin, Water Hammer, Procs. Am. Water Works ass., 24, 341-424.
4. Streeter V.L. and Wylie E.B. 'Hydraulic Transients', McGraw-Hill, New York, 1967.
5. Fox J.A. 'Transient flow in pipes, open channels and sewers', John Wiley and Sons, New York, 1989.
6. Swaffield J.A. and Boldy A.P. 'Pressure surge in pipe and duct systems', Avebury Technical Press, 1993.
7. Swaffield J.A. 'Transient identification of defective trap seals', Building Research and Information, 2005, 33(3), pp245-256.
8. Campbell D.P. 'Transient identification of defective trap seals' Paper B5, CIBW62 Symposium, Brussels September 2005.
9. Stephens M., Vitkovsky J., Lambert M., Karney B. and Nixon J. 'Transient analysis to assess valve status and topology in pipe networks', 9th Int. Conf. Pressure Surge, BHR Group, Chester, 24-26 March 2004 Vol 1 pp211-224.

5. Notation

C_J	Compliance factor	mSp_{actual}	Actual pressure trace
J	Location of defective trap	$mSp_{J=0 \rightarrow N}$	Dataset, defect at location J
N	Number of traps in network	n_{point}	Number of points to be compared
m	Location of pressure monitor		

6. Presentation of Authors

David A Kelly is a Research Associate within the Drainage Research Group at the School of the Built Environment, Heriot-Watt University.



Problem of Air and Water Backflow in High-rise Building Drainage System

Prof. Daniel W.T. Chan, Leo K.C. Law and Eric S.W. Wong

Department of Building Services Engineering
The Hong Kong Polytechnic University

Abstract

Virus transmission through vertical drainage stack is believed to be one of the hypotheses for the SARS outbreak in the Amoy Garden. After the outbreak a review of building drainage system is triggered in the community. This paper starts with a review on the contemporary building drainage system design in Hong Kong, and after that a field study in a 37-storeys high-rise building is reported. When sulphur hexafluoride tracer gas was injected in a flat in 16/F, the gas was detected at 21 floors above the flat under injection (i.e. 37/F), when a suction force was induced in the room due to the sole operation of exhaust fan. The result allows a better understanding on the risk of contaminated air transmission through building drainage system. In addition, a case study of water back flow at the lower floor of a building is also reported. Observed on the vertical stack design, the excessive bendings at the bottom of the vertical drainage stack was believed to induce hydraulic jump that can push the water in the trap seal back to the building. The study result reveals the importance of a proper design, operation and maintenance of drainage system in order to prevent spread of soil waste and contaminated air within buildings.

Introduction

In typical high rise buildings sanitary drainage is provided through vertical drainage stacks, connecting various occupied rooms together. The prevention of cross-contamination among the rooms is principally through the inclusion of a trap with water seal inside. In Hong Kong, Building (Standard of Sanitary Fitment,

Plumbing, Drainage Works AND Latrines) Regulations Chapter 123I under Buildings Ordinance specifies that every sanitary fitment should be provided, individually, with a trap. The resulting typical water trap arrangement in Hong Kong buildings is shown in figure 1.

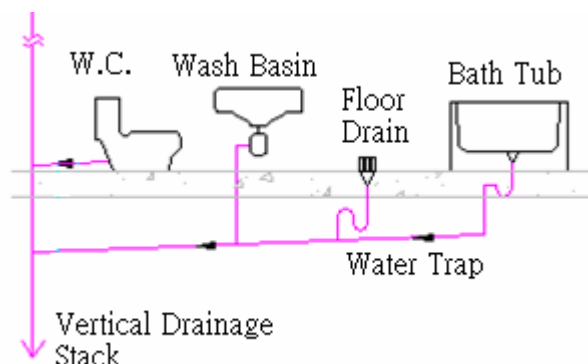


Figure 1 Contemporary water trap design in Hong Kong

This design cannot provide a function of self-priming for the floor drain trap, which was hypothesized to be one of the possible virus transmission routes in the SARS outbreak in 2003. On the other hand, the perceived down flow direction in gravity drainage system, and an observed lower number of reported cases from flats below the index floor, have imposed an uncertainty on where the drainage system plays a role on virus transmission. As a result, the authors performed an investigation through tracer gas injection in a vertical drainage stack in a high-rise residential building in Hong Kong.

Tracer Gas Investigation Method and Results

Sulphur hexafluoride (SF_6) tracer gas was injected to the drainage pipe at 16th floor of a 37 storeys high-rise building. The bottle trap was removed during the experiment, and replaced by a fitting to house the trace gas dosing tube. It was confirmed that no other trap is present along the 40mm diameter horizontal pipe. The 100mm diameter vertical drainage stack was maintained to be dry, to prevent the addition of moisture to the stack which would interfere the measurement result read from the Bruel & Kjaer model 1302 Gas Analyzer. The exhaust fan was switched OFF and the windows and doors were kept close during the investigation. SF_6 concentration inside the horizontal drainage pipe at this floor was kept at a range between 797 to 867 ppm.

At the topmost floor (37th floor) of the building, the SF_6 concentration at such horizontal pipe was also monitored. The exhaust fan was switched ON, the air

velocity at the end of the 40mm horizontal pipe was found to be 2.75 m/s. The SF6 concentration inside was ranged between 228 to 266 ppm. Since SF6 is absent in the atmospheric air, the test result shows that the air from the 16/F can travel upward to the 37/F under the driving force from mechanical exhaust fan at such top floor. It was hypothesized that a similar upward flow would likely to be happened in the Amoy Garden case, if the vertical drainage stack was dry, the water trap of the index flat and the suffering flat(s) at the upper floors were dried, and the exhaust fan of the suffering flat(s) was switched ON to provide a mechanical force to drive the air up.

The risk of trap seal loss and water backflow in high-rise buildings

While the contemporary drainage design shown in figure 1 would impose a risk of water trap seal loss through evaporation together with the absence of self-priming function, the effect of positive pressure induced at the bottommost bending of a high-rise drainage stack should not be neglected. The authors performed another test at a 41 storeys residential building that, when a total flow rate of 138 L/min of water was discharged from the upper floors, the water trap at the lower floor, which was found empty before the experiment, was found to have an air flow velocity of 3.56 m/s, and a paper strip placed near the floor drain confirms that the air was flowing from the pipe to the occupied space. The water in the WC of the floor was also “shooting-out”. The effect of hydraulic jump at the bottom bending of a drainage stack should not be neglected. Positive pressure inside a drainage stack should be properly attenuated through proper pipe design. Attenuators may be necessary if the air and water was back-flowing to the occupied space when the building was already occupied and being use.

In addition to residential buildings, the authors found that there was no immune to the problem of water backflow problem in other buildings, if unnecessary bendings were allowed in the piping network. We have come across a similar problem in a 17 storeys building in a tertiary institutional campus. Water “shoot-out” from WC at 3/F of the building was found during lunch hour, which was anticipated to be the peak hour of drainage stack utilization. An unnecessary bending was found at one floor below (figure 2), due to a lack of space in the pipe-duct service run. This also reveals the operation problem induced due to an inadequate space allocation for building services, at which the design team of future buildings should be aware of.



Figure 2 Unnecessary bendings along the vertical drainage stack

Conclusion

The paper reviewed the possibility of upward air flow in a vertical drainage stack, at dedicated condition, and the risk of air and water back flow if the water seal inside the trap was loss, no matter due to natural evaporation, or due to a high positive pressure at the lower part of the stack due to hydraulic jump in bendings.

References

Chan, D.W.T., Law, L.K.C. and Hung, H.C.K. (2006) Effect of Stack Contamination in High Rise Buildings on the Spread of SARS Virus. *WPC/ISH China Academy Plumbing Symposium*, Mar. 16, 2006, Beijing, China.

Chan, D.W.T., Law, L.K.C., Yeung, N. and Chan, E.H.W. (2005) A Review of Contemporary Drainage Practice in Hong Kong. *Healthy Building – Community Health and the Built Environment*, CII-HK Conference 2005, Nov. 30, 2005, Hong Kong.

Hung, H.C.K., Chan, D.W.T., Law, L.K.C., Chan, E.H.W. and Wong, S.W. (2006)

Industrial Experience and Research into the Causes of SARS Virus Transmission in a High-rise Residential Housing Estate in Hong Kong. *Building Services Engineering Research and Technology*, Volume 27, issue 2 (2006) pp. 91-102.

Law, L.K.C., Chan, D.W.T., Chan, E.H.W. and Law, F. (2005) Ingress of Air from Empty Drainage Trap to Residential Toilets. *Healthy Building – Community Health and the Built Environment*, CII-HK Conference 2005, Nov. 30, 2005, Hong Kong.

A case study of air pressure fluctuations in drainage stacks of high-rise residential buildings

L. T. Wong (1), K. W. Mui (2)

(1) beltw@polyu.edu.hk

(2) behorace@polyu.edu.hk

Department of Building Services Engineering, The Hong Kong Polytechnic University, HKSAR

Abstract

Pressure variation in drainage stack is one of the key design parameters for a healthy drainage system in high-rise residential buildings as it might deplete the water seals of any connected appliances that prevent the ingress of foul gases into a habitable space. In this study, diurnal pressure variations in a drainage stack of a typical in-use high-rise residential building in Hong Kong were investigated. With the survey data of occupant load variations and diurnal WC flushing patterns collected from a number of similar local buildings, a significant association between the expected hourly WC flushes in the building and the air pressure variations in the stack was reported. Mathematical expressions were proposed to correlate the occurrence of maximum air pressure at certain locations in a stack with the expected hourly WC flushes in high-rise residential buildings. The results would be a useful source of reference to the development of control strategies against probable appliance seal loss in high-rise residential buildings.

Keywords

Drainage stack, high-rise, residential buildings, air pressure variations

1 Introduction

Hong Kong is a developed city having a population of 6.7 million and limited area of 1,067 km². The tiny portion (20%) of flat land for construction has led to a densely populated high-rise environment. The tallest residential buildings in Hong Kong are Sorrento (tower 1: 75 floors, 256 m high; tower 2: 66 floors, 236 m high; both were 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) [1]. In addition to the private residential buildings, there are many other government funded ones with heights over 140 m.

Following the massive outbreak of Severe Acute Respiratory Syndrome (SARS) in early 2003, the drainage system in high-rise residential buildings has become a major concern [2-4]. The contaminated single stack system was the suspect of transporting the virus into the living units connecting to it.

Air pressure fluctuation control in vertical drainage stacks, to which building height is a challenge, has been identified as an important factor in ensuring the performance of a building drainage system [2,5]. The transient air pressure generated in a poorly designed drainage stack by the system operations would contribute to the probable trap seal depletion of any connected appliances that prevent the ingress of foul gases into a habitable space [6]. For designing a healthy building drainage system, such pressure with unsteady partially filled pipe flow has been investigated intensively through simulations and laboratory tests [5,7-11]. Simulations based on a four-stack network that illustrated the flow mechanisms within the pipework following both appliance discharges and sewer-generated transients were performed to enable the development of measures like air admittance valve design against excessive air pressure variations in stacks [7]. The influence of design parameters including stack diameter, roughness, height, and applied water flow rate was also examined to determine the air pressure regime within the drainage vent system [8]. By laser measurement of annular flow velocities under representative unsteady flow conditions, the model predictions were validated [11].

Apart from the ventilation pipe designs, the air pressure variations are closely related to the discharge flow rates and patterns of appliances. Indeed, water discharge patterns are transient and dependent on occupant load variations, occupant usage patterns and the types of appliances installed. How the usage varied significantly throughout a day and between appliances was demonstrated [1, 12-14]. Studies showed that the diurnal patterns of total WC flushes could be presented in two distinct profiles, i.e. on an average weekday and an average weekend [12-14]. Nevertheless, stack air pressure variations in high-rise residential buildings due to the occupant usages were not investigated in details.

There are external factors such as wind pressure across openings and operations of mechanical fans or washroom windows/doors which might affect the transient air pressure in a drainage stack, but it is believed that WC flushing operations dominate the stack pressure variations. Based on experimental tests, mathematical expressions were proposed for air pressure transients in drainage stacks due to WC flushing operations [5,8].

This study investigated the diurnal air pressure variations in a drainage stack of a typical in-use high-rise residential building in Hong Kong and correlated the measured pressure variations with the expected hourly WC flushes. The results would be a useful source of reference to the development of control strategies against probable appliance seal loss in high-rise residential buildings.

2 Field studies

The field studies were composed of 2 parts: (1) a survey study of diurnal drainage discharge patterns on typical weekdays and holidays, and (2) measurements of air pressure variations in an in-use drainage stack of a high-rise residential building.

The first study was conducted in 14 high-rise residential buildings of 5 Hong Kong estates [1,4,13-14]. The estates were selected based on their geographical locations, building ages and architectural designs. They provided 26,500 apartments for a population of 113,000. Invitation letters introducing the study objectives, the survey period and details were sent to 1,300 selected households. Representatives of the 597 responded households participated in a face-to-face interview in their respective apartments. The daily occupant load variations throughout a week were surveyed. Most of the interviewees were those occupants staying at home the longest time. During the interview, they were asked to provide information of the appliance usage patterns on the day prior to the interview, and the hourly usage patterns on weekdays, Sundays and holidays. The average time between appliance demands was surveyed. For each installed appliance, its type, physical size, brand name, fill level and usage frequency were recorded. Average flow rates of water taps installed at the sink, washbasin, shower and bath were measured with simple operations by the occupants; the discharge and refilling times of each WC cistern were measured as well. Floor area of each apartment was obtained from the facilities management, direct measurement, or record drawings of piping arrangements.

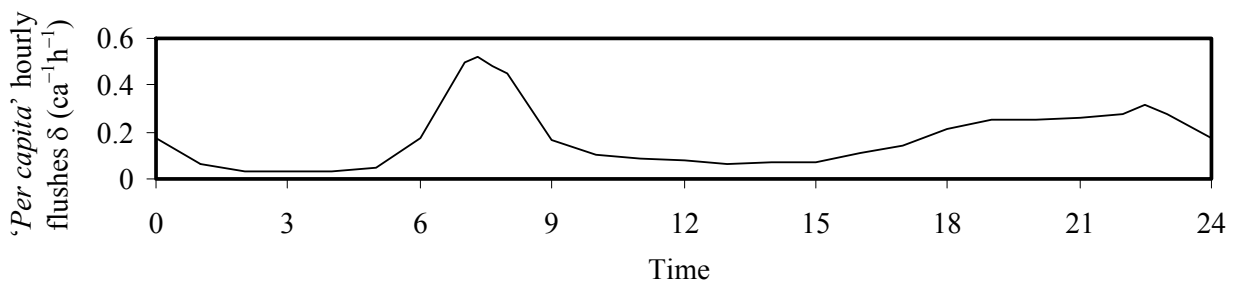


Figure 1: Example diurnal patterns of total flushes [4,12]

Air pressure variations in a PVC drainage stack of a 38-storey in-use residential building in Hong Kong were investigated in the second study. The stack pipe was 150 mm in diameter and fully vented by a 100-mm ventilation pipe with cross vents installed on alternate floors. Both the stack and ventilation pipe extended throughout the building (of height 110 m) and terminated at 1 m above the building roof. The stack collected effluents from the en suite washrooms on every floor. Each of these washrooms was equipped with a WC, a washbasin, a bath tub and a floor drain. This field study employed a data acquisition system which included a pressure sensor (measurement range ± 837 Pa; probable error ≤ 2 Pa) and a data logger with a minimum

sampling frequency of 1 s. The pressure sensor was installed at ‘level 6’ of the stack (i.e. 16 m above the bottom bend of the stack). Taking account of the atmospheric pressure in the washroom, it measured the transient pressure variations in the stack from Monday to Wednesday in a week.

3 Result and discussion

Figure 1 shows the example diurnal patterns of ‘*per capita*’ total flushes δ for an average weekday. A sharp peak occurred during the morning period of 5 a.m. – 9 a.m., with a maximum rate of $0.52 \text{ ca}^{-1}\text{h}^{-1}$ at around 7:30 am. A period of lower flush rate followed from 11 a.m. till 3 p.m. The second peak occurred in the evening and it lasted for about 5 hours (6 p.m. – 11 p.m.). The late night minimum also lasted around 4 hours (2 a.m. – 5 a.m.) at a rate of approximately 0.032 flushes per capita per hour.

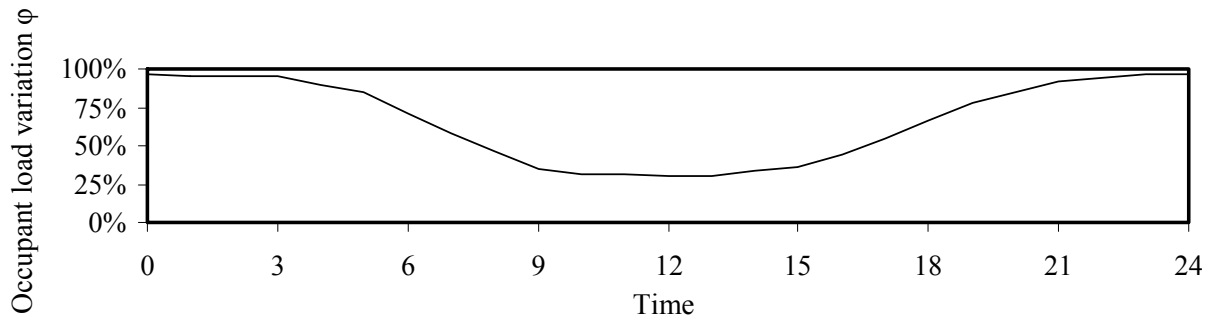


Figure 2: Weekday occupant load variations ϕ of high-rise residential buildings in Hong Kong

It was reported that the average maximum occupant load factor of the 600 apartments surveyed was very close to some design criteria, e.g. $4.5\text{--}9 \text{ m}^2$ per capita as in the local codes of practice [1,4]. Figure 2 shows the occupant load variations as a percentage of the reported ‘full’ occupant load. Loads nearly full were found at midnight and lasted for about 5 hours, they then dropped to the minimum (i.e. 25%) at 9 a.m. for 6 hours as shown.

Interestingly, by plotting against the occupant load variations ϕ on weekdays, the average ‘*per capita*’ hourly flushes δ could be grouped into 4 categories. As shown in Figure 3, these categories are: (1) morning peak period with high usage 0700–1000; (2) low occupancy period with general usage 1100–2300; (3) high occupancy period with low usage 0100–0500; and (4) transitional usage stages from low to high at 0600 and from high to low at 0000. The ‘slope’ in the figure indicates the demands of WC flushes in various periods throughout a day. With an average slope of nearly 1, a significant correlation was found for the morning peak average ($p \leq 0.05$). The ‘steep’ slope indicated a congested demand in that period due to the assumption of a number of occupants flushing the WCs almost simultaneously. In the low occupancy period, there was also a significant correlation between δ and ϕ ($p = 0.0000$) with an average slope of

0.3. In the period of high occupancy with low usage, where the average ‘*per capita*’ hourly flushes was $0.04 \text{ ca}^{-1}\text{h}^{-1}$ with a standard deviation of $0.01 \text{ ca}^{-1}\text{h}^{-1}$, no significant correlation was found between δ and ϕ ($p > 0.95$).

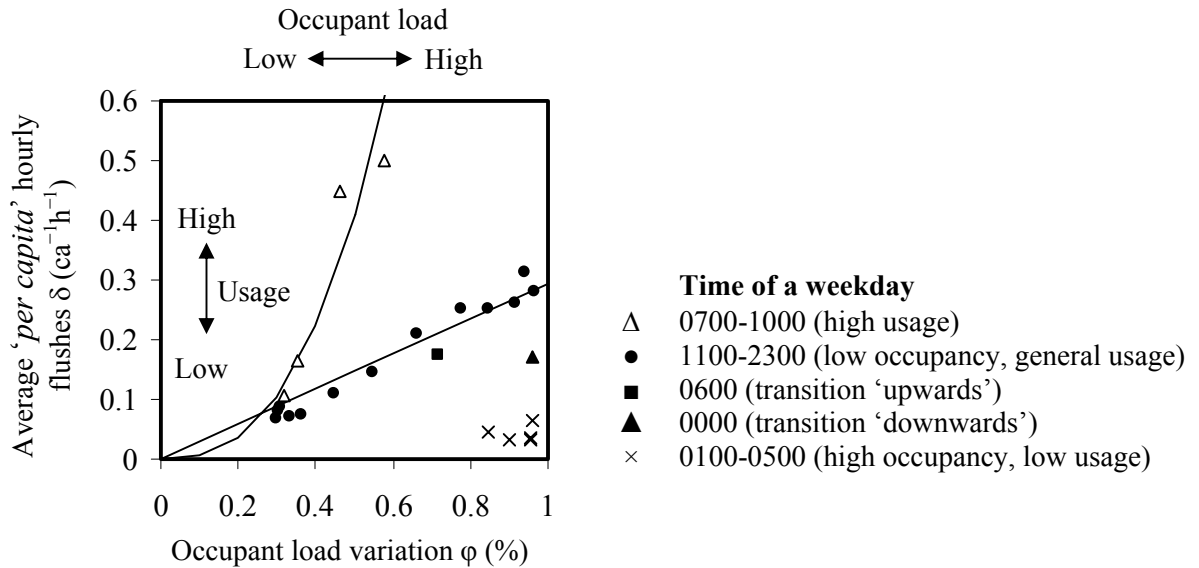


Figure 3: Number of flushes against occupant load variations

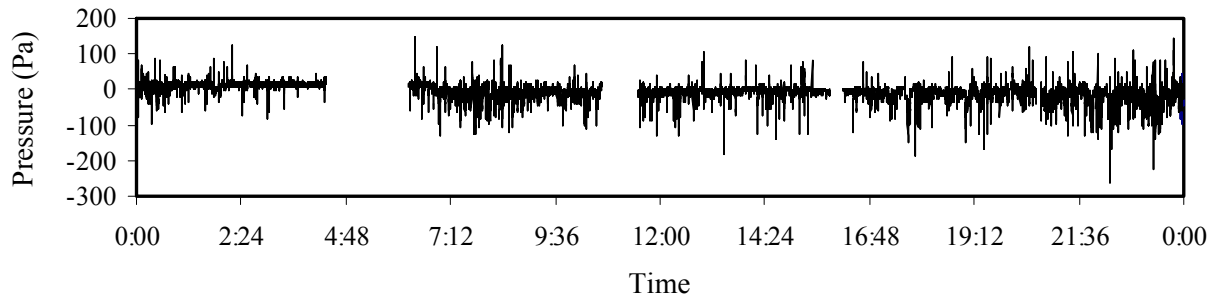


Figure 4: Example diurnal patterns of air pressure in a drainage stack

Figure 4 shows the diurnal air pressure variations measured in the drainage stack. Considerably ‘large’ fluctuations were reported in both the morning and evening peaks as shown. The probability P of air pressure ξ in the stack exceeding certain pressure limits $\pm \xi^*$ is expressed below, where ϕ is the probability density function of ξ in the stack,

$$P = 1 - \int_{-\xi^*}^{\xi^*} \phi(\xi) d\xi \quad \dots (1)$$

In this study, P was also approximated by the proportion of the number of measurements with air pressure fluctuations exceeding the set pressure limits as follows, where N is the number of measurements in the stack with an air pressure ξ ,

$$P = 1 - \frac{N_{-\xi^* \leq \xi \leq \xi^*}}{N_\xi} \quad \dots (2)$$

Apart from the air pressure transients due to human activities and wind pressure across the stack openings (e.g. operation of mechanical ventilation fans), the probability P is correlated with the expected WC flushes. For the air pressure measured at certain stack level, this study proposes the following mathematical expression ($R = 0.6$, standard error = 0.04), where N_f is the expected hourly flushes,

$$P(\xi > \xi^*) = 305 \xi^{*-3.08} e^{(14.55 - 0.053 \xi^*) N_f} ; N_f = \delta \phi \quad \dots (3)$$

Figure 5 shows this P , with the pressure limits ξ^* of 50 Pa, 75 Pa and 100 Pa arbitrarily selected in the study, against N_f . A significant association was found between P and N_f ($p < 0.0001$). As expected, the probability of the stack air pressure going beyond certain limits was proportional to the expected WC flushes. The measurement results showed that the WC flushes would dominate the air pressure variations in a stack and uncertainty of these variations due to other factors was about 8% with 95% confidence intervals.

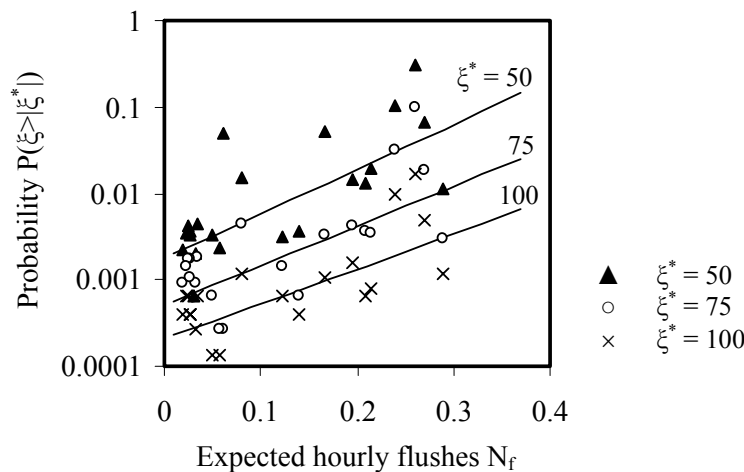


Figure 5: Correlations between stack air pressure and expected hourly WC flushes

4 Conclusion

In this study, diurnal pressure variations in a drainage stack of a typical in-use high-rise residential building in Hong Kong were investigated. With the survey data of occupant load variations and diurnal WC flushing patterns collected from a number of similar local buildings, a mathematical expression was proposed to correlate the occurrences of maximum pressure measured at certain locations in a stack with the expected hourly WC flushes in certain high-rise residential buildings. For the studied building, the probability of transient stack air pressure exceeding certain pressure limits was correlated with the expected hourly WC flushes. The measurement results showed that WC flushes would dominate air pressure variations in a stack and uncertainty of these variations due to other factors was estimated to be 8% with 95% confidence intervals.

5 Acknowledgment

The work described in this paper was substantially supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. PolyU 5129/04E; A/C code: BQ801).

6 References

1. Wong L. T. and Mui K. W., (2004). A survey of the sanitation load for domestic high-rise building estates in Hong Kong, Proceedings of the 30th International Symposium on Water Supply and Drainage for Buildings, CIBW062, CSTB, Paris, France, 16-17 September, Fourth Session-Drainage System, 1-18.
2. Jack, L.B., Cheng, C. L., Lu, W.H., (2006). Numerical simulation of pressure and airflow response of building drainage ventilation systems, Building Services Engineering Research and Technology, Vol. 27, No. 2, pp. 141-152.
3. Fernandes, V. M. C., Goncalves, O. M., (2006). Limits for use of vent elements in building drainage systems considering the risk of infection spread by means of water-seal behaviour and integrity: the case of Brazilian systems, Building Services Engineering Research and Technology, Vol. 27, No. 2, pp. 103-117.
4. Wong, L. T., Mui, K. W., (2004). Determining the domestic drainage loads for high-rise buildings, Architectural Science Review, Vol. 47, No. 4, pp. 355-364.
5. Cheng, C. L., Lu, W. H., Shen, M. D., (2004). An empirical approach: prediction method of air pressure distribution on building vertical drainage stack, Journal of the Chinese Institute of Engineers, Vol. 28, No. 2, pp. 205-217.
6. World Health Organization (WHO), (26 Sep 2003). Inadequate plumbing systems likely contributed to SARS transmission, WHO press release WHO/780, 1-2.

7. Swaffield, J. A., (2006). Sealed building drainage and vent systems—an application of active air pressure transient control and suppression, *Building and Environment*, Vol. 41, No. 10, pp. 1435-1446.
8. Swaffield, J. A., Jack, L. B., Campbell, D. P., (2004). Control and suppression of air pressure transients in building drainage and vent systems, *Building and Environment*, Vol. 39, No. 8, pp. 783-794.
9. Swaffield, J. A., Jack, L. B., (1998). Drainage vent systems: Investigation and analysis of air pressure regime, *Building Services Engineering Research and Technology*, Vol. 19, No. 3, pp. 141-148.
10. Swaffield, J. A., Campbell, D. P., (1992). Numerical modeling of air pressure transient propagation in building drainage systems, including the influence of mechanical boundary conditions, *Building and Environment*, Vol. 27, No. 4, pp. 455-467.
11. Swaffield, J.A., Thancanamootoo, A., (1991). Modelling unsteady annular downflow in vertical building drainage stacks, *Building and Environment*, Vol. 26, No. 2, pp. 137-142.
12. Friedler, E., Butler, D., Brown, D. M., (1996). Domestic WC usage patterns, *Building and Environment*, Vol. 31, No. 4, pp. 385-192.
13. Wong, L. T., Mui, K. W., (2006a). Discharge demand analysis on a drainage stack for residential buildings, *Facilities*, Vol. 24, No. 3/4, pp. 132-140.
14. Wong, L. T., Mui, K. W., (2006b). Modeling water consumption and flow rates for flushing water systems in high-rise residential buildings in Hong Kong, *Building and Environment*, In press.

Biofilms/Corrosion Survey in Water Pipes

Lawrence S. Galowin

larrygales@earthlink.net

Consultant

Abstract

A literature survey on problems in building water pipes concerning corrosion processes, deposition/removal of biofilms, and materials/formations was made. Pipe walls' hazardous biofilm attachments and techniques for removal of microbiologically induced corrosion (MIC) are now commercially available. Past studies of MIC and copper pinhole leaks in water pipes on wall corrosion have brought specific methods for cleanout techniques. Investigations also relate applications to removal requirements of hazardous materials from slimes and biofilm formations. Such concerns can offer input to determinations for viral-bio-radiological selected agents that represent hazardous states. Pinhole leaks in pipes may be attributable to biofilms as causative aspects in pipe deterioration. Recovery of building potable water systems from natural disastrous events (hurricanes, tsunamis, and earthquakes) requires similar considerations. Formations of corrosion products tubercles relate to varieties of failures that includes leakages, pipe blockages and other biological formations that cause upset conditions and threaten building water quality. Slime in systems from hazardous aftereffects (hurricane in New Orleans area) may require special cleaning of contaminants by valid and also unproven methods. The breadth of concerns for elimination of hazardous biofilms attachments including viral-bio-radiological selected agents may be advantageously derived from prior research.

Keywords

Building potable water systems; plumbing water pipe systems, biofilms, biological pipe wall attachments, building water contamination, fouling, pinhole leaks, microbial corrosion.

1. Introduction

Historically, many aspects of biofilm corrosive attacks problems have been of concern for ships, industrial processes, petrochemical, gas and nuclear power industries.

Impacts range from mechanical blockages, reduced flow capacity, wall penetrations and leaks and recent investigations have focused on copper pipe pinhole leaks in buildings. Tuberculation elimination with suppression of localized conditions that reduce 'pitting-type' attack has been demonstrated in removal methods for wet fire sprinkler systems but apparently differ as dependent on fields of applications.

Research applicable to this study was sought for application potentials from understanding developments from microbiologically induced corrosion (MIC). Biofilm 'biofouling' information was found (e.g., internet search references). Usual definitions found in many sources indicate {a partial excerpt}:

Biofouling occurs worldwide in various industries, from offshore oil and gas industries in China and the Indian Ocean, to fishing equipment in the Caspian Sea, to cooling systems in the Chesapeake Bay. Most common biofouling sites are hulls of ships, where barnacles are often found. The most obvious problem of growth on a ship is the eventual corrosion of the hull, leading to the ship's deterioration. Even before corrosion occurs, if left unattended, organic growth can increase the roughness of the hull, thereby decreasing its maneuverability and increasing drag. This domino effect continues when the ship's fuel consumption increases, in some cases by 30%. This in turn has economic and environmental consequences, as increased fuel consumption leads to increased output of greenhouse gases. Economic losses are tremendous, as fuel accounts for up to 50% of marine transportation costs.

Biofouling is everywhere. Parts of a ship other than the hull are affected as well: heat exchangers, water-cooling pipes, propellers, even the ballast water. Heating and cooling systems biofouling might also be found in power stations or factories. Just like a clogged drain in your kitchen or bathroom, buildup of matter inside cooling system pipes decreases performance. Again, fouling causes a domino effect. Equipment must be cleaned frequently, at times with harsh chemicals, and the obstruction of piping can lead to a shutdown of plants and economic losses.

Other excerpts (1) illustrate variety and ranges of interests:

- Causative factors responsible for contaminant biodegradation with investigative research on cause's bioremediation of individual compounds and with mixtures of toxic compounds with a range of recalcitrance. The study is using specially designed microelectrodes and development of a permeable biowall system for bioremediation.
- Effectiveness of Chlorine Dioxide in the Disinfection of Biofilms in Pipes and Food Process Equipment. The food industry concerns for microbial contamination in pipes and process equipment results from microorganisms attached to solid surfaces. Biofilms represent significant health risk because they can harbor pathogens, and direct contact can lead to food contamination. Biofilms are notoriously resistant to many disinfectants, which often react with extracellular polymeric substances (EPS) and other organic constituents that form the biofilm, thus inactivating the disinfectant. Disinfectants may not reach bacteria in the biofilm that may proliferate

after disinfection. Effectiveness of a disinfectant used for biofilm control can be determined by measuring the rate and depth of disinfectant penetration.

- Potential for Pathogen Adhesion to Water Distribution System Biofilms Following a Bioterrorism Attack. Simulations for mechanisms of adherence and retention of fouled iron surface of a pipe wall to which pathogenic cells injected into a model distribution system are being applied. Water distribution systems are vulnerable to intentional contamination and accessible with basic understanding of water supply networks. How biological agents interact with the distribution system, especially the corrosion and “fouling biofilm” located on the pipe wall is required. Chlorine residual in the water may inactivate many planktonic organisms but the fate of organisms trapped within the biofilm is unknown. If pathogens adhere and chlorine residual is ineffective then biofilms may serve as a reservoir for pathogenic microorganisms.

- Drinking water building systems concerns for corrosion and scaling phenomena that impact quality and increase development of bacteria have led to development of determination of degradation risks (2). The methodology applied for development of risk analyses determinations of several deterioration elements for galvanized and copper pipe materials was discussed. Utilization classifications at three levels of degradation by applying techniques from quantification methods to applications were indicated by computer aided assessment tools. An alarm system for building managers information on water system functions that may intervene before degradation was also suggested.

Biofilm materials consist of an organic slime produced and containing bacteria. Slime protects the microbes from the environment and helps them stick to surfaces. Biofilms form on many surfaces under water and is independent of whether surface materials are biological. Such films are found in stagnant and flowing water when nutrients are present. Biofilms are formed on stones where water flows and appears on metal, wood, particles or anything solid. The films function as systems that degrade organic compounds and transform inorganic ones. Biofilms can be useful in nature since they absorb pollutants and reduce buildups by degrading them; in human intestinal tracts provide protection from disease-producing organisms. Applications include usage in sewage and waste water management where trickling filters and bed reactors use biofilms to break down and transform sewage and waste waters. In industrial plants they help in breaking down pollutants as fuels to reduce bacteria and toxic contaminants. Bacteria are buried in the slime so that antibiotics and other chemicals may not act and avoid destruction.

Pinhole copper pipe destructive elements have seemingly not been associated with identified biofilm formations; studies for causative factors lean toward physical electro-chemical aspects leading to pinhole sites development. Chemical deterioration factors have most often been related in explanation of those phenomena.

Potable water quality water restorations are required in many circumstances that result from natural or man-made disasters. Focus was on contamination/corrosion

formations that cause clogging blockages, leaks, and potentials relating to terrorist enigmatic causes for safety of potable water quality in buildings. Other applications to building water systems also apply for recovery from earthquakes and hurricane induced hazards.

In this review fundamentals were sought that govern establishment and growth of wall attachment processes of biofilms, tubercles, and for descriptive analyses of attachment mechanisms from bio-viral-chemo attack on usual piping materials. Wall deterioration studies of attachment phenomena provide for techniques and methods adaptable to clearance in restoration of quality water distribution systems. Elimination of copper pinhole leaks could benefit from understanding phenomena at pipe walls. Advantageous clearance methods from prior MIC investigations of impacts on causes of wall corrosion provide information related to eliminating impacts on building water distribution systems. Biological fouling prevention and/or maintenance requirements of fire sprinkler systems have become obligatory by National Fire Protection Association (NFPA, 3).

2. Information - Interfaces

Preservation of potable water quality water following deterioration from introduced materials can threaten public health and is a vital concern. Serendipitous opportunities exist from studies on potentials for removal of contaminants by linking known explanations of biofilms' research sectors applicable to recovering building water piping systems. Also, potable building water supply foreboding has arisen from hurricane damage flooding of buildings in recovery concerns. Wall attachment materials from known and unknown compounds from terrorist attack with viral/bio/chemo hazardous materials can result in pipe wall cavities residual masses that may later burst into the flow and form other wall attachment mechanisms. Study efforts are required for development of methods applicable to their removal and elimination of persistent conditions. Clamps shown eliminate dripping (4) as communities experience copper pinhole leakages (reported in internet communications). Understanding depositions on water pipe inner walls may provide insights of governing factors in copper pipe pin-hole leaks to situations illustrated.

State of Maryland
Final Report: Task Force to Study Pinhole Leaks in Copper Plumbing

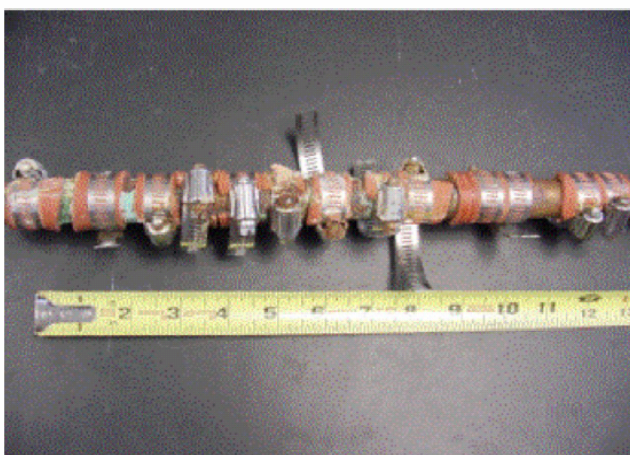


Figure 9: Pipe from Arlington, Virginia Water System with Clamps to Stop Pinhole Leaks
(Courtesy Dr. Marc Edwards)

Telephone discussions with specialists in biofilm MIC research studies shared the conceptual idea that their information can apply in providing insights and understanding for applications to building potable water systems. Extension to current concern for descriptors of biofilm impacts appear common to both problems. Reports from diverse sources have similarities on biofilm information impacts. Potentials appear for health/safety aspects tracing to corrosive deteriorations and material failures due to the 'foreign depositions of microbiological characteristics' and destructive contamination. Particulars are available in research listings from U. S. 'Center for Biofilm Engineering', Montana State University (1).

Citations on bacterial biofilm ranges from formation of plaque that forms on teeth (causes tooth decay) and extends to "gunk" that clogs drains, and also as readily observed on coated rocks at lake edges and piers where biofilms develop. Surface bacteria adherence in aqueous environments indicates biofilms resulting from excretion of slimy, glue-like substances that can anchor to all kinds of materials. Examples include metals, plastics, soil particles, medical implant materials, and tissue. Formations can result from a single bacterial species but mostly consist of many bacteria species. Suspect materials may be recognized from other discolorations and/or as fungi, algae, protozoa, corrosion products and debris. Fundamentally, any surface exposed to bacteria and some amount of water can cause formations of biofilms. Dependence on surrounding environmental conditions anchored materials on a surface may result in detrimental or even beneficial reactions of biofilm microorganisms. Several suspect **organisms may cause biofouling and water contact for a period of time results in organism attachment to surfaces.**

From a study – "Potential for Pathogen Adhesion to Water Distribution System Biofilms Following a Bioterrorism Attack". Simulations for mechanisms of adherence and retention of fouled iron surface of a pipe wall to which pathogenic cells injected into a model distribution system are being applied. Water distribution systems are vulnerable to intentional contamination and accessible with basic understanding of water supply networks. How biological agents interact with the distribution system, especially the corrosion and "fouling biofilm" located on the pipe wall is required. Chlorine residual in the water may inactivate many planktonic organisms but the fate of organisms trapped within the biofilm is unknown. If pathogens adhere and chlorine residual is ineffective then biofilms may serve as a reservoir for pathogenic microorganisms.

3. Framework - Findings

Observations and analyses of inner pipe walls at biological corrosion sites show attachments to the metallic surfaces of tubercles and their distributions of organisms that cause corrosion, blockage and pitting holes in destructive pipe failures. Observers indicate microbial communities in local depositions are attributed to varieties of mechanisms associated with differential oxygen cells, under-deposit chloride concentrations, sulfide attacks, and aspects of acid production. Most investigators indicate microbial corrosion does not occur in absence of biofilms although essential

mechanisms apparently vary due to materials and surface conditions in water that cause pitting and deterioration in pipe systems. Causative factors always appear associated with presence of slime and tubercles caused from biofilm formations in 'attacks' on inner pipe walls. The Copper Development Association (CDA) provides problem references (5) but lacks remediation techniques for prevention. Pin-hole leaks in building potable water copper piping have not been traced to specific causative actions.

The report {required by Maryland State Senate (4)} on the pinhole leak phenomena and deal with its consequences indicated no identifiable specific causes but limited potentials for mitigation were shown. Indicated probable actions from material impurities in copper pipes were found but the specifics of deterioration modes remained undetermined.

Water supply/treatment parameters or/and installation methods were a main concern. Causative deterioration formation was not resolved although examined samples displayed similarities to MIC. Three activities considered were water treatment,

materials, and insurance (costly restorations). The findings were that no specific cause was determinable but research on mitigation and determinations from on-going research may be anticipated. Copper water pipe sample photographs indicated very similar distinguishing aspects to features from deteriorated sample fire sprinkler pipe MIC sections. Photos suggest formation of tubercles on the pipe wall as commonly found in such studies of water filled fire sprinkler pipes.

3.1 Prevention Actions

The Washington Suburban Sanitary Commission (WSSC) has recently applied an orthophosphate chemical additive (phosphoric acid, an EPA approved additive product) to counteract pinhole leaks. The additive can form pipe wall protective coatings which presumably resist attack on the copper pipes. Sufficient time for development of the wall coating is required to determine if the additive fulfills the protective need. Some communities have not approved such practices.

State of Maryland Final Report: Task Force to Study Pinhole Leaks in Copper Plumbing

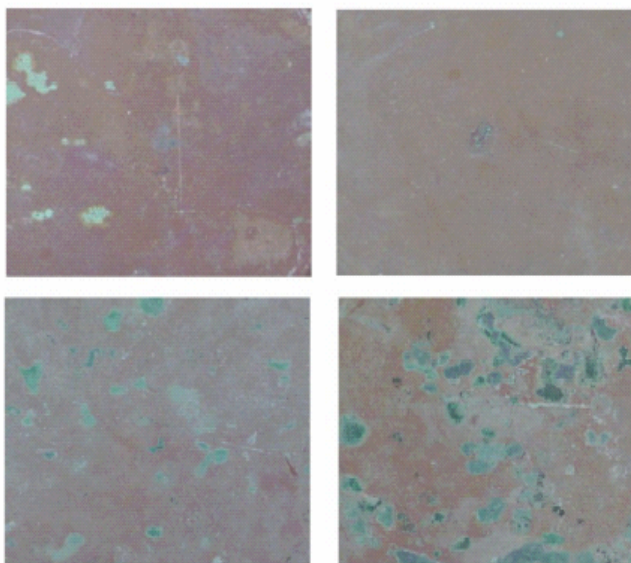


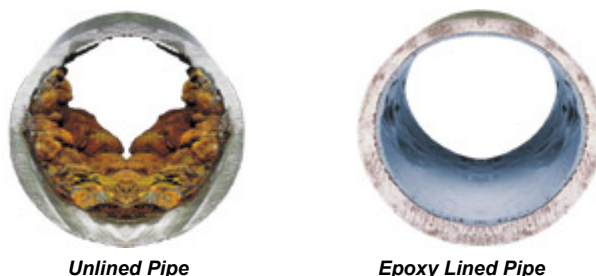
Figure 10: Dried Copper Surfaces After 6 months' Exposure to WSSC Water and Aluminum Solids

The top left picture is with water with 0 mg/L free chlorine. Top right: 1.2 mg/L free chlorine. Bottom left: 2.4 mg/L free chlorine. Bottom right: 3.6 mg/L free chlorine. All samples were exposed to 30 mg/L aluminum solids. Surface areas of each picture are approximately 100 cm² or 12 square inches. (Courtesy of Dr. Marc Edwards)

Prevention of pinhole leaks by a protective pipe wall coating has become commercially available from commercial contractors. Typically, renovation requires inner pipe wall cleaning by an abrasive material injected into the system and followed with an epoxy like coating material spray that coats and protects inner walls {method derives from other countries experiences} and decade guarantees are made against further pinhole leakages. Such coatings are advertised also as a preventive maintenance procedure.

Illustrated pipe sections and excerpts are shown {commercial advertisement (CuraFlo™ epoxy lining process)}.

"..... advanced alternative to the traditional approaches of repairing corrosive or leaking pipes. Pipelining is a cost effective method that coats the inside of the pipe with a durable and safe epoxy. The epoxy is applied with minimal disruption to the property and is often less costly than the traditional repiping alternatives."



The {ACE DuraFlo™¹ system} of pipe restoration is designed to clean the piping system of encrustation build up and then coat the interior of the pipe with a NSF Standard 61 approved epoxy coating material, stopping any future water to metal contact. The size of pipes that can be restored using this process can be as small as 1/2" in diameter. Application within buildings has ranged from smaller walk-up style apartments to high rise facilities. The system of pipe restoration is applied to pipes within the walls eliminating the traditional destructive nature associated with a re-piping job. Typically, 1 riser system is isolated at a time and the restoration of the riser system is usually completed in 1 day with water restored the next day. Too, there are no walls to cut no large piles of waste and no dust. Savings in time and costs when compared to a re-pipe are striking. Piping systems are typically restored in ½ the time and with 30% to 60% cost savings over a repipe job.

The epoxy coating creates a watertight barrier on the interior of the pipe and prevents the water from actually coming in contact with the metallic surface of the pipe. Not only repairing the effects of corrosion but providing the best possible solution to stopping corrosion from reoccurring!

Epoxy coatings are characterized by their durability, strength, adhesion and chemical resistance, making them an ideal product to coat or line the interior of existing or even new piping systems. As a form of corrosion control, epoxy coating is recognized and used by both the County Sanitation Districts of Los Angeles County and in the San Francisco region, the East Bay Municipal Utility District. Durability - pipe restoration coating material (epoxy) properly applied will be expected to give an effective life of at least 75 years. Epoxy lining materials used in drinking waterlines are subject to

* Citation(s) **are not recommendations**; provides only illustration of a commercial method.

strict health guidelines laid out primarily by the National Sanitation Foundation (NSF) with widespread North America acceptance from regulatory communities.

3.2 Insights & Conjectures

Similarities of potable water piping copper pin-hole leak experiences with MIC leakages and destructive pipe failures from corrosion pitting holes, or blockage/stoppages, leads to an hypothesis for correlations between those phenomena. Techniques from cleaning/maintenance of MIC's have not focused on technology transfer for repair/renovation to potable water systems. Related issues resulting from scouring pipe walls has not been evaluated for total eliminations of residuals, especially at pipe size change 'steps' or at valve obstructions where lurking residuals may be encapsulated with unknowns for dislodgement and reentry into the water flow (e.g., valve seats, fixture controls, and any other plumbing system impediments) where streaming smooth flow conditions do not prevail.

Microbiologically Influenced Corrosion (MIC) investigations of fire sprinkler piping systems deterioration have determined sources of corrosion relate to the presence of microbial activities but initiation processes and environments essential for development remains largely unknown. Tubercles distributions of organisms attached to the metallic surfaces at biological corrosion sites were locally observed at depositions where microbial communities' growths occur.

Causative factors that induce deterioration effects on inner pipe walls always appear associated with presence of slime and tubercles caused from biofilm formations. Attribution by investigators relate varieties of mechanisms associated with differential oxygen cells, under-deposit chloride concentrations, hydrogen sulfide generation, sulfur-oxidizing and sulfide attacks, sulfate-reducing, iron-oxidizing, acid-producing, and nitrate-reducing bacteria and aspects of acid production. Subsequent development of differential aeration cells can lead to deterioration and failure of mild steel, copper, stainless steel, and other ferrous and non-ferrous metals used in construction. Plumbing systems extension to galvanized and plastic water supply piping in many buildings may develop comparably similar, although different pipe wall materials may result in other slime and biofilm compositions from copper usages and have potentially other threat scenarios.

Under-deposit pitting often results in pinhole leaks that may occur within months of new installation. At later times, where slimes, discrete deposits, and pinhole leaks develop telltale signs of MIC. Frequent exposure to MIC factors increases the likelihood of *severe* MIC. However, an essential mechanism involved varies due to materials and surface conditions which induce formations. Varied potable water supply conditions and quality treatment methods impacts on constituents and remain as unknowns for induced pitting and deterioration in pipe systems.

Of special interest is an observation that presence of microbes does not result in MIC unless those listed factors appear. Causative factors 'attacks' on inner pipe walls always appear associated with presence of slime and tubercles caused from biofilm

formations. These suggest sufficient indicators related to pinhole leaks in water distribution systems. Other unknowns remain for potential impacts on non-metallic type materials, e.g., plastic piping materials attack in concerns for plastic piping related to chlorine withstand and/or exposure to ultra violet exposures that may be adapted to clearance actions.

Adaptations from known commercially available treatment methods may provide economical and practical recovery in pinhole protective actions and purging recovery from hazardous materials. Measurement(s) means suitable for assuring clearance to human user needs with significant reliability is essential. Presence of hazardous materials by particular identifications may not be essential for clearance requirements but assurances that safe quality must be of established adequacy in clearing potable water systems is paramount

The following excerpted information (5) provides descriptors and micro-photos {source approved}. The findings suggest slime on walls as potential lodgment sites for many varieties of contaminants in attacks on building water supply systems. Such information sources offer understanding that leads to potentials of clearing and restoring quality potable water after disaster events that contaminate water delivery systems in buildings.

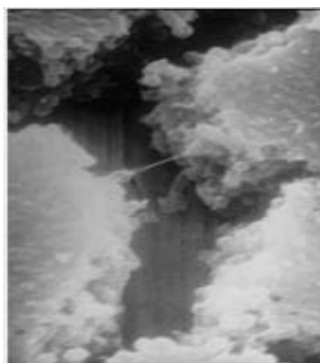


Figure 2. Bacterial biofilm associated with stainless steel tube. Scanning electron micrograph magnification at 5,000X.

Inner pipe walls attached formations is shown in the micro-photo (21) of MIC study of fire sprinklers; the author indicated “.. little is known about the role microorganisms play in initiating or propagating physicochemical corrosion processes ...”. Further - “...tubercles can completely occlude pipes, and more significantly, these deposits can break off and block sprinkler head flow channels. Localized pitting-type attack can also occur underneath tubercles, resulting in through-wall penetration. The resulting acid production, hydrogen sulfide generation and development of differential aeration cells can lead to the loss of essential metallic properties of mild steel, copper, stainless steel and other ferrous and non-ferrous metals.” Causes are dubious “... bacterial biofilms are the initiating and/or propagating agents of MIC; microbial corrosion does not occur in the absence of biofilms. Biofilms

provide localized environmental conditions (decreased pH; differential oxygen cells) initiating or propagating corrosion activities.”

On causes and effects “... mechanisms include development of differential oxygen cells, under-deposit (biofilm) chloride concentration, and sulfide-mediated attack, acidic dissolution of corrosion products and cathodic depolarization of protective hydrogen films. While corrosion of copper piping may present an environmental and economic threat in both fresh water and seawater systems, relatively little is known of the role microorganisms play in initiation or propagation of corrosion events. It is known, however, that bacterial biofilms are the initiating and/or propagating agents of MIC; microbial corrosion does not occur in the absence of biofilms. Biofilms provide the localized environmental conditions (e.g., decreased pH; differential oxygen cells) for initiating or propagating corrosion activities.”

Sulfate-reducing bacteria can cause rapid pitting of 316 SS base metal and welds, leading to through-wall penetration. MIC mechanisms for stainless and mild steels (incompletely understood) usually involve acid production or sulfide-attack. Researchers have described bacterial biofilm-mediated attack of copper in both controlled laboratory experiments and in field studies of tubing in hospital water systems. The slime produced by bacteria may also be important in the dissolution of corrosion products, leading to an increase in corrosion rates.

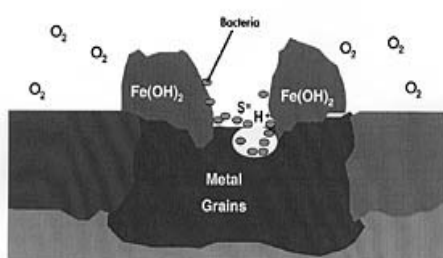


Figure 3b.

Figure 3b. MIC resulting in acid production and sulfide generation leading to pitting-type attack.

Other resource discussions appear on stagnant water in pipes that showed disappearance of chlorine from the treatment supply plant and thereby no longer provide protection from bio-micro formations. Limited public literature provides for concerns of hazardous impacts that result from attachments/growths at deposition sites for wall attached bio-viral-chemo agents and other potentials from unusual or

atypical materials. However, there is no attention to standing or stagnant durations from protective actions of additives as chlorine. Duration of chlorine or similar materials applied for delivery into buildings may not have any concern due to flowing conditions encountered in potable water systems piping. In newer concerns from potentials for attacking water delivery systems, or from earthquakes and hurricanes, similar issues may have emerged for concerns in clearing and eliminating life/death hazardous materials from wall attached sites.

MIC in FPS

Microbes which cause MIC in FPS are mostly bacteria and fungi. These are present in most water used in FPS, even water treated by water suppliers to kill pathogens. The most important groups of bacteria involved in MIC of FPS are:

- Low nutrient bacteria (LNB)
- Anaerobic bacteria (ANA)
- Iron-related bacteria (IRB)
- Acid-producing bacteria (APB)
- Sulfate-reducing bacteria (SRB)

It is important to realize that the simple presence of microbes does NOT result in MIC. MIC results from having the following “MIC factors” present in an FPS on a frequent or constant basis:

1. Susceptible metal (including steels, galvanized steel, copper, stainless steels).
2. Water – essential for microbes to grow and corrosion to occur.
3. MIC-related bacteria
4. Nutrients which are present in water and sediments—very important in controlling microbial growth and MIC.
5. Oxygen which is present in water and air – very important in controlling microbial growth rate and the rate at which corrosion, including MIC, can occur.

When all five MIC factors exist in an FPS, MIC occurs in the following stages.

- MIC-related bacteria grow quickly on metal surfaces and produce slimes (see Figure 1).

MIC results from having
5 MIC Factors present
on a frequent or
constant basis

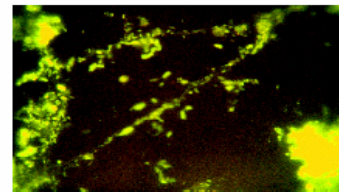


Figure 1. Microbes and microbial slimes on surface of steel exposed to city water for 12 hours as viewed using a high-powered microscope. Several million microbes are present per inch.



Figure 2. Discrete deposits on interior of steel pipe. These deposits are formed by microbes depositing materials from water and by the accumulation of corrosion products.

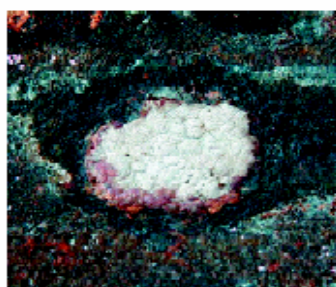


Figure 3. Under-deposit pitting corrosion showing distinct pits-within-pits, which are characteristic of MIC. This type pitting can occur at 0.200" per year and can penetrate FPS pipes within a few months after installation.

- The growth of bacteria ultimately results in the formation of discrete deposits (a.k.a. tubercles or carbuncles; see Figure 2).
- MIC-related bacteria create conditions (principally by producing acids and consuming oxygen) that promote very rapid under-deposit pitting (localized) corrosion (see Figure 3).
- This under-deposit pitting often results in pinhole leaks, which sometimes occur within months of new FPS installation (MIC has been documented to penetrate FPS metals at rates up to 0.200" per year; see Figure 4).

Slimes, discrete deposits, under-deposit pitting, and pinhole leaks are all telltale signs of MIC.

More frequent exposure to MIC factors increases the likelihood of *severe* MIC. Therefore, only those *usually small* portions of the FPS where MIC factors are present frequently—due to the way the FPS is constructed and operated—suffer *severe* MIC. In wet FPS, these areas are typically in: a) larger diameter, horizontal pipes which see frequent water flow and accumulate sediments, and b) in pipes containing air pockets (usually at high points in the FPS—see Figure 5). In dry/preaction FPS, severe MIC is most often seen in horizontal pipes which are likely to accumulate moisture and/or water puddles and sediments (usually at low points and areas adjacent to grooves and fittings—see Figure 6). It is now recognized that frequent flow of untreated water into an FPS—due to retrofits, flow tests, and inspectors' tests performed at remote locations—can contribute to rapid MIC in some portions of an FPS. Reducing the frequency of flow tests and performing flow tests at the riser help prevent MIC. Treatment of waters entering the FPS with agents to prevent microbial growth and reduce oxygen levels in the water is **ESSENTIAL** to controlling severe MIC.

3.3 Commercial Practices

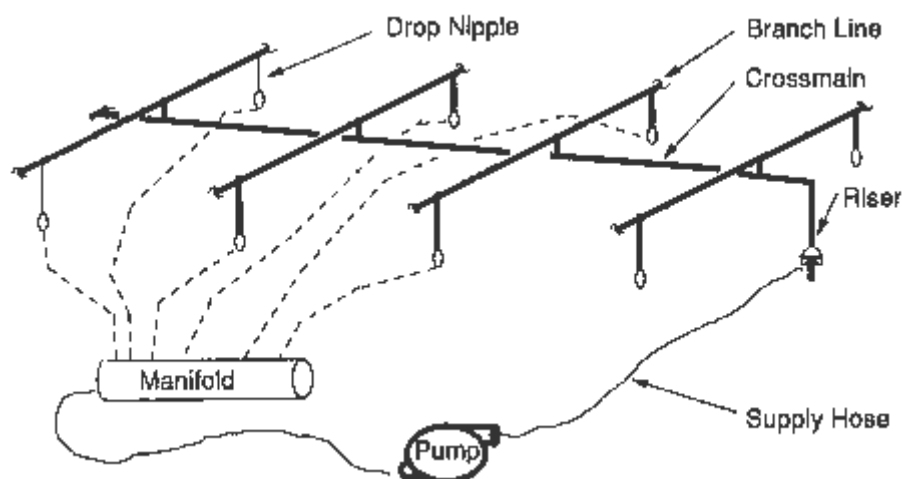
Fire protection water systems clearing are provided by commercial services; those have applications to other water systems. An example (contractor report) on clearing fire protection systems at the McCarran International Airport, Las Vegas, Nevada (6) appears in a case study. A terminal with unusually high number of pinhole leaks fire sprinkler system (less than 10-year-old) and technicians noticed a significant amount of internal buildup of tuberculation nodules in the piping. Use of the PIPE-KLEAN® fps (patent pending) cleaning process was applied to chemically rehabilitate the standpipe system in the International terminal[†]. The laboratory results (at corporate laboratory) from testing the internal buildup showed MIC problems with high levels of iron, as well as aerobic and sulfate reducing bacteria present.

An isolated circulation loop (sketch for purging sprinkler system shown) pumped the "PIPE-KLEAN C" cleaning solution through the standpipe system, circulated for approximately two hours to remove the MIC/internal buildup. Process monitoring of specific gravity, pH and total dissolved solids during the cleaning process tracked the cleaning progress; scanning pipe interior ensured that buildups had been dissolved and removed. Spent cleaning solution was evacuated from the system, neutralized, and discharged to the sanitary sewer with appropriate local regulatory approvals. The cleaning solution chemistry is a low pH, aqueous organic biocleaner with dispersants

[†] Product specific/contractor endorsement is **not implied and provides only an example of** commercial practice.

and inhibitors certified to ANSI/NSF Standard 60 (use in potable water systems/applications).

Figure 1: HERC's patented Mobile Recirculating Unit allows cleaning chemistry to circulate through the system.



Requirements were not identified for assuring extent of satisfactory cleansing and ascertaining extent of partial or complete decontamination for restoration to normal service conditions. Presumably, experiences from methods applied to sample analyses following pre-set completion time(s) for flushing cycle(s) of the cleared system determinations were established.

3.4 Other Fundamental Perspectives

The International Conference on Microbiologically Influenced Corrosion (7) convened experts covering diverse mechanisms on many impacted materials that results in many deleterious influences in the built environment. Aqueous environments that influence the surface chemistry on materials affected by microorganisms which results in catastrophic engineering consequences were themes of presentations. Limited efforts were reported for remedial actions in elimination of copper pinhole leaks in building water systems. Understandings of wall attached biofilms structures from research involve varieties of foreign hazardous materials; however, effective elimination of hazards to potable water quality was not a concern. Relevant summaries from studies follow.

Experimentally determined conditions on pitted copper pipes indicates direct relation with biofilm formation and resultant damaging conditions with field test pipe samples (8). Aspects of pitting in copper pipes of three types noted involvement of microorganisms dates back to 1948 (Rogers). Identified conditions with pitting that prevailed include products of metabolism, e.g., anaerobic sulphate reduction, extracellular acids, secretion of organic sulphur containing compounds, ammonia, and 'slimes and microbiological deposits'. Sample bacterial growth measurements were undertaken; predominant organisms isolated and identified characteristics were

determined. Scanning electron microscopy showed association between presence of bacteria and extracellular materials over corrosion surfaces where more active pitting occurred. Apparent susceptibility of organisms to presence of copper ions is known but some resistant populations even exist with associated biofilms having varying tolerances in the states and dissolutions of water systems and active in the corrosion process.

Experimental deterioration investigation of copper corrosion in the presence of extracellular polymers altered the corrosion rate measured five-fold increase in copper corrosion in presence of bacterium (9). Copper from substratum was found to be bound up within the biofilm and not released into solution. The copper-tolerant bacterium on glass slides concentrated the metal ions from solution. Apparent immobilization of the copper ions within the biofilm occurred from the damaging bacterium and accelerated corrosion may be related to presence of exopolymers.

Incidences in a hospital system of copper pipe failures from pinhole leaks were investigated by laboratory failure analyses of damages that were primarily in cold water horizontal pipe sections (10). Local formations of pustels found were comprised of solid corrosion products mixed with crystallized corrosion products. There was a uniform attack detected under the metallic surfaces after applying pickling techniques. Where pustels were noted pitting attacks led to perforations of the copper pipes. Determinations from chemical analyses revealed that prosthetic disaccharides and hydroxol group with serine and lactate could be detected within the corrosion products leading to microorganisms as the reason for corrosion damages. Installation purification of the pipe system was undertaken by circulation of citric acid (at 10 %) overnight and disposed. Few added perforations followed within days presumed to result from stopped up small pits; no further perforations occurred for a year after treatment. After more than a year installed plastic piping (elsewhere) eliminated similar renewal of problems. Positive long term cleaning other than citric acid appears necessary since later examined copper tube samples did show severe attack remains. Test loops for long term studies were set in place.

4. Perspectives and Significance

Focus on wall attached materials and mechanisms involving deteriorated reliability to practices protecting potable water quality were made. The search included water utility sources and plumbing system established requirements for required procedures, methods, or organized elements in specific requirements for potable water. In the U. S. local control authority exists for many water regulatory aspects whereas national governance is practiced elsewhere.

The existing building inventory includes many materials applied to piping systems from impacts of older or newer regulatory requirements. In this survey no in-depth investigations of multitudes of past regulatory locally established requirements were undertaken. Basically, pipe material requirements usually relate to ASTM standards as referenced in plumbing codes; galvanized steel, copper piping and plastics are in accord with standards for such materials. Changes for types of plastic piping materials

and variations have occurred over the past four decades. Pipe sizing modifications by 'water supply fixture units' in plumbing code tabulations have recently taken into account changes for water conservation requirements.

4.1 Required Plumbing Codes and Standards.

The BOCA Basic Plumbing Code/1978 (11) required "new or repaired potable water systems shall be disinfected prior to use whenever required by the authority having jurisdiction". Detailed requirements provide descriptions for the water-chlorine solution method that required contact standing period of minimal three hours with flushing until chlorine does not remain (compared relative to local supply) and followed by bacteriological examination specified by local authority. Sample repetition was required if contamination persisted. No other portents for hazards that could impact such systems or other safe water needs were particularized for clearing the piping system and apparently not considered.

The National Standard Plumbing Code – Illustrated, 1983 (12) Section 10.9 provided for "Disinfection of Potable Water System" The provision indication was "New or repaired potable water systems shall be disinfected prior to use whenever required by the Administrative Authority. The water-chlorine maintained mixture required three hours specified and followed by clearance flushing (with implied sampling). Repetition requirement was made if finding of bacteriological contamination (unspecified method) recurred. No other hazardous conditions were considered or noted.

The American Society of Plumbing Engineers (ASPE) Data Book, 1983-1984 (13) similarly sets requirement in "Cleaning and Disinfection of Domestic Water Supply Systems". There, the specification included added information on mechanical and pump arrangements with needs:

- All outlets during chlorine injection be fully opened at least twice during injection and residual checked with orthotolidin solution at not less than 50 parts per million at all outlets before valve closure. Retention in the piping not less than 24 hours; residual after retention not less than five parts per million (if less, repeat process). Clearance by clean potable water until residual chlorine shall not be greater than incoming supply. For hot and cold water lines at least one sample submittal to an approved laboratory. Acceptance requires results that show absence of coliform organisms (acceptable test method for results under local requirements). Repeat needs specifics define repeated testing as necessary.

The Uniform Plumbing Code (2003) Chapter 6 'Water Supply and Distribution' provides for water supply and distribution requirements for water system testing. (14). Materials allowable are set in Section 604 and added specialty usages in Section 609.3[‡] provides for ferrous piping as well as copper tubing requirements. The piping system (609.4) provisions establish working pressures and other related factors. Other

[‡] Maximum velocities established due to cavitations deterioration Section 601.12

sections detail pipe identifications for rapid recognition and also requirements and provisions for details concerning installations and pipe sizing.

Disinfection of Potable Water System in Section 609.9 for new or repaired potable water systems requires "... shall be disinfected prior to use whenever required by the Authority Having Jurisdiction". The method to be followed shall be that prescribed by the Health Authority; in case no method is prescribed the following applies if no prescribed method exists. Necessary provisions call for:

609.9.1 - The pipe system shall be flushed with clean, potable water until only potable water appears at the points of outlet. 609.9.2 - The system or parts thereof shall be filled with a water-chlorine solution containing at least fifty (50) parts per million of chlorine, and the system or part thereof shall be valved off and allowed to stand for twenty-four (24) hours; or, the system or part thereof shall be filled with a water-chlorine solution containing at least two hundred (200) parts per million of chlorine and allowed to stand for three (3) hours. 609.9.3 - Following the allowed standing time, the system shall be flushed with clean, potable water until the chlorine residual in the water coming from the system does not exceed the chlorine residual in the flushing water. 609.9.4 - The procedure shall be repeated if it is shown by bacteriological examination made by an approved agency that contamination persists in the system.

The International Plumbing Code, Chapter 6, has comparable provisions.

Apparently no elements of information introduce useful or applicable provision(s) beyond coliform analyses. Consequently, concerns for other hazardous remedial detection purposes and alleviations requires other developments for detecting and eliminating multitudes of hazardous materials (viral-bio-radiological). Emerging literature from on-going research and developments for instrumentation measurements of hazardous materials presence in water mains can become sources for new required guides and codes/standards if unclassified open literature is made available. Materials applicable to newly developed guides and criteria for methods and safety levels can be introduced for required analyses and methods embracing biofilms and linked hazards. Laboratory facility selections appear optional currently for local established requirements; seemingly any facility would suffice for analyses of concern. Other concerns arise for higher levels of dangerous substances analyses in specifications for laboratory types that may have to be at protective level three or four.

4.2 Water Utility Requirements

Utility water system qualities for delivery into building plumbing systems have concerns for foreign materials. The reference American Water Works Association (AWWA) Standard C651-05 (revision of C651-99) 'Disinfecting Water Mains' [15] for potable water supply systems (wells included) provides detailed requirements in systems clearance testing. Provisions indicate required conditions for parameters of concern in procedures and testing results. The scope is for disinfection of new construction and system elements in repairs/maintenance that can cause exposure to

contamination. Infectivity sources are not defined or detailed for alerts and necessity for treatment.

Cooperative actions by consortium of interested parties developed the newly revised document; concerns for drinking water additives were relegated to NSF/ANSI 60 “Drinking Water Treatment Chemicals” and NSF/ANSI 61 “Drinking Water System Chemicals”. NSF/ANSI 60 has no provisions for substances not regulated by contaminant levels in US EPA lists for final maximum contaminant level (MAL). Details provide chlorine disinfection, description of the disinfection procedure, preventive and corrective measures during construction, methods of chlorination, final flushing, bacteriological testing, re-disinfection, and final connections to existing mains, disinfection procedures when cutting into or repairing existing mains, and special procedures for caulked tapping sleeves. Details in Appendices indicate descriptive notes on chlorine residual testing, chlorine dosages, and disposal of heavily chlorinated water.

Provisions for applications of additives as liquid chlorine, or solids of sodium hypochlorite or calcium hypochlorite are specific. The end state findings after disinfection of bacteriological quality by a laboratory test are specified. Detailed methods for application of a selected disinfection material are given since modes of applications/usages require differing techniques. Solids require dissolution, need particular placements and times for solutes to form for the intended function. Charts present required flow rates with flushing requirements for various size pipes and hydrant openings to achieve effective system clearance flushing. Constraints on discharges of heavily chlorinated water and potential need for neutralizing outflow during flushing provides for satisfying locally established regulatory controls of such discharges. Other detailed information is provided; e.g., sterile bottles in sampling procedure (*Standard method for Examination of Water and Wastewater*), no presence of coliforms, recording results. Need for added disinfection when failure to achieve clearance specification is established and the requirement for additional treatments until achievement of satisfactory results. No provision(s) for any materials other than coliform are made; determinations if other hazardous materials (viral-bio-radiological) may occur were not established in this conventional consideration.

5. Conclusions and Recommendations

5.1 Consequence

“Uncharacteristic situations” of biofilm concerns have indicated potentials and realistic aspects from fire sprinkler systems investigated deterioration factors. Those imply paradigm potential applications for concerns in damage recovery of varieties of contamination to building water pipe systems with emphasis on formations of attached slimes. Potential hazardous attack efforts that may introduce multitudes of unusual bio-viral-radiological-chemo materials require specific remedial methods for alleviation. A need for establishing response methods based on assured initially rapid detection/measurement methods looms large. Current open literature has not discussed threat recovery techniques for such concerns.

Developing confidence in the basic steps to overcome unusual degradations of potable water quality requires various considerations for isolating, diminishing and eliminating persistence and damaging extension by confirmed prevention methods. Practices and guides for first line defenders in immediacy reactions to hazards, with minimization of damages to water supply systems require intensive undertakings. Initially, potentials from trial studies derived from MIC sources appear as a useful initial step for remediation. Those would establish draft protocols for emergency reactions and practical and useful guides and practices for immediacy needs and follow-on practices. Dislodgement of slime on walls is an important first step in removals of potential lodgment sites for deleterious contaminants' conditions in building water supply systems. Concerns in restoration must include considerations require pipe materials differences considerations; differing techniques are likely needs for copper, galvanized and plastic water supply piping.

5.2 Research Recommendations

Flushing building plumbing potable water supply systems field tests is required by quantifying water necessary for total flushing (soluble materials or wall attached/removable materials). Determinations are important in events that preclude water mains supply and require stored water tank truck volumes. Potentially hazardous materials in flush water may preclude discharge into waste drain sewers. Assessment and determination of methods for collection/treatment and retention of discharges must also be considered. Potential for reverse osmosis separation of hazardous materials and consolidation of residuals in waste outflow for separation in order to nullify hazardous state(s) needs to be addressed.

Determinations of methods specific to different pipe wall materials in restoration actions need to identify capabilities for withstand of treatment recovery techniques. Investigations are required for utilization of excessive chlorine based additives, or utilization of ultra-violet radiation, or materials impacts from abrasive scouring of pipe walls in order to prevent deleterious materials impacts and induce integrity failures. Investigations related to induced destructive impacts requires attention.

Fundamentals of understanding wall attached growths or adhesion parameters by many deleterious foreign materials (and elimination thereof) need to be examined. Exposure conditions evaluations are required for the susceptibility of all elements that comprise piped building systems, controls/fixtures, appliances and hot water tanks, and water heaters needs to be evaluated. Recovery practices, or simply need for replacement decisions, require study so that response guides provisions (for local published municipal information/procedures) can be prepared for applications by first line responders and local officials.

Fundamental investigations are required on mixtures of flows with solutes and particles or contaminants. Governing laws on wall deposition growths, chemo-kinetics and dynamic time dependencies for chemo-bio rate equations of substances and materials in the water flow need to be determined. Radial dependencies on

diffusion rates must be applied since cylindrical coordinate areas in flow actualities vary inversely with radial distances. Consequently, transport phenomena of species in the flow have altered concentrations of chemical materials and bio-species (peripheral areas increase linearly toward wall surfaces) and govern reaction kinetics and diffusion/transport to/from wall surfaces. Surface tension relations to wall attachment mechanisms and understanding adhesion or release of materials must be developed. Adaptations of computer methods (commercially available methods from aero-space rocket combustion investigations) can apply but require species and mixtures of constituents for these concerns.

Analyses of attachment and release processes at pipe wall surfaces, and/or substrates, requires input from dynamic reaction kinetics with formulations for chemical-bio-flow processes. Examination of details of material compounds at, and within, wall cavities or porous substrates in flows and sub layers on wall locations are necessary. Impacts from introduction of materials, such as surfactants and biocides, which result in foreign materials interactions, require experimental research and advancing applications from fundamentals of theory. Experimental evaluations for many type materials to establish neutralization, removal or extracting hazardous substances must be undertaken.

5.3 Conclusions

Applicable problem sectors were reviewed that relate issues concerning quality assurance of potable water supply in buildings and/or reducing impacts from disruption of water potable qualities. Most aspects of concern were significance of understanding of detection and determinations for compositions/constituents of biofilms and attachment mechanisms/formations that impact on the integrity the piping materials or potentials for water contamination.

Microbial Induced Corrosion (MIC) in wet fire sprinkler systems provided the greatest sources of information and remedial commercial practices for elimination of intrusive films on piping materials. Potable water protection and testing from plumbing codes and standards were inapplicable to specifics and analyses beyond coliform determinations. Water utility supply pipe clearance requirements did not extend plumbing practices but offered more details.

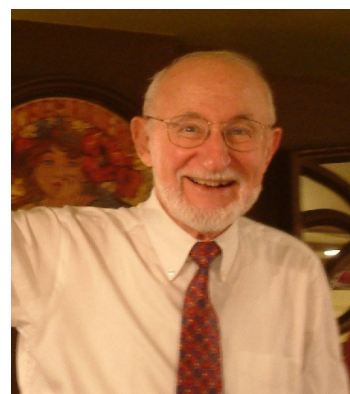
Paramount need for methods of recovery by elimination of deposits in the pipe system from terror type contaminants or naturally occurring biofilms may be advanced from comparable investigative results. Techniques applied for detection and elimination of MIC system degradation sources and deterioration of potable water quality has potentials for extension. Indicated methods for systems renovation may be applicable to building potable water piping restorations and other benefits from research already undertaken.

6. References

1. 'Center for Biofilm Engineering' Bozeman Biofilm National Center, United States Information, Montana State University, Bozeman, Montana
2. Correc, O., Derrien, F., Diab, Y., An Original Tool to Investigate Drinking Water Distribution System, CIB W62 Water Supply and Drainage for Buildings Symposium Sept. 14-16, 2005 Brussels, Belgium
3. National Association for Fire Prevention NFPA, Series 13 Standards (various dates)
4. State of Maryland Final report: Task Force to Study pinhole Leaks in Copper Piping, Dec. 2004, Annapolis, MD
5. Practical Guide to Diagnosis & Mitigation of Microbiologically Influenced Corrosion (MIC) in Fire Protection Systems. BTI, 2005
6. Denver airport corrections
7. Dowling, N. J., Mittelman, m. W., Danke, C. D., Editors, Conference Proceedings on Microbially Induced Corrosion and Deterioration, The University of Tennessee, Knoxville, GA., October 7-12. 1990
8. Chamberlain, A. H., L., Angell, P., Influences of Microorganisms on Pitting of Copper Tube (see {13}, pp 3-65-71)
9. Wagner, P. A., Little, B.J., Microbiologically Influenced Corrosion in the presence of a Copper Tolerant Bacterium, (see {13} pp8-13-15)
10. Fischer, W., Paradies, H. H., Hänsel, Copper Deterioration a Water Distribution System of a County Hospital in Germany Caused by Microbial Induced Corrosion, (see {13}, pp 8-47-48)
11. ASPE Data Book 1983-84, Volume 1 Fundamentals of Plumbing Design, American Society of Plumbing Engineers, Sherman Oaks, CA. (currently - Chicago, IL)
12. Uniform Plumbing Code, IASPMO/ANSI UPC 1-2003, International Association of Plumbing, and Mechanical Officials, Ontario, CA
13. BOCA BASIC PLUMBING CODE 1978, Fourth Edition, Building officials and Code Administrators International, Inc., Chicago, IL
14. National Standard Plumbing Code, Illustrated, National Association of plumbing-Heating Cooling Contractors, Washington, D.C.
15. IAPMO/ANSI UPC 1-2003 Uniform plumbing Code, Twenty-Third Edition, Seventh printing Nov. 2005, Philadelphia Street, Ontario, CA
16. AWWAC651-05 Disinfecting Water Mains American Water Works Association, 01-Jun-2005 36 pages

6. Author

Dr. Lawrence Galowin, consultant, experienced at National Institute of Standards and Technology (NIST) as leader in plumbing research. He is now a Guest Researcher. Consultant - desalination developments based on wave energy pumping for RO methods; potable water relief to worldwide sites by Slow Sand Filtering - performance parameters research.



Sanitary water Systems Diagnosis

F. Derrien,

derrien@cstb.fr

Dep. Hydraulics and Sanitary Equipment, CSTB, France

Abstract

Like any living organism, a sanitary water system is subject to ageing or may suffer diseases. These diseases are mainly corrosion, scaling and/or bacterial growth. Ageing may also make them obsolete, for example not able to achieve a correct flow rate or a sufficient temperature. The evolution of regulations can also oblige to adapt them totally or some parts of them. Water saving measures can also induce modifications. Therefore bodies responsible for these systems are faced to their responsibilities, and obliged to consider the possibility of having system diagnosis in order to know in which condition their systems are, and to be able to plan modifications. Furthermore, a diagnosis, to be credible and inspire the building actors with confidence shall be carried out according to certain requirements, even be certified.

This paper presents a description of different possible diagnosis, on the basis of prescriptions established in order to grant a certification to diagnosis actors. Different levels are considered, from the simple one, being just an identification of some materials like lead or drafting installation diagrams, to most elaborated ones in one or different fields, becoming specialised expertise. The compatibility of the systems with existing regulations, or standards, or technical rules is taken into account. The different topics are backflow prevention, risk of burns, corrosion, scaling, bacterial growth, water saving and energy saving. Amongst considered parameters are the technical skill and also the relationship between the diagnosis actor and the person responsible of the system. At expert level, the evaluation also deals with the way how advice is given or improvement is proposed.

Keywords

Water system, diagnosis, certification

1 Introduction : the necessity of water diagnosis in water distribution systems

The pathologies in buildings caused by water distribution systems, like corrosion and scaling have been studied since many years, and the solution adopted in most cases was to apply water treatments. Today, in front of non constant water qualities, or more severe sanitary and comfort requirements, or in search of installation and maintenance lower costs, systems have to be adapted, and improved. In order to direct correctly the operations and to make them profitable, an inspection, a diagnosis or an expertise proposing solutions are necessary.



Figure 1 – A sanitary water installation

2 The different diagnosis fields

It could appear logical to distinguish between several fields within water systems analysis. This enables to propose different levels for diagnosis services, according to the importance of the building into consideration (health establishment, or aged people hostel) or the severity of existing problems. It is necessary, however, not to compartmentalise this activity, because the different aspects are bound together and can react between themselves. There is no better example than the legionella diagnosis which will obligatorily pass through a hydraulic diagnosis of the system, because so important the flow and temperature conditions are for the biofilm and bacteria development.

The classification, hereafter described, is issued from an analysis realised by collecting data from many investigations made in situ, and from a theoretical study on water system pathologies. Our experience also shows that the diagnosis actors are sometimes led to carry out diagnosis in different fields simultaneously, which oblige them to have other skills than those for which they have been called for.

2.1 At the basis of each diagnosis : inspection, conformity with antipollution regulation

At the basis of each diagnosis, there is an essential minimum, necessary to establish the system identity : this is the technical identification of the system, from its point of entry up to the more penalised point of use. This job includes a layout of the following data from the system itself and from schemes, and concerning :

- the tubes
- the taps and protection systems (valves and backflow preventers),
- hot water preparation system,
- water conditioning equipments, and others like pumps,
- parameters like temperature and pressure,
- heat insulation,
- water analysis.

For each of these elements, a basic diagnosis shall include :

- a description,
- the verification of conformity to standards and certification,
- the list of materials used,
- the layout of dimensions, figures, values, characteristics
- the description of the general condition of the system, disfunctioning, observation of inspection sections if any.

2.2 Technical diagnosis : hydraulics, corrosion and scaling

Compared with the basic diagnosis, this action, leading to an evaluation of risks and a proposition of corrective actions, is at the level of an expertise. In addition to those listed here above, the following hydraulic elements are taken into account :

- pumps and boosters,
- equilibrating valves,

with, for each of these elements, in addition to the performance levels, the position of regulation systems (valves, pump regulators).

It will result :

- the establishment of one or several diagrams and/or descriptive schemes of the installation,
- the listing of different data (temperature, pressure and flow rates, water analysis, consumption and operation history, observation and analysis of materials, description of any disfunctioning, water conditioning system state),

This leads to a synthesis and a risk evaluation based on :

- hydraulic parameters (stagnation, dead legs, flow inversion, water hammers, cavitation),
- materials (characterisation of corrosion and scaling condition of the system, analysis of corrosion products, evaluation of commissioning),
- water quality (determination of its characteristics from water analysis parameters, its compatibility with materials, its nature in terms of scaling possibilities),
- water conditioning characteristics (estimation of its compatibility with the materials and water parameters, its necessity and the quality of realisation),
- data describing a misuse of the system (bad maintenance, some parts out of order).

The diagnosis shall then lead to the proposition of corrective actions, having in mind the concern to take into account regulations, standards, technical guides and state of the art :

- hydraulical : prescription of equilibrating valves, new dimensioning of various elements (pumps, boosters),
- materials : proposition of new materials or replacement products, prescription of actions to increase the security of the system or avoid future repairs, often expensive,
- water quality : determine the origin of the non conformity,
- water conditioning : installation and ajustement of equipments,
- whole system : check the logbook or create it if non existing.



Figure 2 – Uniform corrosion of galvanized pipe

2.3 Water and energy saving diagnosis

In the frame of a sustainable development logic, this action, always as an addition to the basic diagnosis, deals with the :

- history of water consumptions,
- disfunctioning of the system, especially leakages.

This results in the following actions :

- anlysis of water and energy consumptions,
- study of invoices and lists,
- identification of weak points (energy losses, leakages, non insulation of pipes, oversizing),
- study of heat production,
- study of heat distribution,

This will lead to a :

- comparison with ratio models,
- detection of abnormal points in the various contracts and invoices,

The diagnosis will propose corrective actions, with the concern of taking into account regulations, standards, technical guides and state of the art :

- prescription of urgent operations in case of leakages or important disequilibrium,
- proposition of introduction of more efficient managing,
- installation of water saving systems,
- new dimensioning of equipments,
- proposition of alternative solutions (solar systems, water reuse)
- installation of equipments for limiting enrgy losses.

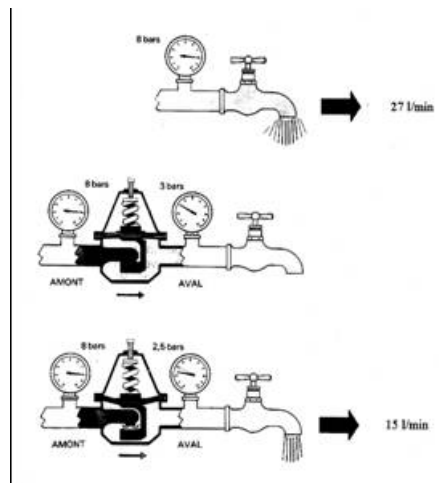


Figure 3 – Example of water saving system : pressure reduction system

2.4 Sanitary risk diagnosis : burns, legionella, lead

This expertise action is based on the same principles as technical expertise, according to the importance of the system functioning on the bacterial growth. It integrates, in addition to the technical audits of the systems :

- temperature, pressure and flow rate measurements,
- water analysis, in particular research of legionella, and conformity to sanitary requirements,
- a discussion with users and managers
- lead identification (for example, using standard NF P 41-021).

The diagnosis shall be followed by a synthesis and risk evaluation in relation to :

- materials (lead for example),
- burns,
- legionella development. This specific risk will be based on intervention forms (disinfection), on the results of bacterial analyses, on the investigation of materials used, on the estimation of scaling or corrosion condition of the system and of its design (example dead legs), and on sanitary hot water temperature,
- the functioning of water conditioning equipments,
- the hydraulic functioning of the system itself.

As it is for other expertises, it will be proposed corrective actions concerning :

- the presence of lead : indication of system parts to be treated, proposition to use other materials or products, definition of urgency,
- burns : proposition of sytem modifications (diagram, equipements, urgency),
- legionella : procédure of maintenance and disinfection, proposition to put in conformity the system according to the state of the art (standards, regulations), improvement of the hydraulic functioning of the system.



Figure 4 – Lead pipe in a house system

3 Diagnosis certification

3.1 The needs for certification

The important necessity of diagnosis results in the arrival on the market, besides historical actors, of a great quantity of participants which neither notoriety nor competencies are known. It is then necessary to ask to a third body, himself accredited, to proceed to companies certification, in order to check if their skills are in conformity to their claim in the field of application and if the diagnoses they realise are in conformity to known systems of reference and to standards if they exist.

In addition, the certification will put forward a skill record as well as overlapping risks from one activity to the other, without having the adequate skill.

3.2 Certification structure

The REEX (Réseau d'Eau Expertise) certification evaluates the skill of an entity to proceed to a good diagnosis of a water system in a building. In order to answer the question of distinguishing several levels of skill and different fields of application, the certification has been structured as follows :

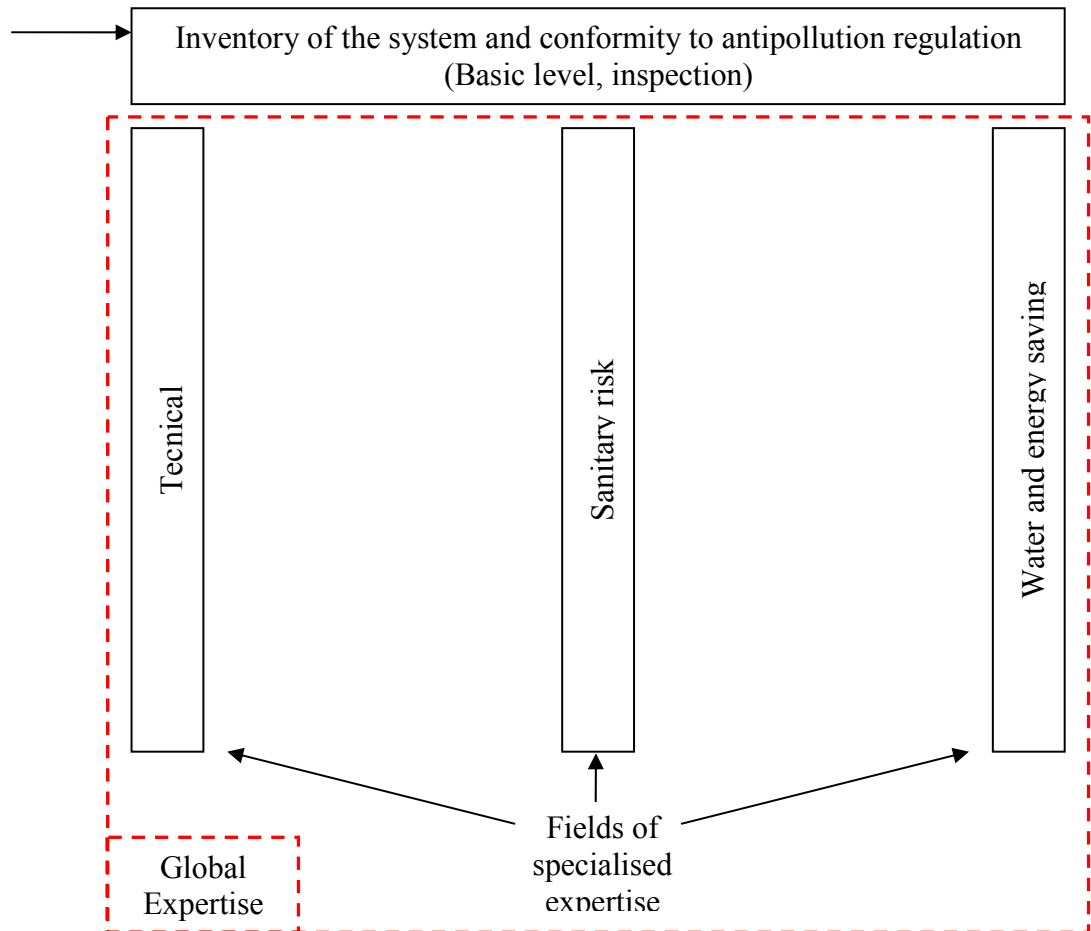


Figure 5 – Certification structure

The level "inspection" corresponds to the basic work of all diagnosis. The different expertise levels can be specialised in one of the three different fields that are identified or be merged in the global expertise. Each certification level authorises to get a certificate. Only global expertise permits the use of the REEX logo.



Figure 6 – Certification logo

3.4 Common points to certified diagnosis actors

REEX certification integrates also the following requirements, being simultaneously a matter of service providers and technical expert. They are :

- welcome and reception skills,
- the ability to answer clearly to requests, and to make out a contract proposition,
- the quality of the initial technical study,
- the conformity of analysis and technical synthesis,
- the redaction of the inspection and of the resulting recommendations.

4 Conclusions

Diagnosis actions find more and more a place in the field of water systems in buildings. Not yet well formalised until last years, they have permitted an improvement of knowledge in different technical sectors. The necessity of knowing better how the water systems function and the strong demand from dealers has led to the creation of a certification based on the evaluation of diagnosis actors. The certification rules and requirements have been written with the concerned professionals.

5 References

1. O. Correc, F Derrien, Y Diab. *Développement d'une méthode de diagnostic des installations de distribution d'eau dans les bâtiments*. Revue française de génie civil, 2003, vol 7, n°1/2003
2. F. Derrien. *Solutions for reducing lead content in potable waters*. CIB W62 2002 28th International Symposium, 18-19 September 2002, Iasi, Romania.
3. B. de Gouvello, G. Bazar, F. Derrien, *Collecting and reusing rain water in buildings for collective use. The French situation*, First American Rainwater Harvesting Conference, 21-23 juin, Austin (Texas), USA.
4. O. Correc, F. Derrien, Y Diab . *Development of a tool for predicting the risk of degradations in water supply installations inside buildings* . Eurocorr'2004 . Long Term Prediction and Modelling of Corrosion . Nice. Septembre 2004.
5. F. Derrien, F. Bellenger, O. Correc . *The need for certification in the field of water distribution systems*. CIB W062 2004. 30th International Symposium. September 16-17, 2004. Paris.
6. O. Correc, F. Derrien, Y. Diab. *Degradation Risk Assessment in Drinking Water Distribution Systems*. CIB W062 2004. 30th International Symposium. September 16-17, 2004. Paris.

7. N. Couillaud, F. Bellenger, P. Riederer. *Analysis and optimisation of hydronic networks in buildings*, 2nd workshop Matlab/Simulink for Building simulation, CSTB, Paris, 14/15 October 2004.
8. F. Derrien : *Comment prémunir ses réseaux contre les risques de légionelles ?* . Salon des Maires de France, 19 novembre 2003.
9. F. Derrien . *Les réseaux d'eau chaude sanitaire, conception, maintenance*. Colloque ISPAIA, Gérer le risque légionelles, Ploufragan, 18 novembre 2004.
10. A. Mienné . *Entretien des réseaux de distribution, gestion du risque légionelles*. Colloque ISPAIA, Gérer le risque légionelles, Ploufragan, 18 novembre 2004.
11. O. Correc, F. Derrien, Y. Diab. *An original tool to investigate drinking water distribution system*. CIB W062 2005. 31st International Symposium. September 14-16, 2005. Brussels.

6 Author presentation

Francois Derrien is working at Centre Scientifique et Technique du Bâtiment (France) in the department Hydraulics and Sanitary Equipment where he is responsible for Research and Development. He is specialised in corrosion and behaviour of materials in contact with water.



Modeling system demands for domestic flushing in residential buildings

K. W. Mui (1), L. T. Wong (2),

(1) behorace@polyu.edu.hk

(2) beltw@polyu.edu.hk

Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China.

Abstract

Domestic flushing water demands are transient and influenced by occupant load variations as well as appliance usage patterns. For proper planning of flushing water supply and treatment plant facilities in Hong Kong, this study proposes a mathematical model to describe the flushing water demands for high-rise residential buildings. The model parameters were identified from a recent survey on the WC usage patterns of occupants in 14 high-rise residential buildings of Hong Kong. The occupant load factor, diurnal variation of flushing, discharge and refilling durations and volume of WC cisterns recorded from 597 households were used to determine the uncertainties of the system demands and the risks of overloading the flushing water plant. The model predictions were compared with field measurements from typical residential buildings in Hong Kong. Uncertainties due to appliance usage patterns, occupant load variations and discharges to the drainage system were also demonstrated, it was found that the user demand contributed significantly to the uncertainties. The output of this study provides a template in developing a demand model for the flushing water system design of high-rise residential buildings. Together with the consideration of the associated risks of plant overloading, the model would be useful for calculating the capacity of a flushing water plant.

Keywords

Flushing water system, design flow rate, residential buildings

1 Introduction

Toilet flushing has been identified as one of the key issues in sustainable water system designs for buildings as it could be the single activity contributing to the highest water consumption in domestic applications, about 30-40% of the public water supply is used

to carry foul waste from toilets [1, 2]. For a practical water plant design with a balance between construction and operation costs, the risk of overloading the plant shall be considered regarding the probable maximum water flow rates [3].

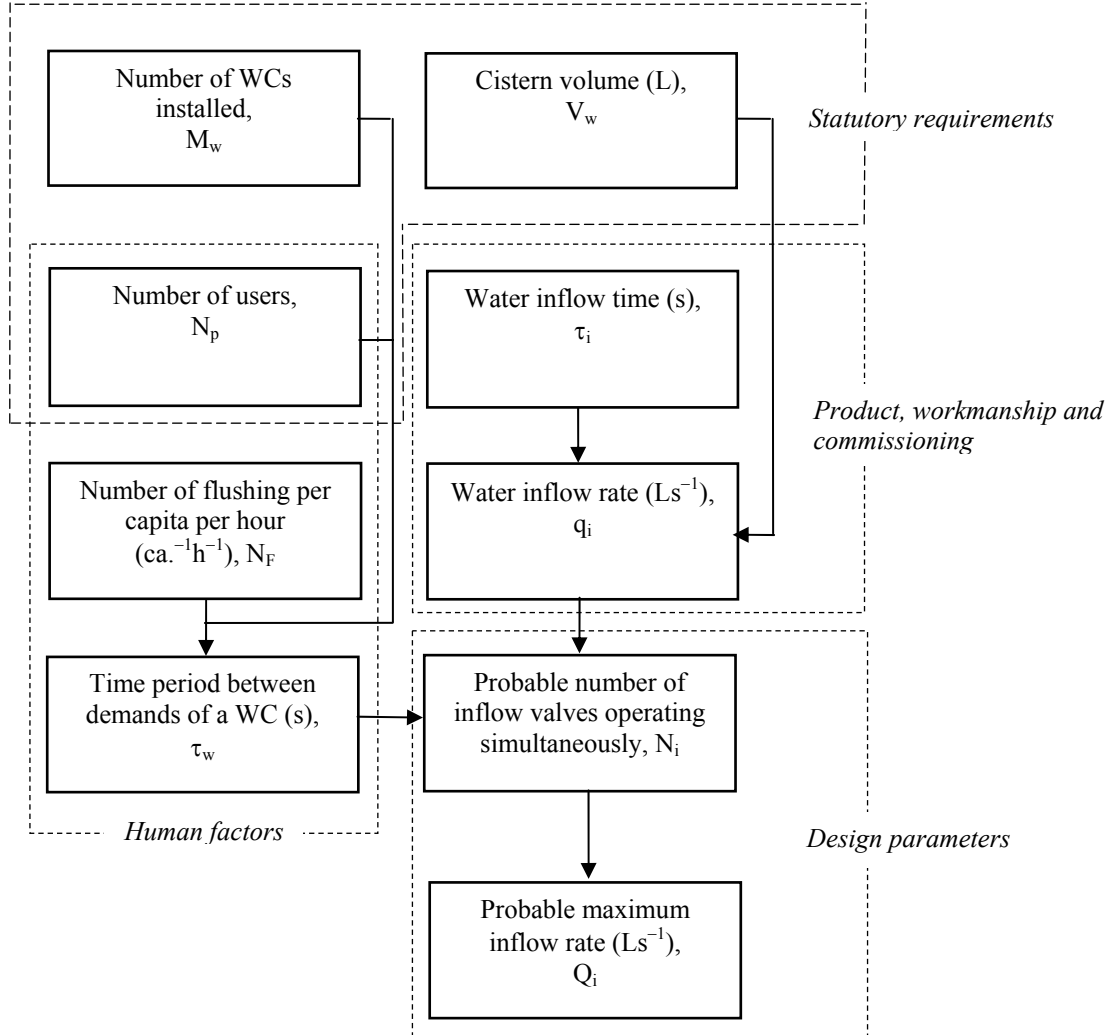


Figure 1: Dependence of model parameters

The transient flow rates of a flushing water system are dependent on a wide range of factors including climate, culture, economy, appliance installation, individual demands, occupant age and gender [4-6]. Indeed, variations of the estimated probable maximum flow rates in different design approaches are significant. For a system consisting of 100 WCs each installed with a low level cistern of 9 L volume, the probable maximum flushing water supply flow rate varies from 1 to 4 L s⁻¹ while the probable maximum discharge flow rate is from 3 to 7 L s⁻¹ [4-6].

Traditionally, the probable maximum flow rates are determined by the probability theory at an allowable failure rate, i.e. the plant could be overloaded in certain period of time [5-9]. Apart from the macroscopic regional variations of consumption and

appliance flow rates, variations due to end users such as individual demands, occupant load and behavioral changes will all lead to uncertainties of the model parameters for these flow rates [10, 11].

This study investigates the flushing water demands for high-rise residential buildings in Hong Kong and a mathematical model is proposed for flushing water supply and treatment plant facilities. A recent survey on domestic WC usage patterns in 14 high-rise residential buildings of Hong Kong was used to identify the model parameters [12-15]. The uncertainties due to appliance usage patterns, occupant load variations and discharges to the drainage system were also studied.

2 Probable maximum demands

Figure 1 shows the design parameters, composed of the statutory requirements, human factors, and appliance installation, used in determining the probable maximum flow rates for a number of WC cisterns in simultaneous operations. Probabilistic approach was used to study the simultaneous operations from a group of sanitary appliances for plumbing and drainage systems [5-9].

Suppose a WC cistern would draw flushing water repeatedly on demand, the probability of the cistern valve in operation p_i is,

$$p_i = \frac{\tau_i}{\tau_w} \quad \dots (1)$$

The operating time of filling up the cistern τ_i (s) would be related to the product design, appliance installation workmanship and settings. And the mean time interval between two flushing discharges τ_w (s) would be related to the user demand patterns expressed by the hourly demands per capita N_F ($\text{ca.}^{-1}\text{h}^{-1}$).

The total number of WC operations in an hour is $N_F N_p$ as follows, where the design number of users N_p (ca.) is determined by the floor area A_f (m^2) and the occupant load factor O_{lf} ($\text{m}^2\text{ca.}^{-1}$) or the occupant-area ratio O_a (ca.m^{-2}) [15].

$$\tau_w = \left(\frac{3600}{N_F N_p} \right); N_p = \frac{A_f}{O_{lf}} = O_a A_f \quad \dots (2)$$

For the nominal provision of one WC allowing up to 8 occupants ($N_{pn} = 8$) with a nominal occupant load factor O_{lfn} of $9 \text{ m}^2\text{ca.}^{-1}$, the nominal occupant load would be $N_p = A_f / O_{lfn} = A_f / 9$ and the number of WCs required for a residential building would be $N_w = N_p / N_{pn} = A_f / 72$ [15].

Assuming the appliance operations are binomially distributed, the probability of N out of M identical appliances operating would be given by the following, where $(1-p)$ is the probability of the appliances not operating and C_N^M is the binomial coefficient,

$${}_M P_N = C_N^M p^N (1-p)^{M-N} ; C_N^M = \frac{M!}{N! (M-N)!} \quad \dots (3)$$

In some engineering applications, a system would be designed for a maximum acceptable failure rate in order to minimize the cost and only N (out of M) installed appliances would be allowed to operate simultaneously. Whenever more than N appliances are operating, the system would be considered a ‘failure’ and the failure rate λ at that instant can be determined by the sum of the probabilities (i.e. the proportion of time) of $N + 1$ up to M outlets operating simultaneously.

$$\lambda = P(N+1) + P(N+2) + \dots + P(M-1) + P(M) = \sum_{j=N+1}^M P(j); N < M \quad \dots (4)$$

In a system with M identical appliances installed, the probable maximum number of appliances N operating simultaneously at an allowable failure rate λ could be approximated by a normal distribution [5-7], where p is the probability of simultaneous operation for an appliance, and z is the number of standard deviations σ from the mean that will result in the least value of N not exceeding the λ set.

$$N = Mp + z\sigma ; \sigma = \sqrt{Mp(1-p)} \quad \dots (5)$$

For $\lambda = 1\%$, the corresponding value of z is 2.33. It is suggested $z = 2.5$ is a ‘safer’ choice in practice because the normal approximation of N would be underestimated in small systems, e.g. $M < 30$ [5, 11, 12]. Apart from the normal distribution approximation, Equation (4) could be approximated by the Sterling’s formula to yield a result with an error function [5, 11, 12],

$$\sum_{Mp-z}^{Mp+z} P = \text{erf} \left[\frac{z}{\sqrt{2Mp(1-p)}} \right] \quad \dots (6)$$

For the ‘acceptable’ failure rate set at 1% [5, 11, 12],

$$N = Mp + 1.8\sqrt{2Mp(1-p)} = Mp + 2.55\sigma \quad \dots (7)$$

The average water inflow rate q_i (Ls^{-1}) of the WC cistern with a volume V_w (L) would be determined by the time of filling it up τ_i (s),

$$q_i = \frac{V_w}{\tau_i} \quad \dots (8)$$

At the particular risk of overflowing/overloading the system, equipment for M WC cisterns can be sized to cater for the probable maximum inflow rate Q_i (Ls^{-1}), where P_{wi} is the probability of the system having simultaneous inflow operations [11],

$$Q_i = q_i MP_{wi}; P_w = N/M \quad \dots (9)$$

As shown in Figure 1, the values chosen for the parameters related to human factors, i.e. O_{lf} , N_p , N_f , and related to appliance installation, i.e. τ_i , and q_i , would affect the probable maximum flow rates and water consumption significantly. The choice of these parameters at different confidence levels α of certain ‘allowable failure rate’ for some engineering system designs and the linked uncertainties of the estimations are concerns of the system designers.

3 Review of survey studies

A total of 1300 households in 14 typical high-rise residential buildings (38-42 floors and up to 150 m above ground) in Hong Kong were randomly picked [12-14]. The buildings were selected based on various geometrical locations, building ages and architectural designs to study the usage patterns of different flushing water systems. Invitation letters were sent to introduce the study objectives, the survey period and details through the estate management offices. Representatives of 597 households participated in a face-to-face interview survey in their respective apartments. During the interview, they were asked to provide information of the usage patterns on the day prior to the interview, and the hourly usage patterns on weekdays, weekends and holidays. For each installed appliance, the discharge time, refilling time and average usage time were measured and its type, physical size and brand name were recorded. Finally, the hourly water consumption, occupant load factors and hourly occupant load profiles of two of the selected buildings were recorded for model verifications.

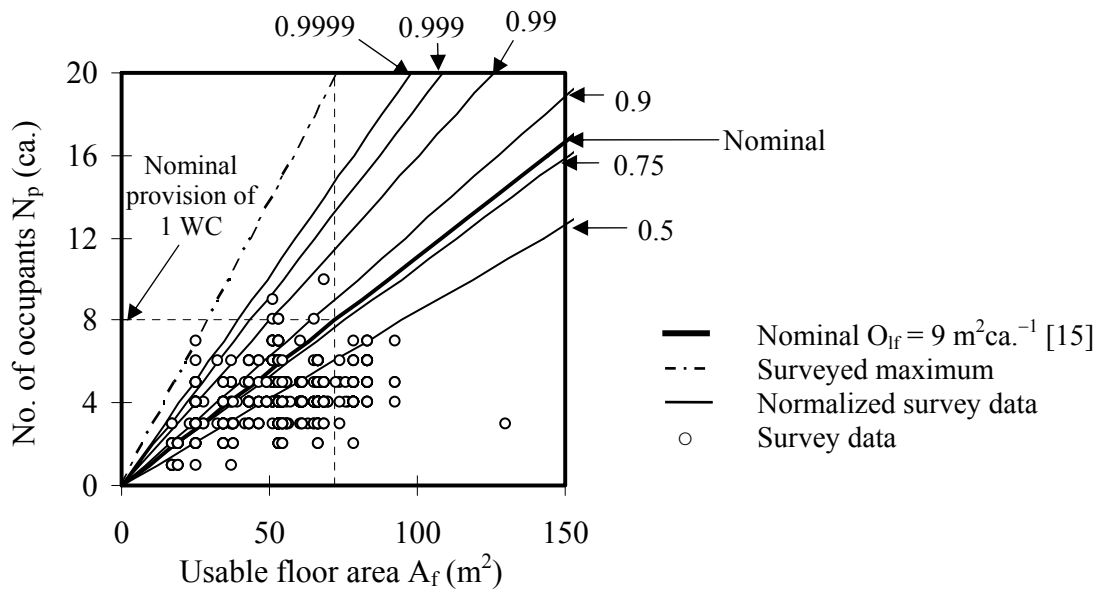


Figure 2: Occupant load factors of high-rise residential buildings in Hong Kong

The surveyed occupant-area ratios O_a (ca.m^{-2}) were normally distributed. Confidence levels α of O_a were determined and the corresponding O_{lf} were calculated and shown in Figure 2. It was found that the result of O_{lf} at $\alpha = 0.75$ was very close to the nominal value of $9 \text{ m}^2\text{ca.}^{-1}$. To illustrate the maximum number of occupants served by a WC (i.e. the design O_{lf} for local residential buildings), a horizontal dotted line is shown at $N_p = 8$ [15]. The probable number of users at various confidence levels of the survey results for the nominal provision is also shown in the figure by a vertically extended dotted line.

In the study, the actual diurnal WC usage patterns of some respondents on a weekday were also recorded and compared with the surveyed patterns. There was no significant difference between the recorded and the surveyed hourly demands per capita ($p > 0.05$). Table 1 shows the results of the hourly demands per capita for flushing a WC. Comparing with the results obtained from some cities by Friedler et al. [2] and Webster [7], a higher demand was found in this study.

Table 1: Hourly demands per capita for flushing a WC, N_F ($\text{ca.}^{-1}\text{h}^{-1}$)

Sample / Source	⁺ Webster [7]	⁺ Friedler <i>et al.</i> [2]	⁺ This study	[*] Wong and Mui [12-14]
Sample maximum, N_{Fx}	0.32	0.52	0.875	2
Sample mean, μ_{NF}	0.10	0.17-0.20	0.275	0.48
Standard deviation, σ_{NF}	0.09	0.12	0.13	0.26
Sample size (persons), N_s	79	76	85	597

* Interview survey; ⁺ Field observation

A sample experiment followed to verify the creditability of the demand patterns surveyed. It was found that the control valve of some WC cisterns was adjusted to a relatively low flow rate that yielded a long ‘tail’ of the frequency distribution for inflow time τ_i (s). A log-normal distribution was used to describe the cistern inflow time. The sample maximum average inflow rate found was 0.75 Ls^{-1} while the surveyed average was 0.1 Ls^{-1} . The results were consistent with the design values used in some design guides [4-6].

The model parameters O_a , N_F , τ_i , and ϕ_t obtained from the survey results are summarized in Table 2.

Table 2: Model parameters

Model parameter [12-14]	Mean, μ	Standard deviation, σ
Occupant-area ratio, O_a (ca.m^{-2})	0.084	0.032
No. of flushing per capita per hour, $\log_e N_F$ ($\text{ca.}^{-1}\text{h}^{-1}$)	- 1.130	0.600
Inflow time, $\log_e \tau_i$ (s)	4.500	0.550
Occupant load daily variation factor, ϕ_t	0.785	0.125

4 Risk of plant overloading

In order to illustrate the influences of the uncertainties, a high-rise residential building of 40 floors with a flushing water system serving all WCs was chosen as the base case. There were 20 WCs on each floor giving a total of 800 WCs in the system. Capacities of the upstream equipment supplying the flushing water were designed for the probable maximum inflow rate Q_i .

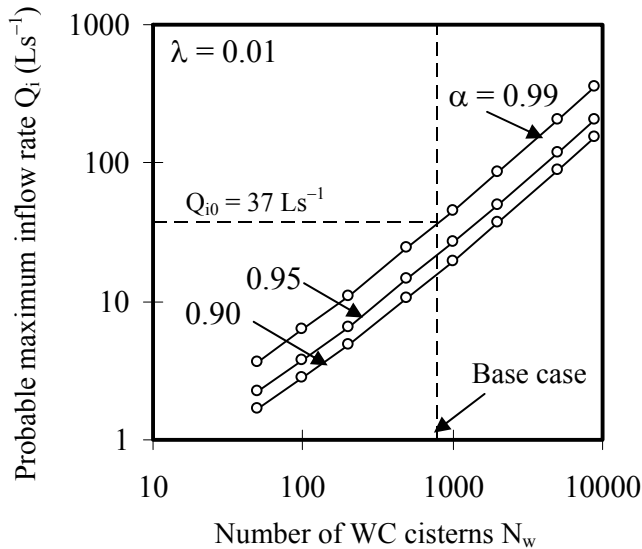


Figure 3: Probable maximum flow rates for a flushing water supply system

Figure 3 shows the probable maximum inflow rates due to a number of WCs with an allowable failure rate $\lambda = 0.01$ at significance levels $\alpha = 0.9, 0.95$ and 0.99 . The base case flushing water inflow rate Q_{i0} was determined and indicated as well.

The probable failure rates of overloading the water supply plant (i.e. the periods of time when the system flow rate is exceeding the capacity of the plant) at certain design inflow rates normalized by the base case design flow rates Q_{i0} (37 Ls^{-1}) are shown in Figure 4. As expected, a higher capacity of the plant would result in a lower risk of overloading.

The failure rate is subject to the uncertainties of the choice of input parameters. In this study, the design parameters chosen were inflow rate q_i (Ls^{-1}), occupant-area ratio O_a (ca.m^{-2}) and the number of hourly flushing by an occupant N_F ($\text{ca.}^{-1}\text{h}^{-1}$). To illustrate their relative influences on the system, their uncertainties at confidence levels $\alpha = 0.5, 0.75, 0.9, 0.95$ and 0.99 are shown in Figure 4. When the mean values of the design parameters (i.e. at $\alpha = 0.5$) were taken, the current design practice (i.e. the base case) was found leading to a design with the claimed allowable failure rate $\lambda = 0.01$. As shown in Figure 4(d), a higher risk of plant overloading will be expected if all uncertainties of the design parameters are considered.

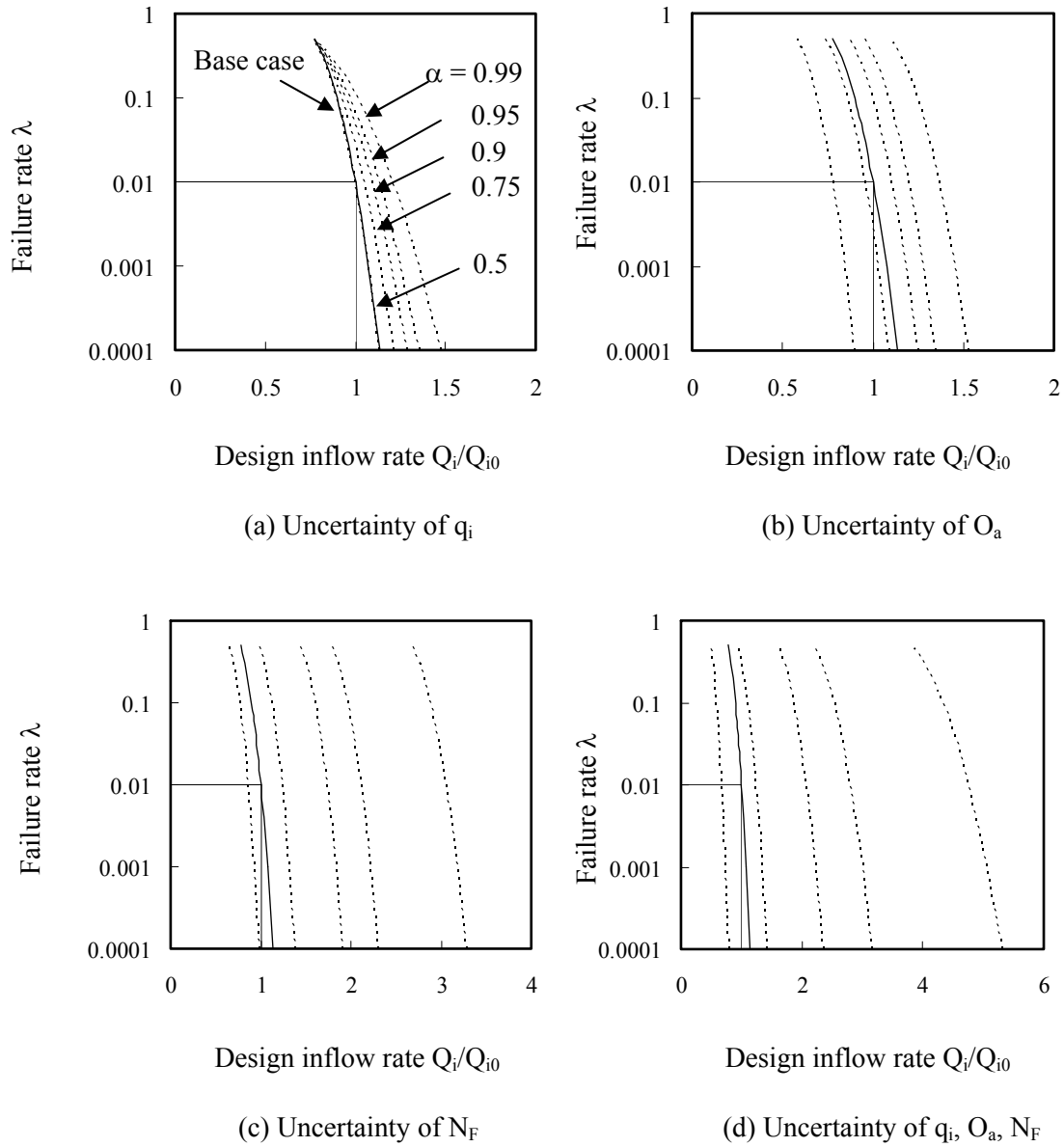


Figure 4: Failure rates of upstream flushing water plant at different design inflow rates

Variations S of the design flow rate at failure rate $\lambda = 0.01$ as given below, where Q (Ls^{-1}) is the design flow rate and Q_0 (Ls^{-1}) is the base case design flow rate, would be used to indicate the sensitivities of the design parameter uncertainties. For the upstream equipment of the base case building, the variations S due to the design flow rate q_i , occupant-area ratio O_a and number of flushing per capita per hour N_F are 0.49, 0.48 and 1.65 respectively.

$$S = \left(\frac{Q_{\alpha=0.99} - Q_{\alpha=0.5}}{Q_0} \right)_{\lambda=0.01} \quad \dots (10)$$

5 Conclusion

For the assessment of the flushing water supply plant capacity for large residential developments, this study proposes a domestic flushing water demand model regarding the probable maximum flow rates from a number of WCs. A field survey of 14 residential buildings in Hong Kong with 597 households was conducted and the results were used to quantify the model parameters at various confidence levels for local residential buildings. The model was applied to assess the risk of overloading a flushing water supply plant due to the variations of user behavior, appliance designs and installation. It was reported that user demands contributed greatly to the uncertainties of the risk while appliance flow rates did less significantly. The proposed model will be useful for urban planning for flushing water facilities and water treatment in cities of high dense environment similar to Hong Kong.

6 Acknowledgement

The work described in this paper was partly supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. PolyU 5305/06E).

7 References

1. Lazarova V., Hills S. and Birks R., (2003). Using recycled water for non-potable, urban uses: a review with particular reference to toilet flushing, *Water Science and Technology: Water Supply*, Vol. 3, No. 4, pp. 69-77.
2. Friedler E., Butler D. and Brown D. M., (1996). Domestic WC usage patterns, *Building and Environment*, Vol. 31, No. 4, pp. 385-392.
3. Fewkes A. and Ferris S. A., (1982). The recycling of domestic waste water – a study of the factors influencing the storage capacity and the simulation of the usage patterns, *Building and Environment*, Vol. 17, No. 3, pp. 209-216.
4. Laws of Hong Kong, Chapter 123I Building (standards of sanitary fitments, plumbing, drainage works and latrines) regulations (1997).
5. Plumbing services design guide, The Institute of Plumbing, Essex, UK (2002).
6. Hunter R. B., (1940). Methods of estimating loads in plumbing systems, Report BMS65, National Bureau of Standards, Washington.
7. Webster C. J. D., (1972). An investigation of the use of water outlets in multi-storey flats, Proceedings of the symposium on water demand in buildings (CIB commission W62), 19-20 September, Building Research Establishment, Watford, UK.

8. Swaffield J. A. and Galowin J. S., (1992). The engineered design of building drainage systems, Ashgate, Cambridge.
9. Wise A. F. E. and Swaffield J. A., (2002). Water, sanitary and waste services for buildings, 5th Ed., Butterworth Heinemann, London.
10. Friedler E. and Butler D., (1996). Quantifying the inherent uncertainty in the quantity and quality of domestic wastewater, Water Science and Technology, Vol. 33, No. 2, pp. 65-78.
11. Wong L. T. and Mui K. W., (2006). Modeling water consumption and flow rates for flushing water systems in high-rise residential buildings in Hong Kong, Building and Environment, In press.
12. Wong L. T. and Mui K. W., (2004). Determining the domestic drainage loads for high-rise buildings, Architectural Science Review, Vol. 47, No. 4, pp. 347-354.
13. Wong L. T. and Mui K. W., (2004). A survey of the sanitation load for domestic high-rise building estates in Hong Kong, Proceedings of the 30th International Symposium on Water Supply and Drainage for Buildings, CIBW062, CSTB, Paris, France, 16-17 September, Fourth Session-Drainage System, 1-18.
14. Wong L. T. and Mui K. W., (2005). Determination of domestic flushing water consumption in Hong Kong, Facilities, Vol. 23, No. 1, pp. 82-94.
15. Wong L. T., (2003). Occupant load assessment for old residential high-rise buildings, Architectural Science Review, Vol. 46, No. 3, pp. 273-277.

Visualization of water distribution systems in 4D

Matjaž Nekrep Perc (1), Eugen Petrešin (2)

(1) matjaz.nekrep@uni-mb.si

(2) eugen.petresin@uni-mb.si

(1) Faculty for Civil Engineering, University of Maribor, Smetanova 17, SI-2000 Maribor, Slovenia

(2) Faculty for Civil Engineering, University of Maribor, Smetanova 17, SI-2000 Maribor, Slovenia

(1)

(2)

Abstract

Our goal in present paper is to describe our research in more descriptive and lively visualization of water distribution system together with visualization of environment where water distribution system is placed. We are linking data from DTM (digital terrain model), orthophoto together with geographical data about water distribution system and data about dynamical processes in the pipe lines system during time.

We have tried to link all those data together in some new more descriptive and interesting way.

Result is 4D model of terrain, water distribution system and dynamical processes through time.

Our approach can be used in case of visualization of planned water distribution system (model) and in visualization of working water distribution systems in real time.

Keywords

Water distribution system/ Civil engineering / Visualization / Building technology/ Digital terrain model, 4D

1 Introduction

Our idea was to give planners, supervisors or even users of water distribution systems more illustrative visual information about dynamical processes in water distribution systems.

Our first goal was to improve visual presentation of water distribution systems models, but later we use the same approach and tools also for real time control over the water distribution system and also for comparing model and real life.

2 Model

We use data from water distribution system modeling software as input data which describes pipe line network geometry and technical characteristics and also processes through the time and geographical data about region from several sources.

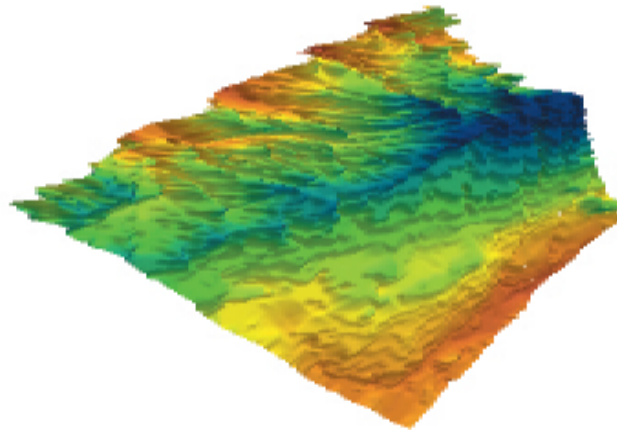


Figure 1: Digital terrain model DTR

In many countries public data about terrain are available. We have digital terrain data and “orthophoto” data about all country is existing in Slovenia.



Figure 2: Orthophoto of earth surface

Also global models as a “Google Earth” are available globally and improved every day.



Figure 3: Ljubljana town view with Google Earth

Towards data in digital terrain model and optical information from orthophoto a lot of additional information about infrastructure may be available and useful in our application. For example all buildings geometry model is available in Slovenia. In our model we try to use all that data in unique model.

Beside a lot of public available data a strong, fast and in most cases affordable public informatics infrastructure is at our disposal in many countries. For example mobile networks, WLAN networks, ADSL.

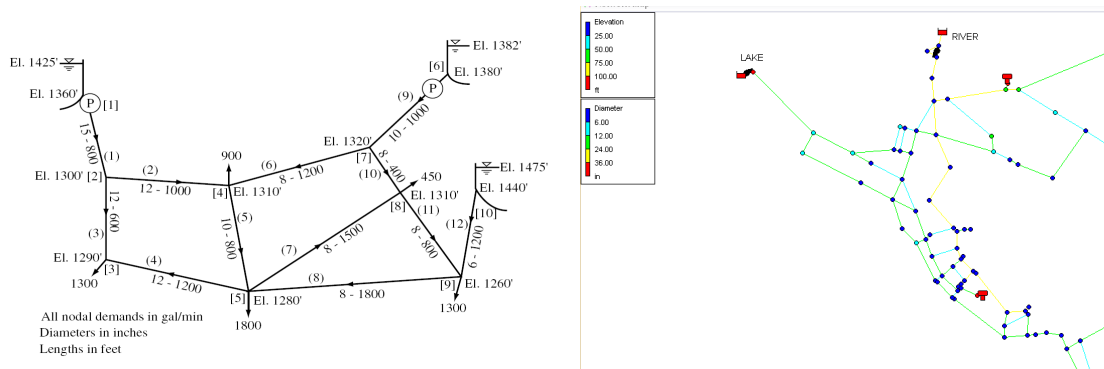


Figure 4: Example of water distribution network in typical software solution

So we have a lot of free or low cost data about our environment, affordable wireless informatics infrastructure and small and cheap computers called java enabled phone always in our pocket.

We just have to force all that wealth to serve our needs.

We use the same sources and the same technology for:

1. Model visualization of planned water distribution systems
2. Real time visualization of working water distribution system

The technology we describe can be used to illustratively visualize all types of dynamical processes in natural and urban environment together with more or less realistic surroundings through the time.

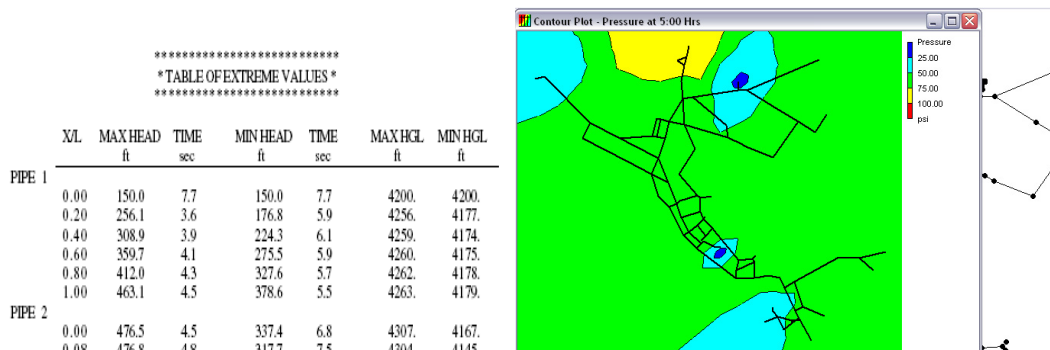


Figure 5: Some more documents from water distribution systems modelling software (EPANET, WaterCad)

Current water distribution systems model's visualizations are pure technical documents. We have pipeline networks plans with data about connections, lengths... , some time depending diagrams and several numerical tables. We can offer more just with connection of same model linked with existing public data and through public information networks.

We use geographical data from several sources as "realistic" scenery for our model, we add 3D geometrical data about our pipe line system together with time dimension which describes dynamical processes in pipe line network.

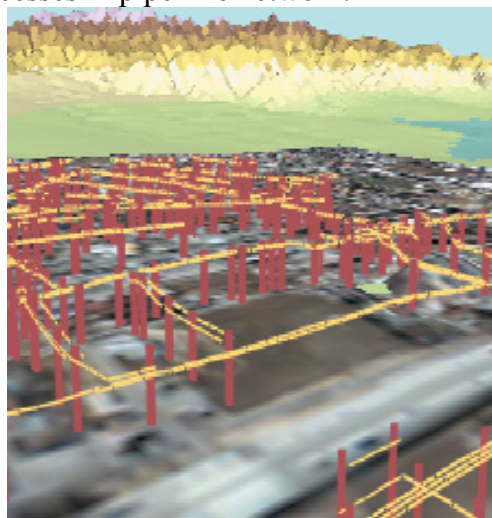


Figure 6: Link of the digital terrain model, orthophoto and 3D infrastructure model

3 Conclusions

This paper presents the basic platform for 4D water distribution systems visualization, describes the integration of existing public data about environment, informatics and communication infrastructure with our water distribution system's model or real time data from water distribution system and defines conditions for successful recognition. We decided to use Java3D for publishing linked to establish hardware independent architecture. We hope that we can offer more lively and descriptive visualization of dynamical processes in water distribution system with use of cheap existing data and technologies not only for office use but also for technology independent mobile users.

4 References

- Ziv Baida. Architecture Visualization: MSc. Thesis, Vrije Universiteit Amsterdam, The Netherlands, 2002.
- Bruce E. Larock, Hydraulics of pipeline systems, CRC Press LLC, Boca Raton, Florida 2000
- Tobias Skog. Ambient Information Visualization, Department of Applied Information Technology IT-University of Göteborg, Göteborg 2006
- C. Jun a, J. Koo, J. Koh, Developing a water pipe management system in Seoul using the GIS, Korea Science & Engineering Foundation, Seoul 2002
- David K. Modjeska, Hierarchical Data Visualization In Desktop Virtual Reality, A thesis submitted in conformity with the requirements for the degree of Doctor of Philosophy Graduate Department of Computer Science University of Toronto, Toronto 2000
- Sebastian Loebbert, Visualisation of Two-Dimensional Volumes, Technischen Universitaet Berlin, Berlin 2004.
- Bonsang, K., Fisher, M. (2000). "Feasibility study of 4D CAD in commercial construction". Journal of construction engineering and management.
- Sriram, V. (1998). "4D CAD in construction". Fall.
- Collier E., Fisher, M. (1996). "Visual-Based Scheduling: 4D Modeling on the San Mateo County Health Centre". Proceeding of the third congress on computing in civil engineering.
- Guid, N. (2001). "Racionalniška grafika". Fakulteta za elektrotehniko, računalništvo in informatiko Maribor.
- IAI (2006). "Industry foundation classes". (available at <http://www.iai-na.org/technical>).
- Kathleen McKinney Liston (1999). "Designing 4D contexts for construction planners". Doctoral consortium.
- Chau, K.W., Anson, M., Zhang, J.P. (2004). "Four-dimensional visualization of construction scheduling and site utilization". Journal of construction engineering and management.
- Leinonen, J., Kahkonen, K. (2003). "Virtual reality applications for building construction". (available at <http://cic.vtt.fi/4D/4d.htm>).

5 Presentation of Authors

Dr. Eugen Petrešin is a Professor and Head of Chair for Hydraulics at the Faculty for Civil Engineering



Matjaž Nekrep Perc, B.SC. Civil. Eng. is a Teaching Assistant at the Faculty for Civil Engineering, postgraduate student of Informatics sciences and author of many working solutions of CAM in civil engineering.



Multi-phase flow characteristics of a siphonic roof drainage system under part load conditions

Abdullah Öngören (1), Ralf Materna (2)

(1) abdullah.oengoeren@geberit.com

Geberit International AG, Basic Sanitary Technologies, Switzerland

(2) ralf.materna@geberit.com

Geberit International AG, Technology Department, Switzerland

Abstract

In this study various aspects of multi-phase flow characteristics of a series of typical siphonic roof drainage (SRD) systems are investigated. It is a commonly accepted fact that the SRD systems are rarely operated at full load since a heavy rainfall which is a priori requirement for such an operating condition occurs seldom. On the other hand, the part load operating conditions cause significant air suction and mixing in the SRD system which turns the flow activities into a multi-phase phenomenon. Various aspects of this phenomenon have been investigated in the past in the literature; however, a complete set of information necessary to develop design criteria covering the requirements of part load conditions is still not available.

In this study, a series of experiments have been designed to obtain data which provide a basis to help improving the existing design criteria which takes not only the primed flow requirements but also multi-phase flow constraints into consideration. Here it is exclusively reported on the new experimental methods utilized to collect data characterizing the investigated SRD systems. A summary of the measurement results obtained by means of these new techniques is provided and the newly detected features of multi-phase flow examined in these results are discussed.

Keywords

siphonic roof drainage; multi-phase flow; effective velocity.

1 Introduction

The use of siphonic roof drainage (SRD) systems is a common practice especially for buildings possessing substantially large roof areas since they provide a high degree of freedom and flexibility to the architects and contractors. Such drainage systems need no slope in pipe work and fewer pipes and fittings than a classical gravity drainage system.

An overview of these and other advantages of SRD systems is given in the literature [1,6]. The technical information, which specifies the design guidelines for SRD systems, is described in the standards EN 12056-3 [2], VDI-3806 [3] and ASTM F2021-00 [4].

Despite all their advantages, SRD systems have a major drawback that they can only reach their maximum efficiency during a heavy rainfall where the drainage pipes are nearly fully filled. For a moderate or low rainfall intensity, the SRD system is often partially filled since a considerable amount of air is sucked into the system along with water. The behavior of this air-water mixture flow should be considered in designing such systems especially if an accurate estimation of working pressures under part load conditions is required. Moreover, the nature of mixture flow is important to assess the dynamic and acoustic characteristics of a SRD system. The studies which are devoted solely to these aspects of SRD systems and relate the obtained data directly to the corresponding design guidelines are scarce in the literature.

In this study, it is aimed to investigate the characteristics of multi-phase flow composed of air-water mixture in various single outlet SRD systems which typical of this class. The piping configurations composed of pipes having three different diameters and two different vertical lengths are systematically investigated to collect sufficient data which allow drawing conclusions which represent the characteristics of this type of SRD. Special interest is also devoted to examine the effect of air content in the piping systems on effective flow velocities and pressures.

A high tower test stand, which allows the installation of a ~ 10 m high vertical drainage pipe combined with a ~ 3 m long horizontal downpipe and a rainwater outlet, is available to conduct the tests. The test stand possesses a variable speed pump, which can generate the part load conditions simulating a range of rainfall intensities. Besides the results of the experimental investigations, computational fluid dynamic (CFD) method is utilized in order to examine the details of air suction process during a part load discharge of a SRD system visually. It is expected that this approach help understanding primarily the contribution of outlet configuration in the development process of multi-phase flow.

2 Experimental and Computational Techniques

2.1 Test stand

The siphonic roof drainage (SRD) systems under investigation have been installed in the high tower test stand of Geberit Labs. All the tested systems are composed of mainly a 2.8 meter long horizontal feed pipe extending from a roof outlet and a vertical standpipe connected to it after an elbow. Three different systems made of DN56, DN63 and DN75 size standpipes are investigated in this study in order to examine the geometrical effects on the characteristics of air-water mixing. The height of the standpipe is varied in each case between 5 and 10 meters in order to change the potential capacity of the systems and carry out the tests under a wide range of flow conditions. A total of 6 different SRD configurations are tested during the studies. It is intended to cover an adequate range of systems so that the results obtained in this study can be

representative of typical multi-storey buildings where SRD systems are often implemented. A sketch displaying the overall configuration of the SRD system installed in the test tower is given in Figure 1.

The outlets of the SRD systems are mounted freely in the middle of a collector tank to minimize the water surface effects especially when the measurements are carried out with a low water level. However, in order to compensate for the effects stemming from the bottom wall near the outlet entrance, a square plate which is sufficiently larger than the outlet diameter has been placed underneath the outlet. Detailed configurations of these parts are also illustrated in Figure 1.

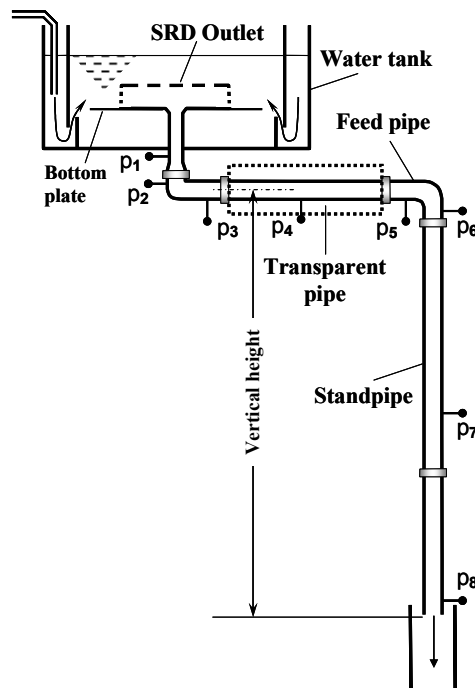


Figure 1 – A sketch illustrating the overall configuration of a typical SRD system tested in this study. The pressure tap locations are also marked in this figure as points p₁-p₈.

The water is supplied to the collector tank by a recirculation pump. The flow rate of the pump is regulated to the given levels of the test program by means of a manual controller. However, the flow rate is also monitored continuously during the tests by reading the output of a flow meter mounted on the water feed line. The flow meter output is also recorded along with the other measured data. After adjusting the flow rate, in each case a settling time which is long enough to reach the quasi-steady state conditions before starting the measurements are allowed. This time is on the order of 10 minutes for each test case. The flow rate is varied in a range of 0 to 16 lt/s. This range includes the maximum operational range of the SRD outlets used in this study. The average height of excess water over the outlet is also measured and recorded utilizing a calibrated static pressure transducer mounted on the bottom of the tank. It is expected that the procedure and the flow conditions selected during the tests of this study cover all relevant features of a typical rainfall event which can affect the flow characteristics in SRD systems.

2.2 Pressure measurements

The measurement of pressure distribution along the feed and standpipes has been accomplished by mounting pressure transducers at 8 different locations along the SRD piping as illustrated in Figure 1. Precise selection of the transducer locations is especially important in order to obtain an accurate spatial distribution of the pressure in the SRD system which can be compared to the estimated values obtained by utilizing the standard SRD calculation methods (e.g. as suggested by VDI [3]). Four equally spaced pressure taps drilled around the periphery of the SRD pipe are connected to the same transducer by means of miniature tubes in order to determine the average local

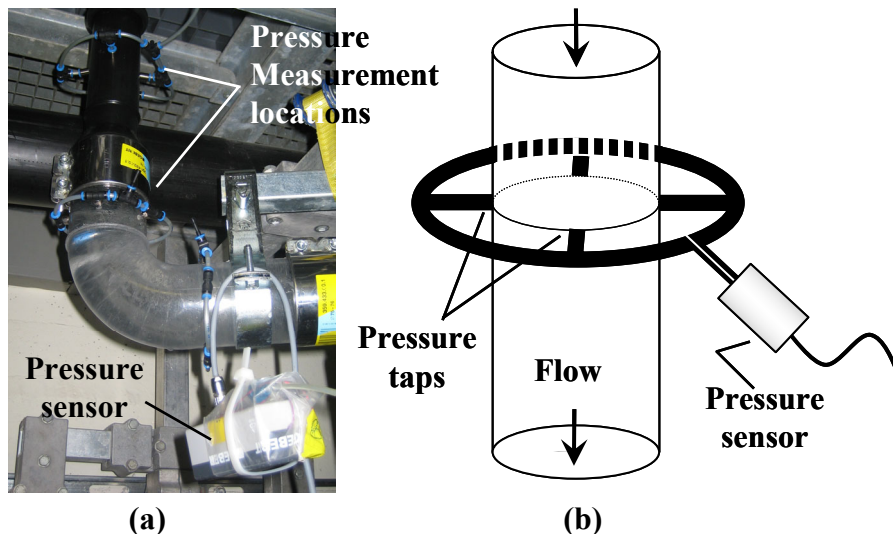


Figure 2 – The set-up utilized to detect spatially average pressure at various locations along the SRD pipework.

pressure at each selected location. The use of such a method is necessary since the systems examined in this study operate mostly under partly filled conditions which cause a spatially varying pressure distribution at the pressure tap locations. A photo illustrating some samples of average pressure detecting set-up is given in Figure 2(a). A detailed illustration of this set-up corresponding to the photo shown in this figure is displayed in the sketch given in Figure 2(b).

2.3 Effective velocity measurements

It is relatively straightforward to determine the overall flow rate in a siphonic roof drainage (SRD) system as discussed above and calculate an average local velocity assuming that the system is fully filled with water. On the other hand, in cases where the system is partly filled; moreover, when there is an appreciable amount of air contained in water, it becomes a challenging task to determine the effective local velocities with an acceptable accuracy. In fact, the use of special equipment dedicated to such measurements is required for this purpose. In this study, a special application of image velocimetry is adopted to measure these velocities. This method involves, primarily, the visualisation of the flow inside the system with a high speed camera at a location where the most relevant features of the air-water mixture flow is clearly visible. This location is determined to be the pipe section immediately upstream of the elbow connecting the horizontal feed pipe to the standpipe. This location is indicated by the

dotted line markings in Figure 1. This portion of the pipe is manufactured from a transparent material so that the visualization of the flow from outside the pipe is possible. The transparent pipe and the elbow where the flow visualization is carried out is shown below in Figure 3.

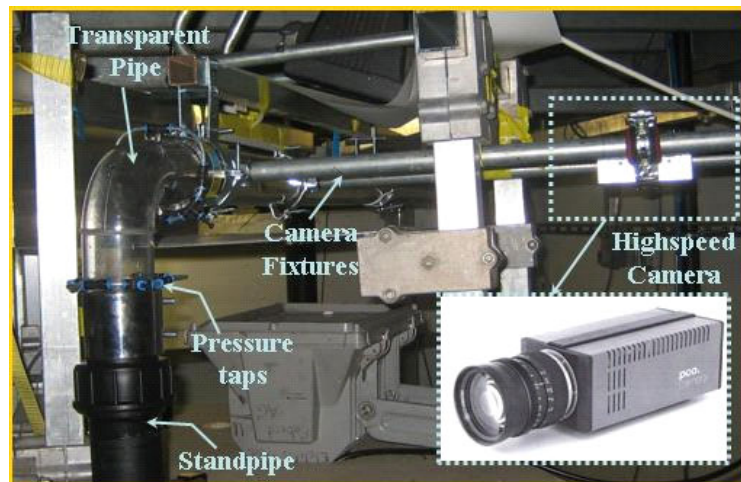


Figure 3 – A photo displaying the visualization set-up including the high speed camera system and it's positioning. The high speed camera is shown in the caption.

The high-speed camera used in this study allows to record 640 full frames per second, which is fast enough to determine the local flow velocities quantitatively and to detect all the flow activities needed for an accurate analysis of the flow. The local flow velocities in the examined systems are determined by marking and tracking fine air bubbles recorded in the visualization sequences of flow flow inside the transparent pipe. A customized particle tracking software is used for these calculations. The software can perform the tacking work and tabulate the corresponding velocities automatically so that the time required to accomplish such a process could be minimized.

The validity of this method has been verified by seeding solid particles having a material density similar to that of water in the SRD system and utilizing them as the tracking markers instead of air bubbles. Such particles are assumed to follow the water movements in their vicinity precisely and therefore minimize the most of the secondary effects which can cause deviations in the measurement results. In fact, there has been detected virtually no difference between the velocities obtained with air bubbles and solid particles. The photos shown in Figure 3 display a view of the transparent test pipe and the high-speed camera system for a typical measurement configuration.

3 Results

3.1 Characteristics of SRD systems according to the present standards

A series of baseline investigations have been carried out in order to verify the conformity of the parameters used to design the SRD systems examined in this study. For this purpose, the overall characteristics of the systems have been estimated by means of the calculation methods described in the existing standards [3] and compared with the results of the measured values. The distribution of pressure along the piping

from the outlet to the free end of the drainage is an important indicator displaying the adequacy of the SRD system according to the standards. A typical example of the baseline tests accomplished a priori to the main investigations is shown in Figure 4

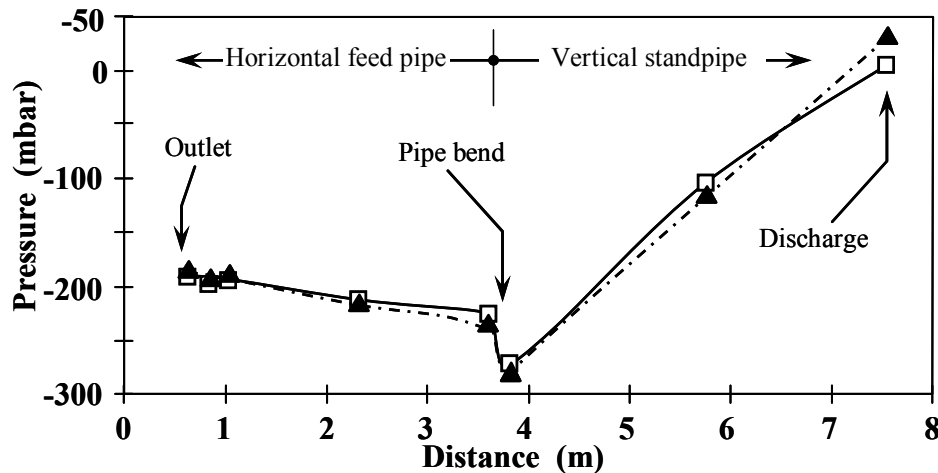


Figure 4 –Pressure distribution along a typical SRD system tested in this study under primed conditions. System height=5m; Pipe size=DN63; Flow rate=11.7 lt/s; □-measured; ▲-theroretical.

where the pressure distribution along a 5m high DN63 size system under a primed flow condition is displayed. As observed in this figure, starting immediately after the outlet, negative suction pressure generated in the piping decreases gradually along the horizontal feed pipe up to the connection to the standpipe. The connection of the feed pipe to the standpipe is realized through a 90° large radius bend as mentioned above. A relatively steep change in the pressure which appears over the bend can be attributed to the losses resulting from the additional acceleration of the flow in the bend itself. The pressure increases gradually and almost linearly on the downstream of the bend in the standpipe up to the discharge end where the pressure rises again to the atmospheric pressure. The pressure variation in the same system has also been estimated by means of the standard VDI method [2] and plotted in Figure 4 in comparison to the measurements. A very close agreement is observed between the two distributions indicating that the assumptions made to formulate the similarity rules applied in designing the test systems are appropriately accurate.

3.2 CFD visualisation of air suction process under part load conditions

The air suction process in the SRD outlet has been investigated in detail by means of CFD (Computational Fluid Dynamics) simulation techniques before starting the relatively cumbersome experiments to study the multi-phase flow phenomena in the SRD systems. It is expected that this approach provides a broad view and understanding of these local flow mechanisms which affect the multi-phase flow characteristics appearing in the downstream parts of the systems. Although, the CFD simulations have been carried out under both part load and primed conditions, here in this paper only the results belonging to the part load condition will be discussed. The simulation of a SRD outlet has been carried out under the boundary conditions corresponding to a part load state of the corresponding system which is slightly under the design condition. This

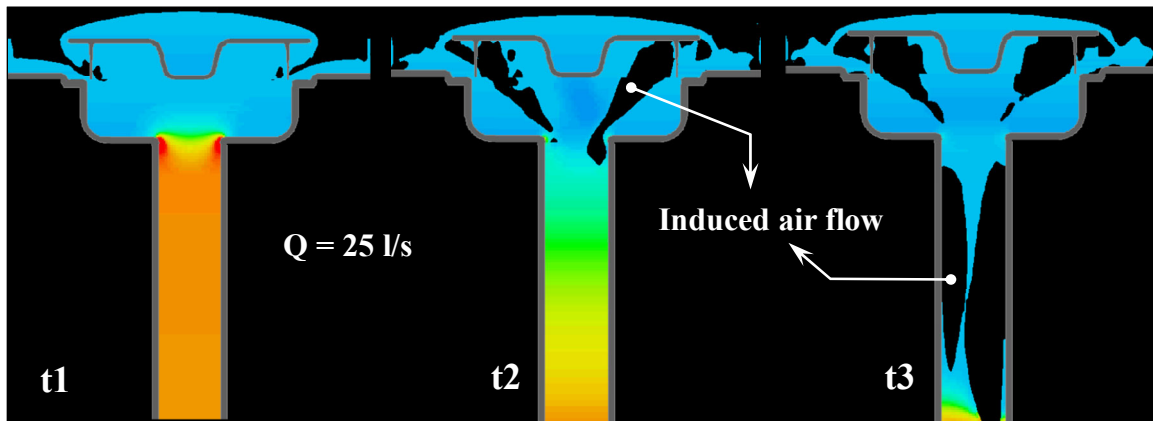


Figure 5 – CFD simulation pictures illustrating the time variation of air suction process in a typical SRD system operating below the design conditions.

state allows visualising the extensive break-up of air bubbles which dominantly controls the multi-phase flow structure related closely to the functioning of the SRD system. A series of pictures displaying the time development of air suction process in a typical SRD system is shown in Figure 5. The initial phase of the suction process is examined in the leftmost picture of Figure 5. The entrainment of small bubbles is observed in this picture as they enter the collection chamber of the outlet. At a later time of this process as the suction continues the bubbles grow and occupy almost the half of the collection chamber. Thereof, they proceed to enter the vertical downpipe which connects further downstream the outlet to the horizontal feed pipe. This activity is displayed in the middle picture of Figure 5. The rightmost picture of the series illustrates the air bubbles as they move downstream in the downpipe. They are now large enough to occupy a whole cross-section of this pipe which can momentarily block the flow into the system. The temporary changes in the volume of air bubbles cause excessive dynamic pressure pulsations in the piping. These pulsations, in turn, augment the bubble break-up initiates a foaming process further downstream in the downpipe. The influence of these upstream events on the multiphase characteristics later in the feed and standpipes will be discussed further in the proceeding sections.

3.3 Two-phase flow characteristics of the examined SRD systems

The multi-phase characteristics of the flow inside all the tested SRD systems have been examined by carrying out a series of a high speed camera visualisations in the horizontal part of the feed pipe at a location near the upstream side of the bend to the standpipe. This location is found to be appropriate for the visualisation because the air sucked into the system from the outlet is assumed to have enough time until it reaches this location to develop the characteristic flow structures which dominate the SRD system. The visualisations have been accomplished for various flow rates selected in the whole operating range of each system. The development of the two-phase flow regimes observed in a 10m high SRD system composed of DN75 size piping are illustrated in Figure 6. When the system is operating under part load conditions, the water received can only partly fill the SRD-piping by forming a layer of water at the bottom side of the horizontal pipe leaving an air layer at the top side. This layer possesses a relatively turbulent free surface (See Fig. 6a and 6b) which can entrain a significant amount of

air near the surface. As the flow rate is raised over 5 lt/s, this entrainment becomes augmented and forms a bubbly zone between water and air layers. The bubbly zone becomes gradually thicker as the flow rate is increased further and it eventually occupies the whole upper side of the feed pipe when the flow reaches a level of about 7 lt/s, as observed in Figure 6c. Any further increase in the flow rate results in a reduction in the amount of bubbles until they disappear totally at a flow rate over 13 lt/s where

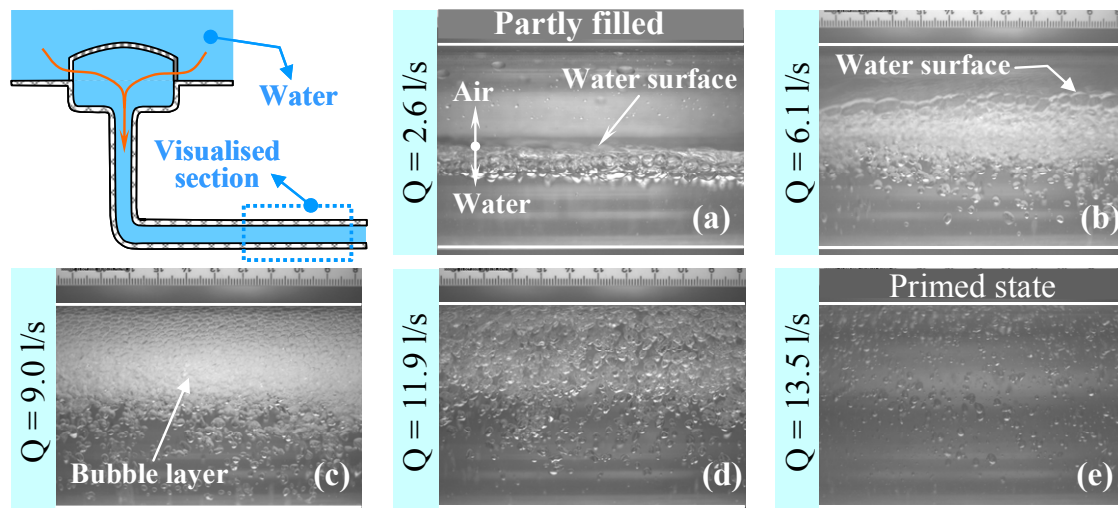


Figure 6 – Photos displaying the typical flow regimes observed in the SRD systems tested in this study as a function of the flow rate. Height=5m; Pipe size=DN75.

the SRD system reaches to a fully primed condition. This development is observed clearly in figures 6d and 6e. Air bubbles follow precisely the water activities in this regime. It should be recalled here that the fully primed condition corresponds to the maximum design point of the SRD system under consideration where significantly high flow velocities are reached in the piping meaning a very efficient drainage of the rainwater with a high capacity.

3.4 Effective velocity of water-phase under part load flow conditions

A siphonic rainwater drainage system is designed to function most efficiently when it is fully primed. However, it reaches this condition rarely since the design criteria requires the occurrence of a maximum rainfall which is statistically observed only over a long period of time, e.g. every 30 to 50 years. This means that a typical SRD system operates almost always under unprimed part load conditions during its lifetime. Therefore, it is very important to know not only the flow behaviour under primed conditions but also those under part load conditions.

The flow mechanisms characterising the operation of an unprimed SRD system differ principally from those of a primed system. The influence of these mechanisms on the time dependent variations of water-phase velocities should be taken into consideration in evaluating the performance of a SRD system. The water-phase velocity can be estimated accurately by determining the filling fraction inside the piping and the amount of dispersed air bubbles appearing in water. It is expected that an accurate estimation of flow velocities will allow a better estimation of all other operational system parameters and leads to a SRD design functioning optimally in a wider range of rainfall conditions.

Various aspects of these features, primarily the role of air content in SRD system performance, are discussed by Wright et. al in the literature [5].

The effective flow velocity discussed hereon, V_e , is determined utilising the method of image velocimetry described in the previous section 2. The effective velocity belonging to a system composed of a 10m long DN75 piping has been estimated by this method and plotted in Figure 7 in comparison to the theoretically determined distribution as a function of mean flow rate. The idealized full flow design of a SRD system is accomplished by utilising the hydraulic design methods described elsewhere in the literature [3].

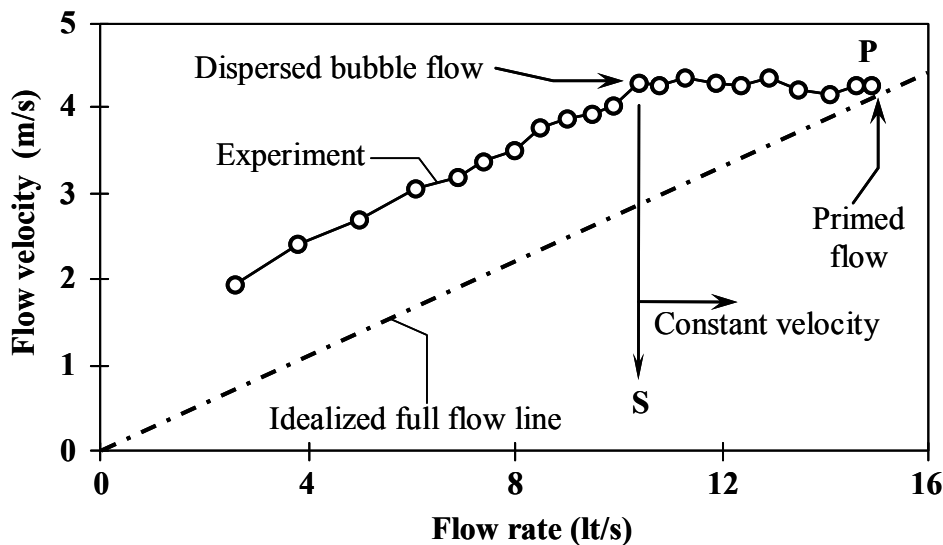


Figure 7 – Effective flow velocity in a SRD system as compared to the ideal distribution in the operational range up to the fully primed state. System height=10m; Pipe size=DN75.

The idealized full flow velocity for a given SRD system is linearly dependent on the flow rate where the rate of change is solely dependent on the system geometry. The dotted line plotted in Figure 7 represents the idealized flow velocity line. The experimentally determined V_e belonging to the same case is plotted as round symbols in the same figure. A linear dependency of V_e on the flow rate is observed in the low flow rate range as given in this figure. Despite this similarity qualitative of the two cases there is a significant deviation in the quantitative values. The V_e is consistently higher than the idealized full flow values in the whole range of flow rates up to the point of full priming. This is an expected behaviour considering that a substantial amount of air is mixed with water during the unprimed state of operation which can reduce the water flow area appreciably and hence increase the water velocity.

Even more interesting to mention here is that the V_e reaches to its maximum level (point S) at a flow rate which is much lower than the design limit of the system. This result is clearly in contrary to the prognosis of the idealized full flow calculation. The maximum V_e level is retained even if the flow rate is increased further until the priming conditions are reached. This behaviour is recognisable as a plateau extending from point S to point P in Figure 7. The occurrence of such behaviour can be directly related to the formation of a homogeneous bubble distribution in water instead of a two layer

distribution where air-water mixture behaves as a quasi-single phase. This unique behaviour has not been observed in the previous studies reported in the literature according to the best knowledge of the present authors.

3.5 Multi-phase behaviour of SRD systems under part load flow conditions

The multi-phase flow studies discussed in the previous section have been extended to other sizes of SRD systems in order to generalize the observations ascertained. The results are summarised in Figure 8 and 9. The effective flow velocities, V_e , for three different SRD systems of sizes, DN 56, 63 and 75 each having a vertical height of 5 m have been measured and displayed in Figure 8. The effective velocity data belonging to each case indicates a linear increase in the low flow rate ranges where the entrance of a

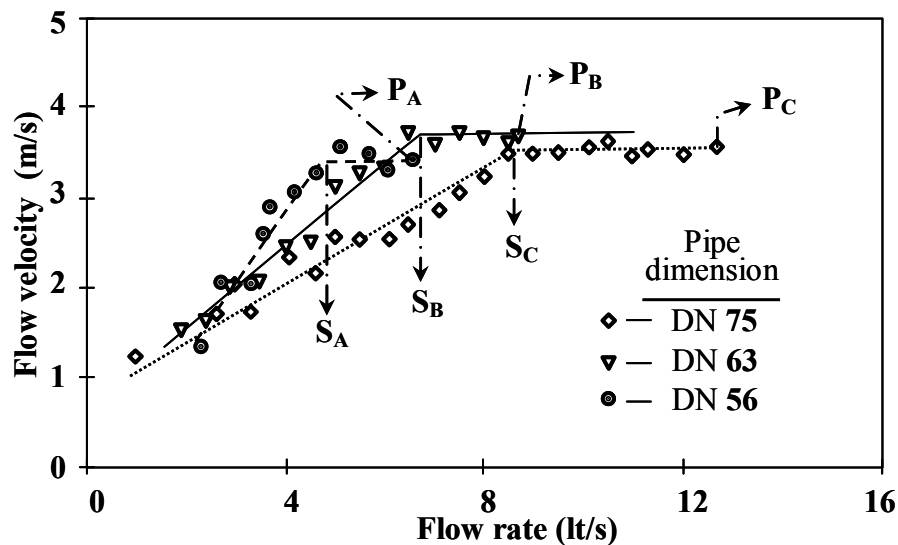


Figure 8 – Effective flow velocity as measured utilizing the image velocimetry technique in three different SRD systems as each having a vertical height of 5 m.

significant amount of air into the SRD piping is observed. This range ends when the V_e reaches to a maximum and levels to a plateau. The V_e remains constant thereafter until the primed state is comprehended. The flow rates corresponding to maximum effective velocities and the priming conditions are indicated by the letters S and P, respectively.

The experiments were repeated with the SRD systems composed of pipings having the same dimensions as above but a vertical height two times larger than the previous ones, namely 10 m, in order to examine the effect of potential capacity of the SRD system on the multi-phase flow characteristics. The results are summarized in Figure 9. Typically the same characteristics are observed as in the previous sections discussed above, where the effective flow velocity, V_e , increases in all cases until it reaches to a maximum plateau value appreciably below the primed design conditions. The V_e remains constant from the point of maxima (S) up to the point of primed state (P). It is observed that the scatter in the data increases on the lower end of the flow rate range in all cases. In fact, the mean line of the data belonging to DN63 in Figure 9 clearly deviates from the linearity in this range. This deviation is attributed to a reduction in the accuracy of the measurement technique which increases with decreasing flow rates. A further examination of the results presented in this section has indicated that there is a well

defined relation between the conditions of maximum velocity plateau and the primed conditions. It has been observed that in all of the measured cases the ratio of the flow rates corresponding to the effective velocity maxima (Q_S) and the primed flow

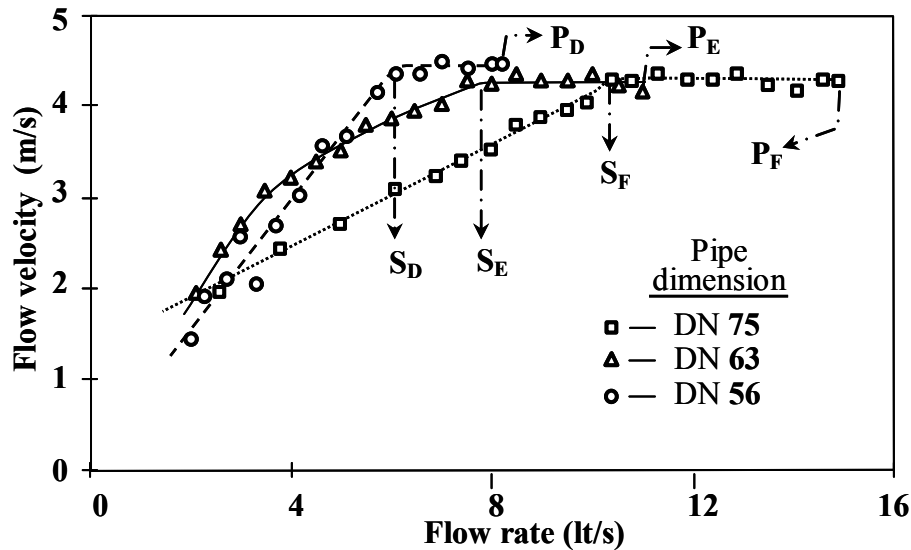


Figure 9 – Effective flow velocity as measured utilizing the image velocimetry technique in three different SRD systems as each having a vertical height of 10 m.

condition (Q_P), i.e. Q_S/Q_P , has almost a constant value. These values have been calculated and given in Table 1. The Q_S/Q_P has been determined to be ~ 0.7 for the cases investigated in this study. This value conforms well with the values reported in the literature for similar cases [1,5].

Table 1 – Q_S/Q_P ratios of all tested cases

Pipe Size	Height (m)	Q_S (lt/s)	Q_P (lt/s)	Q_S/Q_P
DN 56	5	4.7	6.5	0.72
DN 63	5	6.5	8.7	0.75
DN 75	5	8.5	12.7	0.67
DN 56	10	6.1	8.2	0.74
DN 63	10	7.7	11.0	0.70
DN 75	10	10.4	14.9	0.70

Conclusions

This paper investigates the multi-phase flow characteristics of siphonic rain drainage systems operating under part load conditions. A new image velocimetry technique which is composed of a high speed camera and a particle tracking software is used to measure the effective flow velocities in the vicinity of appreciable air content in water. This technique is proved to be very reliable in determining such velocities. The use of this new technique also made it possible to examine the transition process of flow regimes from multi-phase air-water occurring under part load conditions to single phase water flow existing under primed conditions in more detail. The flow characteristics under both part load and primed conditions are determined to be qualitatively similar irrespective of piping dimension. One of the most important results of this study is the observation of a flow regime where the effective flow velocity in the piping remains

constant for a relatively wide range of flow rates. It is assumed that the breaking-up of large air pockets into small size dispersed bubbles and their transition to a homogeneously distributed regime is the cause of this unique flow phenomenon. It is also observed that the onset of this flow structure is well related to the ratio of flow rates corresponding to the velocity maxima and primed condition. This ratio is found to be a constant around $Q_s/Q_p \sim 0.7$ for the cases of this study.

Acknowledgments

The authors acknowledge the contributions of Mr. Bruno Meier and Mr. Christian Renggli who carried out the experiments and performed the data acquisition diligently with an utmost enthusiasm and accuracy.

4 References

5

- 1 Swaffield JA and Wise AFE – *Water, Sanitary and Waste Services for Buildings*, Fifth Ed., Butterworth-Heinemann Ltd, London, UK, 2002.
- 2 Anonymous, European Standard EN 12056-3 Gravity drainage systems inside buildings- Part 3: Roof drainage, layout and calculation. European Committee for Standardisation, June 2000
- 3 Anonymous, VDI-Richtlinien VDI 3806 Roof drainage with siphonic system, VDI-Handbuch Sanitärtechnik, 1. Auflage 2002
- 4 Anonymous, ASTM Standard Specification F 2021-00 Design and installation of plastic symphonic roof drainage systems, ASTM, June 2000
- 5 Wright GB, Swaffield JA and Arthur S – Investigation into the performance characteristics of multi-outlet siphonic rainwater systems, 27th Int. Symp. on Water Supply and Drainage for Buildings, CIB W062, Sept 17-20, Portoroz, Slovenia, 2001.
- 6 Bramhall MA – Siphonic roof drainage systems, American Society of Plumbing Engineers Convention, Nashville TN USA, 2000.

5 Presentation of Authors

Dr. Abdullah Öngören is the head of Basic Sanitary Technologies Department at Geberit International A.G. (Switzerland), where he is widely involved in research and development of sanitary equipment, and rain and waste water drainage systems. He is specialized in flow induced vibration and noise and CFD applications in sanitary equipment and systems.



Dr. Ralf Materna is the head of Technology Department at Geberit International A.G. (Switzerland), where he has been involved in many projects related to sanitary and construction technologies. His special interests are in the field of building physics with main focus on acoustics in sanitary applications as well as hydraulics of wastewater and symphonic drainage systems.



Calculation Method for the Loads of Cold and Hot Water Consumption in Office Buildings based on the Simulation Technique

Sabro Murakawa (1), Hiroshi Takata (2), Kazuhiko Sakamoto (3)

(1) muraka@hiroshima-u.ac.jp

(2) takatah@hiroshima-u.ac.jp

(3) sakamoto.kazuhiko@takenaka.co.jp

(1) Professor/ Graduate School of Engineering, Hiroshima University, Japan

(2) Research Associate/ Graduate School of Education, Hiroshima University, Japan

(3) Takenaka Corporation

Abstract

The authors have advanced the development of calculation method based on the data of water usage for daily, hourly, and instantaneous loads in the time series through a day by using a personal computer. The method is applied by the Monte Carlo Simulation technique. In our recent studies, the calculation method was developed for practical level [1]. The calculation method for the loads of cold and hot water consumption in office buildings was proposed at the CIB-W62 symposium [3], [4], based on the results of a questionnaire and measurement investigation carried out in 3 office buildings. In those papers, the applicability of calculation method was verified by comparing with the values of measurement and simulation.

In case of Japan, there are several techniques as for the existing method of calculating the instantaneous maximum flow rate [5]. Therefore, in this paper, the calculation models of the toilet's fixtures and the hot water service rooms in office buildings were developed by applying the results of the analysis for the conditions of the fixture and water usage. The simulation for calculating the time series loads was carried out by using the model. Also, the applicability of the calculation method with the use of computer simulation was verified by comparing the values of existing methods and measurements.

The calculation method with the use of computer simulation has flexibility of conditions for the number of workers and the specific types of toilet's fixtures such as the type of saving water, etc. Estimation of the water demands on the difference of influential factors was analyzed by changing the number of workers and the type of toilet's fixtures.

Keywords

Water Consumption, Monte Carlo Simulation, Fixture Usage, Office Buildings

1. Introduction

The authors are now developing the calculation method for cold and hot water consumption based on the fixture usage in the time series through a day. The method applies the Monte Carlo Simulation technique to calculate the instantaneous flow rates, hourly and daily water consumption by a personal computer.

On the previous papers, we proposed the method that was applied for apartment houses [1], restaurants [2], office buildings [3, 4], etc. In case of office buildings in those papers, we showed the calculation results by the models that were set up based on the results of investigation for an example of office building.

In this paper, we propose the standard calculation models for cold and hot water consumption in office buildings based on the data that were put together the measurement values in IN, D and F building [3, 4]. On the basis of the models for toilets and hot water service rooms, we show the calculation results. And we compare the results with the measurement results and the existing design values.

2. Outlines of the calculation method

On the calculation of water consumption by the Monte Carlo Simulation technique, we start the simulation from the occurrence by people's water usage at the fixtures equipped with the characteristics of the objective building.

As for the characteristics of office building, we have to grasp the basic data affected to the water consumption such as the number of workers, the composition of male and female, the contents of business, the schedule of going out through the office hours, cold and hot water supply systems, the number of fixtures in each usage, the type of water saving fixtures or standard fixtures, etc.

After the basic data are set up for the objective building, the calculation of cold and hot water consumption can be carried out according to the procedure shown in Figure 1.

In this calculation, we have a hypothesis that the probability of the frequency of water usage occurs at random for a decided period [1].

We have to set up the calculation model as follows.

- (1) The frequency of water usage in each period through a day
- (2) The average values and the distributions of the duration of water usage and the discharge flow rate
- (3) The cold and hot water temperature used

According to the calculation model of water demands, we generate the pseudo-random numbers by using personal computer. The generated random numbers are applied to calculate the occurrence time interval of water usage, the duration of water usage and the discharge flow rate. If we have to consider the temperature of using water, we also generate the random numbers to decide the water temperature used.

The simulation is carried out with repetition until we can get the stability for the

calculation results. These results of water consumption are shown with one second interval through a day. Therefore, the instantaneous maximum flow rate, peak hours and daily consumption are calculated by using the statistic technique.

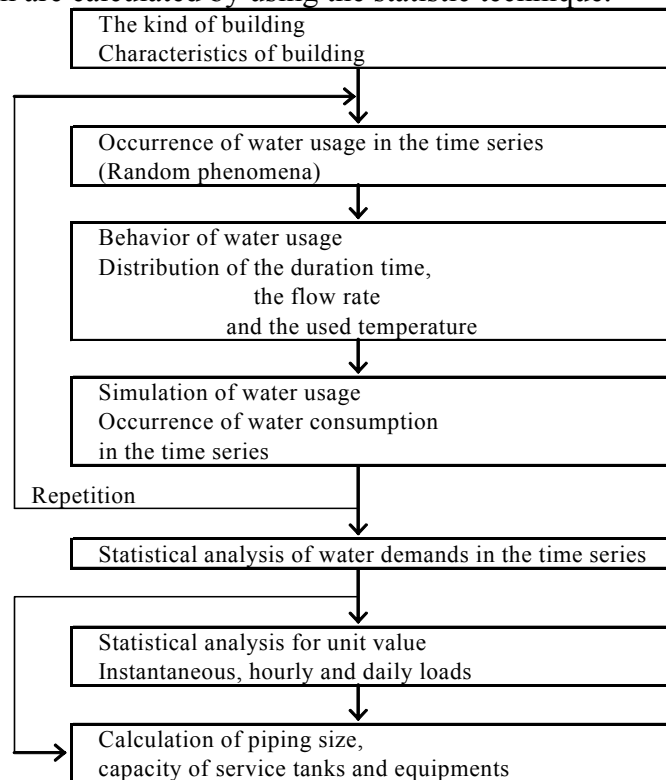


Figure 1 – Procedure for calculation of cold and hot water demands

3. Calculation model of water demands

3.1 Number of workers occupied in the office

The consumption of water in the toilets of office buildings depends on the number of office workers mainly. Based on the recent our investigation for the number of workers in each office floor, the hourly ratios of the number of workers occupied in the office to an enrollment are set in four models shown in Figure 2. In these four models, each shows as the average model, the maximum model that is occupied by no trip persons through the office hours, the model that all workers stay at the floor through the office hours, and the minimum model that is occupied by many trip persons who are attached to the sales department etc.

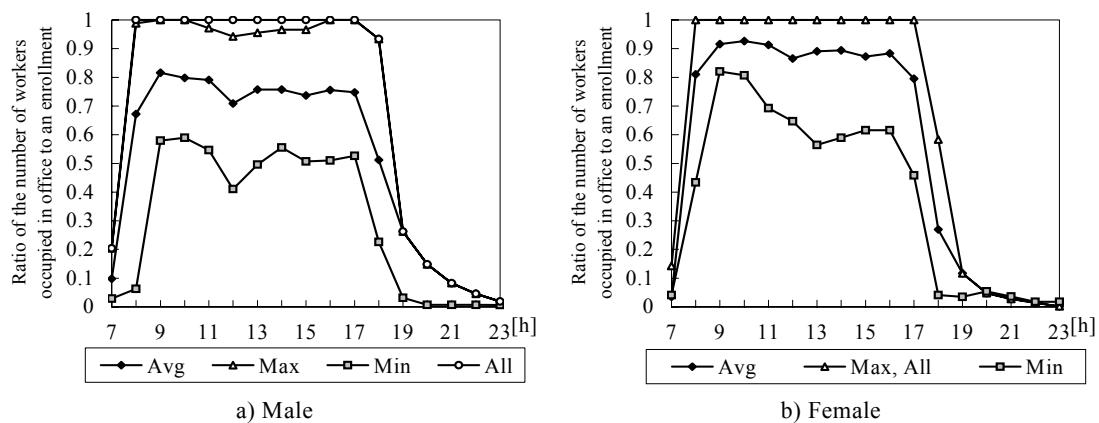


Figure 2 – Hourly ratios of the number of workers occupied in the office to an enrollment

3.2 Calculation model of water demands in the toilets

On the basis of the measurement results of the sanitary fixture usage and water consumption in the office buildings, we made the calculation models of water demands which are shown in Table 1. As for the toilet model, this model is composed of sub-models; the arrival model to each fixture, the occupancy model in each fixture, the water volume model discharged from each fixture and the frequency of fixture operation. The models can be evaluated for the fixtures of saving water except the male and female water closets. If we have planning of water closet for saving water types, the average values of duration time of water discharge [sec], and flushing flow rate [L/min] may be estimated with 6.0 [sec], and 100 [L/min] respectively.

When we calculate the water demands in the time series, such as instantaneous, hourly and daily loads of water consumption, we have to apply not only the models shown in Table 1 but also the frequencies of fixture usage which are shown in Figure 3. The Figure shows the average frequencies of fixture usage per person occupied in office floor and per hour.

Table 1 – Calculation models of water demands

		Male			Female		Slop sink
		Water closet	Urinal	Basin	Water closet	Basin	
Arrival model	Arrival ratio [person/min]	Set in each times					
	Arrival interval distribution	Exp.					
Occupnacy model	Duration time of occupancy [sec]	260	37	12	110	17	56
	Distribution	Erl.3	Erl.7	Hyp.2	Erl.3	Hyp.2	Hyp.3
Water volume model	Duration time of water discharge [sec]	6.5	5	6	6.5	11	56
	Distribution	Exp.	Erl.10	Erl.3	Exp.	Erl.3	Hyp.3
	Flow rate [L/min]	120	30	5	120	5	12
	Distribution	Erl.6	Erl.10	Erl.10	Erl.6	Erl.10	Erl.3
Fixture operation model	Frequency of fixture operation	1.37	1	1	1.17	1	1

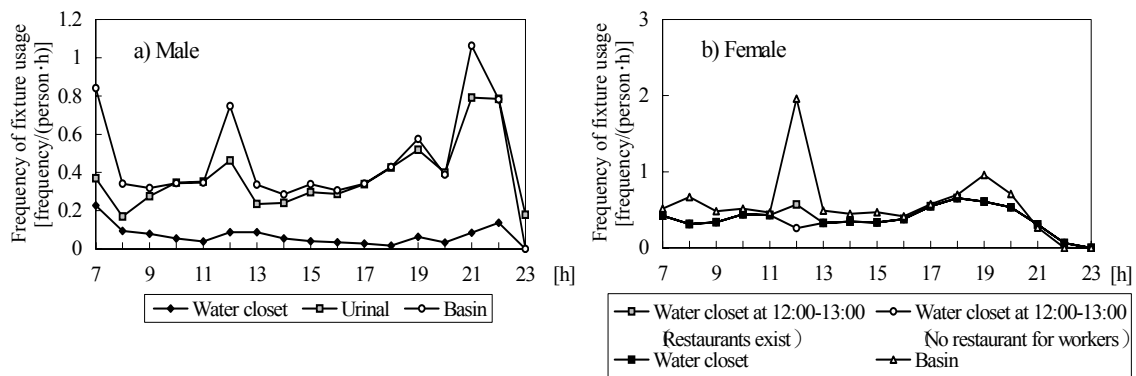


Figure 3 – Frequencies of fixture usage

3.3 Calculation model of cold and hot water demands in the hot water service room

Based on the measurement results in D building, Table 2 shows the calculation model of cold and hot water demands in the hot water service room. The model is composed of sub-models; the arrival model to each fixture, the water volume model discharged from each fixture and the temperature model of cold and hot water usage in each fixture.

We have a hypothesis that the probability of the frequency of arrival to the hot water service room by the office workers occurs at random for a decided period.

Figure 4 shows the average frequencies of fixture usage per person occupied in office floor and per hour. Also, the Figure shows the hourly ratios of frequencies for hot water, cold water and mixing hot and cold water.

4. Verification of the calculation results

4.1 Outline of the simulation

In this paper, we carry out the simulation as an example of F building, and compare the calculation results with the measurement results and existing values for practical design. This simulation is excluded the basins and slop sinks in the toilets, when it compares with the measurement results.

Table 2 – Calculation models of cold and hot water demands in the hot water service room

	Usage		Mixing hot and cold water			Hot water			Cold water		
	Times on		7·8	16·17	other	7·8	16·17	other	7·8	16·17	other
Arrival model	Arrival ratio [person/min]		Set in each season and each times								
	Arrival interval distribution		Exp.								
Water volume	Flow rate		Flow rate [L/min]			10			8		
			Distribution			Erl.3			Erl.4		
		Winter	Average value [sec/frequency]			35	56	23	10	19	7
			Distribution			Hyp.2	Hyp.3	Hyp.2	Hyp.2	Hyp.4	Hyp.4
		Spring	Average value [sec/frequency]			29	58	20	13	19	5
			Distribution			Hyp.2	Hyp.3	Hyp.2	Exp.	Hyp.2	Hyp.3
			Ratio of the frequency of cold water			45	70	23	16	35	9
			Ratio of the frequency of mixing hot and cold water			Exp.	Hyp.3	Exp.	Exp.	Erl.2	Hyp.2
			Ratio of the frequency of hot water			30	68	24	18	32	7
			Frequency of fixture usage			Hyp.2	Hyp.3	Hyp.2	Exp.	Exp.	Hyp.3
Temperature model	Autumn	[sec/frequency]	Distribution			Hyp.2	Hyp.3	Hyp.2	Exp.	Exp.	Hyp.3
			Average value [°C]			34.8			60.0 *		10.0 *
	Winter	[°C]	Distribution			Erl.9					
			Average value [°C]			33.8			60.0 *		17.7 *
	Spring	[°C]	Distribution			Erl.13					
			Average value [°C]			34.2			60.0 *		22.6 *
	Summer	[°C]	Distribution			Erl.16					
			Average value [°C]			33.7			60.0 *		20.2 *
	Autumn	[°C]	Distribution			Erl.13					
			Average value [°C]								

[Note] *: The designer set up the appropriate temperature to the conditions.

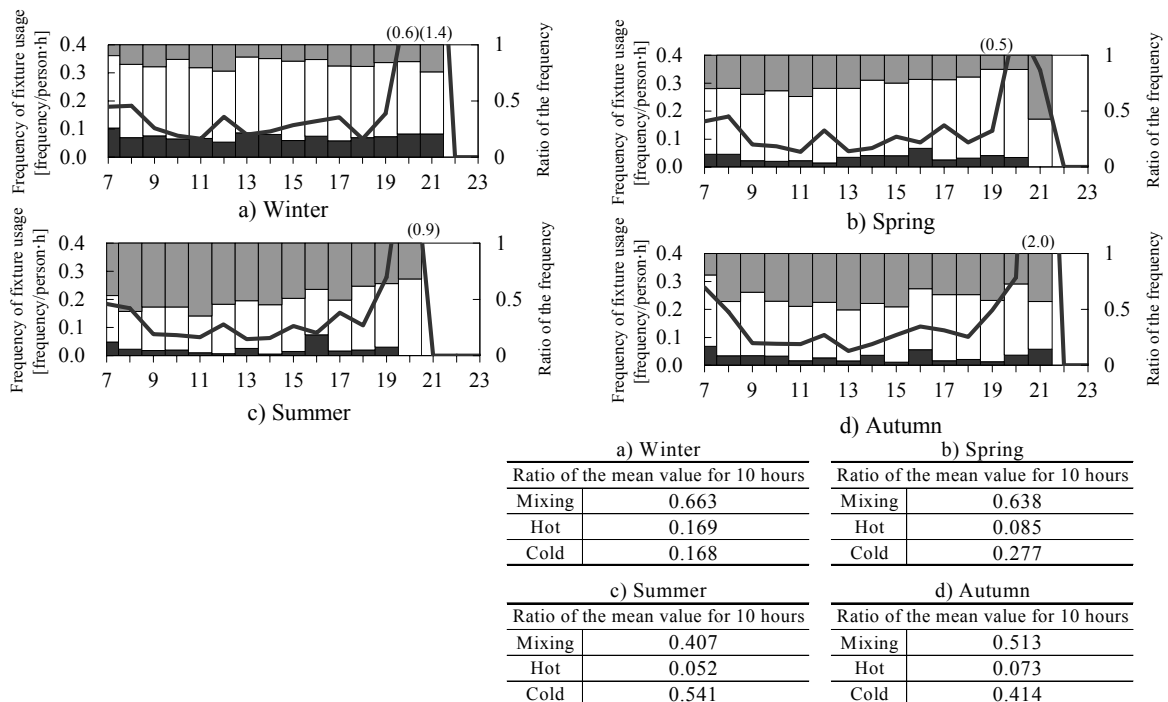


Figure 4 – Frequencies and ratios of fixture usage in the hot water service rooms (D building)

Outlines of F building are as follows. Total floor area: 18,256 m², 14 stories, Number of sanitary fixtures: 38 in each fixture type (water closet, urinal, basin for male and water closet, basin for female), Number of workers: male 673, female 186 in all stories.

In this simulation, we apply the average model for the ratio of number of worker's occupancy on the office floor according to the investigation results in F building. The calculation loads of water consumption are output at one-second interval. As for the instantaneous flow rate, we propose to apply the values of one-minute interval.

4.2 Instantaneous water demands

Figure 5 shows the instantaneous flow rates based on the simulation and measurement values for male and female water closets and male urinals in F building. In each hourly trial, we had a hundred trials. Therefore, these values were calculated by six thousands samples. The measurement results from the maximum values to the failure factor 0.2% values show the equivalent width in the calculation results between the failure factor 0.1% values and 5% values.

In Japan, we have four kinds of calculation methods for the estimation of instantaneous maximum flow rate [5]. These are as follows.

- (1) The new convenient method using new loading unit proposed by S. Murakawa
- (2) The method by the duration time of water usage as a ratio of the occupied time for using at the facility and fixture flow unit.
- (3) The methods by the estimation of number of simultaneous uses of fixtures
- (4) The method by the fixture unit, which is called the Hunter's method

In this paper, we select the two kinds of failure factor; 0.05% and 0.1%, for the calculation by the method (2). And, as for the calculation by the simulation method, we show the calculation values from the maximum to the failure factor 5%.

In case of the measurement results in F building, we show the maximum value, the values of failure factor 0.1% and 0.2%.

Table 3 shows the comparison of the calculation results by existing methods with the simulation and measurement results for the instantaneous water demands.

When we compare the total values of water closet and urinal with each method, we know that the calculation results of failure factor 0.2% by the simulation method approximate to the maximum value of measurement results. However, the calculation results by the existing method for practical design show very high values in comparison with the measurement results. Therefore, the calculation values by every existing method show the over design for the actual conditions.

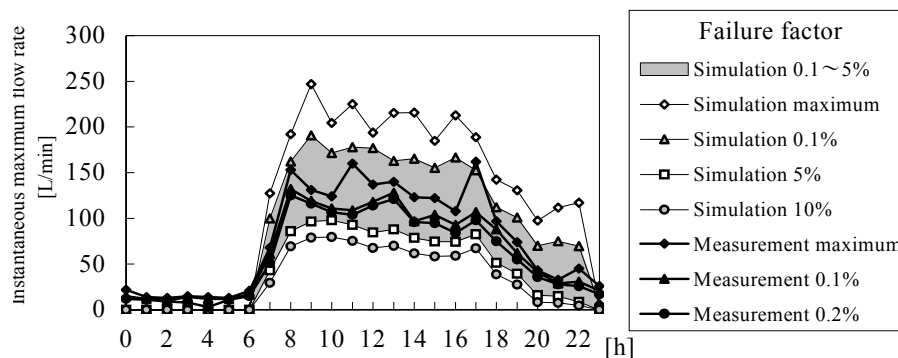


Figure 5 – Instantaneous flow rates based on the simulation and measurement**Table 3 – Comparison of the calculation results by existing methods with the simulation and measurement results**

	Male			Female		Slop sink	Water closet + Urinal	Water closet + Urinal + Basin	All fixtures in Toilet
	Water closet	Urinal	Basin	Water closet	Basin				
(1)	360	140	70	450	70	-	600	650	-
(2)	178	71	39	223	30	263	347	382	534
(2')	138	58	32	177	25	230	275	303	445
(3)	678	445	148	678	148	125	-	-	-
(4)	500	350	125	500	125	100	800	850	860
(a)	198	34	9	180	13	60	239	250	250
(b)	146	26	7	143	12	34	177	179	181
(c)	132	25	7	136	12	30	171	173	176
(d)	94	21	6	98	10	23	138	140	141
(e)	78	19	6	85	9	18	117	120	122
(f)	58	17	5	67	8	13	97	99	101
(A)	-	-	-	-	-	-	162	-	-
(B)	-	-	-	-	-	-	132	-	-
(C)	-	-	-	-	-	-	125	-	-

Unit:[L/min]

[Note] (1)-(4): Existing method

(1) The new convenient method using new loading unit

(2) The method by the ratio for duration time of water usage and fixture flow unit, Failure factor 0.05%

(2') The method by the ratio for duration time of water usage and fixture flow unit, Failure factor 0.1%

(3) The methods by the estimation of number of simultaneous uses of fixtures

(4) The method by the fixture unit, which is called the Hunter method

(a)-(f): Simulation method

(a) Maximum

(c) Failure factor 0.2%

(e) Failure factor 2%

(b) Failure factor 0.1%

(d) Failure factor 1%

(f) Failure factor 5%

(A)-(C): Measurement

(A) Maximum

(B) Failure factor 0.1%

(C) Failure factor 0.2%

4.3 Hourly and daily water demands

Figure 6 shows the hourly water demands of the simulation and measurement for male and female water closets, and male urinals. The maximum and average values are almost same in each. Figure 7 shows the average values of the simulation in each fixture usage in the toilets. The volumes of water consumption for water closet and urinal account for about 90% in the toilets.

Figure 8 shows the daily water demands of the simulation and measurement for the toilets excluded the basins and slop sinks. Both of the results show the stability of values.

Table 4 shows the design values for F building, and daily and hourly values based on the simulation and measurement. The design values show over specification in comparison with the practical water consumption.

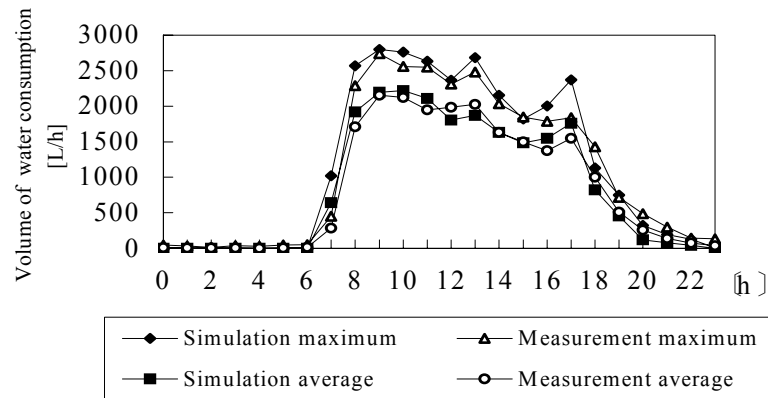


Figure 6 – Hourly water demands based on the simulation and measurement

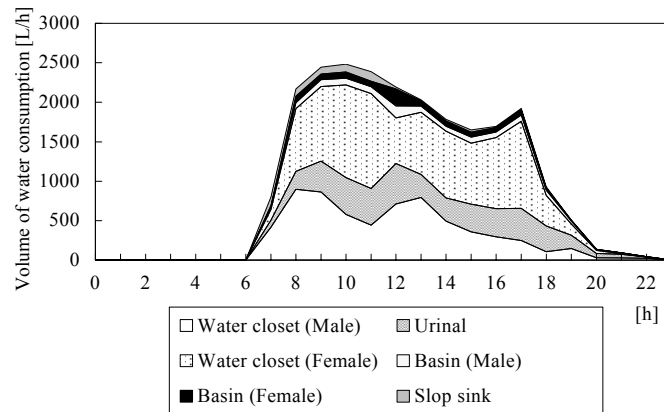


Figure 7 – Hourly water demands in each fixture usage based on the simulation

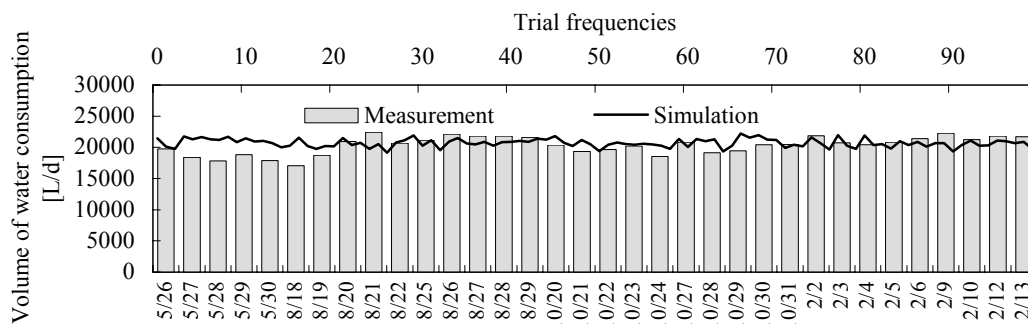


Figure 8 – Daily water demands based on the simulation and measurement

Table 4 – Design values, simulation and measurement values

		Daily water demands [L/d]	Hourly water demands	
			Average [L/h]	Maximum [L/h]
Design value		140,582	14,058	21,087
Simulation	Average	20,708	1,855	2,796
	Maximum	22,194		
Measurement	Average	20,344	1,800	2,737
	Maximum	22,424		

5. Estimation of water demands based on the difference of influential factors

In this chapter, we have the comparison of the water demands which are calculated

with the difference of the influential factors; the number of workers occupied in the office and the type of saving fixtures as an example of F building. And we show the usefulness to apply the simulation technique for the estimation of water demands.

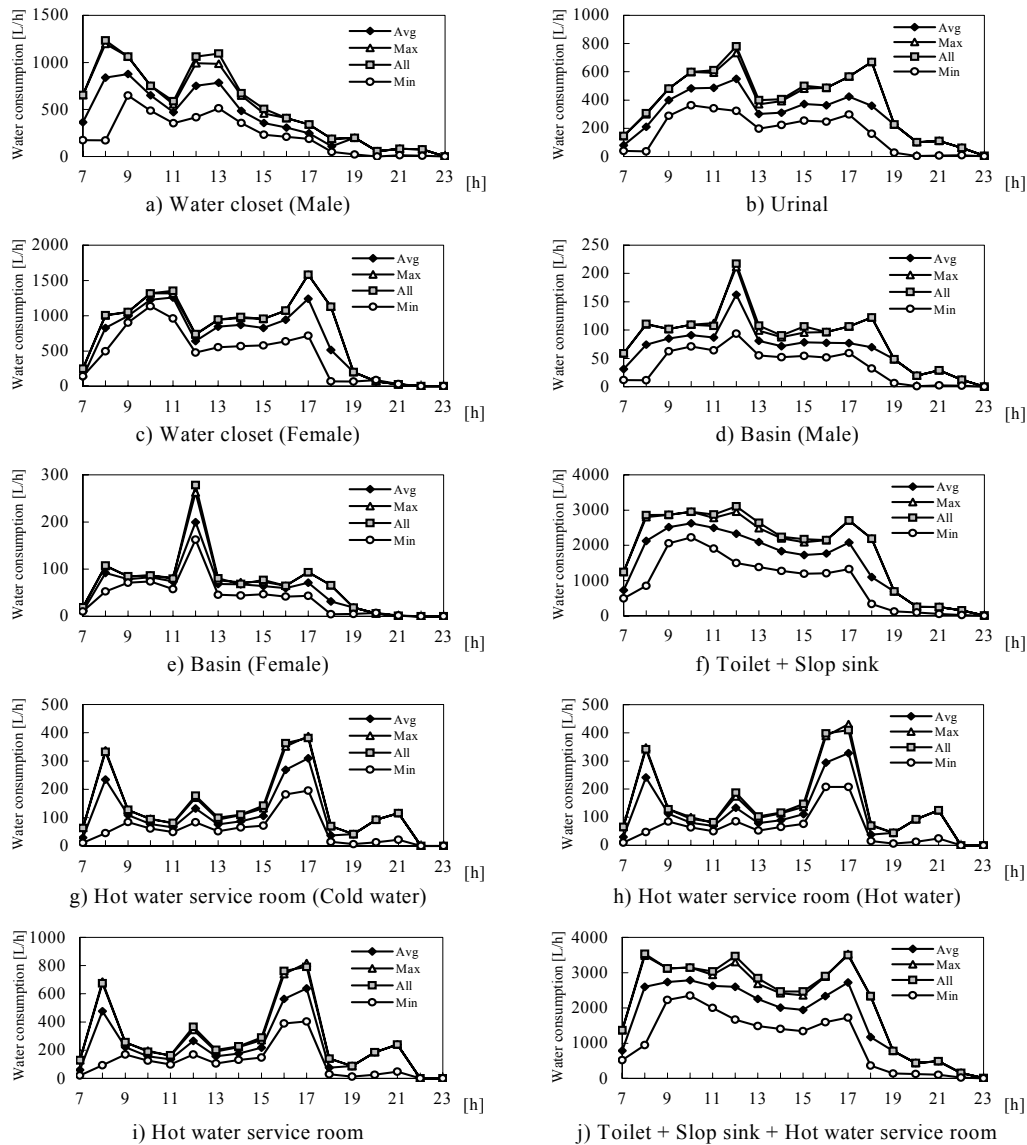


Figure 9 – Hourly water demands based on the simulation

5.1 Influence by the number of workers occupied in the office

We abbreviate the results of the instantaneous flow rates calculated by the simulation. Figure 9 shows the hourly water demands in the toilets and hot water service rooms calculated by the simulation, which was changed for the factors on the number of workers occupied in the office. The changing patterns were applied by the four models described in Chapter 3. Table 5 shows the average and maximum values of the hourly water demands in each pattern, and the ratios of each hourly load to the hourly load calculated on the average model.

From these results, it is easy to grasp the peak values and peak hours on the water demands in each changing pattern of the number of workers occupied in the office.

Figure 10 shows the daily water demands in each model. Also, Table 6 shows the

average and maximum values of daily water demands in each pattern, and the ratios of each daily load to the daily load calculated on the average model. These hourly and daily water demands estimated are applied to design the receiving tank, elevated tank, etc. Therefore, it is very important to grasp the characteristics of working environment in the offices on the accurate calculation for water demands.

Table 5 – Hourly water demands and ratios of each load to average load

		Model on the number of workers occupied in the office	Water closet + Urinal	Male toilet	Female toilet	Toilet + Slop sink	Hot water service room	Toilet + Slop sink + Hot water service room
Hourly water demands [L/h]	Average	Avg	1,933	1,056	1,052	2,159	300	2,459
		Max	2,333	1,353	1,193	2,597	388	2,986
		All	2,386	1,401	1,202	2,656	392	3,048
		Min	1,317	673	766	1,491	183	1,674
	Maximum	Avg	3,131	1,932	1,941	3,391	984	3,566
		Max	3,630	2,385	2,077	3,960	1,156	4,318
		All	3,630	2,566	2,077	3,960	1,147	4,282
		Min	2,609	1,316	1,673	2,906	742	3,043
The ratios of each load to the load calculated on the average model	Average	Max	1.21	1.28	1.14	1.20	1.29	1.21
		All	1.23	1.33	1.14	1.23	1.30	1.24
		Min	0.68	0.64	0.73	0.69	0.61	0.68
	Maximum	Max	1.16	1.23	1.07	1.17	1.17	1.21
		All	1.16	1.33	1.07	1.17	1.17	1.20
		Min	0.83	0.68	0.86	0.86	0.75	0.85

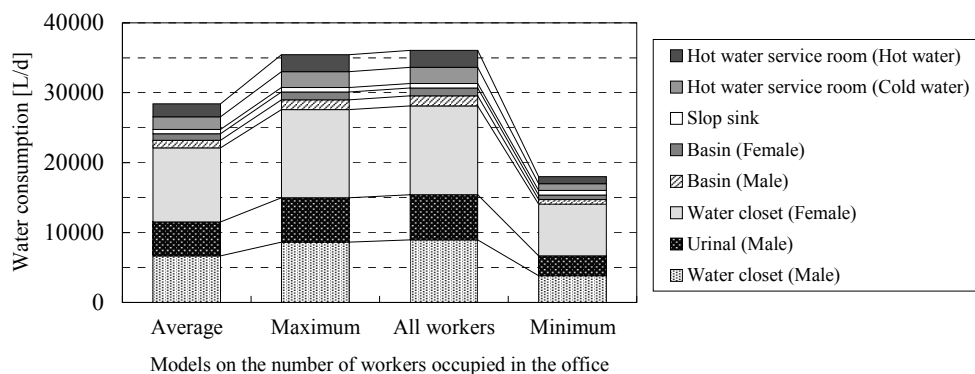


Figure 10 – Daily water demands in each model

Table 6 – Daily water demands and ratios of each load to average load

		Model on the number of workers occupied in the office	Water closet + Urinal	Male toilet	Female toilet	Toilet + Slop sink	Hot water service room	Toilet + Slop sink + Hot water service room
Daily water demands [L/d]	Average	Avg	22,101	12,602	11,519	24,767	3,653	28,420
		Max	27,579	16,396	13,716	30,758	4,668	35,426
		All	28,105	16,877	13,805	31,345	4,701	36,046
		Min	14,078	7,298	8,079	16,038	1,965	18,003
	Maximum	Avg	23,519	13,732	12,980	26,127	4,289	30,118
		Max	29,681	17,729	15,268	32,923	5,566	37,549
		All	29,990	18,186	15,160	33,372	5,156	38,069
		Min	15,150	8,541	9,118	17,317	2,558	19,291
The ratios of each load to the load calculated on the average model	Average	Max	1.25	1.30	1.19	1.24	1.28	1.25
		All	1.27	1.34	1.20	1.27	1.29	1.27
		Min	0.64	0.58	0.70	0.65	0.54	0.63
	Maximum	Max	1.26	1.29	1.18	1.26	1.30	1.25
		All	1.28	1.32	1.17	1.28	1.20	1.26
		Min	0.64	0.62	0.70	0.66	0.60	0.64

5.2 Influence applied the type of saving water for water closet

The simulation conditions shown in Table 1 except the conditions of male and female water closets are applied for the planning of saving water. Therefore, if we have planning to put the type of saving water for water closet, it is better to change the average values of duration time of water discharge, and flushing flow rate into 6.0 [sec], and 100 [L/min] respectively as for the simulation model.

The simulation was carried out with the same conditions shown in Table 1 except the conditions of male and female water closets that were mentioned above as an example of F building.

Figure 11 shows the instantaneous maximum flow rates that were calculated with the failure factor 0.1% and 5.0% for male and female water closets and male urinals. These values are compared with the saving water type and conventional type of water closet in the toilets. In case of the values calculated by the failure factor 0.1%, the maximum difference in each hour shows about 50 [L/min]. It affects the design of piping diameter for water supply network system.

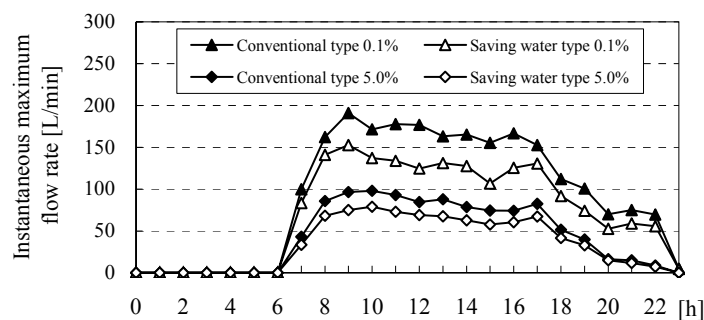


Figure 11 – Instantaneous maximum flow rates in the toilets (Water closet + Urinal)

Figure 12 shows the hourly values of saving water type in comparison with the values of conventional type. Also, Table 7 shows the daily and hourly values in comparison with each type. In this case, when we have planning of saving water types, the daily water demands composed by male and female water closets and male urinals is decreased about 12% against the conventional type. When we compare the daily water demands with the composition of male and female water closets, the saving water type

is decreased about 18% against the conventional type.

Therefore, it is very important for us to design the water supply system with the water saving fixtures.

The simulation technique based on the fixture usage is useful for the estimation of water demands under the different conditions.

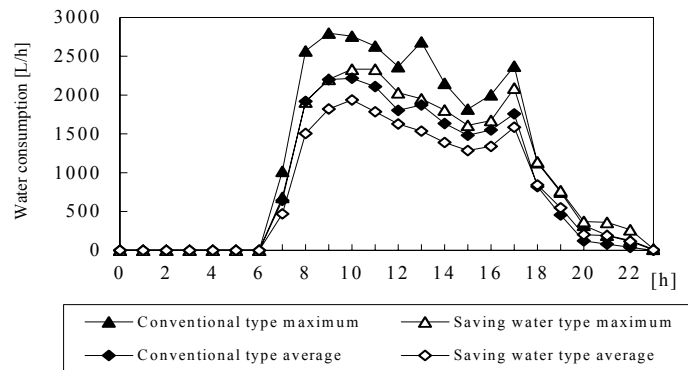


Figure 12 – Hourly water demands in the toilets (Water closet + Urinal)

Table 7 – Daily and hourly water demands

		Daily water demands [L/d]	Hourly water demands	
			Average [L/h]	Maximum [L/h]
Conventional type	Average	20,708	1,855	2,796
	Maximum	22,194		
Saving water type	Average	18,186	1,581	1,714
	Maximum	19,609		

6. Conclusion

We had measurement on the water consumption of each fixture in the toilets and hot water service rooms in the three office buildings, IN, D and F building, during the four seasons from March, 2002 to February, 2004.

In this paper, we proposed the calculation method for cold and hot water demands to apply the Monte Carlo Simulation technique. Based on the measurement results in the buildings mentioned above, we showed the calculation models for the toilets and hot water service rooms. Also, we showed the models on the number of workers occupied in the office based on the analyzed data of the other investigations in addition to the data of the three buildings.

We carried out the simulation by using these models, and calculated instantaneous flow rates, hourly and daily water demands in time series through a day.

The estimation results as an example of F building were similar to the measurement results. When we compared the simulation results with the calculation results by the existing methods used in the practical design, it was clarified that the differences of the results showed very large values. The values calculated by the existing methods had over specification for the plumbing design. We showed that the Monte Carlo Simulation technique was useful for the estimation of water demands changed by the influential factors in the buildings.

Acknowledgment

The authors wish to express their gratitude for the subsidy of science research from the Ministry of Education, Culture, Sports, Science and Technology (Project number: 13450237, Head investigator: Saburo Murakawa).

References

1. Saburo Murakawa, Hiroshi Takata: Development of the Calculating Method for Cold and Hot Water Consumption based on the Fixture Usage in the Time Series through a Day -A Case Study of Apartment House-, Proceedings of CIB/W62 International Symposium on Water Supply and Drainage for Buildings, pp.1-13, Iasi Romania, Sept. 2002
2. Saburo Murakawa, Hiroshi Takata, Daisaku Nishina: Development of the Calculating Method for the Loads of Water Consumption in Restaurant, Proceedings of CIB/W62 International Symposium on Water Supply and Drainage for Buildings, pp.1-14, Paris France, Sept. 2004
3. Hiroshi Takata, Saburo Murakawa, Yuko Yamane: Development of the Calculating Method for Loads of Water Consumption in the Office Buildings, Proceedings of CIB/W62 International Symposium on Water Supply and Drainage for Buildings, pp.249-264, Ankara Turkey, Sept. 2003
4. Hiroshi Takata, Saburo Murakawa, Daisaku Nishina, Yuko Yamane: Development of the Calculating Method for the Loads of Cold and Hot Water Consumption in Office Buildings, Proceedings of CIB/W62 International Symposium on Water Supply and Drainage for Buildings, pp.1-16, Paris France, Sept. 2004
5. Saburo Murakawa: Methods Described in “HASS206” and Suggestion for Calculation of Instantaneous Maximum Flow Rate of Water in Buildings, Technical Proceedings of the CIB/W62 International Symposium on Water Supply & Drainage for Buildings, pp.141-156, Washington D.C., Sept. 1992

Presentation of Authors

Saburo Murakawa is the Professor at Graduate School of Engineering, Hiroshima University
1-4-1, Kagamiyama, Higashi-Hiroshima City, 739-8527, Japan.



A Study on the Hot Water Consumption in a Hot Spa Facility

Naoki Yamamoto (1), Saburo Murakawa (2), Hiroshi Takata (3)

(1) m060480@hiroshima-u.ac.jp

(2) muraka@hiroshima-u.ac.jp

(3) takatah@hiroshima-u.ac.jp

(1) Graduate School of Engineering, Hiroshima Univ., Japan

(2) Graduate School of Engineering, Hiroshima Univ., Japan

(3) Graduate School of Education, Hiroshima Univ., Japan

Abstract

In designing and planning of building systems, we need the accurate estimation of energy consumption and the correct decision of performance and capacity. Therefore, it is important to survey and study on the actual condition of hot water consumption which is largely affected with energy consumption in each building. In Japan, many hot spa facilities, which are public bathhouses, are built because of the people's concern for health in these days. However, the data of hot water consumption which applies to designing and planning are insufficient. On the existing designing and planning, the volume of hot water consumption is estimated roughly and the hot water supply systems are not designed optimally. Therefore, the purpose of this study is to clarify the characteristics of hot water consumption of a hot spa facility located in Hiroshima City.

The objective hot spa facility has two bathrooms for male and female, a restaurant, and a massage room, etc. As for the hot water supply system, the hot water is heated by four electric water heaters, four CO₂ heat pump water heaters, and two hot water boilers. As for the measurements of hot water consumption and temperature, the measurements were carried out at four seasons over a year and all data were recorded in every one-minute. We obtained the data for the number of customers from the manager in this building.

Based on these data, at first, the number of customers in the restaurant and the bathrooms were analyzed and the customer's tendencies of fluctuation which divided into weekday, Saturday, and holiday were clarified. Next, the hot water consumption, temperature, and the energy consumption were analyzed. Finally, the efficiencies of hot water supply system were verified by the volume of energy supply and energy consumption.

Keywords

Hot water consumption, Hot spa facility, Hot water supply system, Energy consumption

1. Introduction

In recent year, we need the accurate estimation of energy consumption and the correct decision of performance and capacity in designing and planning of the building systems. Therefore, it is important to survey and study on the actual condition of hot water consumption which is largely affected with energy consumption in each building. Many studies of the loads of hot water consumption in various buildings such as houses, hotels, office buildings, etc. have been reported before. However, in hot spa facilities, the data of hot water consumption which applies to designing and planning are insufficient.

This paper shows the characteristics of hot water consumption and the efficiencies of hot water supply system by measuring cold and hot water, heavy oil and electric consumption, and cold and hot water temperature in a hot spa facility.

2. Outline of the investigation

2.1 Outline of the facility

This investigation was carried out for a hot spa facility located in Hiroshima City, Japan. The outline of the facility is shown in Table 1. The hot spa facility consists of two bathrooms for male and female, a restaurant, a massage room, etc. As for the cold water supply system, it has two water tanks to supply water to the restaurant and the bathrooms respectively. Hot water supplied to the restaurant is heated by four electric water heaters. And hot water supplied to the bathrooms is heated by four CO₂ heat pump water heaters and two hot water boilers. As for other equipment, hot spring water is supplied to the hot spa bathtubs by water pumps.

Table 1 - Outline of the facility

Location	Hiroshima City, Japan			
Building Type	Hot spa facility			
Constraction	1 story	Restaurant, Massage room, Shop, etc.		
	2 story	Bathrooms, Sauna		
Open hours	Bathrooms: 10 a.m.-1 a.m., Restaurant: 11 a.m.-11:30p.m.			
Term of Constraction	May～November, 2004		Scale	2 stories
Structure	Steel		Total floor area	3,589m ²
Cold water supply system	<Supply to bathrooms>	Water tank (150m ³)		
	<Supply to restaurant>	Water tank (15m ³)		
Hot water supply system	<Supply to bathrooms>	CO ₂ heat pump water heaters (Electricity)		
		60kW×4, Capacity (2500L×2×4)		
		Two hot water boilers (Electricity, Heavy oil) 930kW×2		
	<Supply to restaurant>	Heavy oil tank (20m ³)		
		Electric water heaters 5.4kW×4, Capacity (460L×4)		
	Hot water storage tank (15m ³)			
Other equipment	Hot spring water supply system, Hot spring water tank (6m ³)			

2.2 Outline of the measurement

The measurement was carried out through one year from spring, 2005. Table 2 shows the period of measurement. Figure 1 shows the distribution diagram of cold and hot water and the locations of meters and sensors for measurement. Heavy oil consumption which is supplied to hot water boilers is measured at M14. Cold water consumption (from M1 to M5) is measured by investigator who keeps a note of instrument reading on the date of setting up measuring instruments and the data capture. Other hot water consumption and temperature are measured automatically every one minute. In addition, we measure electric consumption every one minute to grasp how to operate and energy consumption of the heat source equipment. As for CO₂ heat pump water heaters, we measure cold and hot water consumption, electric consumption, and cold and hot water temperature around CO₂ heat pump water heaters every ten minutes.

Table 2 - Period of measurement

	Period of measurement	Date of data capture
Spring	1 May, 2005 ~ 30 June, 2005	13 May, 2 June, 1 July
Summer	7 August, 2005 ~ 4 September, 2005	23 August, 5 September
Autumn	15 October, 2005 ~ 13 November, 2005	31 October, 14 November
Winter	14 December, 2005 ~ 17 January, 2006	27 December, 11, 18 January

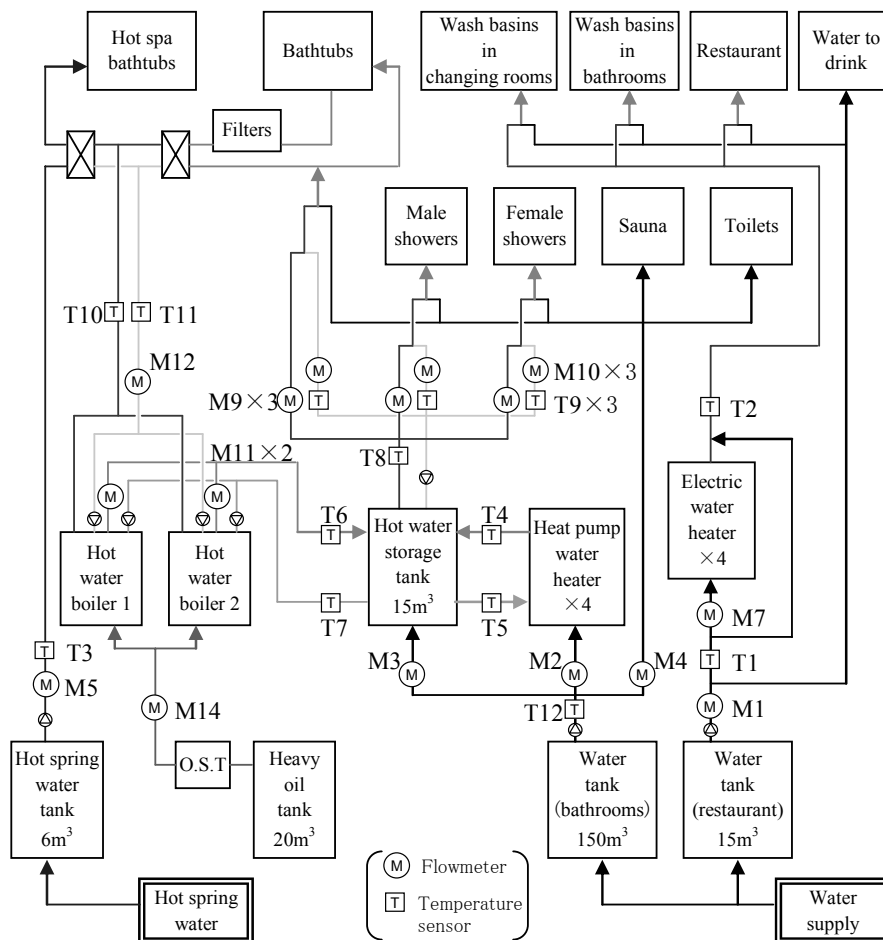


Figure 1 - Distribution diagram of cold and hot water

3. Fluctuation of the number of customers in the facility

Figure 2 shows the daily number of customers used the bathrooms and the restaurant in May, 2005 as an example. This figure shows the ratio of the number of customers in each day to the average number of them per day in May. The tendency of the fluctuation of the ratio is similar both in the bathrooms and in the restaurant. The ratios of weekdays are clearly different from the ratios of Saturday and holidays. Therefore, we divided them into 3 divisions; “weekday”, “Saturday” and “holiday”, and analyzed by the divisions.

Figure 3 shows the hourly number of customers used the bathrooms and the restaurant in autumn. This figure shows the ratio of the hourly number of customers to the average number of customers per day in each division. In the bathrooms, the number of customers increases from the evening to the night. Especially, the time-zones which have the largest number of customers are between 8 p.m. and 9 p.m. on weekday and Saturday, and between 5 p.m. and 6 p.m. on holiday. In the restaurant, the number of customers increases between noon p.m. and 2 p.m. for lunch time, and between 7 p.m. and 9 p.m. for dinner time. The largest hourly ratio in the restaurant is larger than that in the bathrooms and occupies 13%-17% of the number of customers per day.

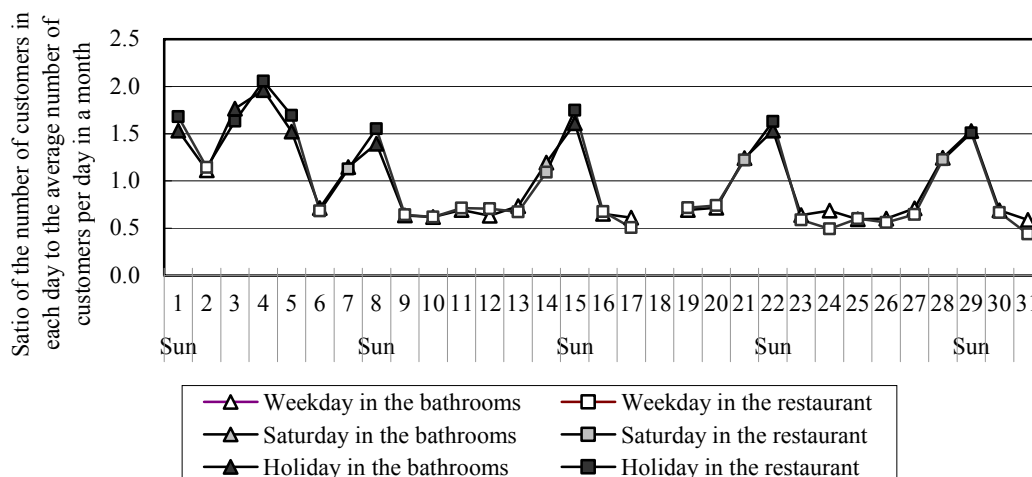


Figure 2 - Daily number of customers used the bathrooms and the restaurant in May, 2005

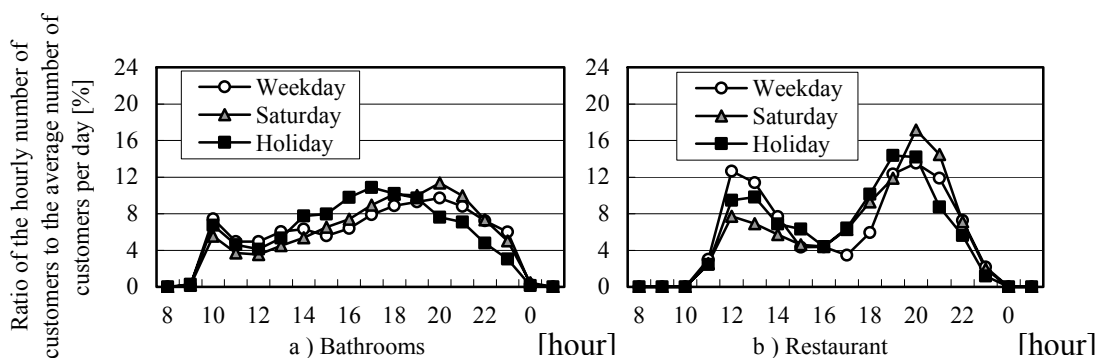


Figure 3 - Hourly number of customers used the bathrooms and the restaurant in autumn

4. Loads of hot water consumption

4.1 Volume of hot water consumption

Figure 4 shows the ratio of cold and hot water consumption in each season. The volume of hot water consumption is analyzed by converting to the volume of 60°C hot water consumption. As for the volume of hot water consumption in the restaurant, we presume that the hot water supply temperature from electric water heaters is 75°C. The ratio of the hot spring water consumption occupies 30%-37% of all water consumption. The ratio of hot water consumption, which is total hot water consumption in the bathrooms, the bathtubs, the restaurant, and the hot spa bathtubs, occupies 52%-65% of all water consumption in the facility.

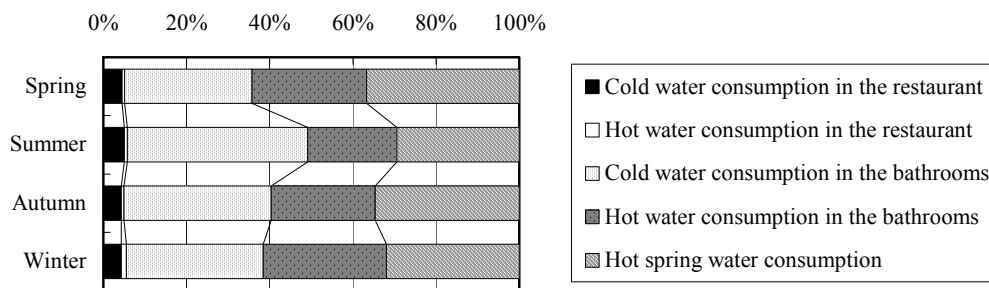


Figure 4 - Ratio of cold and hot water consumption in each season

Table 3 shows statistics of daily hot water consumption in the male bathroom, the female bathroom, the bathtubs, and the restaurant. The volume of hot water consumption in each system is calculated as the difference between the hot water consumption measured in the supply pipeline (M9) and hot water consumption measured in the return pipeline (M10). “Male bathroom” and “Female bathroom” in this table show the volume of hot water consumed mainly in taking a shower in each bathroom. As for the male bathroom, the female bathroom, and the restaurant, the volume of hot water consumption in winter is larger than that in summer, and the volume of hot water consumption on holiday is larger than that on weekday. These differences of the volume are affected by the fluctuation of cold water supply temperature and the number of customers. However, the difference of the volume of hot water consumption in the bathtubs is small as compared with other used systems. As for the volume of hot water consumption in the male bathroom and the female bathroom, the volume in the female bathroom is more 15%-40% than that in the male bathroom. The hot water consumption in the restaurant occupies a small ratio to the whole facility.

Table 4 shows the average hot water consumption per person and per day in each system. In each system, the values on Saturday and holiday which many customers visit are less than the values on weekday. Furthermore, as for the volume converted to 41°C hot water consumption, the volume of hot water consumption in the male and female

bathrooms is 68-88[L/person/day]. According to the previous paper by S. Murakawa, this volume is equivalent to the volume of hot water used sparingly in taking a shower.

Table 3 - Statistics of daily hot water consumption in the male bathroom, the female bathroom, the bathtubs, and the restaurant

		Spring			Summer			Autumn			Winter		
		Ave.	S.D.	Max	Ave.	S.D.	Max	Ave.	S.D.	Max	Ave.	S.D.	Max
Whole facility [m ³ /d]	Weekday	88.5	7.8	107.8	76.1	12.8	106.9	89.2	17.0	140.6	105.7	24.2	176.9
	Saturday	116.8	4.8	124.4	87.7	5.8	96.3	112.0	9.4	126.0	137.0	11.5	150.3
	Holiday	133.7	12.9	160.8	99.1	5.0	103.8	129.7	11.5	141.2	165.7	33.3	205.0
Male bathroom [m ³ /d]	Weekday	15.0	2.0	23.7	14.3	1.2	17.8	14.8	3.4	20.1	24.8	4.6	39.8
	Saturday	24.9	1.7	27.2	20.1	1.0	21.1	26.3	3.3	30.0	36.3	3.1	39.8
	Holiday	29.9	3.3	36.3	23.9	1.8	27.0	30.7	6.0	37.0	44.0	9.0	53.9
Female bathroom [m ³ /d]	Weekday	18.9	2.4	29.4	19.3	1.7	23.0	19.7	3.7	26.1	29.6	6.5	46.5
	Saturday	32.1	2.8	35.9	27.5	2.8	31.2	33.9	0.9	34.8	42.8	3.3	46.3
	Holiday	41.2	5.2	52.4	32.8	2.2	35.1	40.0	5.7	46.9	56.0	11.9	70.8
Bathtubs [m ³ /d]	Weekday	52.4	7.0	70.6	40.1	12.9	73.7	52.7	18.6	113.3	47.6	14.6	83.4
	Saturday	56.6	8.0	68.6	37.0	5.3	44.5	48.7	10.0	62.3	52.4	11.6	67.7
	Holiday	58.3	6.2	67.3	38.6	4.3	46.5	55.0	9.9	65.9	58.1	15.6	78.0
Restaurant [m ³ /d]	Weekday	2.1	0.5	3.7	2.5	1.1	6.2	2.0	0.4	2.6	3.7	2.4	10.6
	Saturday	3.2	0.5	3.9	3.0	1.2	4.7	3.1	0.4	3.5	5.6	3.9	11.4
	Holiday	4.4	0.6	5.1	3.7	0.7	4.8	4.0	0.4	4.7	7.6	2.3	10.7

Table 4 - Average hot water consumption per person and per day in each system

		Spring	Summer	Autumn	Winter
Whole facility [L/person/day]	Weekday	112.4	73.7	106.6	104.5
	Saturday	81.0	56.6	74.6	82.8
	Holiday	71.5	50.0	71.0	73.1
Male and female bathrooms [L/person/day]	Weekday	43.0	32.5	40.9	53.6
	Saturday	39.5	30.7	40.2	47.6
	Holiday	38.0	28.6	38.6	44.0
Bathtubs [L/person/day]	Weekday	66.8	38.8	63.4	47.4
	Saturday	39.3	23.9	32.4	31.8
	Holiday	31.2	19.6	30.2	25.8
Restaurant [L/person/day]	Weekday	8.1	6.7	8.3	11.4
	Saturday	6.8	6.0	7.3	11.5
	Holiday	6.6	5.2	6.9	11.4

Figure 5 shows the hourly volume of hot water consumption in each system. The fluctuation of hot water consumption in the bathrooms is similar to the fluctuation of the number of customers in the bathrooms. Therefore, the difference of volume is large among the 3 divisions of the week. In the bathtubs, large volume of hot water is consumed by pouring water after the back washing of filters between 1 a.m. and 2 a.m.. The volume of the hot water consumption for the back washing decreases somewhat in winter. In the restaurant, the volume in the daytime of winter is the largest of all seasons because hot water supply temperature became higher than ordinary temperature owing

to trouble of the mixing bulb. In night, the volume of hot water consumption between 11 p.m. and midnight is the largest in a day because of a cleanup before closure.

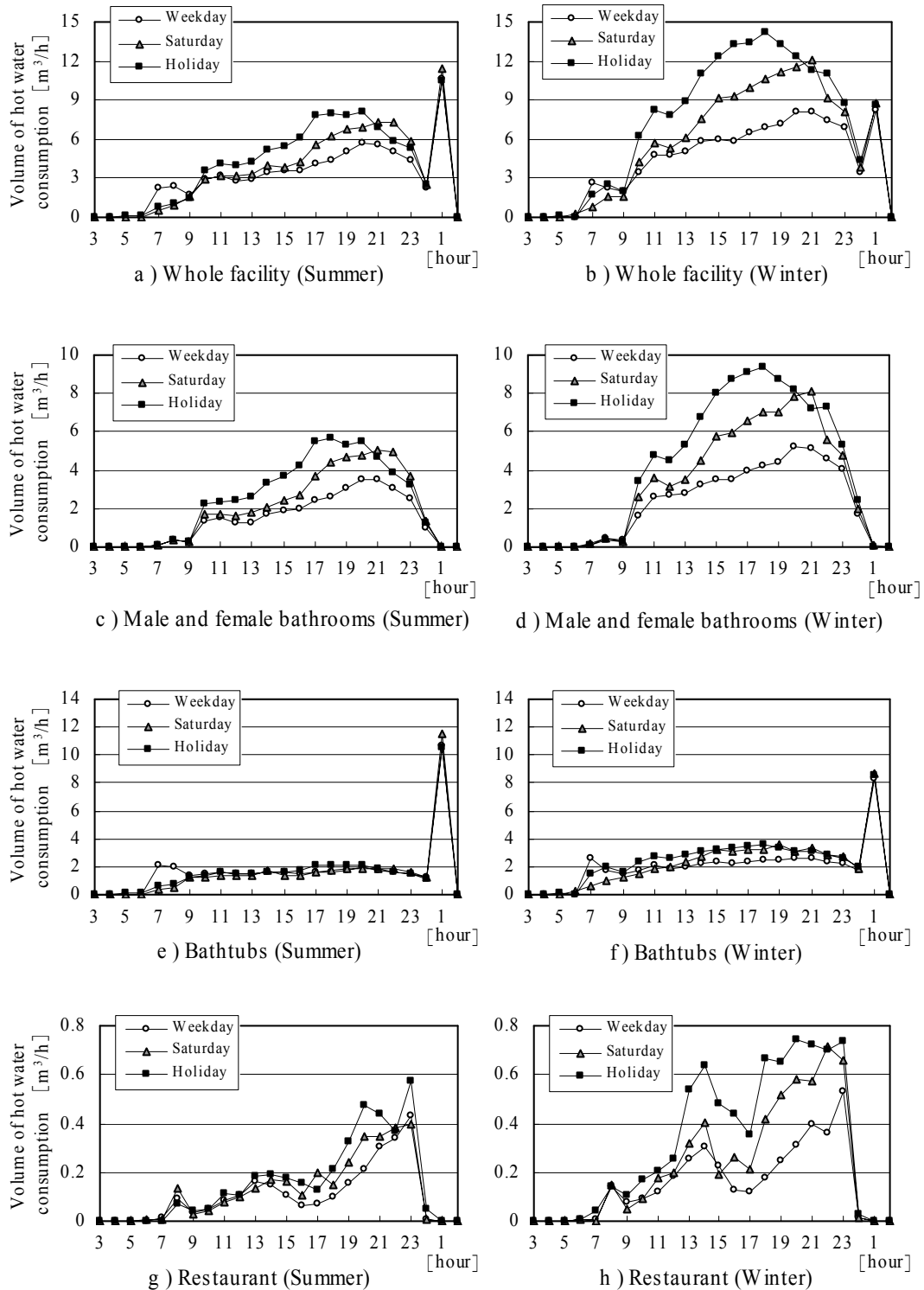


Figure 5 - Hourly volume of hot water consumption in each system

4.2 Heat loads for hot water storage tank

Figure 6 shows the cumulative distributions for the fluctuation of every ten minutes heat loads for hot water storage tank through a day in summer and winter. The heat loads for hot water storage tank are “Input heat loads” and “Output heat loads”. Input heat loads mean the heat loads to rise temperature of water in hot water storage tank by CO₂ heat pump water heaters and hot water boilers. And, output heat loads mean the total heat loads to consume hot water in the bathrooms and the bathtubs, the plumbing heat loss by circulation of hot water, etc. Both loads in winter are larger than those in summer. Furthermore, in summer, Input heat loads have spare volume in comparison with output heat loads. However, in winter, the difference of each load is little. Therefore, the accumulated input heat loads have similar fluctuation pattern with the accumulated output heat loads in the bathrooms and the bathtubs.

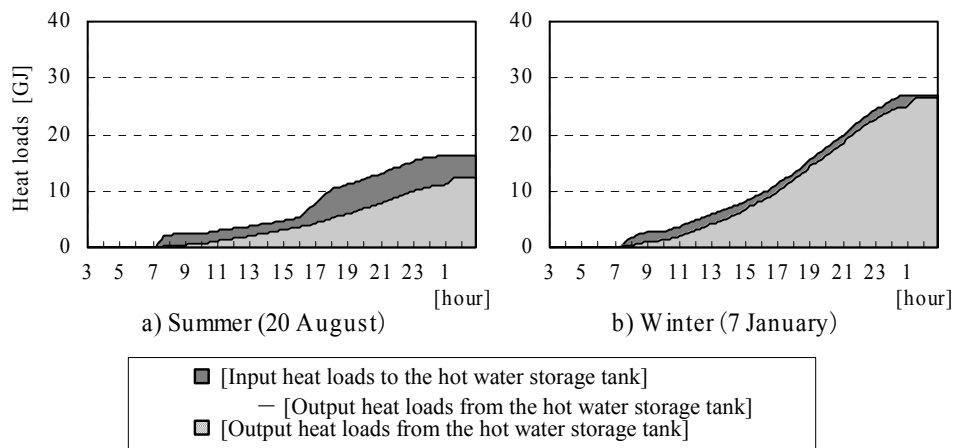
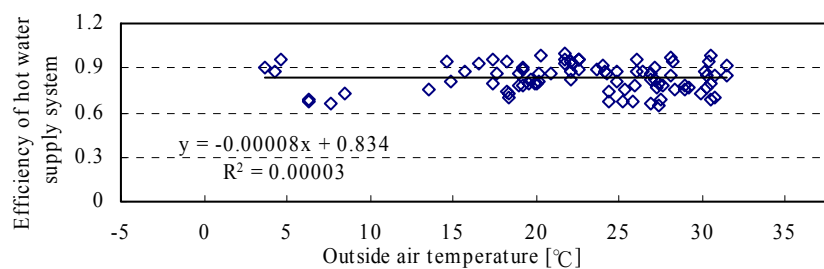


Figure 6 - Cumulative distributions through a day for the fluctuation of every ten minutes heat loads

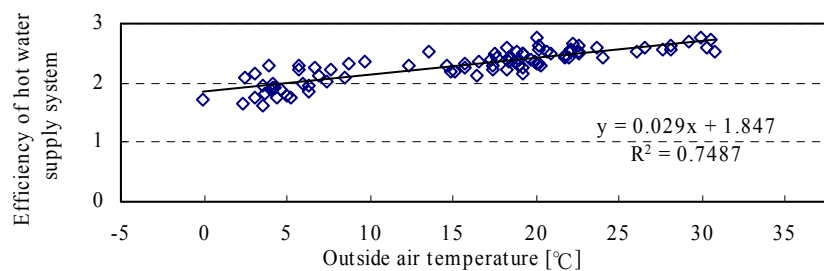
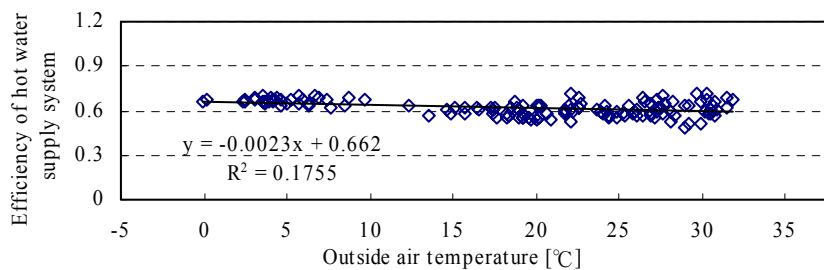
5. Efficiencies of hot water supply system

The efficiencies of hot water supply system are calculated as the ratio of the consumed energy consumption to the supplied energy consumption in a day. The consumed energy consumption shows the heat loads consumed to rise water supply temperature by each hot water supply system. Furthermore, the supplied energy consumption is converted to the primary or second energy of the electric and heavy oil consumption in each hot water supply system. As for the efficiencies of hot water boilers and the whole facility, we adopted the converted value to the second energy because the boilers and the whole facility used both electric power and heavy oil as energy source. As for the efficiencies of electric water heaters and CO₂ heat pump water heaters, we adopted the converted value to the primary energy because the heaters used only electric power as energy source.

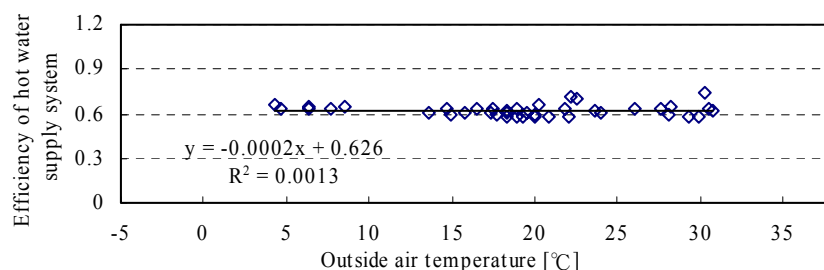
Figure 7 shows the relationships between the outside air temperature and the efficiencies of hot water supply system. The efficiencies of electric water heaters hardly correlate with the outside air temperature, and the average value is about 0.83 in each season. In CO₂ heat pump water heaters, the efficiencies tend to become larger as the outside air temperature become higher. In hot water boilers, the average value of efficiency is about 0.62. The values tend to become smaller slightly with rise of the outside air temperature. As for the whole facility, the values show similar tendency to the hot water boilers.



a) Electric water heaters

b) CO₂ heat pump water heaters

c) Hot water boilers



d) Whole facility

Figure 7 - Relationships between the outside air temperature and the efficiencies of hot water supply system

6. Conclusions

In this paper, we studied about the characteristics of hot water consumption of a hot spa facility located in Hiroshima City.

First, we clarified the tendencies of the fluctuation of the number of customers in the bathrooms and the restaurant. As a result, each tendency of weekdays is clearly different from the ratios of Saturday and holidays. Next, we showed the statistics of daily and hourly hot water consumption in the male bathroom, the female bathroom, the bathtubs and the restaurant. The fluctuation of hot water consumption is influenced by the water temperature and the number of customers. Finally, the efficiencies of hot water supply system were calculated as the ratio of the consumed energy consumption to the supplied energy consumption in a day. As for the whole facility, the efficiencies are between 0.55 and 0.75 through a year.

Acknowledgements

The authors wish to express their gratitude for the great cooperation by Chugoku Electric Power Co., Energia Real Estate Co. and people involved in the hot spa facility.

References

1. S.Murakawa et al. – Analysis on the cold and hot water consumption in each usage of office buildings , A study on the calculating method of cold and hot water supply demands based on the analysis of water usage in the time series (Part 1) : Investigation Reports of Architectural Institute of Japan, No.589, March 2003.
2. S.Murakawa et al. – A study on the design requirement of equipment for taking a shower (Part 2) : Investigation of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, No.58, June 1995.

Presentation of Author

Naoki Yamamoto is the Graduate student at Graduate school of engineering, Hiroshima University.

1-4-1, Kagamiyama Higashi-hiroshima
739-8527, Japan



CFD Simulation on Stagnant Area in Bathtubs at Spa Facility

N. Ichikawa (1), Y. Kondo (2), Y. Nagasawa (3), T. Ogasawara (4)

(1) nichij@js7.so-net.ne.jp

(2) Yasushikondoh@aol.com

(3) nagasawa@aae.kagoshima-u.ac.jp

(4) g0474003@sc.musashi-tech.ac.jp

(1) Professor, Dr. Eng., Tokyo Metropolitan University, Japan

(2) Professor, Dr. Eng., Musashi Institute of Technology, Japan

(3) Research associate, Dr. Eng., Kagoshima University, Japan

(4) Graduate Student, M. Eng., Musashi Institute of Technology, Japan

Abstract

In Japan, Legionellosis infectious disease has been a serious problem in big bathtubs with water circulation system installed in hotels, spa, public bath, training facilities etc. Legionella occurs in the bathtub by various causes. It can be supposed that a bathtub has such infectious risk when water is stagnant in it. This paper presents CFD (Computational Fluid Dynamics) simulation on water flow within an experiment tank and the stagnant region in the tank is studied numerically. The CFD can predict the detail of water flow in the tank and the results are compared to the experiment. In this paper, the age of water is proposed as an index of exchange efficiency of water in a tank. The age of air is widely used as an index of ventilation efficiency by HVAC (Heating, Ventilation, and Air Conditioning) engineers, and the similar index, i.e. the age of water, is applied to water exchange efficiency.

Keywords

Bathtub, Legionella, CFD (Computational Fluid Dynamics), Water Exchange Efficiency, Age of Water

1 Introduction

In Japan, Legionellosis infectious disease has been a serious problem in big bathtubs with water circulation system installed in hotels, spa, public bath, training facilities etc. Legionella occurs in the bathtub by various causes. It can be supposed that a bathtub has such infectious risk when water is stagnant in it. In Society of Heating, Air-conditioning and Sanitary Engineers of Japan (SHASE), the committee on the measures of Legionella was set up for three years from 2003 ¹⁾. The structural review of the circulation type bathtub system was performed in the subcommittee, and F. Kiya (chairperson at committee), N. Ichikawa, et al. were reported the result of research in CIB-W62 symposium 2005 ²⁾. In order to reducing such infectious risk, it is also important that the stagnant region in the bathtub is predicted and the location of the water inlet of the bathtub is planed so as not to cause the stagnant area with the possibility of breeding Legionella bacteria.

The age of air is widely used as an index of ventilation efficiency by HVAC (Heating, Ventilation, and Air Conditioning) engineers to evaluate ventilation properties in room. In this paper, the age of water, which is similar to the age of air, is proposed as an index of exchange efficiency of water in a tank. The stagnant area in water tanks with different position of water inlet is studied with index of exchange efficiency of water in a tank based on CFD simulation.

2 Water Exchange Efficiency

The age of air is widely used as an index of ventilation efficiency by HVAC engineers. This index which is proposed by M. Sandburg et al. 3), S. Murakami 4) shows the indoor ventilation properties. This index can evaluate the air exchange efficiency and it means the time of life in three stages, such as the age of air, the residual life time of air and the residence time of air. In this paper, in order to examine the exchange efficiency of water in a tank, the age of water, the residual life time water and the residence time of water are proposed. These indexes correspond to the air exchange efficiency. The illustration of water exchange efficiency is shown in figure 1, and the outline of the water exchange efficiency is described below.

(A) The Age of Water

This index is expressed time from when fresh water enters in the tank to when water arrives at the point P in the tank. When this value is small, it means that water reaches at the point P quickly, and water will be supplied effectively to the point. On the other hand, when this value is large, it means that it will takes long time that water arrives at the point and water reaching at the point is polluted.

(B) Residual Life Time of Water

This Index is expressed the time until the water at a certain point is passed out of the tank. When this value is small, it means that the water at the point P is passed out of the tank immediately and the pollutant generated at the point P is exhausted without diffusing in the tank. On the other hand, when this value is large, it means that exhausted time is long. Therefore, the pollutant generated at the point affect the wide area in the tank.

(C) Residence Time of Water

This index is expressed time from when water is supplied in the tank to when water is exhausted outside the tank, and it means time to stay in the tank. This value is calculated by adding the age of water to the residual life time of water. When this value is small, it means that water is supplied and exhausted effectively.

In this paper, the dimensionless time normalized by nominal exchange time calculated as the water tank volume divided by the flow rate, is used. Therefore, when the value is smaller than 1.0, it means that water is supplied effectively.

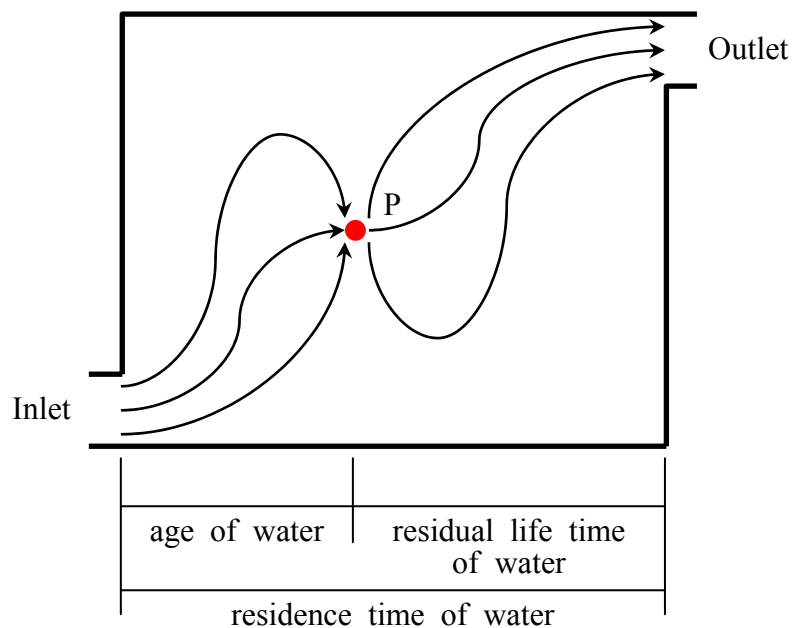


Figure 1 - Illustration of Water Exchange Efficiency

3 Outline of CFD Simulation

3.1 Analyzed Model

The analyzed model is shown in figure 2. This model was applied size (2m wide, 2m long, and 0.6m depth) of the tank which is a condition of experiment water tank ^{1), 2)}. The water outlet is located on the upper of one wall, and the location of water inlet is parallel to that of outlet. The conditions of CFD simulation are shown in table 1. The turbulence model is Standard k- ϵ model, and simulation is conducted with under isothermal condition.

In this paper, some cases with the different locations of water inlet are supposed and the stagnant area in water tank is studied with the water exchange efficiency based on CFD simulation.

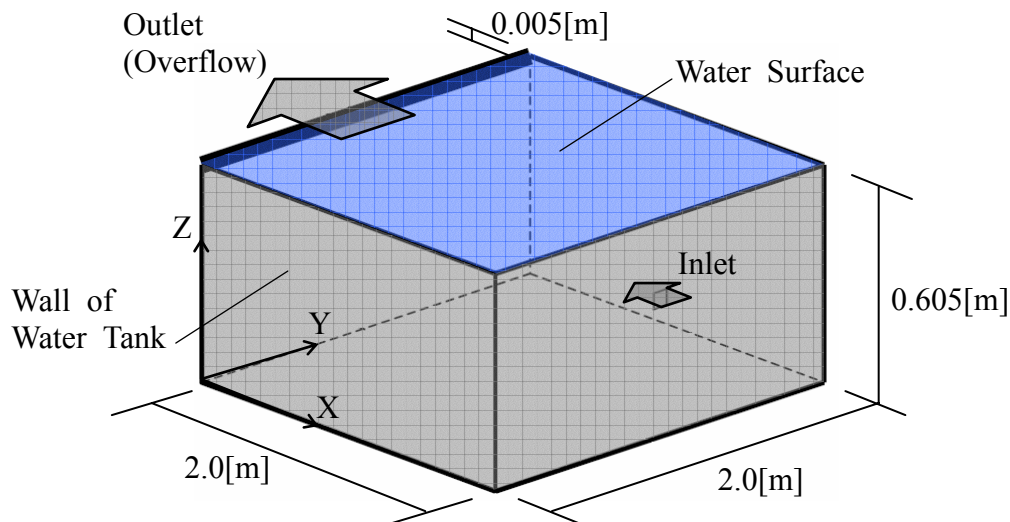


Figure 2 - Analyzed Model of Water Tank

Table 1 - Conditions of CFD Simulation

Model Size	X (2.0[m]) x Y (2.0[m]) x Z (0.605[m])
Mesh	X (27) x Y (42) x Z (28) = 31,752 [meshes]
Dynamic Coefficient of Viscosity	1.0×10^{-6} [m ² /s]
Turbulence Model	The Standard k- ϵ Model
Inlet Conditions	$Q_{in}=100$ [L/min] ($U_{in}=2.1$ [m/s]), $Re_{in}=58,500$
Outlet Conditions	$Q_{out}=100$ [L/min] ($U_{out}=0.17$ [m/s])
Surface Conditions	Water Surface: Free Slip Wall Surface: Generalized Log Law (Velocity)
Thermal Conditions	Isothermal

3.2 Case Studies

In this simulation, four cases shown in figure 3 are analyzed. These cases are different from the location of water inlet. The water inlet of Case 1 is located at the center of Y direction and the level from the bottom of the water tank is 0.4[m]. That of Case 2 shown in figure 3(b) is located at the middle of Y direction as Case 1, but the level is lower than that of Case 1 and the inlet is located at 0.2[m] from the bottom. The simulated region of these two cases is supposed to be a half of model because the shape of tank is symmetry. In Case 3 and Case 4, the water outlets are located at 0.2[m] from one wall in Y direction, but the level of water outlet in Case 3 is different from that in Case 4. The results of simulation are compared at the X-Y plane shown in figure 3.

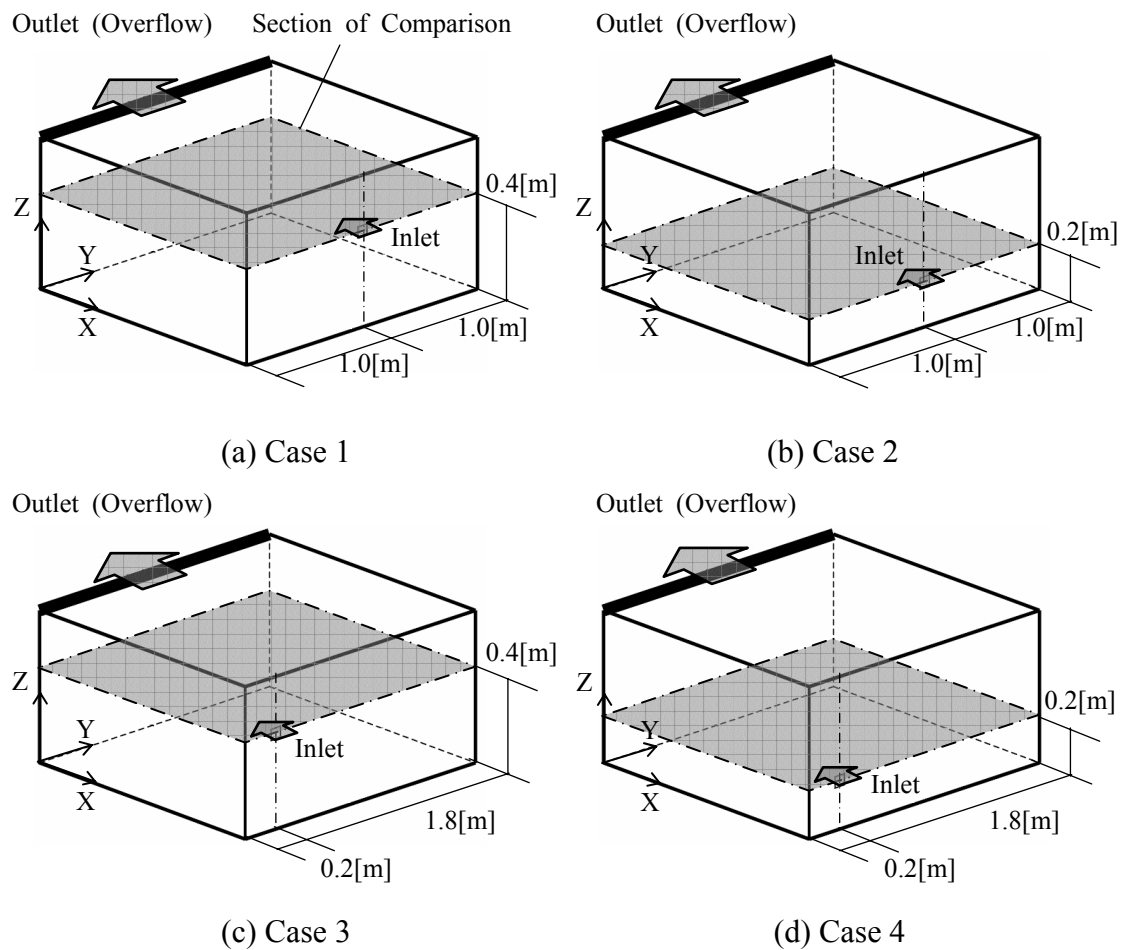


Figure 3 - Analyzed Cases

4 Results and Discussion

4.1 Result of Water Exchange Efficiency

(a) The Age of Water

The distributions of the age of water on four cases with the different positions of the water inlet are shown in figure 4. In these simulations, the circulating flow due to the influence of the wall, which is on the opposite side of the inlet, was reproduced. In Case 1 and 2, two circulating flow were formed in the tank, and in case 3 and 4, one circulating flow was formed in the tank. In the area where the value of the age of water is smaller than that of 1.0, water is efficiently supplied. And the areas where the value is larger than that of 1.0 appear at the corner of the tank and near the jet flow by the circulating flow.

(b) Residual Life Time of Water

The distributions of the residual life time of water are shown in figure 5. In the area where the value is smaller than 1.0, water is passed out of the tank immediately and the contaminants in this area is exhausted without diffusing in the tank. In Case 1 and 2, the areas that are larger than 1.0 were observed at the corner in the tank. It considered that water is exhausted at once compared with Case 3 and 4, and the risk of breeding bacteria in Case 1 and 2 is lower than Case 3 and 4.

(c) Residence Time of Water

The distributions of the residence time of water are shown in figure 6. When this value is larger than 1.0, it means that time to stay in the tank is long and it is easy for water in this area to be polluted. The risk of polluting water in the vicinity of the water inlet is low because water is supplied and exhausted effectively in all cases.

4.2 Stagnant Region

The stagnant regions of four cases are shown in figure 7. As described above, in the region where the value of residual life time of water is larger than 1.0, water stay in the tank for long time and the contaminants generated in this region is affected across the water tank. In this paper, the stagnant region is supposed the region where the value is larger than 1.075. The locations of the water inlet is effected the distribution of the stagnant region.

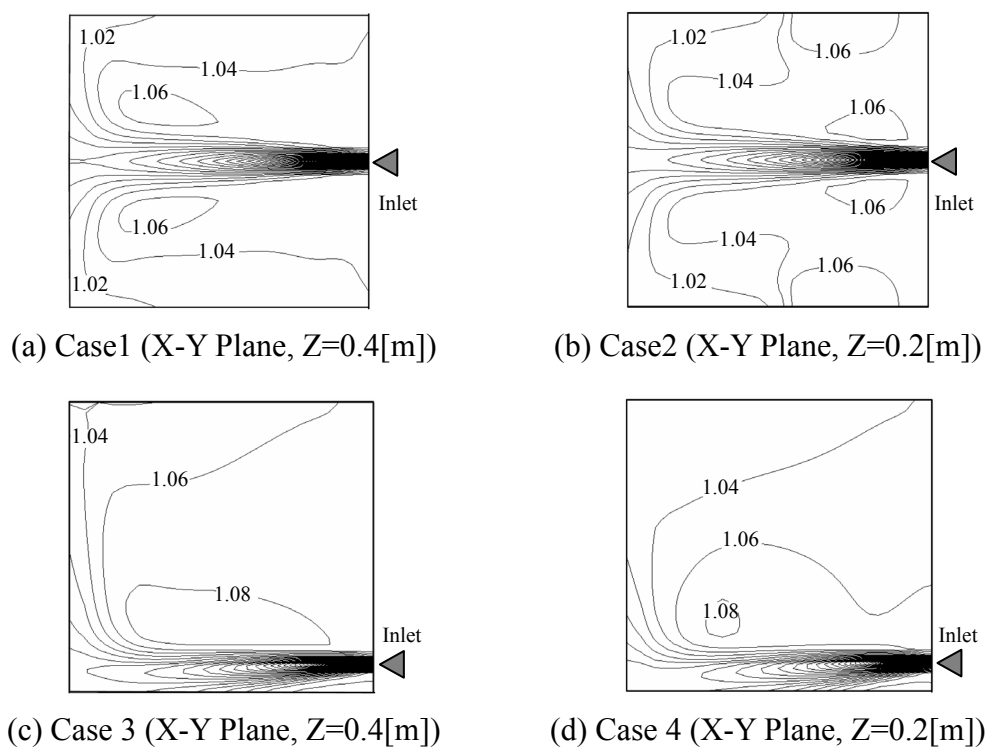


Figure 4 - The Distribution of Age of Water

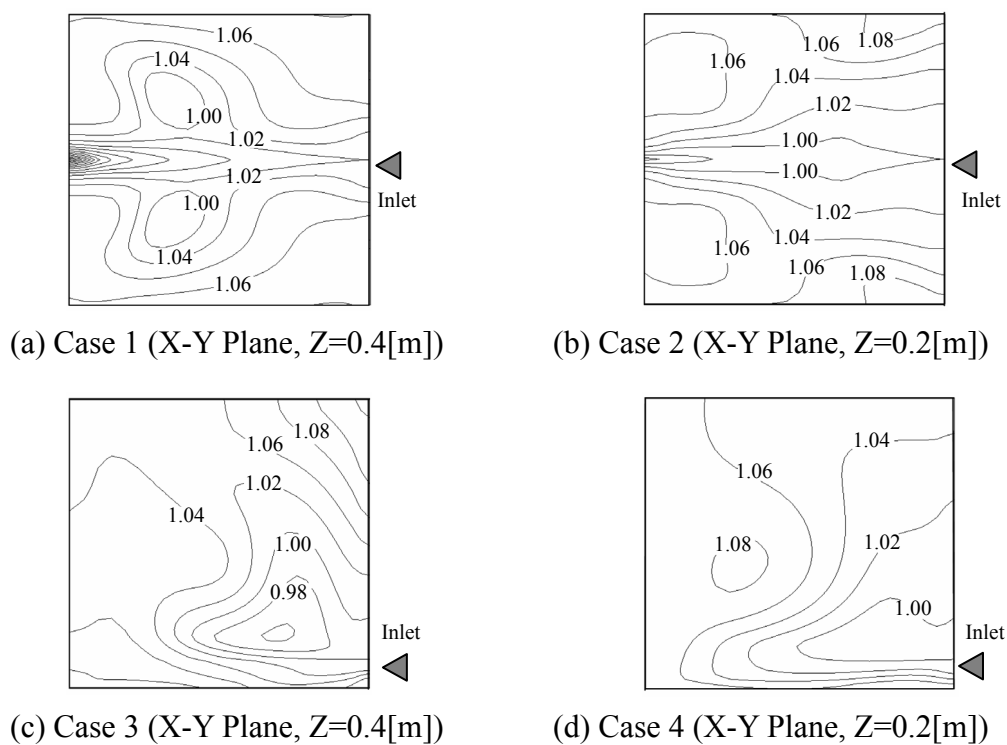


Figure 5 - The Distribution of Residual Life Time of Water

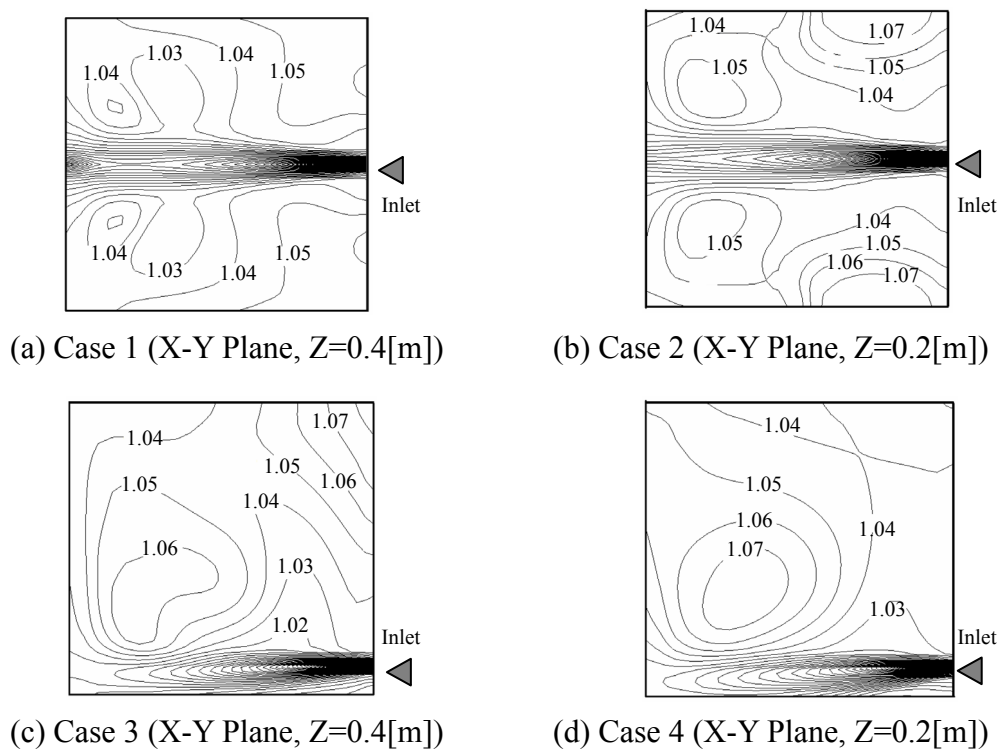


Figure 6 - The Distribution of Residence Time of Water

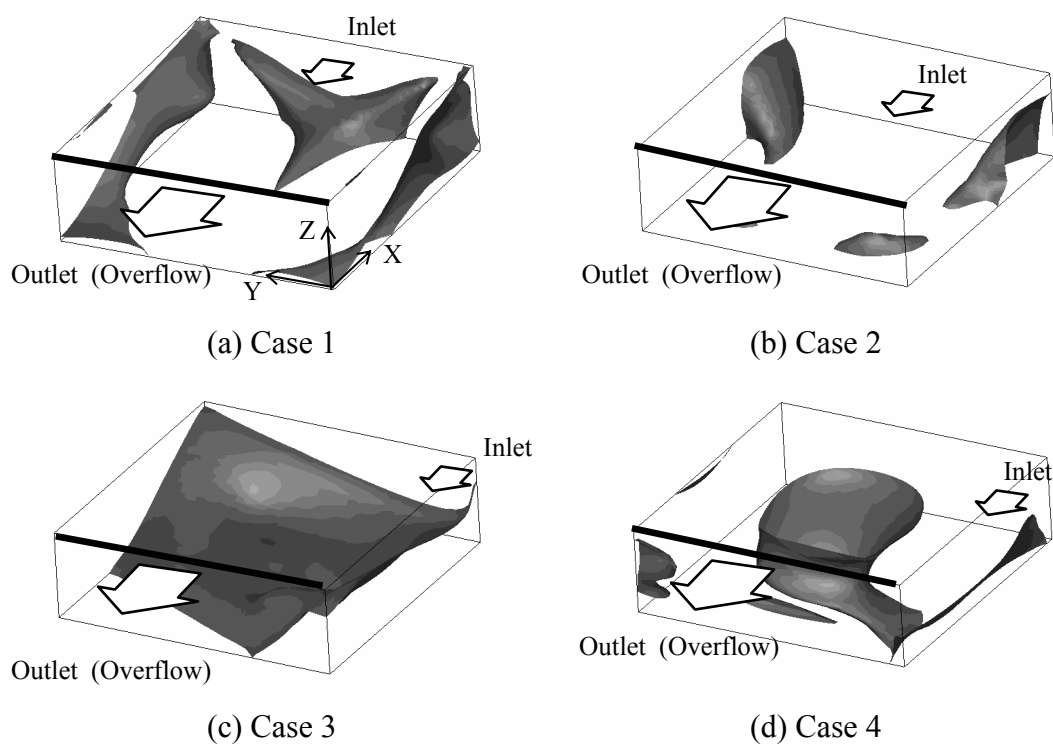


Figure 7 - Comparison of Stagnant Region

5 Categorization of bathtub shapes

The shape of the bathtub, is based on the architectural plan decided by the architect or the owner's likes and taste. Therefore, it is difficult to categorize bathtub shapes for various existing bathtubs. However when analyzing fluid dynamics of bathtubs, it is necessary to have some categorization of shapes. Furthermore when conducting computer simulation of CFD it becomes very important. Therefore we the thesis writers have started to investigate shape of the bath dimension, position, dimension, numbers, and flow rate etc. of the inlet and outlets from bath facilities architectural blueprints.

Table 2 is a example of categorizing bathtub shapes. Here we have created 4 major bathtub categories and further subdivided each category. Type1 is the basic regular form for 4 types. Type 2 is an altered form of the basic form. Type 3 is a combination form (Type 1+Type 2). Type 4 is free design form (bathtubs that do not fit into the above categories).

Table 2 - Categorization of bathtub shapes

	Shape of bathtub
Type 1	Basic regular form (rectangle, polygon, circle, ellipse)
Type 2	Altered form of Type 1
Type 3	Combination form (Type 1+Type 2)
Type 4	Free design form

6 Conclusions

This paper reported on the analysis of water flow inside the bath using CFD and categorization of bath shapes. The conclusions of this research are as follows.

- (1) we proposed it is possible to create an estimating method for stagnant water inside circulating bath systems by applying the concept of ventilation index (age of air) as water exchange efficiency.
- (2) although it was a limited conditions of analysis, we reached the following conclusions from the experiment and CFD.
 - (a) it is possible to recreate the experiment of flow inside the bath using CFD.
 - (b) it is possible to estimate the region of water stagnation from the water exchange index (age of water, residual lifetime of water, residence time of water)
- (3) proposed categorization of bath shapes which was considered difficult, and

futile in Japan. This paper represents the conception of water exchange efficiency, such as the age of water, which is similar to the age of air and is proposed as an index of exchange efficiency of water in a tank. And CFD simulation were carried out for the analyzed model of water tank and the stagnant area in water tanks with different position of water inlet is studied with index of exchange efficiency of water in a tank based on CFD simulation.

7 References

- 1) Report of the committee (SHASE): Countermeasure of Legionella in the bath facilities, 2005.3
- 2) Fumitoshi Kiya, Noriyoshi Ichikawa, et al.: Recent Movement for Countermeasure to Legionella in the Public Bath in Japan, CIB-W62 Symposium, 2005.9
- 3) M. Sandberg and M. Sjoberg: The use of moments for assessing air quality in ventilated rooms, Building and Environment, 18, 181-192, 1983
- 4) Shuzo Murakami: Computational Environment Design for Indoor and Climates, University of Tokyo Press, 2000.9

8 Presentation of author

Noriyoshi Ichikawa is professor at Tokyo Metropolitan University, Graduate School of Urban Environmental Sciences, Department of Architecture and Building Engineering. 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.



A circulation type bathtub system affects water saving greatly. He studies water saving positively for approximately 20 years. This study was conducted as a part of the “Comprehensive Verification Method for water saving effectiveness of housing sanitary facilities”, program 2004 (Representative ; M. Otsuka) supported by Ministry of Education, Culture, Sports, Science and Technology of Japan

Change in Water Consumption in a Quarter of a Century and Study on Water Load Calculation Method

Shinji KOSAKA, KOSAKA Consultants Ltd.

Abstract:

Water consumption in buildings will be determined by many factors, such as number of occupants, the saturation level of water saving plumbing fixtures, etc.

The water consumption in buildings, for example, office buildings, department stores, hotels, hospitals, etc., at present, in Japan, has decreased sharply, to a level of about 50% of the water consumption 25 years ago. Factors that influence the water consumption in buildings were examined.

The following are the report and study on the estimated calculation method of the water consumption (Water Load Calculation Method-WLCM), based mainly on the number of occupants, the ratio of men and women, the kinds of plumbing fixtures and the frequencies of use of plumbing fixtures.

Keywords:

Water Consumption, water load calculation method, water supply system

1. Introduction

There is a tendency of increasing in domestic water consumption per person, with a rise in the standard living. However, on the contrary, water consumption in buildings, such as office buildings, department stores, hotels, hospitals, etc., has a tendency of decreasing, recently, in lieu of increasing in domestic water consumption. Water supply system for buildings, in Japan, has special characteristics of installing receiving tanks in many buildings. The capacity of a receiving tank is, in many cases, determined as about 1/2 of the water consumption per day in the building. The water consumption per day has been calculated with the use of an original unit that is derived

from statistically treated actual measurements of a completed building. For example, in case of an office building, the original unit of the water consumption is 50 liters per day for men, and 100 liters per day for women. However, with the increase of complex use buildings, with the difference of working hours, with the difference in the ratio of men and women, and with the improvement of water saving plumbing fixtures, a new calculation method of assuming water consumption per day, by establishing design conditions, is considered necessary. Determination of an excessive capacity of receiving tank based on the past and old data may lower residual chlorine concentration due to a long time detention of water in the receiving tank. This is not desirable from a standpoint of hygiene.

Conditions of water supply system in buildings, in Japan, a change in water consumption for the past 25 years, and primary factors that cause a decrease of water consumption, were examined. At the same time, Water Load Calculation Method of assuming daily water consumption and examples of test calculations are stated herein.

2. Water supply system in Japan

Method of supplying city water to a building, after detention of water in a receiving tank, is prevailing in Japan, at present, in lieu of supplying city water directly to a building. Until recent years, supply of city water directly to a building of over 3 stories, has not been admitted by water utility managers, due to the reason that the pressure of the city water main distribution pipe was set at about 200kPa. **Fig.-1** shows the number of Tokyo metropolitan government institutions in which receiving tanks are installed. Number of institutions in which a receiving tank of less than 10 m³ capacity was installed were 192,942, and that of more than 10 m³ capacity was installed were 29,890, in 2004. **Fig.-2** shows the percentage of different types of water supply system installed in the institutions that were completed in 1984, 1994 and 2004, respectively. When compared with those in 1984, the percentage of each street pressure water service system-SPWSS and pressure water service system-PWSS was increased to 20%, in 2004. However, booster pump system-BPS, pressure tank system-PTS and gravity water supply-GWS are still installed in approximately 80% of the buildings. Receiving tanks are installed in all booster pump system-BPS, pressure tank system-PTS and gravity water supply-GWS.

As shown in **Fig.-1** (Right), the installation of receiving tanks has a tendency of decreasing, with the beginning of the use of pressure water service system in about 1992, in Japan.

However, there are many earthquakes in Japan and therefore, due to the reasons that a minimum of functions of hospitals can be secured, for several days, with the supply of water from receiving tanks, even if the supply of city water were interrupted by earthquakes, and from a standpoint of disaster prevention, receiving tanks are still installed in most of the hospitals.

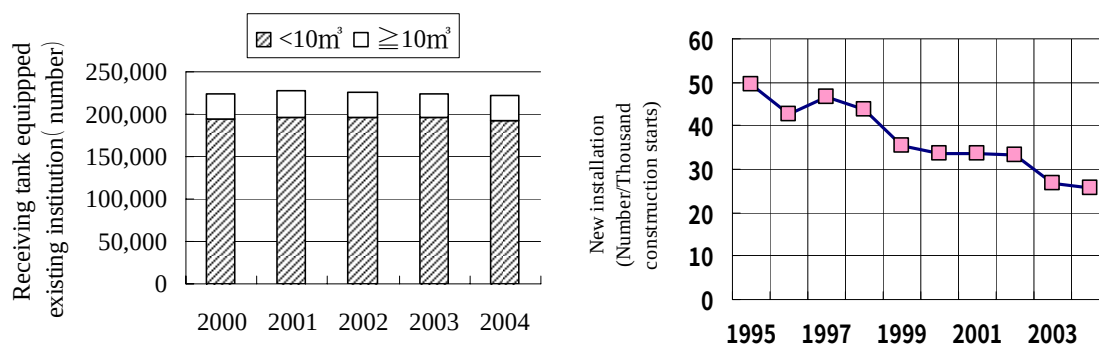


Figure1 Number of existing receiving tank (Tokyo) and new installation of receiving tank *1), 2)

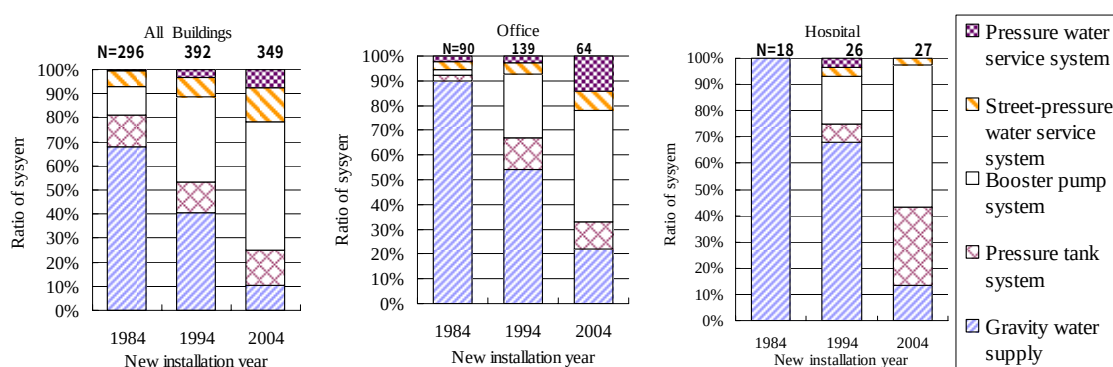


Figure 2 Water supply system in Japan *3)

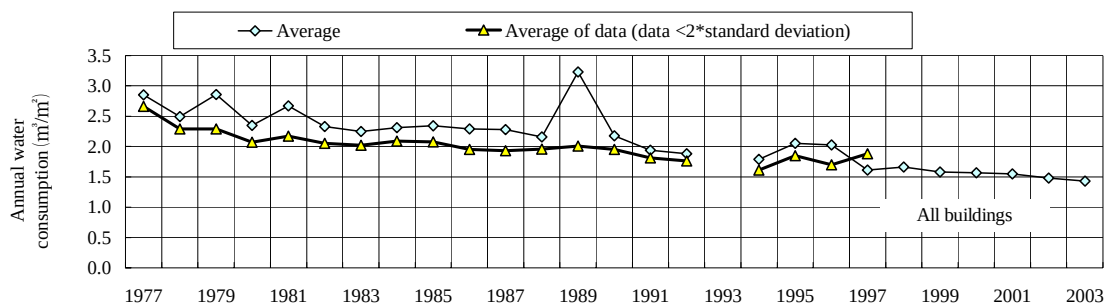
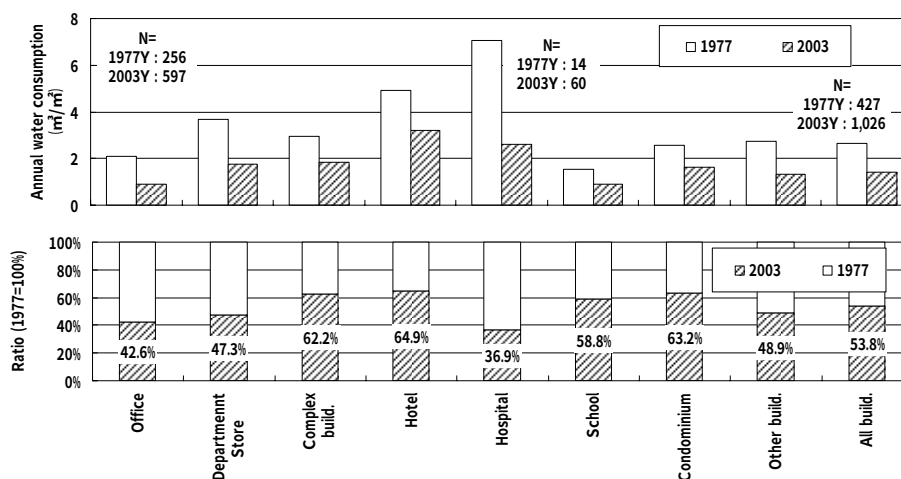
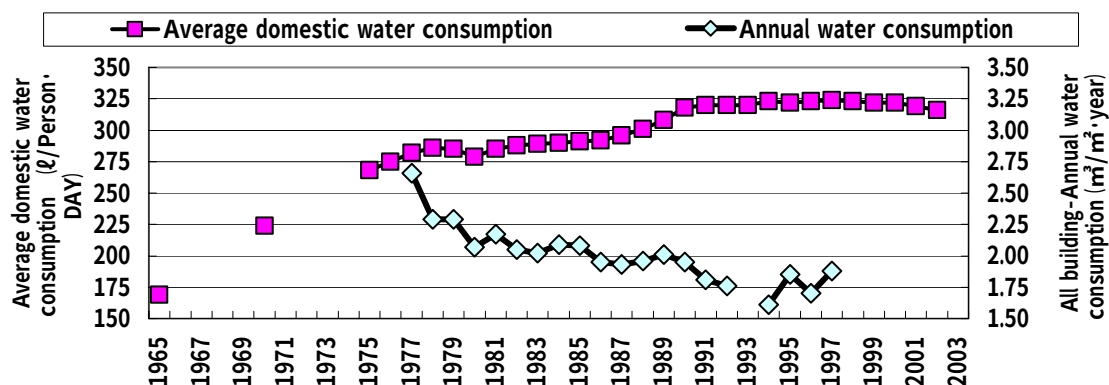
3. Change in water consumption and the primary factors

In view of annual water consumption per unit of square meter, for the past 25 years, water consumption in 2003 is drastically decreased to a degree of 50% of that in 1977, in many building uses, as shown in **Fig.-3** and **Fig.-4**. Annual water consumption per unit of square meter and domestic water consumption per day per person in all buildings are as shown in **Fig.-5**. This shows that the water consumption per unit of square meter of buildings has a tendency of continuously decreasing, while domestic water consumption is increasing. Primary factors of decreasing water consumption are considered as follows:

- Increase of the use of water saving plumbing fixtures (There is a change in standard specifications stated in design drawings. However, there is no data on shipment.)
- Increase of vending machines and increase of the shipment of mineral water, as shown in **Fig.-6**.
- Increase of non-potable water supply system (water recycling system) as shown in **Fig.-6**.
- Decrease of makeup water consumption as a result of decreasing of number of cooling towers due to the use of air cooled condensing units, as shown in **Fig.-6**.
- Increase of occupancy areas per person in office buildings is as shown in **Fig.-7** and

Fig.-8.

As a factor for increasing of water consumption in buildings, there is an increase of women workers, as shown in **Fig.-9**. However, it is considered that the primary factors as stated in above a. through e. have more impact on the decrease of water consumption.

**Figure 3 Change in average water consumption (m³/m² year) *4)****Figure 4 Change in average annual water consumption (m³/m² year) *4)****Figure 5 Daily domestic water consumption & annual water consumption *4), 5)**

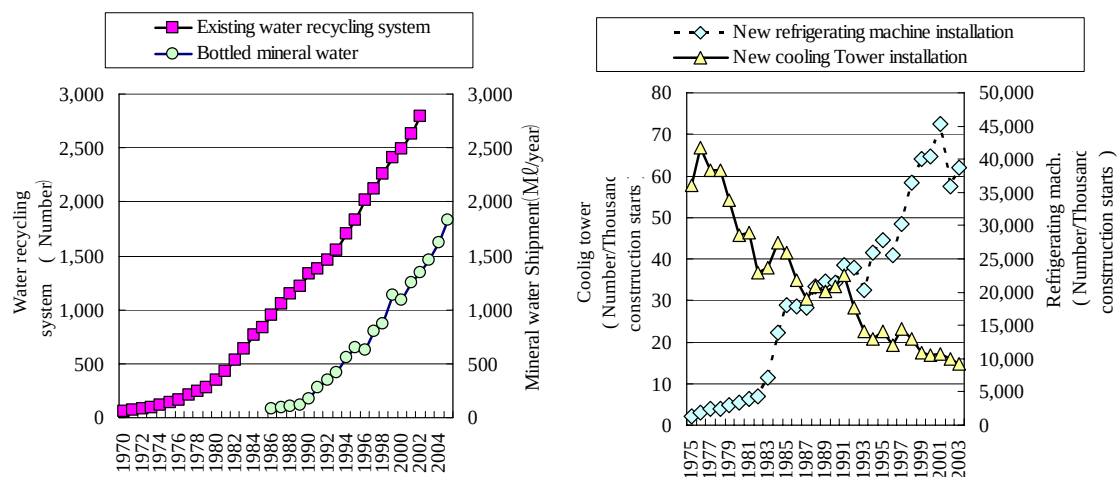


Figure 6 Water consumption decrease factor *5), 6)
Left: Increase of water recycling system & mineral water shipment
Right: Decrease of new installation of cooling towers

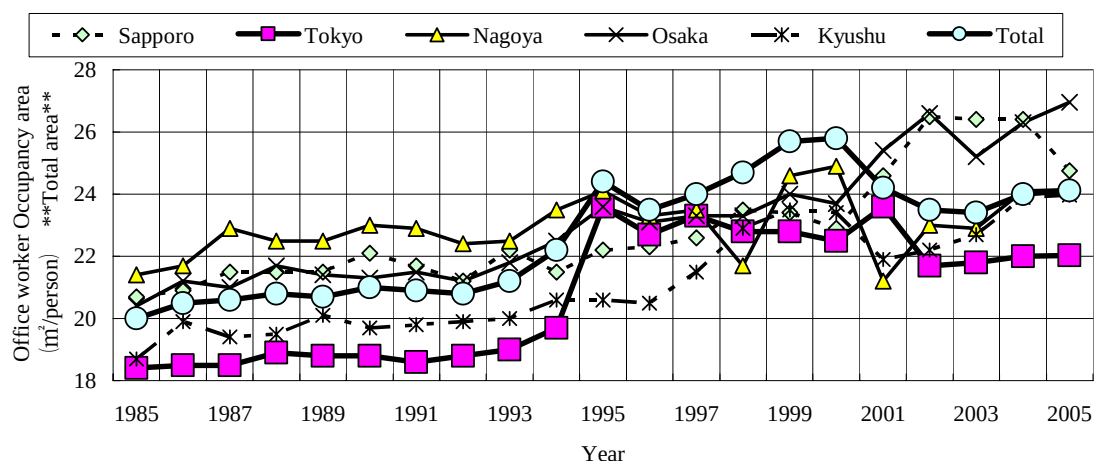


Figure 7 Office workers Occupancy area *7)

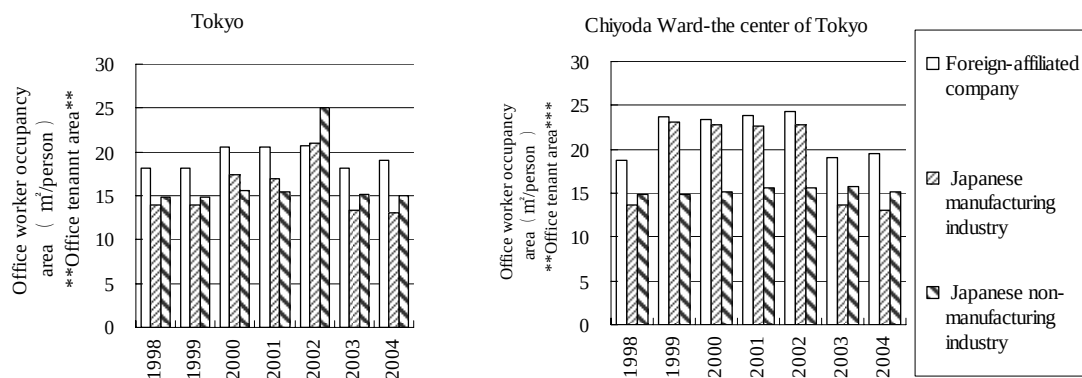


Figure 8 Office workers Occupancy area (Japan-Foreign) *7)

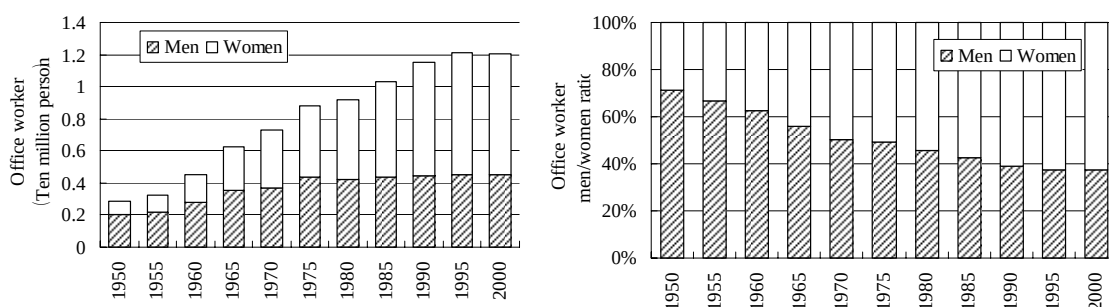


Figure 9 Change of the number of men and women workers and the ratio *8)

4. Method of calculations of water consumption (Water Load Calculation Method)

In designing air-conditioning system equipment, heat load calculations will be performed. In designing plumbing system, and in selection of equipment and devices, such as receiving tanks, Water Load Calculation Method, based on the conditions of scales and uses of buildings, building occupants and plumbing fixtures will be proposed. A summary of flow of calculations is as shown in **Fig.-10**. For heat load calculations, hourly load will first be calculated. On the other hand, in the case of Water Load Calculation Method, daily water load, or water consumption will first be calculated. Hourly load, or maximum hourly water consumption can be calculated from the patterns of use of water during 24 hours.

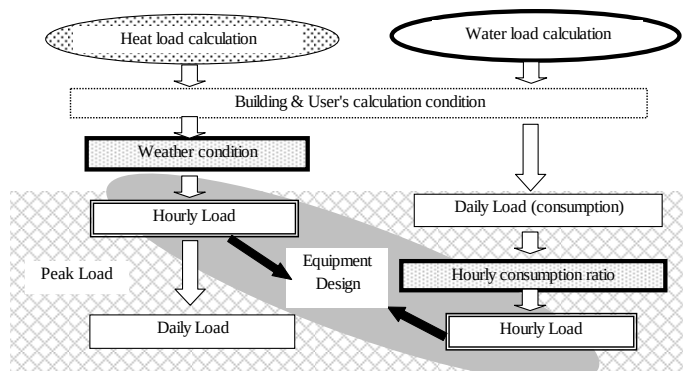


Figure 10 Water load calculation and heat load calculation *9)

Water Load Calculation Method will use the following items for calculation.

- Water consumption by the act of building occupants.
- Water consumption due to building scale and equipment capacity.
- Water consumption for landscaping, water spreading and other uses.
- Others.

4.1 Water consumption by the act of building occupants

Many of the items out of “a. Water consumption by the act of building occupants” are calculated based on the use of plumbing fixtures as a result of physical demand of persons. Water consumption per fixture is calculated based on the following formula.

Water consumption per one use of fixtures is established as shown in **Table-2**.

Frequencies of use per hour (Times/Hour) as shown in **Table-2** are derived so that calculations can be made in line with the duration or number of hours persons are staying in a building, based on the frequencies of use of water closets and urinals per day as shown in **Table-1**.

Factors given in **Table-2** are the factors to calculate the number of times that a flush valve is operated during per use of a water closet. Water consumption is calculated by establishing a sort of water. Sort of water "1" shows potable water and sort of water "2" shows non-potable water.

Rotation given in **Table-3** is to show the steady flow of customers for the calculation of water consumption in stores, etc.

Plumbing fixture water consumption (Liters / m² a day) W_{Lf} is calculated as follows:

$$W_{Lf} = P_f \times F_u \times D_s \times R_o \times F_a \times F_b$$

P_f : Plumbing fixture water consumption (Liters / Time) Table-1

F_u : Frequency of use per hour (Times / Hour) Table-2

D_s : Duration of staying in a building (Hours / Day) Table-3

R_o : Rotation (Times / Day) Table-3

F_a : Factor No. 1 **F_b** : Factor No. 2

Table-1

Frequencies of use of water closet and urinal *10)
(During normal office work hours)

Sex	Water closet	Urinal (Urine)
	Times/Day	Times/Day
Men	0.4	2.9
Women	0.2	2.7

Table-2 Conditions of water load calculations (Plumbing fixtures) *9), 10), 11)

Plumbing fixture	Water consumption		Use times of Plumbing fixture		Factor	Sort of water	Plumbing fixture cleaning		
	Non-water saving	Water saving	Men	Women			Number	Cleaning Times	Usage rate
	ℓ/Time	ℓ/Time	Times/h	Times/h			Number/m ²	Times/Day	%
Water closet	15	10	0.047	0.326	1.0	2*	0.0047	1	300
Urinal	6	4	0.320	-	1.0	2*	0.0047	1	300
Lavatory	10	5	0.367	0.326	1.0	1*	0.0025	1	100

Note: 1* potable water, 2* non-potable water

Floor cleaning 1ℓ/m²

There are cases that it is not possible to specify the data for water consumption per one use, like the water consumption for bathing, shower, restaurant, coffee shop, etc., and there are cases that it is difficult to separate the fixtures, when multiple of fixtures are used simultaneously. In these cases, water consumption will be calculated based on

the water consumption per one use, with the use of past statistic data, etc.

If detailed data are available as a result of future investigations, calculations will be made with the use of water consumption for each plumbing fixture.

4.2 Water consumption due to building scale and equipment capacity

”b. Water consumption due to building scale and equipment capacity” includes makeup water load for equipment and cleaning. Makeup water for cooling towers is calculated based on the cold heat source capacity per unit of floor area by type of use. Water consumption per unit of floor area is used for calculation of cleaning of a general type floor and kitchen floor. Water consumption for cleaning of plumbing fixtures is calculated assuming the frequency of use based on the number of fixtures per unit of square meter, by type of use, derived from as-built building service data. In case actual number of plumbing fixtures and cooling towers are known already, these values will be used.

4.3 Water consumption for landscaping, water spreading and other uses

”c. Water consumption for landscaping, water spreading and other uses” includes those to be used everyday throughout a year or to be used periodically. “Water consumption per minute, “Water consumption x the time to be used” will be calculated. Water consumption for these should be calculated separately, since there is not much data available in the past statistic values and also in order to grasp the ratio of these against the entire water consumption.

5. Examples of test calculations of water consumption

5.1 Conditions of test calculations

Method of using the original unit of 50 Liters / Day for men and 100 Liters / Day for women, that was used for calculation of water consumption for office buildings, cannot calculate the effects of water saving plumbing fixtures and the influence of number of operation of flushing valves. Test calculations of daily water consumption in office buildings, where a percentage of water consumption, due to the act of building occupants, is comparatively large, were made with the use of Water Load Calculation Method, proposed this time. Makeup water for cooling towers was not calculated. Potable water and non-potable water (flushing water) were separately calculated as designated by the sort of water as shown in **Table-2**. Calculations were made assuming the actual situations with the use of water consumption per use of a fixture as shown in **Table-2** and frequency of use per hour. In Japan, there are cases that a flush valve is operated more than once during each use of the fixture. According to some data, men operate a flush valve 1.5 times, while women operate a flush valve 2 times,

during each use of the water closet, as shown in **Table-4**.

Daily water consumption varies by the conditions of occupant density, ratio of men and women, duration of time staying in the office, etc. Test calculations were made as to 16 cases, based on the conditions as shown in **Tables-2, -3** and **-4**. As a result of the test calculations, examinations on the use of buildings, on the change of the use of buildings, on the effects of the use of water saving plumbing fixtures, on the optimization of waste water treatment system with the understanding of flushing water, etc., will be possible.

Table-3 Conditions of water load calculation (Persons) *9)

Case NO.	Person	Person density	Work or Stay hour	Rotation	Men & Women ratio (%)	
		Person/m ²	h/Day	Times/Day	Men	Women
1~4	Office worker	0.1	9	1	70	30
	Guest	0.01	1	1	50	50
5~8	Office worker	0.1	9	1	80	20
	Guest	0.01	1	1	50	50
9~12	Office worker	0.15	9	1	70	30
	Guest	0.01	1	1	50	50
13~16	Office worker	0.15	9	1	20	80
	Guest	0.01	1	1	50	50

Table-4 Water load calculation (Case study list) *9)

CASE NO	Worker density (Person/m ²)		Ratio Men:Women		Plumbing fixture		Flush valve operation time (Men/Women)	
	0.1	0.15	7:3	2:8	Non-water saving	Water saving	1.0/1.0	1.5/2.0
Offic-1	○		○		○		○	
Offic-2					○			○
Offic-3						○	○	
Offic-4						○		○
Offic-5				○	○		○	
Offic-6					○			○
Offic-7						○	○	
Offic-8						○		○
Offic-9		○	○		○		○	
Offic-10					○			○
Offic-11						○	○	
Offic-12						○		○
Offic-13				○	○		○	
Offic-14					○			○
Offic-15						○	○	
Offic-16						○		○

5.2 Results of calculations

Results of calculations for daily water consumption in office buildings of the total floor area of 10,000 m², are as shown in **Table-5, Fig.-11, -12, -13** and **-14**. The results show that a daily water consumption, in some office building of the same scale, becomes approximately 3.6 times of other office buildings, depending on the conditions of ratio of men and women, whether water saving plumbing fixtures are adopted or not. With the use of Water Load Calculation Method and depending on the building conditions, daily water consumption can be calculated, and lowering of residual

chlorine concentration due to a long time detention of water in the receiving tank can be prevented with the selection of optimum receiving tank. Also, the control of water level in the receiving tank may prevent the lowering of residual chlorine concentration. The ratio of potable water and non-potable water (flushing water) can be calculated as shown in **Fig.-11**, and rationalization of water system separation by use and of planning of water recycling system can be made.

Table-5 Results of daily water load in office buildings

CASE	1 : Potable water	2 : Non-potable water	Total water	Potable and Non-potable water ratio		Unit Water Supply Quantity		Water Supply Quantity Office area=10,000m ²	
	ℓ/m ² Day	ℓ/m ² Day	ℓ/m ² Day	1 : Potable water	2 : Non-potable water	ℓ/Person Day	Ratio (Office-11) =100%	m ³ /day	Ratio (Office-3) =100%
Office-1	4.3	3.3	7.6	57%	43%	76	172%	76	157%
Office-2	4.3	4.9	9.2	47%	53%	92	207%	92	189%
Office-3	2.6	2.2	4.9	50%	50%	49	110%	49	100%
Office-4	2.6	3.2	5.9	42%	58%	59	133%	59	122%
Office-5	4.1	4.3	8.4	49%	51%	84	191%	84	174%
Office-6	4.1	7.9	12.0	34%	66%	120	272%	120	248%
Office-7	2.6	2.9	5.4	46%	54%	54	123%	54	112%
Office-8	2.6	5.3	7.8	32%	68%	78	177%	78	162%
Office-9	5.9	4.8	10.7	55%	45%	71	161%	107	220%
Office-10	5.9	7.1	13.0	45%	55%	87	196%	130	268%
Office-11	3.4	3.2	6.6	47%	53%	44	100%	66	137%
Office-12	3.4	4.7	8.2	39%	61%	55	123%	82	169%
Office-13	5.6	6.3	11.9	47%	53%	80	180%	119	246%
Office-14	5.6	11.7	17.3	32%	68%	116	261%	173	357%
Office-15	3.3	4.2	7.5	43%	57%	50	113%	75	155%
Office-16	3.3	7.8	11.1	29%	71%	74	167%	111	229%
N-WSL Ave.	5.0	6.3	11.3	44%	56%	91	100%	113	100%
WSU Ave.	3.0	4.2	7.2	42%	58%	58	64%	72	64%
Average	4.0	5.2	9.2	43%	57%	74		92	

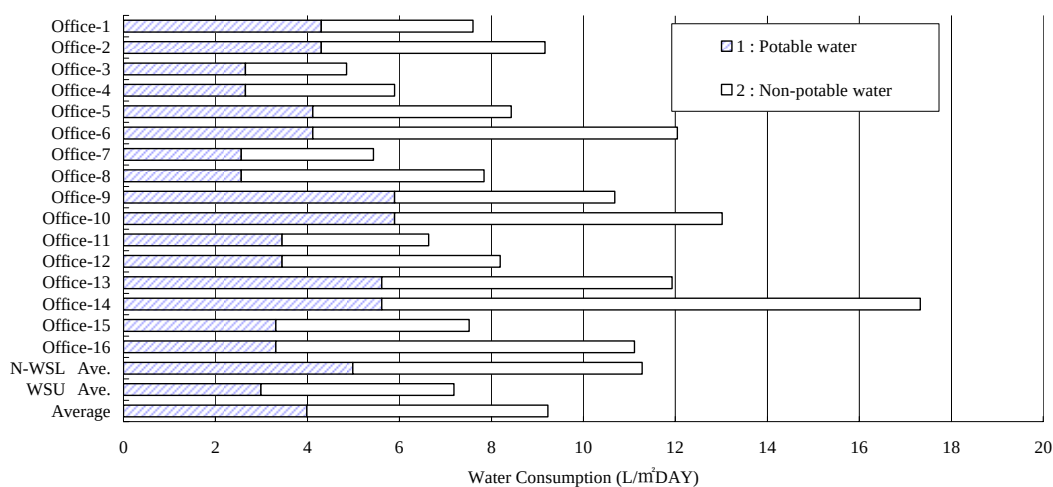
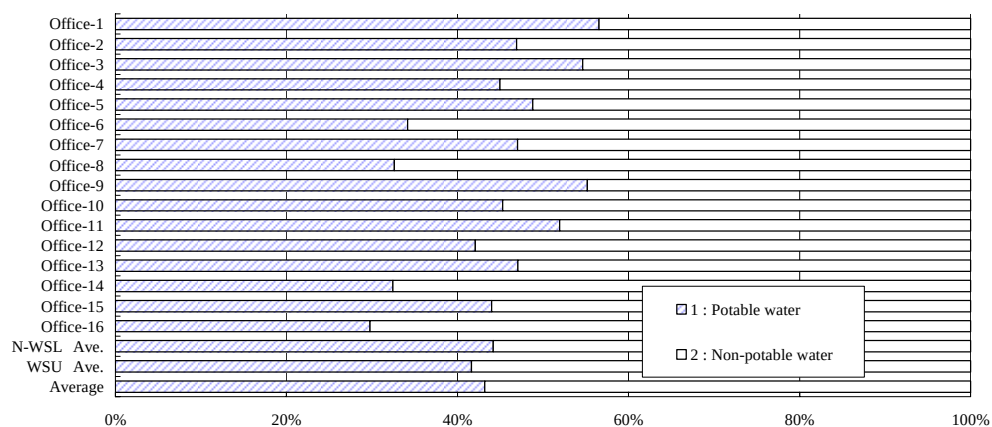


Figure 11 Results of daily water load in office buildings (Potable water & non-potable water) -Quantity



**Figure 12 Results of daily water load in office buildings
(Potable water & non-potable water) –Ratio**

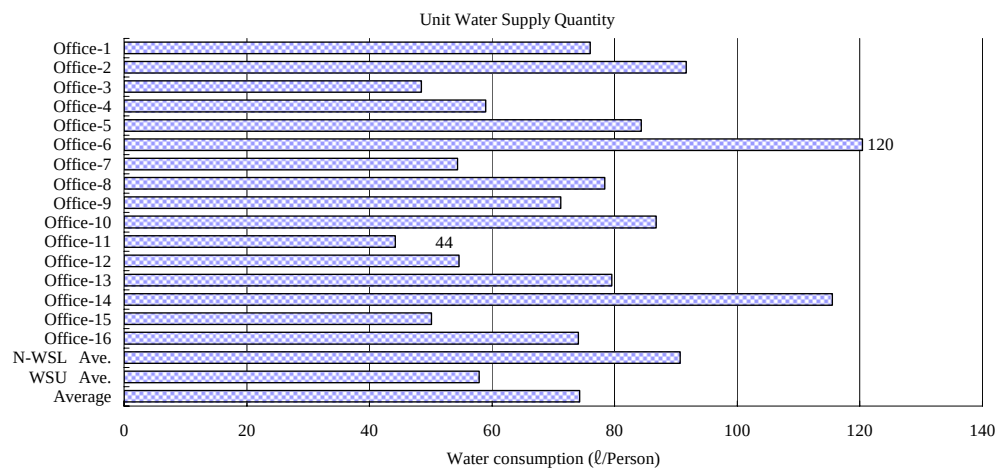


Figure 13 Daily water load (Persons)

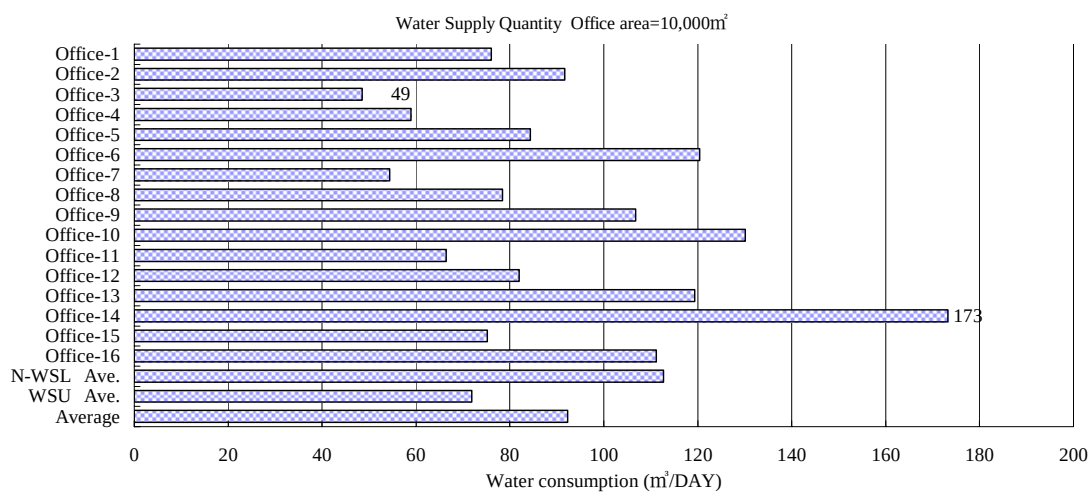


Figure 14 Daily water load (10,000 m² office buildings)

6. Conclusion

In Japan, receiving tanks, elevated tanks, and water supply pump system are installed in buildings as building services. For the effective use of water resources and for the optimum design of plumbing system, the Water Load Calculation Method, subject to the conditions of buildings, building occupants and plumbing fixtures, is necessary. If daily water consumption is available, hourly water loads can also be calculated based on the daily water consumption. Therefore, it is considered that the establishment of the Water Load Calculation Method, and the continuation of collection of conditions for calculations, from now on, will contribute to the effective use of water resources and also to the regional planning.

7. References

- 1) Waterworks in Tokyo: Bureau of Waterworks Tokyo, 2006year
- 2) Shipping report of tank: Water Tank Committee of Association of Living Amenity
- 3) Air-conditioning & sanitary as-built data: Yamauchi Planning Inc., 1984, 1994, 2004year
- 4) Researching report of building energy consumption: The Building Energy Manager's Association of Japan, Tokyo, 1977-2003year
- 5) Water resources in Japan: Ministry of Land, Infrastructure and Transport, 2004 pp.253, 266, 277
- 6) Year book of machinery statistics: Ministry of International Trade and Industry, 1974-2004year
- 7) Survey of existing building condition: Building Owners and Managers Association, Japan, Tokyo, 1985-2005
- 8) Annual report on the labor force survey: Statistics Bureau Management and Coordination Agency Government of Japan, 1950-2000year
- 9) S. Kosaka, S. Yanagimura: The new calculation method of the water consumption (Water Load Calculation), Papers of annual meeting of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, (2001, 2002, 2003, 2004, 2005)
- 10) The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (2001) SHASE Handbook 4 (Plumbing), pp, 115, 167
- 11) Report of the committee (SHASE): The maximum water consumption calculating method based on user's action, 2003.2

8. Presentation of Author

Shinji Kosaka is qualified Registered Consulting Engineer. He is the Representative of the KOSAKA Consultants Ltd. and a mechanical engineer for building services. He has been participating in the Committee of SHASE for over 30 years, and is also conducting research activities from the standpoint of practical business.



Research and Standard for the Air-Gap in Japan

F. Kiya(1), K. Yamada (2), S. Yanagimura (3), K. Maejima (4), H. Kose (5)

(1) kiyaf001@kanagawa-u.ac.jp

(2) yamada-k11@jcom.home.ne.jp

(3) sa-yanagimura@suga-kogyo.co.jp

(4) ken-mae@rc5.so-net.ne.jp

(5) hkose@eng.toyo.ac.jp

(1) Professor, Kanagawa University, Japan

(2) Consultant, Yamada Consulting Office, Japan

(3) Manager, Suga Kogyo Co, Ltd., Japan

(4) Engineer, Morimura Design Office, Japan

(5) Associate Professor, Toyo University , Japan

Abstract

The air-gap between water outlet and water surface in water tanks or plumbing fixtures has been old subject in the world, however those standard's basis are not cleared in detail.

For example, the air-gap in tanks is on the assumption that there is overflow pipe having enough capacity, however it is not cleared how much capacity is enough.

In Japan, there are separate standards in the ordinance of the Ministry of Health, Labour and Welfare under the Waterworks Law. The one is two times of water outlet inner diameter for small diameter, which has been used in the field of waterworks. The

other is based on SHASE(The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan.) standard for large diameter.

So the committee for research of the problems and proposing the new standard was set up in SHASE. From 2003 to 2005, investigation of literatures, and experimentations on the air-gap and overflow pipe, examination for the standards and so on were carried out.

In this paper, those situation and outline of the activities of the committee and proposal of the new standard are introduced.

Keywords

Air Gap, Standardization, Water Tanks, Plumbing Fixtures

1. Introduction

The air-gap between water outlet and water surface in water tanks or plumbing fixtures has been old subject in the world for the purpose of water pollution control in water supply system by back siphonage action. However those standard's basis has not been cleared in detail.

For example, the air-gap in tanks is on the assumption that there is overflow pipe having enough capacity, however it is not cleared how much capacity is enough.

In Japan, there are separate standards in the ordinance of the Ministry of Health, Labour and Welfare under the Waterworks Law.

The one is two times of water outlet inner diameter for small diameter under 25mm, which has been used in the field of waterworks shown in Table-1.

The other is based on SHASE(The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan.) standard for large diameter over 25mm, shown in Table-2.

Those situation is not desirable and unify the standard has been needed.

Therefore the committee for research of the problems and proposing the new standard was set up in SHASE. From 2003 to 2005, investigation of literatures, and experimentations on the air-gap and overflow pipe, examination for the standards and so on were carried out. 1).

2. Standards of Several Countries

Several countries have the standards for the air-gap shown in Figure-1. Those standards are almost linearly increasing tendency.

Furthermore there are some problems such as how to set up datum surface and distance from near wall shown in Figure-2 and Figure-3.

3. Research Works in Japan

The SHASE standard shown in Table-2 was basis on the paper²⁾ presented by Shinohara et al in 1973. In that research work, vacuum tank and vacuum pump were used for experiment system, and small size outlets (6~30 mm) were used. Therefore continuously vacuum pressure was kept, and over charge tendency was treated as the result.

After set up the ordinance of the Ministry of Health, Labour and Welfare in 1997, another research work was carried out at the Japan Water Research Center for the purpose to unify the separate standard.

The experiment system is shown in Figure-4. Example of the result of the experiment is shown in Figure-5, which was presented in the technical report ³⁾ of the introduction of the committee's report. It is shown that 25mm is the separate point of the tendency.

4. The Committee of the Air-Gap

The committee for research of the problems was set up in SHASE. From 2003 to 2005, investigation of literatures, and experimentations on the air-gap and overflow pipe, examination for the standards and so on were carried out.

After careful discussion and consideration, proposal of the new standard has been established. For the capacity of overflow pipe, it is shown in another paper.

5. Proposal of the New Standard

For the purpose of simplify the expression and unify the separate standard, proposal of the new standard was established as shown in Table-3. There are supplementary items as follows.

- 1) Distance from near wall to center of the outlet should be kept 2D. In the case of over 25mm, it is desirable to keep over 3D.
- 2) Datum surface is bottom level of the overflow pipe in the case of horizontal connection, and upper level of the overflow pipe in the case of vertical connection.
- 3) It should be selected that overflow pipe has enough capacity, and vertical connection is much better.

6. Acknowledgments

The authors acknowledge to members of the committee and supported persons of the experiment, and related organization of Japan Water Research Center and Japan Valve Manufacturer's Association.

7. References

- 1) Report of the committee of the Air-Gap, SHASE, 2006.3
- 2) Shinohara et al : For the Air-Gap in Water Supply System, Journal of SHASE, Vol.47, No.12, pp29~44, 1973.12
- 3) Kiya et al : Experimental Study on the Air-Gap, Journal of SHASE, Vol.78, No.6, pp19~27, 2004.6

8. Presentation of Author

Fumitoshi Kiya is Professor of Kanagawa University, in Department of Architecture, Faculty of Engineering, and Professor emeritus of Tokyo Institute of Technology.

He is specialist in the field of plumbing and built environment. He has been in W062 since 1972, the first symposium held in BRE, England.

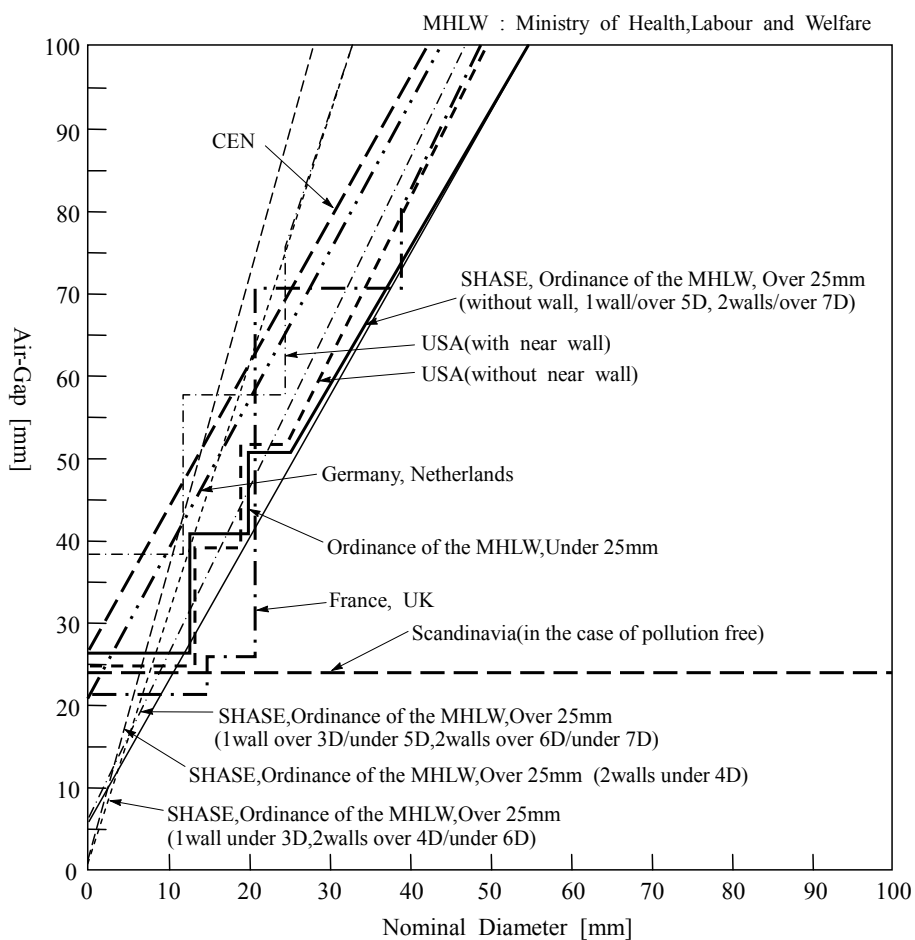


Table-1 Minimum Size of Air-Gap Under 25mm of Nominal Diameter

Nominal Diameter	Distance between Near Wall and Center of Outlet	Distance between Overflow Surface and Center of Outlet
Under 13mm	25mm	25mm
Over 13mm / Under 20mm	40mm	40mm
Over 20mm / Under 25mm	50mm	50mm

Table-2 Minimum Size of Air-Gap

without near wall	with near wall						
1.7D'+5	1 near wall			2 near walls			
	Distance from wall			Distance from wall			
	under 3D	over 3D under 5D	over 5D	under 4D	over 4D under 6D	over 6D under 7D	over 7D
	3.0D'	2.0D'+5	1.7D'+5	3.5D'	3.0D'	2.0D'+5	1.7D'+5

**Figure-1 Comparison of Air-Gap Standards in Several Countries**

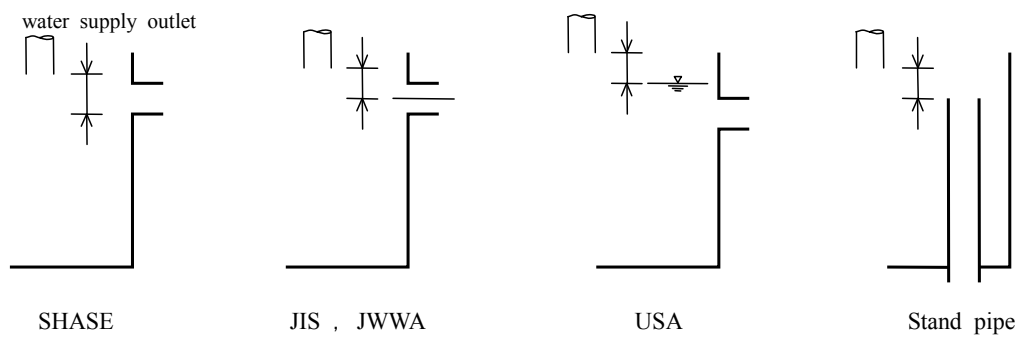


Figure-2 Several Datum Surface

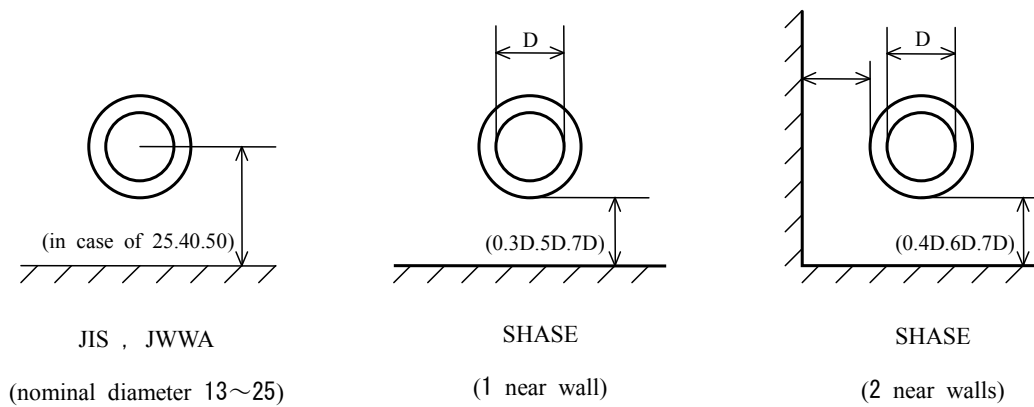


Figure-3 Distance from the Wall in Several Standards

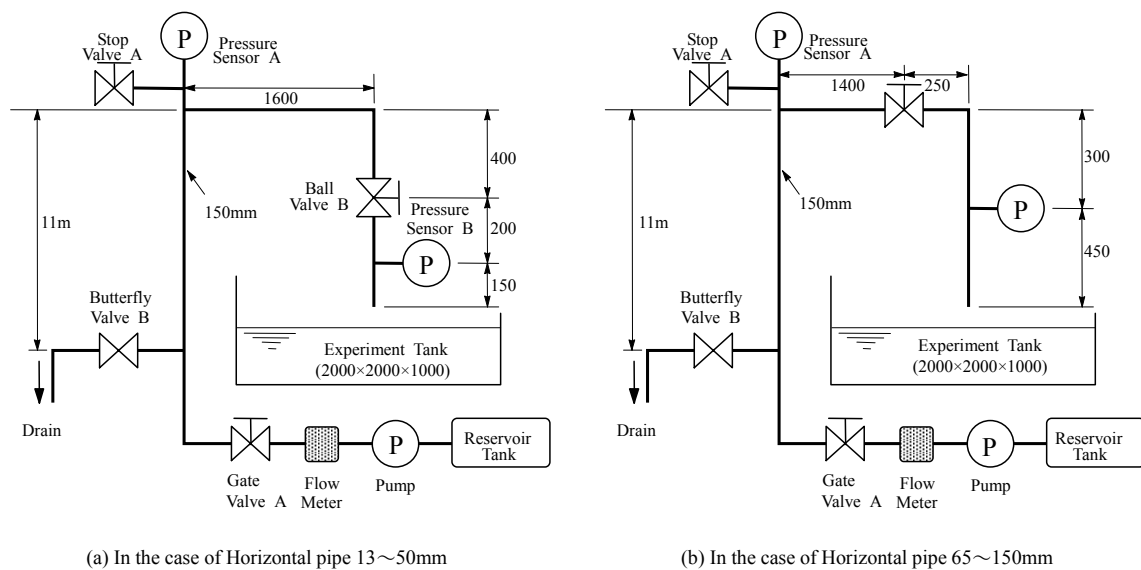


Figure-4 Outline of Experiment System[mm]

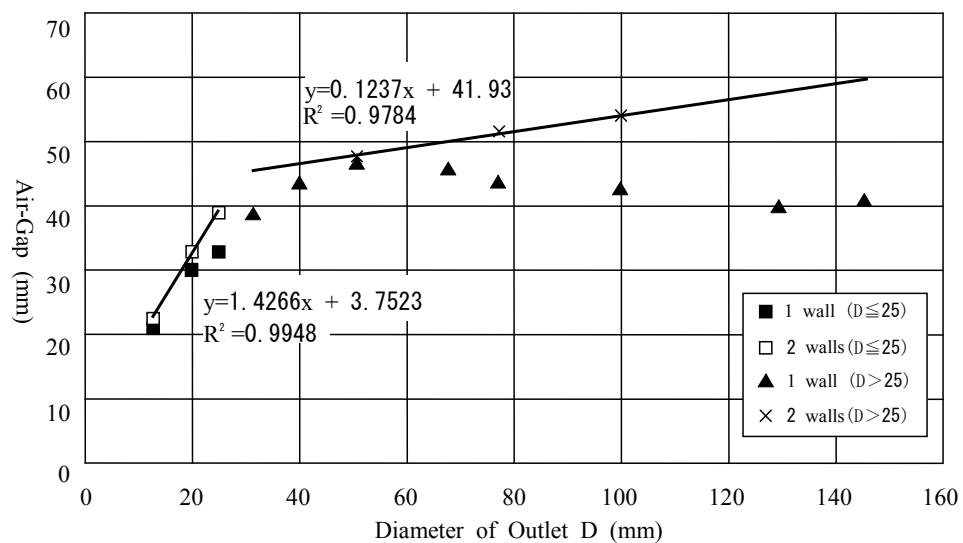


Figure-5 Result of Experiment (Distance from the wall=0D)

Table-3 Proposal of the New Standard

Nomonal Diameter	Air-Gap (over mm)
13	25
20	40
25	50
32	60
40	70
50	75
65	90
80	100
100	115
125	135
150	150

Study on Maximum Flow Rates and Sizing Method of Overflow Pipes in Water Tanks

**X.W. Wang (1), F. Kiya (2), K. Maejima (3), S. Yanagimura (4),
C. Yoneda (5)**

(1) SUGA Co., Ltd., Research and Development Center, syo-o@suga-kogyo.co.jp

(2) Kanagawa University

(3) P.T. Morimura & Associates, Ltd.

(4) SUGA Co., Ltd., Research and Development Center

(5) SUGA Co., Ltd., Research and Development Center

Abstract

When examining the standard of the air-gap in open tanks with overflow pipes, it is necessary to determine the height of the highest water level and maximum capacity of overflow pipe in tanks. However, it is not cleared not only to determine the height and the capacity, but also to decide the size of overflow pipe. Therefore, the experimental study was carried out for the purpose to obtain them.

In this paper, it was reported the experiment result concerning the FRP water tank with overflow pipe of inside diameters 50 mm and 100 mm. As a result, empirical formulae of the height by incoming flow rates and inside diameters, and the maximum flow rate of overflow pipes are shown. Moreover, methods to decide the size of overflow pipes are proposed.

Keywords

Experiment, Air-Gap, Water Level Change, Overflow, Maximum Flow Rate of Overflow Pipe, Sizing Method of Overflow Pipe

1. Introduction

Setting the air-gap to prevent the back-siphonage is a simple and reliable method. There are the standard of the air-gap in each country. In Japan, a study on small size pipes by diameters 9 mm to 30 mm by Shinohara et al. had been carried out, and the standard published in SHASE-S206-2000 which is based on the result is the standard of SHASE (The Society of Heating Air-conditioning and Sanitary Engineering of Japan). Experimental grounds on the overseas standards such as the United States and Europe are not clear; the experiment of the one to exceed diameters 40 mm or 50 mm was not

carried out in any case.

As the standard of the air-gap, it is required that overflow pipe have enough capacity. However, it is general to assume the size of the overflow pipe to be two size-ups of the diameter of water supply pipe, but clear grounds have not been shown. It is necessary to confirm this validity and the drain capacity of overflow pipe.

To secure the air-gap in water tank with an overflow pipe (hereinafter referred to as water tank), it is necessary to accumulate the basic data for examination the standard of air-gap, such as the maximum drain flow rate and the highest possible water rising level in water tank.

The authors carried out the experiment on FRP water tank with overflow pipe of the inside diameters 50 mm and 100 mm. In this paper, the experiment result on the maximum flow rate, the water level change situation in a water tank, and the method of sizing an overflow pipe are presented.

2. Experiment Overview

2.1. Experiment equipment

The water tank used to the experiment was made of FRP, the size was 1000×1000×2000 mm, and the overflow pipes of diameters 50 mm and 100 mm were installed on each side of the open water tank. The experiment apparatus is shown in Figure 1, and the specification of the experiment materials is shown in Table 1. To make easy for experiment, the ball valves were installed in each overflow pipes, and switching to each pipe in each experiment.

Moreover, the horizontal sectional area of this experiment water tank was assumed to be 1.0 m², because it was estimated that the speed of water level rising from the base level and time until stabilizing the water level were different for a different sectional area, and requested water level rising relation to flow rate and the drain capacity of overflow pipe were not change.

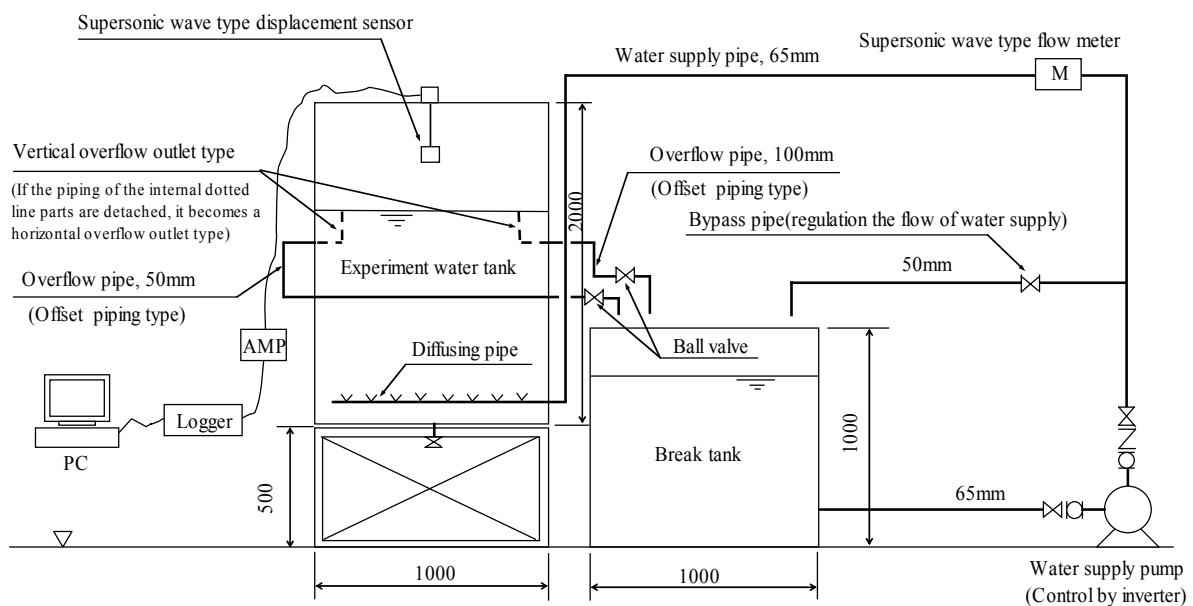


Figure 1 Experiment apparatus

Table 1 Specification of the experiment materials

Item	Specification
Water tank for experiment	Material : made of FRP, single panel type Size:1000×1000×2000 mm
Break tank	Material: made of FRP, single panel type Size:1000×1000×1000 mm
Bell mouth	Material : PVC Pipe diameter : 100 mm, bell mouth part : 145 mm 50 mm, bell mouth part : 75mm
Overflow pipe	Material : VP Diameters:100 mm, 50 mm
Water supply pump	Capacity: 65 A× 500 L/min×10 m×1.5 kW
Inverter	200V, 1.5 kW, 0~50 Hz
Highly accurate supersonic wave type displacement sensor	Time base range:80~300 mm Resolution: 0.1 mm
Data logger	16ch, Sampling interval: 0.1 s
Supersonic wave type flow meter	Application diameter:φ13~φ100 Time base range:-32~0~+32 m/s

It is necessary to keep the stability of the surface of the water to measure the water level change in the water tank when experimenting. Then, the diffusing pipe was installed to connected the water supply pipe (diameter 65 mm) in the tank, the sectional area of the diffusing pipe is 4 times wide of it of the water supply pipe, and the result, the flow velocity in the diffusing pipe has been decreased to about 1/4. In addition, the SUS punching board was installed in the upper layer on the diffusing pipe at the direction of the water flow cross section, and the stabilization of the surface of the water in the tank was achieved. As a result, the water level change in the tank was less than 0.1 mm when water was to be supplying, and the accuracy of the experiment was improved.

2.2. Experiment conditions

Two kinds of outlet types of each overflow pipe (the vertical overflow outlet type and the horizontal overflow outlet type) were set; piping routes was set to each overflow outlet by a straight piping and a offset piping. Table 2 shows the combination and each classification of the overflow outlet type and the piping route of the overflow pipes. Moreover, the piping route and the length on each classification in the vertical overflow outlet type and the horizontal overflow outlet type are shown in Figure 2 and Figure 3. The flow rate was changed to 8 types of overflow pipes shown in Table 2 respectively, the experiment on 112 patterns in total was carried out, and water levels rising in the tank and the maximum drain flow rates of the overflow pipe were confirmed. The flow rates in each experiment pattern are explained in the experiment result.

2.3. Experiment method

Water was supplied from the water supply pump to the experiment water tank, the water level change in the tank was measured by the supersonic wave type displacement sensor, the flow rate and the water level change data were recorded on the personal computer. The water supply flow rate was set according to overflow diameters by 30~780 L/min

(maximum capacity of the water supply pump), and the flow was regulated by installed inverter control of the pump and manual control the ball valves in water supply bypass pipe.

As experiment procedure before experiment of each pattern, first, water is supplied more than overflow respect in the experiment water tank. Then, the water supply was stopped, overflowed afterwards, and the water level that comes to stabilize was recorded as a reference point of the water level in the tank. Naturally, the reference point of the vertical overflow outlet type and the horizontal overflow outlet type is different. Next, to avoid the flow rate change at the time of standing up of the water supply pump and to obtain the steady flow rate water supply, the water level in the tank was adjusted about 10 mm (partially 5 mm) lower than the overflow rim (reference point), then water was to be supplying according to prescribed flow rate, and the water level rising in the tank was recorded.

Table 2 Pattern classification and sign of overflow pipes

Overflow pipe diameter, mm	Vertical overflow outlet type		Horizontal overflow outlet type	
	Piping routes		Piping routes	
	Straight piping type (VS type)	Offset piping type (VO type)	Straight piping type (HS type)	Offset piping type (HO type)
100	V100S	V100O	H100S	H100O
50	V50S	V50O	H50S	H50O

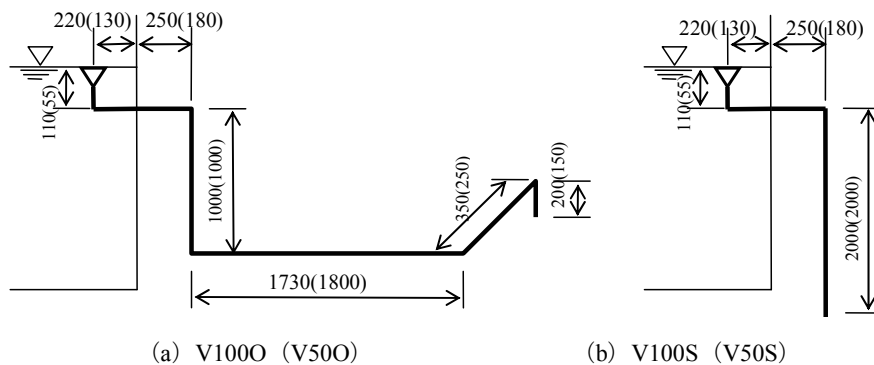


Figure 2 Vertical overflow outlet type

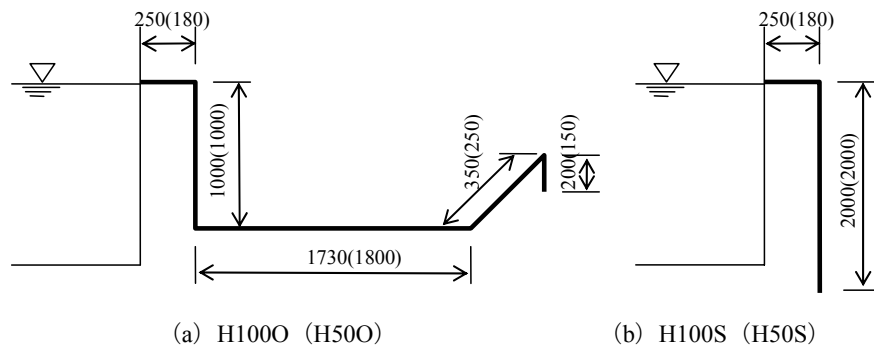


Figure 3 Horizontal overflow outlet type

Note: some both overflow piping lengths of the diameters 100 mm and 50 mm differs in the convenience of the device production as for Figure 2 and Figure 3, and the numerical value in () shows the length of the diameter 50 mm in the figures.

The reference point of the water level in the tank used to calculate the water rising level was made to the bell mouth top side for the vertical overflow outlet type as shown in Figure 4, and made a pipe inside bottom for the horizontal overflow outlet type.

In addition, Water was supplied continuously in the tank within the range of the drain capacity of the overflow pipe, and the case which the water level in the tank almost does not change is called "Water level constancy", in case which the water level rises continuing with the time is called "Rising continuance"

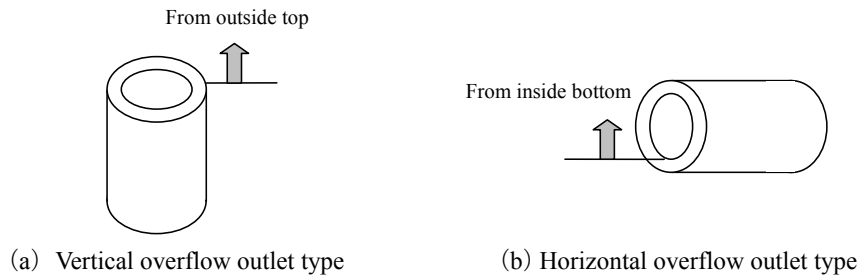


Figure 4 Reference point of water level

3. Experiment result

3.1. Water supply flow rate and water level rising in vertical overflow outlet type

The flow rate was changed to the vertical outlet type overflow pipe, and it was experimented on 28 patterns to the pipes of the diameters 50 mm and 100 mm respectively. As one example, Figure 5 shows the result of the water level rising at V50O (refer to table 2) in case of changing the flow rate from 30 to 180 L/min. When flow rate is 170 L/min or less, the water level in the tank becomes constant after the time passes, the water level in the water tank was raising continuance while flow rate is 180 L/min; it was confirmed that the maximum drain flow rate in V50O is about 170 L/min.

Figure 6 shows the maximum water level rising on the overflow bell mouth top side (water level reference point) in each experiment pattern. The water level rises according to flow rate increase, it doesn't depend on the piping route of the overflow pipe, and al-

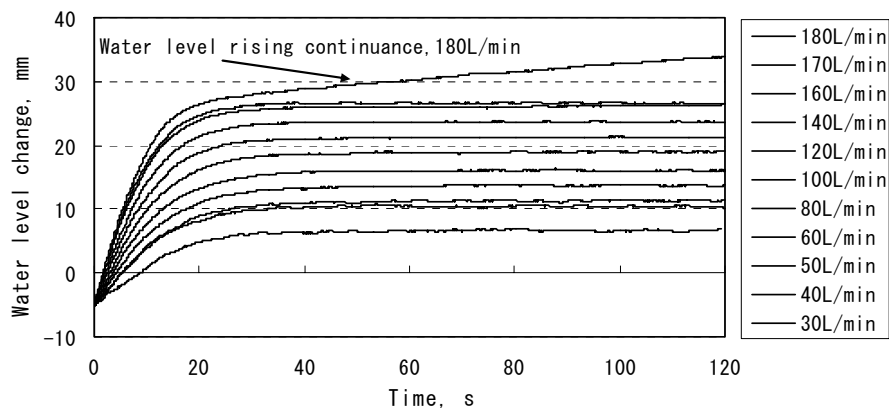


Figure 5 Flow rate and water level change in V50O

most the same water rising level for the same flow rate and the same size of overflow pipe. The water rising level of the diameter 50 mm is higher than it of the 100 mm for the same flow rate.

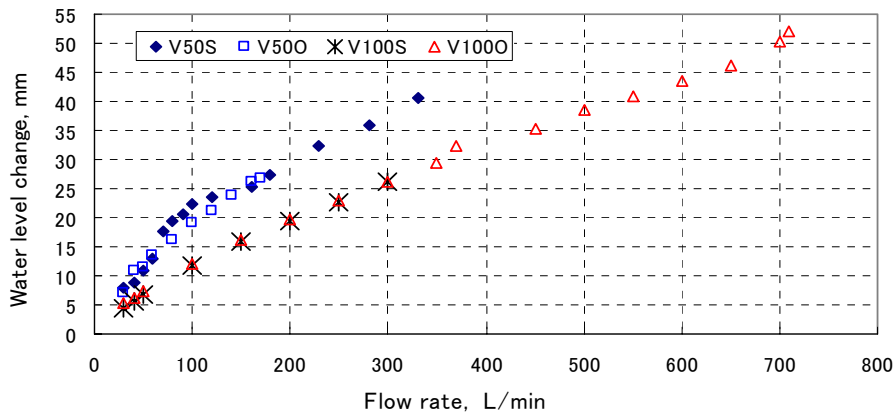


Figure 6 Water rising level and flow rate in vertical overflow outlet type

3.2. Water supply flow rate and water level rising in horizontal outlet type

The flow rate was changed to the horizontal outlet type overflow pipe, and it was experimented on 56 patterns in total of 30 and 26 respective to the pipes of diameters 50 and 100mm. As one example, Figure 7 shows the result of the water rising level at H50O in case of changing the flow rate from 30 to 200 L/min. When flow rate is 190 L/min or less, the water level in the tank becomes constant after the time passes, the water level in the water tank was raising continuance while flow rate is 200 L/min; it was confirmed that the maximum drain flow rate in H50O is about 190 L/min.

Figure 8 shows the maximum water level rising at the bottom side on the overflow pipe inside (water level reference point) in each experiment pattern. The water level rises according to a flow rate increase in H100O and H100S, it doesn't depend on the piping route of the overflow pipe, and almost the same water level rising for the same flow rate and same size of overflow pipe. For H50O and H50S, though the siphonage is repeatedly generated in H50S, and the water level doesn't rise to a flow rate increase. Even if the same size of overflow pipe, the water level rising in a straight piping type is higher than the offset piping type as a whole.

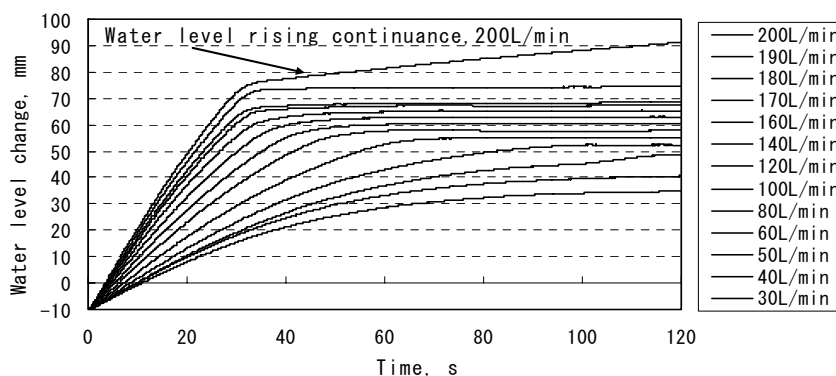


Figure 7 Flow rate and water level change in H50O

Figure 9 shows the water level change when siphonage was generated at water supply flow rate 100 L/min in H50S. The siphonage occurs repeatedly after becoming the maximum water rise in the tank; the range of the water level change is almost the same when siphonage is generated in each time, and the water level rising before the first siphonage is generated is the maximum.

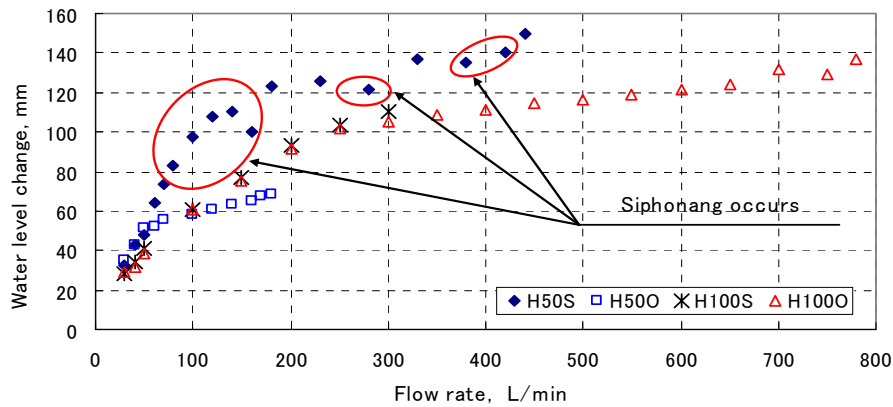


Figure 8 Flow rate and water rising level in horizontal overflow outlet type

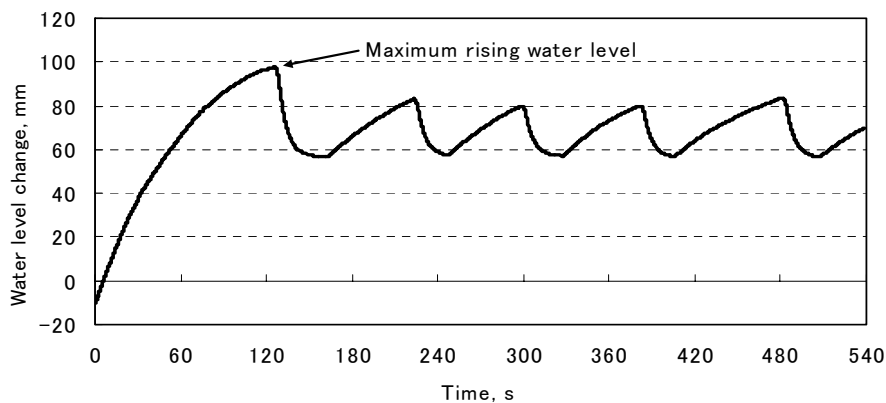


Figure 9 Water level change when siphonage is generated (H50S, 100 L/min)

3.3. The maximum flow rate of overflow pipes

Table 3 shows the maximum drain flow rate of the overflow pipes of diameters 50mm and 100mm. The maximum flow rate in horizontal outlet type is more than the Vertical outlet type in the diameter 50 mm, and even if the same overflow outlet type, the straight piping type is about twice as large as the offset piping type. In the diameter 100mm, only V100O was able to be confirmed to the maximum drain flow rate by restricted experimental conditions.

Table 3 Maximum drain flow rates

Overflow pipe diameter, mm	Maximum drain flow rate, L/min			
	V50S	V50O	H50S	H50O
50	360	170	440	190
100	V100S	V100O	H100S	H100O
	—	710	—	—

4. Discussion about water level rising

4.1. Vertical overflow outlet type

The water level rising in the water tank as h , and overflow diameter as d , a multivariate multiple regression analysis was performed about the ($h/d \leq 1.0$) experiment data that the siphonage was not generated. It doesn't depend on diameter in the same outlet type and the same piping route of overflow pipe, and it is possible to express by one regression formula in the condition of $h \leq d$.

Equation (1) was obtained for the VS type (Vertical outlet Straight piping type), and equation (2) was obtained for the VO type (Vertical outlet Offset piping type) in the condition of $h/d \leq 1.0$. The multiple correlation coefficients are 0.994 and 0.999 respectively, which shows the both correlations are high.

$$h = 9.870 \frac{Q^{0.731}}{d^{0.700}} \dots\dots\dots (1)$$

$$h = 8.104 \frac{Q^{0.715}}{d^{0.627}} \dots\dots\dots (2)$$

where, h = water rising level in water tank, mm
 Q = overflow flow rate, L/min
 d = internal diameter of overflow pipe, mm

The water rising level as which the straight piping and the offset piping type are almost the same in case of the same flow rate and same diameter, moreover, the actual overflow piping route is general a straight piping, therefore, equation (1) of the straight piping type is used to examine sizing method of the vertical outlet type overflow pipe.

4.2. Horizontal overflow outlet piping type

In the experiment of vertical overflow outlet type, it was possible to express by one regression formula in the condition of water rising level $h \leq d$ if the same piping route, but in horizontal overflow outlet type, as water rising level situation in $h \leq d$ (the siphonage was not generated) and the water level uptrend of $h > d$ (the siphonage might be generated in H50S) is different, a multivariate multiple regression analysis was performed for the experiment data separately in case of $h \leq d$ and $h > d$.

Each empirical formula in $h \leq d$ and $h > d$ of the HS type (Horizontal outlet Straight piping type) is expressed as (3) and (4). The multiple correlation coefficients are 0.999 and 0.953 respectively.

$$h = 11.518 \frac{Q^{0.626}}{d^{0.265}} \quad (h/d \leq 1.0) \dots\dots\dots (3)$$

$$h = 48.991 \frac{Q^{0.352}}{d^{0.260}} \quad (h/d > 1.0) \dots\dots\dots (4)$$

Each empirical formula in $h \leq d$ and $h > d$ of the HO type (Horizontal outlet Offset piping type) is shown in formula (5) and (6). Either of the multiple correlation coefficient is 0.999.

$$h = 16.541 \frac{Q^{0.618}}{d^{0.341}} \quad (h/d \leq 1.0) \dots\dots\dots (5)$$

$$h=3.292 \frac{Q^{0.234}}{d^{0.462}} \quad (h/d>1.0) \dots\dots\dots (6)$$

As well as the Vertical outlet piping type, the actual overflow piping route is general a straight piping, so, it is thought that formula (3) and formula (4) for straight piping type only has to use when empirical formula to be used.

Moreover, because the water rising level from the state ($h>d$) that the overflow pipe goes under water as shown in Figure 8 is more gradual than the case of state $h \leq d$, to make the calculation concise, formula (3) is the safety side is used to examine sizing method of the horizontal outlet type overflow pipe.

5. Examination of sizing method for overflow pipe

5.1. Water supply flow velocity (flow rate)

Overflow outlet might be submerged by the water which supplies the flow velocity (flow rate). Under the condition, it is assumed that the time is required to drain it until becoming a reference point of water level from rising water level in the tank by shape and a plane area of the water tank, when sudden stop of the water supply. There is a possibility that a back-siphonage is generated at once in this time though it is not easy to think.

As the standard of the air-gap, it is required overflow pipe having enough capacity; it is general to assume the size of the overflow pipe to be two size-ups of the size of water supply pipe. So far the flow velocity of water supply is calculated at flow velocity 2 m/s. When water flowing to the tank as continuously as the water supply pipe, the corrosion measures etc. for pipes are considered, and 1.0 to 1.2 m/s of flow velocity is preferable, according to circumstances, the water supply flow velocity can be selected even 2.0 m/s.

5.2. Sizing method for overflow pipe

As a method of sizing overflow pipe, two methods in the following are proposed. Method A: So as not to exceed allowance rising point, then the size is decided; method B: the size of overflow pipe is made to 2 size-ups of the water supply pipe, and the water supply flow velocity to the tank is limited. Where, the height on the permissible rising point is set as well as air-gap standard value. In method A, after the water supply flow velocity to the water tank is decided, and then water supply flow rate Q and water rising level h are known, the size of the overflow pipe can be calculated by using formula (1) or formula (3). In method B, water rising level h and the overflow pipe size d are known, the water supply flow rate can be calculated by using formula (1) or formula (3), and then the water supply flow velocity can be decided.

The relation between the water supply flow velocity (flow rate) and water level rising and diameter in vertical outlet type overflow piping are shown in Table 4, and the case of horizontal outlet type is shown in Table 5. Though the water supply flow velocity and the size of overflow pipe are not shown in the table, these can be calculated by using formula (1) or (3).

When Table 4 was compared with Table 5, in the same water supply flow rate, the water rising level of the vertical outlet type in the tank is lower than that of the horizontal overflow outlet type. Therefore, the vertical overflow outlet type is preferable designing

Table4 Size of overflow pipe and water level rising in vertical outlet type

Water supply Pipe Diameter, D, mm	Velocity of water supply, V, m/s				Overflow Pipe Diameter, d, mm	Velocity of water supply, V, m/s			
	1	1.2	1.5	2		1	1.2	1.5	2
	Flow Rate of water supply*, Q, L/min					Water level rising in water supply flow rate shows left, h, mm			
						Vertical overflow outlet type, $h=9.870Q^{0.731}/d^{0.700}$			
20	17	20	25	32	32	6.9	7.8	9.2	11.0
					40	5.9	6.7	7.8	9.4
					50	5.1	5.7	6.7	8.0
25	28	35	42	65	40	8.5	10.0	11.5	15.8
					50	7.3	8.6	9.8	13.5
					65	6.1	7.1	8.2	11.2
32	50	62	75	100	50	11.1	13.0	15.0	18.5
					65	9.3	10.9	12.5	15.4
					80	8.0	9.4	10.8	13.3
40	70	87	105	145	65	11.9	13.9	16.0	20.2
					80	10.3	12.0	13.8	17.5
					100	8.8	10.3	11.8	14.9
50	120	150	180	250	80	15.2	17.9	20.5	26.0
					100	13.0	15.3	17.5	22.2
					125	11.1	13.1	15.0	19.0
65	200	250	300	400	100	18.9	22.2	25.4	31.4
					125	16.2	19.0	21.7	26.8
					150	14.2	16.7	19.1	23.6
80	280	350	405	570	125	20.7	24.3	27.1	34.8
					150	18.2	21.4	23.8	30.6
					175	16.3	19.2	21.4	27.5
100	500	600	730	1000	150	27.8	31.8	36.7	46.1
					175	25.0	28.5	32.9	41.4
					200	22.7	26.0	30.0	37.7

Table 5 Size of overflow pipe and water level rising in horizontal outlet type

Water supply Pipe Diameter, D, mm	Velocity of water supply, V, m/s				Overflow Pipe Diameter, d, mm	Velocity of water supply, V, m/s			
	1	1.2	1.5	2		1	1.2	1.5	2
	Flow Rate of water supply*, Q , L/min					Water level rising in water supply flow rate shows left, h, mm			
						Horizontal overflow outlet type, h=11.518Q ^{0.626} / d ^{0.265}			
20	17	20	25	32	32	27.0	29.9	34.4	40.1
					40	25.5	28.2	32.4	37.8
					50	24.0	26.6	30.5	35.6
25	28	35	42	65	40	34.8	40.0	44.8	58.9
					50	32.8	37.7	42.2	55.5
					65	30.6	35.2	39.4	51.8
32	50	62	75	100	50	47.1	53.9	60.7	72.6
					65	43.9	50.3	56.6	67.8
					80	41.6	47.6	53.6	64.1
40	70	87	105	145	65	54.2	62.1	69.9	85.5
					80	51.3	58.8	66.1	80.9
					100	48.4	55.4	62.3	76.3
50	120	150	180	250	80	71.9	82.6	92.6	113.7
					100	67.8	77.9	87.3	107.2
					125	63.9	73.4	82.3	101.0
65	200	250	300	400	100	93.2	107.2	120.1	143.8
					125	87.9	101.0	113.2	135.5
					150	83.7	96.3	107.9	129.1
80	280	350	405	570	125	108.5	124.7	136.6	169.1
					150	103.3	118.8	130.2	161.1
					175	99.2	114.0	124.9	154.7
100	500	600	730	1000	150	148.5	166.4	188.1	229.0
					175	142.5	159.7	180.6	219.8
					200	137.6	154.2	174.3	212.2

* : Flow rates are calculated by **Hazen-Williams Equation** (SHASE-S206-2000, p208)

on engineering design.

6. Conclusion

The experimental investigations of FRP water tank with the overflow pipes of inside diameters 50 mm and 100 mm were presented. The following conclusions were obtained:

- (1) When the siphonage is not generated in both vertical overflow outlet type and the horizontal overflow outlet type, the water rising level in the tank is almost equal without depending on the piping route in case of the same overflow outlet type.
- (2) In the case of the same overflow outlet type of the overflow piping, the influence that the piping route gives the capacity of overflow pipe is great. The overflow capacity of the straight piping type is about twice as large as the offset piping type.
- (3) Water rising level in the vertical outlet type of the overflow piping is lower than horizontal overflow outlet type; it is thought that the straight piping route of the vertical overflow outlet type is preferable.
- (4) Empirical formula where water rising level in the water tank to be presented by flow rate and size of overflow pipe was shown.
- (5) The sizing method of the overflow pipe by presented empirical formula was proposed.

Acknowledgments

This project is performed as the activity of "Water supply and drainage sanitary equipment committee, air-gap review subcommittee", of the Society of Heating, Air-conditioning and Sanitary Engineers of Japan. The authors thank Tomoo Inada and Hideharu Doi in Suga Co., Ltd.; Ryuma Ouchi and Yuta Yamafuji in Kanakaga University (at that time), they have cooperated in experiment, and authors wish to thank all the committee members.

References

- 1) Takamasa Shinohara et al. The air-gap of large diameter in the water supply system, SHASE Vol.47, no.6, 1973.12, pp.29—44
- 2) Takamasa Shinohara et al. The air-gap of large diameter in the water supply system, SHASE Symposium, 1997.10, pp.185—188
- 3) Ken Majima, et al. Water Rise in Water Tanks with Overflow Pipes (Part 1) Preliminary Experiment on Water Closet Flush Tanks and Small Tanks, SHASE Symposium, 2005.8, pp.26~29
- 4) Xinagwu Wang, et al. Water Rise in Water Tanks with Overflow Pipes (Part 2) Experimental Study on Water Level Change and Flow Rate of Overflow Pipes, SHASE Symposium, 2005.8, pp.29~32
- 5) Fumitoshi Kiya, et al. Experimental study on the air-gap, SHASE Vol.78, no.6, 2004.6, pp.19-27

- 6) Plumbing Code, SHASE—S206—2000, the Society of Heating, Air-conditioning and Sanitary Engineers of Japan, 2000,3, pp.58,59
- 7) Roy B.Hunter, Gene E.Golden, and Herbert N.Eaton. Cross connection in Plumbing System, April 1938, Research Paper RP1089 Part of Journal of Research of the National Bureau of Standards, Volume 20.
- 8) F.M.Dawson, A.A.Kalinske. Report on Plumbing Cross Connections and Back Siphonage Research. 1938, Technical Bulletin Number 1, National Association of Master Plumbers of the United States, Incorporated.

Presentation of Author

Xiang-Wu Wang, Ph.D., is the Researcher at SUGA Co., Ltd., Research & Development Center. His Specialized field is architectural environmental engineering; he also acts as referee of overseas paper edit committee of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, and committee of water environmental committee of Architectural Institute of Japan.



Shower head design: Increasing performance at lower flow rates

D. Woolf (1), I. Pau (2), M. Shouler (3)

(1) Darren.woolf@arup.com

(2) Irene.pau@arup.com

(3) martin.shouler@arup.com

(1), (2), (3) Ove Arup & Partners, London, UK

Abstract

The Market Transformation Programme (MTP) supports the development and implementation of UK Government policy on sustainable products and reduces the environmental impact of products across the product life cycle by collecting information, building evidence and working with industry and other stakeholders. MTP supports the UK Government's strategy on sustainable development and underpins the product policy aspect of the framework for sustainable consumption and production. This study was commissioned by the MTP. A copy of the detailed report (in colour) can be found on the MTP website at <http://www.mtprog.com/Publications.aspx> (UK Government Shower Performance: Market Transformation Programme – Shower Report).

The UK shower market has a wide range of shower systems with different operating pressures and associated shower head performances. This study will provide a greater understanding of the physics relating to the performance of the spray emanating from a shower head and the potential to reduce flow rate while maintaining good performance. The study is a quantitative approach using computer models validated against experimental data.

Often shower head performance is only judged by visuals of the spray profile. It will be shown that it is possible to maintain a good spray profile at lower flow rates, maximising water coverage on the body, by reducing the size of the holes in the spray head. It will also be shown that water temperatures on the body are only slightly lower using small holes with low flow rates than large holes with high flow rates. The spray profile is also more likely to collapse resulting in collision of droplet streams with large holes. It will be shown that atomiser sprays result in greater temperature loss in transit to the body, well understood in practice, due to the smaller droplet sizes and are therefore not an efficient means of delivery. It will also be shown that surface pressure is extremely difficult to assess.

A wide variety of performance indicators will be discussed including a possible route for manufacturer driven change in combination with educating the users. In addition to the adoption of performance indicators such as time-based products, measures such

as the imposition of flow rate limiters (flow restrictors) through to colour coding of shower heads to match systems correctly when purchasing products and better informing users with flow gauges will be discussed.

Keywords

Shower, performance, flow rate, physics, droplets

Executive Summary

Within the home, water use for showering is increasing as a percentage of overall household usage (currently 13% but expected to rise to 17% by 2020). This is due to householders taking more showers instead of baths and a tendency towards higher flow rate products. The purpose of this study is to determine the potential for reducing water consumption of showering products through numerical analysis.

This study:

- Explores the physics of shower sprays and potential to reduce flow rate while maintaining good performance
- Briefly describes the range of shower systems in the UK market
- Validates computational data against experimental data and British Standards
- Discusses performance indicators and possible options for industry

Initially it was shown, by comparing measured data to computer predictions, that the numerical (CFD) model is an appropriate tool to predict the performance of many types of shower sprays.

The key findings from the CFD model were that it is possible to increase the water coverage over the body at lower flow rates while maintaining the spray profile by adjusting (reducing) the size and optimising the layout of the holes. This can be achieved with a water temperature over the skin that is slightly lower than at higher flow rates. A smaller size of hole will also lead to an increase in the skin pressure.

This work demonstrates that a reduction in flow rate can be achieved without compromising the delivery performance of a shower. Therefore overall savings can be made by manufacturers adopting the analysis techniques suggested in this study.

There is almost a direct correlation between reducing flow rate and reducing energy costs, i.e. half the flow rate leads to half the energy usage and costs.

1. Introduction

The aim of the project is to study different types of shower heads and compare their performances based on a number of criteria such as flow rate and associated comfort. The study is therefore designed to provide a greater understanding in the physics relating to showers and gauge the potential for reducing water usage while maintaining performance. This could possibly lead to the introduction of performance indicators.

Performance indicators can be very wide ranging in their application and across various parameters. Figure 1 shows many types of performance indicators, for example:

- One used to understand complex unrelated and often subjective multiple inputs to provide an overall indication of performance or strengths and weaknesses, e.g. spider diagrams
- A banded approach using a Standard Assessment Procedure (SAP), e.g. an energy rating system
- A direct usage approach based upon one variable, e.g. flow rate for a water rating system

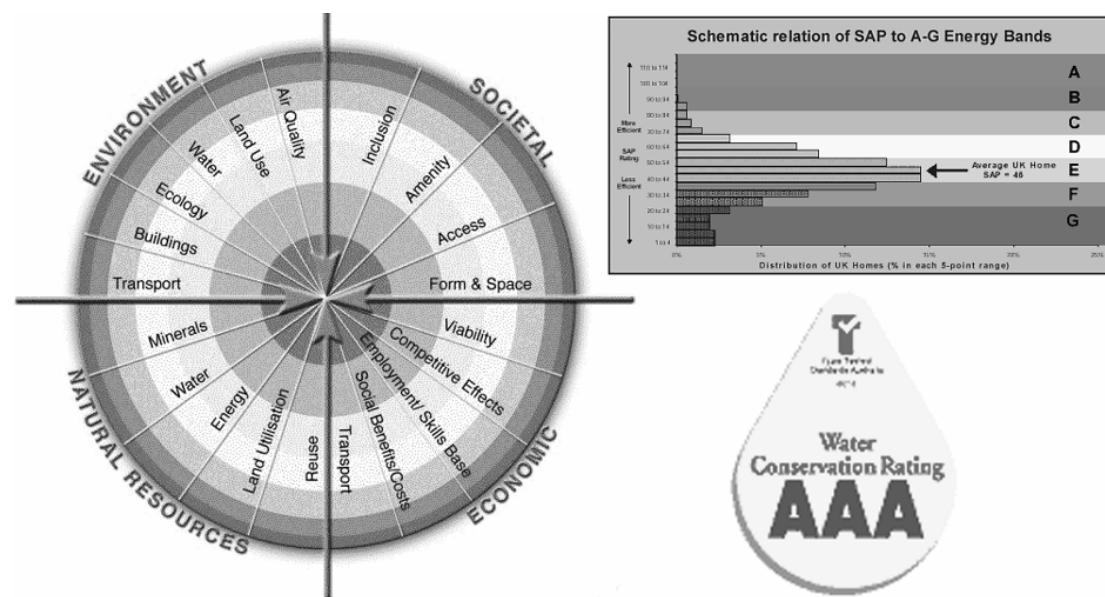


Figure 1: Examples of performance indicators

When we talk about the performance of showers, we can break that down into the four areas illustrated in Table 1 with suggestions for possible subjects requiring further consideration. Of prime concern is water consumption where a certain tested shower product could be related to a rating system or be sold by the length of usage time for an environmentally friendly shower. If energy were to be included in the calculations of performance, then some standardization may be needed in the reporting of usage across different UK shower systems throughout the year which could also possibly include the energy loss within the water from the shower head onto the skin. Objective comfort is the main focus for this study where the quantitative effectiveness of the delivery of water and heat to cover the skin of a mannequin has been assessed. The subjective comfort is more of a qualitative assessment which is the main focus of the work being carried out at Liverpool John Moores University.

Water consumption: • Possible tie in with BREEAM environmental rating system for homes • Time-based approach?	Energy consumption: • Standardized reporting for mean operational performance • Consider effectiveness of delivering heated water onto the skin
Objective comfort: • Assess the performance of the shower head • Assess water coverage and heat transfer over the body	Subjective comfort: • Use appropriate numbers of independent assessors to generate comfort scale • Could be contrary to low water consumption ideal

Table 1: Shower performance indicators

This study uses a numerical approach called computational fluid dynamics (or CFD) to build a virtual model of a shower cubicle (with or without a mannequin) and then outputs a solution of the shower cubicle environment (Figure 2). The cubicle environment is defined by the air movement, air temperature and moisture levels. The environment that a person feels is also dominated by the water movement over the skin and its associated temperature. The impact of the flow rate and temperature of water emanating from the shower head on the cubicle and person environment is also calculated within the CFD model.

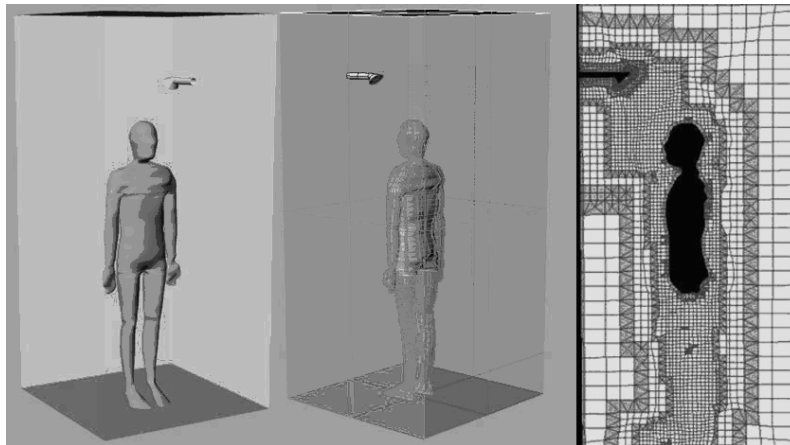


Figure 2: Views of the computational model

2. Experimental data

In order to provide additional confidence in the numerical predictions, experiments have been carried out in parallel to the computational study as part of an ongoing research project under the guidance of Dr David Phipps, Liverpool Centre for Environmental Technology at Liverpool John Moores University. Although the

primary purpose of the research work is to examine possibilities for water saving particularly in power showers, a secondary consideration was to provide some validation data to compare against the computational model used in this study.

Flash photography was used to freeze the spray jet/droplets to capture the instantaneous spray form at low and high flow rates (Figure 3). To the naked eye, the majority of sprays look as if they are made up of continuous streams for some distance from the spray head but the photographs and theory based upon Weber number calculations indicate a stream of droplets under the majority of supply conditions with early break up of the jets.



Figure 3: Instantaneous spray form at low (left) and high (right) flow rates

Comparisons were made between measurements at a chosen flow rate and the computational predictions for the same shower head operating at the same flow rate using a British Standard, BS 6340-4:1984, which specifies the requirements for, amongst other things, the functional testing of domestic shower heads.

Spray form was compared using a 150mm diameter annulus gauge with 3 measurement zones (centre cylinder, inner annulus, outer annulus). A 60s period was measured at a height where the spray was fully captured to determine the mass and percentage mass per zone to compare against the guidelines and virtual gauge in the computational model. Both the measurements and the predictions were within the desired BS ranges with a maximum difference in any zone of 7% (Table 2).

Zone	% area	BS guidance by zone (%)	Measurements		Predictions		Difference (%)
			Mass (kg)	% by zone	Mass (kg)	% by zone	
Centre cylinder	12.0	0 to 35	1.17	32	1.04	25	7
Inner annulus	32.4	10 to 70	0.86	23	1.04	25	2
Outer annulus	55.6	25 to 85	1.68	45	2.08	50	5
Total	-	-	3.71	-	4.16	-	-

Table 2: Comparison of annulus gauge measurements and predictions

Spray trajectory was also compared with guidance values falling within acceptable limits and, in addition, the water temperature at various distances from the spray head was measured and compared to predictions. Temperatures at each height were measured radially into the shower cone using thermocouples mounted in heat sink so effectively averaging the temperature between the inner and outer spray regions. Similarly, for the predictions, the outer and inner cone temperatures were averaged. The values are given for distances of 0.05, 0.25, 0.45, 0.65, 0.85 and 1.50m from the spray head for similar ambient temperatures and a good correlation is shown (Figure 4). CFD is therefore an appropriate tool for predicting the water droplet temperature variation with height as well as spray form and trajectory.

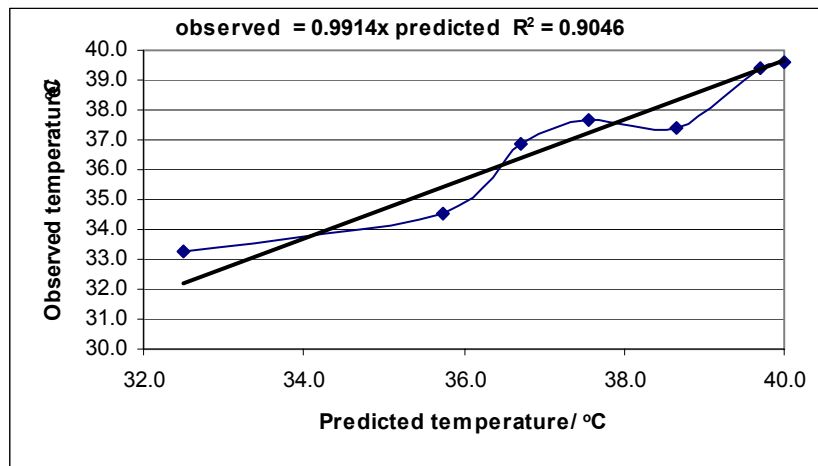


Figure 4: Comparing water droplet temperature variation with height

3. Background to the study

In order to reduce the number of possible variables for the study, a number of different boundary conditions were fixed as follows:

- Surface of the mannequin had a fixed temperature applied.
- Shower head was fixed to an angle of 45°. The number and definition of the injection points for the spray head represented 16 case scenarios with a fixed water temperature at the injection points of 40°C.
- The case scenarios included variations in flow rate (from 3 to 30l/s), size/number/position of holes in the shower head and, in one case, an atomized spray.
- The shower walls and floor were treated as zero heat transfer surfaces with the top of the shower having a pressure boundary with zero gradient (temperature and moisture).
- The plug hole was again a pressure boundary with zero gradient (temperature and moisture) allowing loss of water.

4. Results

Initial calculations were carried out to determine the appropriate time of analysis when to compare the results from different case scenarios. Figure 5 shows the thickening and running of the water film over the surface of the mannequin and over time from when the shower is switched on. It was decided to take the 5.0 second time period as an appropriate time from which to compare the various case scenarios. In reality, a long shower would result in a steady increase in air and skin temperatures which would require a long-term transient simulation with separate model for skin temperature. This approach is prohibitive for this multi-case study.

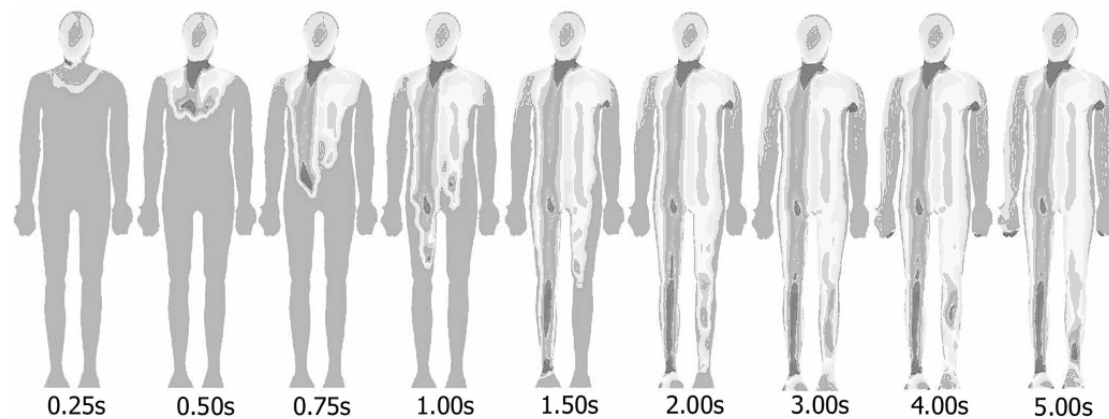


Figure 5: Generation of the water film over time

A number of results were presented for each of the case scenarios to provide a detailed insight to the shower physics. In this paper a comparison will be shown between two shower heads the operation mode of outer sets of holes only. In the first case (on the left in the images) the flow rate is 6.0l/s and it has small holes. In the second case (on the right of the images) the flow rate is 15.0l/s and it has large holes.

The full MTP report contains more detailed information not possible to present here. Figures 6 and 7 show the predicted air temperature, speed and moisture content distributions on a vertical section through the centre of the mannequin. The change in heat and moisture between the air and water phases is taken into account in the calculations. As the spray passes through the air towards the mannequin, it entrains and heats up the air with the warmest regions (air and water) closest to the spray head with this heating up outweighing the losses due to evaporative cooling. The amount of entrainment and heating up is dependent on the number, size and speed of droplets. The air phase conditions are only slightly different between the low and high flow rate cases.

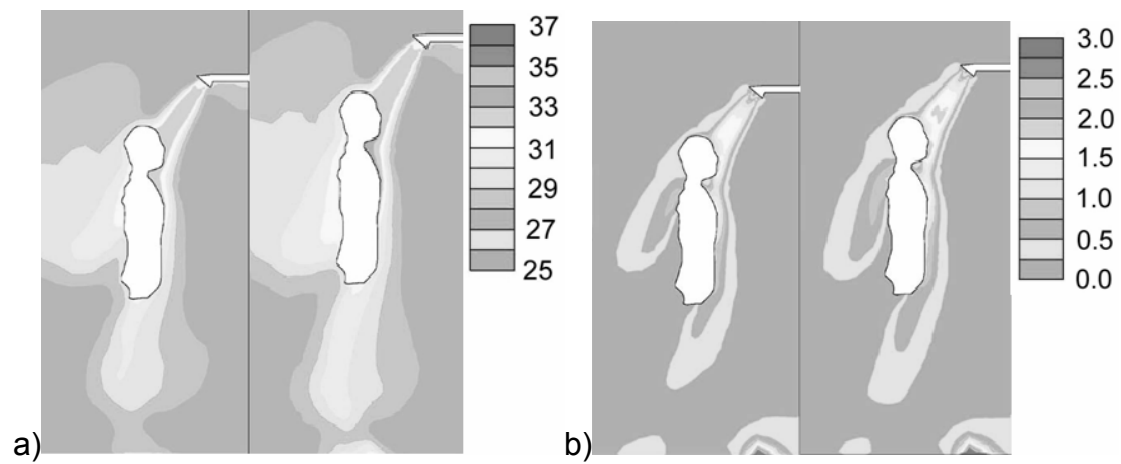


Figure 6: Predicted a) air temperature (in °C) and b) air speed (in m/s) distributions

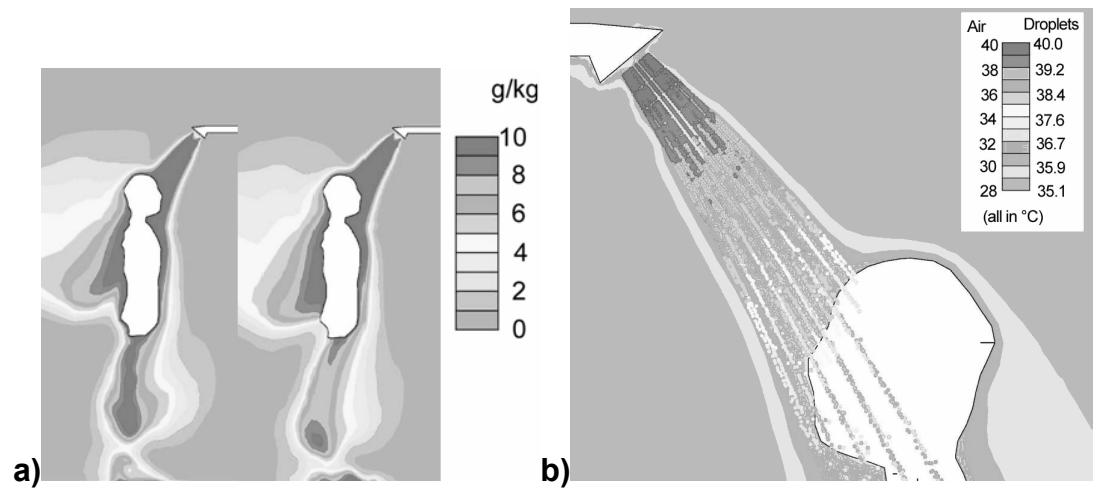


Figure 7: Predicted a) air moisture content distribution and b) combined air & droplet temperatures

Figure 8 shows the predicted heat transfer coefficient and heat flux distributions between the surface of the mannequin air/film next to it. These values vary considerably between spray impact regions, surface run-off areas and non-wetted areas.

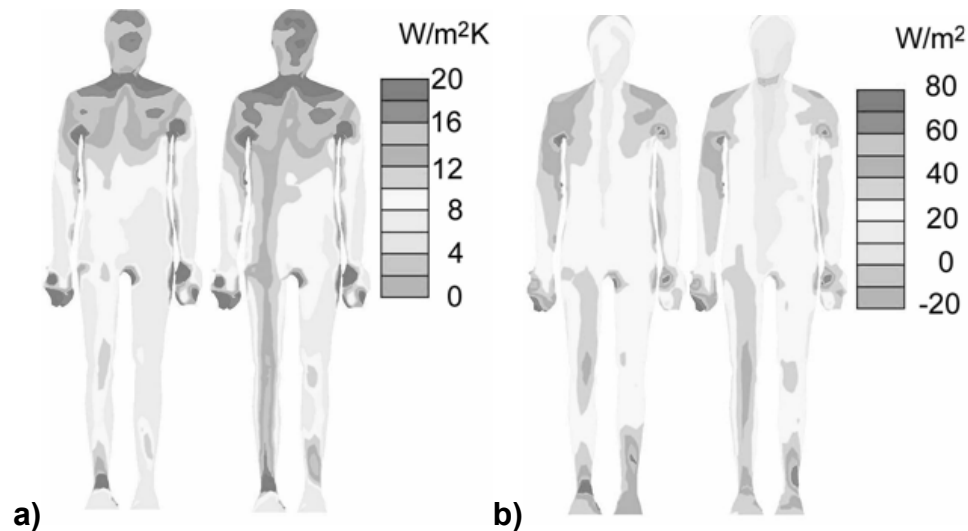


Figure 8: Predicted surface a) heat transfer coefficients and b) heat flux distributions

Figure 9 shows the water film thickness and temperature next to the surface of the mannequin. The mannequin has an undulating surface which causes the water film thickness to vary as it runs down the surface. The location and thickness of the film is largely dependent on the area of impact with the surface and flow rate. In reality this would be ever changing due to the movement of the body within the spray. In the two cases shown here, there is a similar water coverage but with a slightly thinner film thickness in the low flow rate case, i.e. water coverage can be maintained at lower flow rates if the size (and number) of holes are adjusted to maintain the spray profile. The water film temperature only varies by about 1K as well.

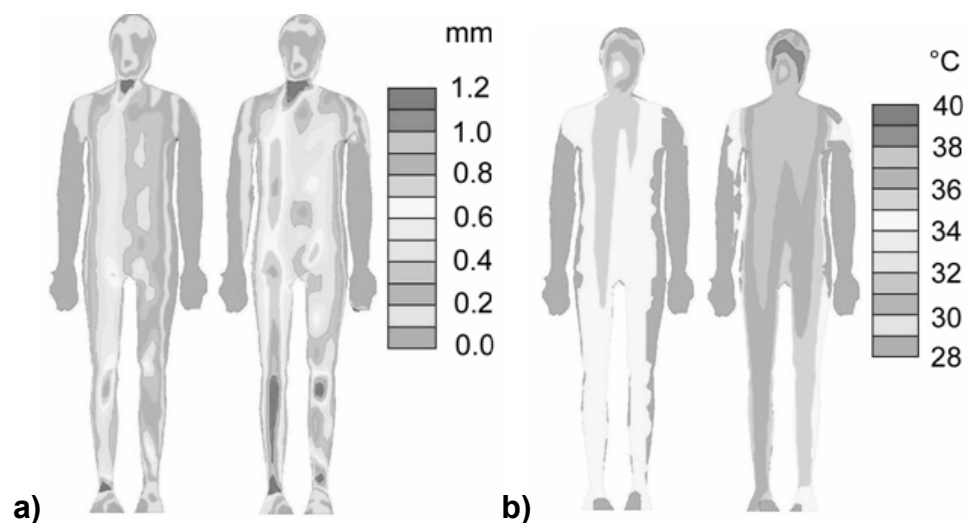


Figure 9: Predicted water film a) thickness and b) temperature

Figure 10 shows the water droplet temperature and pressure (in fact force per unit mass) exerted by the droplets on the surface of the mannequin. The temperature of the droplets reduce as they fall through the air largely because of the exposure of the surface of the droplet to the air, i.e. size of droplet, speed of droplet and the ambient air temperature. The smaller droplets were predicted to have a temperature reduction of about 2.5 to 3.0°C over the larger droplets. Although it was difficult to assess the true surface pressure due to the complexity of droplet impact at the surface, an indication was provided by calculating surface force per unit mass which showed that the surface pressure is likely to increase with smaller holes, i.e. the size and speed of droplet on impact could therefore be designed to provide a higher surface pressure at lower flow rates.

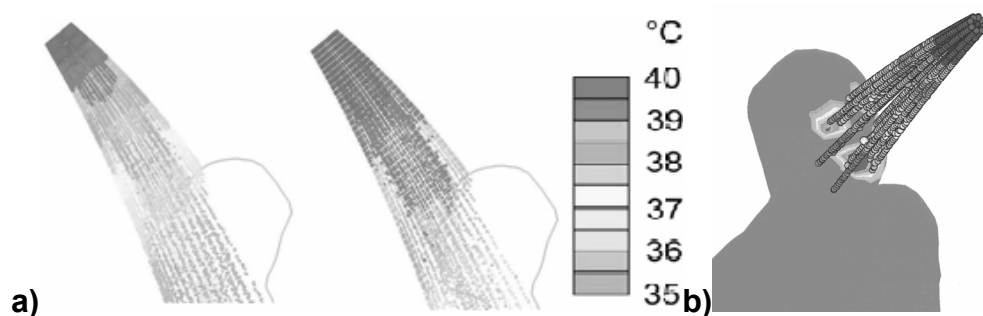


Figure 10: Predicted droplet a) temperature and b) pressure on the surface (or force per unit mass)

For a 15l/min shower at 40°C, energy usage increases by 9% if the supply temperature is increased by 3K but reduces by 60% if the flow rate is reduced to 6l/min (assuming a typical mains temperature of 8°C). At the lower flow rate, energy usage also increases by 9% if the supply temperature is increased by 3K but the overall energy usage is now 40% of that at the higher flow rate, i.e. it is far more economical, in terms of energy usage, to reduce the flow rate and then, if necessary, slightly increase the water temperature to compensate for lower water temperature hitting the skin (smaller droplets). Halving the flow rate leads to halving the energy usage and associated costs.

5. Summary and conclusions

The key physics in the study were as follows:

- Quick break-up of the spray jets into droplet streams
- Trajectories largely dependent on spray head definition, momentum and gravity. Inter-stream collisions will occur with certain combinations.
- Spray interacts with air generating movement and heating it
- Evaporation occurs taking heat out of air and adding moisture to it
- Surface heat flux dependent on air/film coverage and temperatures
- Water droplet temperatures reduce due to exposure with the air and the inner core is warmer than the outer one
- The greatest heat loss is in a spray with smallest size of droplets
- Complex physics within impact region making true surface pressure difficult to assess

The key findings in the study were as follows:

- Water film coverage and spray profile can be maintained at lower flow rates by adjusting size and number of holes
- Water film temperature is slightly lower at lower flow rates
- Water droplet temperature was slightly lower with smaller holes due to smaller droplet sizes
- There is not a significant difference in water coverage and film temperature between having outer, middle or inner sets of rings
- Surface pressure at the skin can be increased at lower flow rates by reducing the size of the holes

The limitations of the work are as follows:

- The geometric and time varying relationship as a person moves within a shower to increase performance in terms of rinsing and water coverage was not included
- Further development would be required to include the effects of hardness of water, amount of hair (surface roughness), body shape and water droplets which are part air, e.g. aerated, champagne and possibly pulsed streams
- Relating the quantitative to the qualitative aspects of shower comfort (and degree of discomfort!)
- Very high flow rate showers have much more droplet parcels to track impacting the required compute times and possibly the hardware requirements for the analysis

Other conclusions are:

- CFD (Langrangian approach) is an appropriate tool for predicting the performance of many types of shower sprays although surface pressures may be problematic.
- A Standard Assessment Procedure (SAP) or British Standard type assessment could be set up based upon the delivery performance of the shower. Consideration of multiple operational modes over a year may be needed.
- Many manufacturer or user drivers may need to be considered for market change. For the manufacturer this could include performance indicators, flow restrictors, strengthening British Standards, introducing a computational assessment scheme and better standardization for the reporting of performance. For the user this could include performance indicators, better purchase information, advertising and increasing consciousness whilst taking the shower.
- There is almost a direct correlation between reducing flow rate and reducing energy costs, i.e. half the flow rate leads to half the energy usage and costs.

6. Recommendations for future work

- Continue work with manufacturers to assist in the analysis of future shower products.
- Further develop the model to allow manufacturers to drive the solution.

7. Acknowledgments

We would like to thank Dr. David Phipps, Liverpool Centre for Environmental Technology at Liverpool John Moores University, for the experimental data taken from a project originated and funded by United Utilities Plc. We have visited a number of shower manufacturers, namely Aqualisa, MIRA and Triton, who provided a good insight to the industry. We would also like to thank Computational Dynamics Ltd for their software support.

8. References

- BS 6340-4: 1984 “Shower units – Part 4: Specification for shower heads and related equipment”
- Buonfiglioli and Mendonça (2005) “LES-VOF Simulation of Primary Diesel Spray Break-up with Synthetic Inlet Perturbations” ILASS Americas, 18th Annual Conference on Liquid Atomization and Spray Systems, Irvine, CA
- Lin and Reitz (1998) “Drop and spray formation from a liquid jet” Annual Review of Fluid Mechanics 30:85–105
- Pitts *et al* (2000) “Water conservation: Low-flow showers and flow restrictors” IP 2/00, BRE Water Centre

9. Presentation of Author

Darren Woolf obtained a Ph.D. in fluid mechanics at the University of Leeds using experimental and computational fluid dynamics (CFD) techniques. Since joining Arup in 1995 he has been involved in a large number of building environment and water related projects throughout the world using advanced analysis to assess and optimise the performance of systems.



Provision scales of sanitary accommodation in public toilets

L. T. Wong (1)

Department of Building Services Engineering,
The Hong Kong Polytechnic University, Hong Kong
(1) belt@polyu.edu.hk

Abstract

Sanitation is one of the essential facilities in buildings. The unit of sanitary accommodation required in some public toilets is currently calculated at a failure rate of providing immediate service to meet the user demands. As a user is very likely to feel anxious about the time needed to get to the service desired, the waiting time would probably be a better criterion for specifying the unit of sanitary accommodation required in toilets for large spaces. In this study, a procedure of determining the probable user waiting time for an appliance in a public toilet is proposed based on a queuing theory. A simple queuing system for water closets and washbasins was developed by the measured waiting time from experiments. The corresponding probability of queuing for a specific appliance/service was determined. For average waiting times of 1 s and 10 s, the number of appliances required was calculated and compared with the current one in common use. Applied examples with input parameters, including the user arrival rate and appliance service time for the users, derived from the observation of the use of washrooms in a large shopping mall in Hong Kong were illustrated. This procedure offers flexibility for the design of sanitary accommodation to meet various service standards in terms of the probable user waiting time for different appliances.

Keywords

Sanitary provisions, public toilet, occupant demands, queuing theory

1 Introduction

A large shopping mall is usually designed to house various types of retailers, cinemas, playgrounds, and areas for exhibitions and multifunctional activities to attract thousands of customers. The demands for sanitary accommodation in shopping malls can be very different,

both in terms of the interval between user arrivals and the appliance service time. Such demands depend very much on the nature of activities being held in the mall, the composition of retailers and the length of time a customer spends in the facility. The uncertainty of this 'casual' usage/arrival pattern presents considerable difficulties in quantifying the demands.

Queuing theory has been applied to evaluate the provision of washroom appliances for well-defined usage patterns with an arbitrary choice of limiting failure rate λ [1, 2]. For some offices and institutional buildings, arrival patterns and service time using the Poisson distribution were assumed and water closet (WC) provisions with a limiting failure rate of 0.01 were determined. This approach seems to be suitable for WC demands that peak in certain short periods but remain relatively low for other periods, e.g. in offices before lunch or in schools during recesses [1].

In Hong Kong, the minimum acceptable number of WCs serving a design population for local shopping malls is prescribed by law [3]. However, this statutory requirement might be inadequate in that long waiting time to get to the sanitary services during peak hours at some shopping malls has been reported recently [4, 5]. In several cases, additional WCs have actually been installed to reduce the user waiting time.

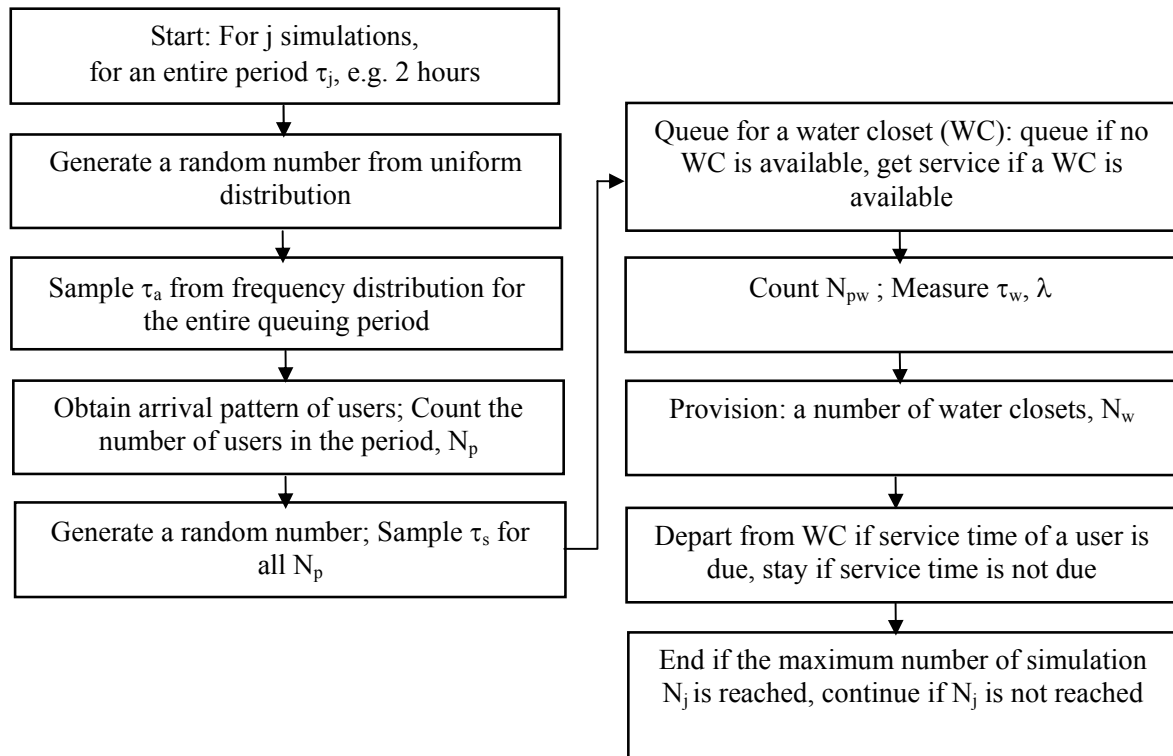


Figure 1: Block diagram of Monte Carlo simulation for a simple queuing process [5]

Although user satisfaction regarding sanitary services has not been examined against the choice of limiting failure rate in many designs, the user waiting time is one primary concern for quantifying such user satisfaction. This paper proposes a simple queuing model for determining the probable user waiting time which is correlated with the user satisfaction from the WC

provisions in some large shopping malls. In particular, surveys on the maximum waiting time expected by a user, the frequency distributions of the time between user arrivals and the total service time were conducted at a large shopping mall in Hong Kong. A procedure of determining the waiting time and the failure rate of a certain level of WC provision was then illustrated with the computation of acceptable WC provisions required for some shopping malls.

2 Simple queuing model

A simple queuing model has been proposed to quantify the services provided by certain sanitary provisions as shown in Figure 1 [5]. For a typical shopping mall washroom, a WC, in comparison with other appliances like a washbasin or a face towel station, is assumed to be used first with the longest service time. The description of the queuing system requires the specification of a queuing discipline and certain user characteristics. In this study, the first-come-first-served queuing discipline is assumed [1]. Upon arrival, a user will have immediate access to an available appliance or queue for the desired service. Once served, the user will leave the appliance for the next process, i.e. queue for another appliance such as a washbasin or leave the washroom. Since the users are characterized by the time between user arrivals τ_a (s) and the service time of a WC τ_s (s) in the model [1, 4-5], for simplicity, a user is assumed to queue in all situations and a constant service time distribution is adopted.

For a level of service of the WC provision L_s expressed by the design occupant load N_o (ps.) served by a number of WCs N_w , i.e. $L_s = N_o/N_w$, the mean user waiting time τ_p (s) can be determined from the waiting time of the users for the appliance τ_w (s) in simulation j of the queuing system (Figure 1) as follows, where N_j is the total number of simulations, and N_p (ps.) is number of users given by the mean time between user arrivals $\langle \tau_a \rangle$ (s) and the total simulation time τ_j (s),

$$\tau_p = \langle \tau_w \rangle = \frac{\sum_{N_p} \sum_j (\tau_w)_{j, N_p}}{N_{pw} N_j} ; N_p = \frac{\tau_j}{\langle \tau_a \rangle} \quad \dots (1)$$

N_{pw} (ps.) is the number of users who have waited for a WC in the queuing process. It is determined by the number of users having a waiting time for the appliance larger than zero (i.e. $\tau_w > 0$ s),

$$N_{pw} = N_p - N_p \Big|_{\tau_w=0} = N_p \Big|_{\tau_w>0} \quad \dots (2)$$

And the failure rate λ of providing immediate service to the users is determined by all the users who need to wait for a WC (i.e. N_{pw}) in all j simulations,

$$\lambda = \frac{\sum (N_{pw})_j}{\sum (N_p)_j} \quad \dots (3)$$

3 Case study

A shopping mall in Hong Kong with a floor area of 62,000 m², consisted of 5 floors above ground and a basement, housed various retailers, cinemas, food courts, restaurants, department stores, a theme park, game centers and other exhibition areas, was selected for this study [6]. A total of 22 washrooms (11 male-female pairs) were distributed inside the mall for the general public. Each of the washrooms contained a number of WCs, washbasins, hand dryers, paper towels, and urinals (for male washrooms only).

A preliminary survey on the hourly user arrival rates was conducted at the 22 washrooms on a weekday and a weekend. The results showed that an average demand for a washroom at the weekend would be 40% higher than that on a weekday. The demand for a female washroom was about 14% higher than that for a male one at the same time and location. It was reported that no queue was found outside all male washrooms from all the observations; however, queues were found at 7 (out of 11) female washrooms.

In the study, the washroom of the highest demand was selected to illustrate the queuing model for determining the time between user arrivals τ_a (s) and the user service time τ_s (s). This 'model' washroom was a female one serving a design population N_o of 600 persons, and had hourly arrival rates of 200 and 400 persons during the weekday and weekend demand peaks respectively (about 33% and 67% of the design population). Its WC number was later increased from 6 to 8 after the surveys.

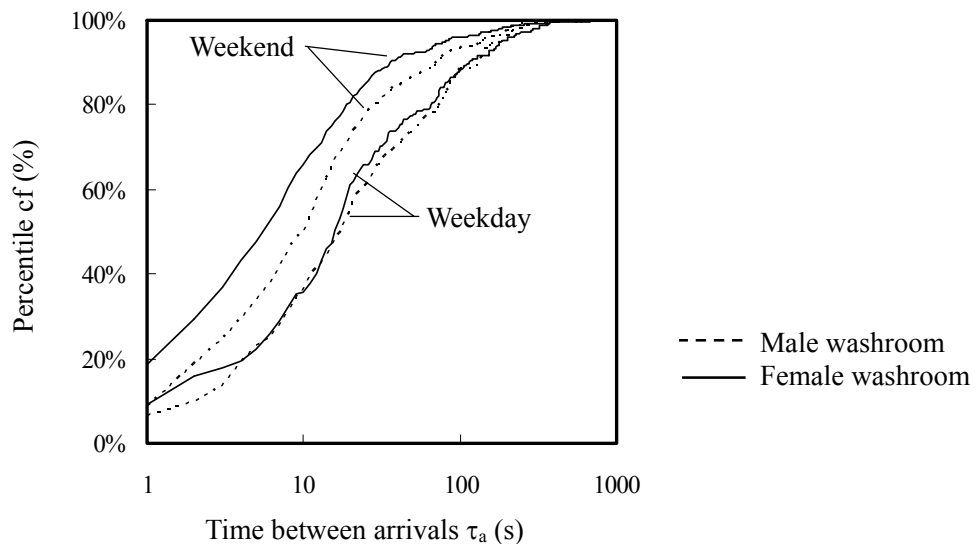


Figure 2: Time between user arrivals

The CCTV records of the main entrance of this washroom were reviewed and τ_a and τ_s were recorded again for periods of 6 hours during peak times. The recorded data was then sorted for

the male-female washroom pair using this same entrance and the frequency distributions are shown in Figure 2. While their median arrival times on weekdays were similar, the mean arrival times of these two washrooms were much higher during weekends, i.e. 10 s for the male washroom and 6 s for the female one. The average arrival rates found at these male and female washrooms were 6.7 and 4.6 persons per minute weekends, and 2.7 and 3.2 persons per minute weekdays, respectively.

The time of each individual spent in the ‘model’ washroom was determined from the video records. Since the process details of an individual using a washroom poses considerable ethical and practical problems, this time was taken as the total user service time. Walking time to a service station (i.e. a WC or a washbasin) was excluded in this study for simplicity, so the total user service time was approximated by the sum of WC service time and washbasin service time. For a female toilet in offices, it had been reported earlier that about 80% of the total service time would be spent on a WC. This was applied to determine the service time τ_s (s) of a WC in the ‘model’ washroom. The results, together with those found in offices for comparison, are shown in Figure 3(a) [1].

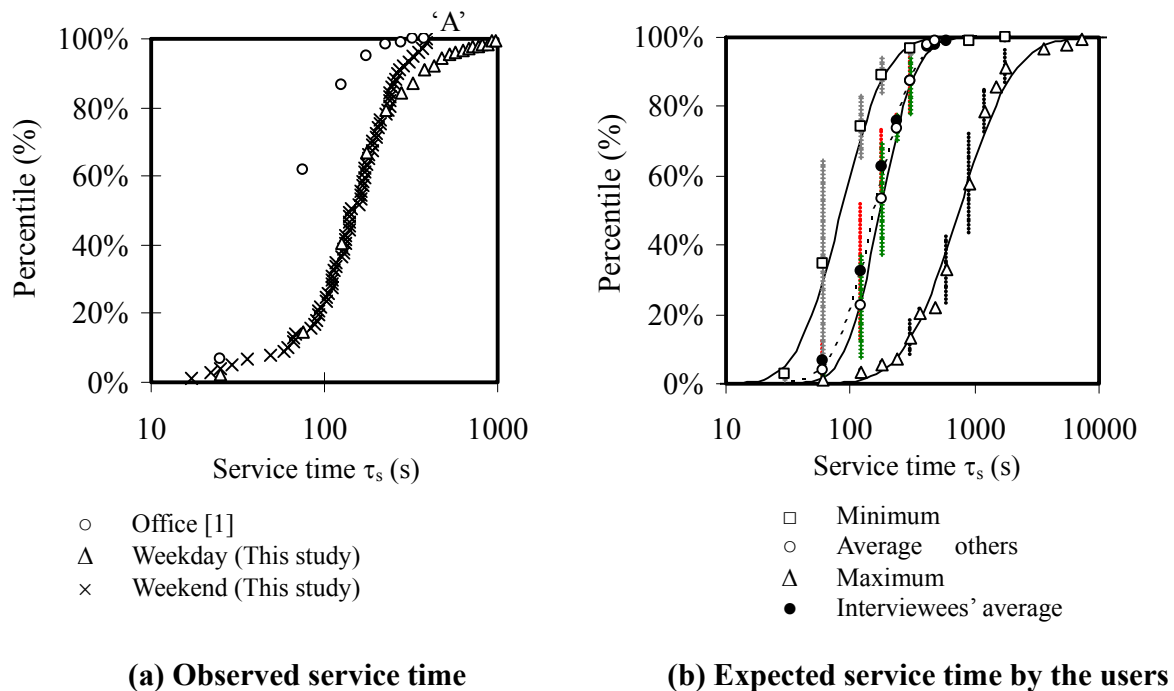


Figure 3: Service time of a water closet

The WC service time observed in the shopping mall was generally longer than that found in offices, though their longest service times were very close. Interestingly, the average observed on a weekday was almost the same as the weekend average. Besides, a user might occupy a WC

much longer during ‘less busy’ hours (on weekdays) as indicated by ‘A’ in the figure.

3.1 Questionnaire Survey

A questionnaire survey on public sanitary provisions was conducted to study the service time and user satisfaction. A total of 150 random washroom users were invited and 100, of them 85% aged 15-24, 10% aged 25-34, and 5% aged 35 or above, were interviewed. This was the assumed typical age group distribution of shopping mall visitors. The service times of the interviewees and estimations of the maximum, average and minimum service time of a WC/washbasin/urinal for all other users were recorded. Willingness to withdraw from waiting at certain queue length was indicated on a semantic differential scale (Very likely, Likely, Equal chance, Unlikely, Very unlikely). The maximum acceptable waiting time for the services was surveyed.

Figure 3(b) shows the expected service time of a WC by the washroom users. The predicted mean service times by the interviewees and by other users were 160 s and 175 s respectively, there was no significant difference found between them ($P > 0.19$), nor between them and the measured average which was 145 s ($P > 0.3$). The maximum prediction range (980-1800 s) covered the maximum service time measured (1000 s). Likewise, the predicted minimum (about 20 s) agreed with the measured values (15-20 s). However, far longer service times (1.5-2 hours; $\leq 0.5\%$ of all samples) were expected by all users: the mean and median of the maximum acceptable waiting times were 360 s and 300 s respectively.

For the surveyed female washroom, the average maximum acceptable queue length that a user would be ‘very likely to give up’ was $N_q = 16$ persons. Taking the average service time $\tau_s = 145$ s and the number of WCs $N_w = 8$, the average waiting time τ_p (s) found was 290 s, which reasonably agreed with the results expected by the interviewees (300-360 s).

3.2 Numerical experiments

Numerical experiments for the probable performance of a sanitary provision using the surveyed data were conducted in order to study the acceptable number of provisions in the selected female washroom regarding the user expectation. The simulation model for the WC queuing process described by Eq. (1) to (3) was written in Fortran and executed by a personal computer.

By applying the Monte Carlo simulations to the number of provisions (from 4 to 16 in this case), the probable failure rate λ of providing immediate service and the probable user waiting time τ_w (s) were ‘measured’ from the numerical queuing process [4, 5]. Each simulation was repeated with a preset number of WCs, accompanied by the sampled arrival time τ_a (s) and service time τ_s (s) of an individual user. All design parameters including their average values, standard deviations and histograms were computed from the simulations. The proportion of vacant/occupied time for each appliance could also be determined.

The maximum number of repeated simulations N_∞ was limited by the computing memory and related to the simulation peak periods τ_j . In this study, the total effort of simulations, where $\tau_j = 7,200$ s, was $\tau_j N_\infty = 200$ million. The sensitivity of the number of repeated simulations N_j to the

output parameters ϕ was examined with the convergence criterion arbitrarily set at error $\xi = 0.5\%$, based on the required computing effort of 43 million.

$$\xi = \frac{\phi_j - \phi_{j-1}}{\phi_j} \leq 0.005 \quad \dots (4)$$

Figure 4 shows the probable failure rate of providing immediate service and the probable user waiting time by WC provision determined from the selected female washroom during daily peaks. The results showed that the numbers of WCs required for immediate service at the failure rate of 0.01 during weekday and weekend peaks would be $N_w = 7$ and 12. As expected, the provisions satisfying the weekend peak demands would satisfy the weekday ones as well. The results also showed the probable mean user waiting time would correlate with the number of WCs installed ($P \leq 0.005$). The maximum and minimum waiting times of the users who had waited for a service are shown in the error bars for weekend peak demands.

In order to cope with both weekday and weekend demands, the levels of service required should be 81 and 48 persons per WC for an allowable mean waiting time of 1 s, and 105 and 72 persons per WC for an allowable waiting mean of 10 s. Since the WC number of the ‘model’ washroom was increased from 6 to 8 after the surveys, the probable maximum user waiting time with the new provision (i.e. 8 WCs for a design population $N_o = 600$ ps.) would be up to 36 s, with the probability of occurrence $= 1 \times 10^{-6}$.

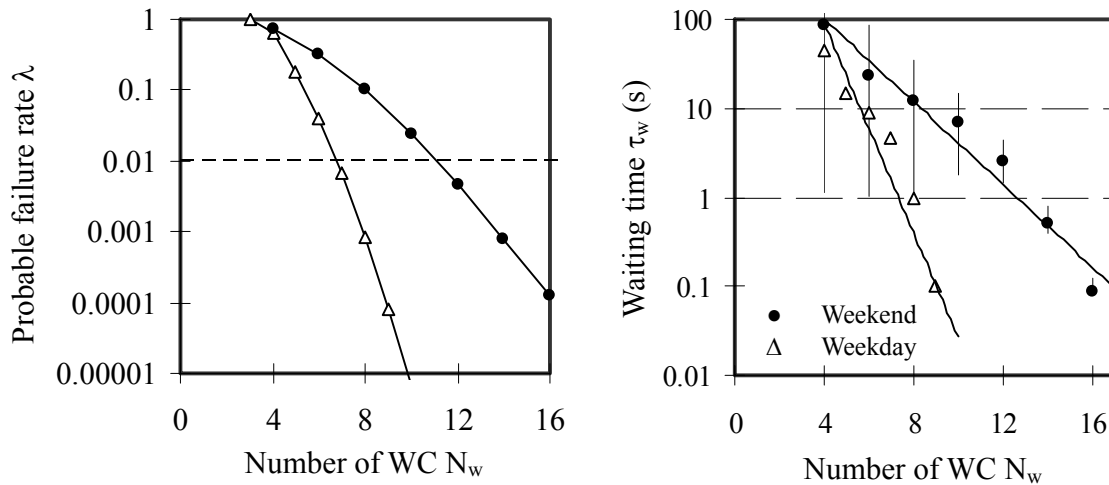


Figure 4: Washroom performance by WC provision

4 Conclusion

In Hong Kong, current WC installations appear to be satisfactory with respect to the minimum statutory requirements. However, inadequacy of sanitary provision has been reported recently regarding ‘long’ waiting time for the desired services in some large local shopping malls.

In this study, the WC provisions in a female washroom at various levels of user satisfaction were examined. In particular, a mathematic procedure, formulated from in situ measurements of the user arrival pattern, WC service time and acceptable waiting time in a large Hong Kong shopping mall, was used to determine the probable user waiting time and failure rate of a WC provision at various service levels simulated by a simple queuing process. The process assumed that a WC would be used first with the longest service time on a first-come-first-serve basis and a user would always queue for a service. Moreover, a constant user service time was adopted. All of these might limit the accuracy of waiting time predictions.

Nevertheless, the procedure offers flexibility for the design of sanitary accommodation to meet various service standards in terms of acceptable user waiting time. This approach also leads to develop quantitative measures, by selecting the suitable time between user arrivals τ_a (s) and user service time τ_s (s), for evaluating the performance of a sanitary accommodation installation based on certain user behaviour for other premises having similar nature.

5 Acknowledgement

This work described in this paper was partly funded by the Research Grants Council, HKSAR (PolyU 5129/04E; BQ801).

6 References

1. Davidson, P. J. and Courtney, R. G., (1976). Revised scales for sanitary accommodation in offices, *Building and Environment*, Vol. 11, No. 1, pp. 51-56.
2. Wistort, R. A., (1995). A critique of queueing theory approaches to plumbing design, ASPE Research Foundation, CA.
3. Laws of Hong Kong, Building (Standards of sanitary fitments, plumbing, drainage works and latrines) regulations, Chapter 123I, (1997).
4. Wong, L. T. and Yau, C. L., (2004). Sanitary accommodation scales for large shopping malls, *Architectural Science Review*, Vol. 47, No. 4, pp. 355-364.
5. Wong, L. T. and Yau, C. L., (2005). Modelling water closet demand in shopping centres, *Facilities*, Vol. 23, No. 9/10, pp. 453-465.
6. Chow, W. K. and Wong, L. T., (1999). Thermal environment design of atria in the Hong Kong Special Administrative Region: a survey study, *Architectural Science Review*, Vol. 42, No. 4, pp. 235-251.

The Proposals for Design of Humanized Public Toilet

Frank M.H. Wu

mhwuarch@ms5.hinet.net

Honorable Chairman of Taiwan Toilet Association

Professor of National Taiwan University of Science and Technology, Department of Architecture, Taiwan

Abstract

Public toilet are facilities we use everyday, but it seems to be thought of as dirty, smelly, and unsafe. How to eliminate this kind of image is of key importance, it deserves everyone's concern and effort to amend such problem. The design priority for public toilet is humanization - it has to be designed with the need of user's behavior. Secondly, the brightness, good ventilation and safety are important as well. Thirdly, it should be easy to clean and maintain. According to this understanding and based on my previous personal experiences of toilet designs, I would be glad to present this information to the benefit of our "toilet family" as a whole in the hope that it will meet with overwhelming support.

Keywords

Humanization; Safe and comfortable; Toilet behavior of disabled people; Dressing platform for ladies.

1 Introduction

Public toilets are places that everyone must use everyday; the distinction of toilet design is an issue of concern. Does it accord with our daily behavior of use or whether it is easy to clean? Taipei began to promote cleaning programs since 2000. In recent years, department stores, cinemas, restaurants, stations, markets, parks, schools, and all administrative units have dedicated their utmost efforts to work on the cleanliness. The city implemented new plans as well, that really did make some noticeable improvement in public toilets. However, in the design of public toilets there remain a lot of problems waiting to be improved. In the following we will present some examples and discussion:

2 Design of toilet used by disabled people

Most of the designs for toilets used by physically disabled people do not meet the needs of users. This is often because the designer did not understand the way in which disabled people use the toilet, and rarely have a chance to accompany them to go to toilet. Therefore, they always refer to existing information and simply copy old designs with little evolution or modifications. This is a mistake that should not be made. There are few criteria that we have to pay more attention to:

- (1) The door width for disabled toilet should be 90 cm, preferably equipped with light manual sliding door that should not have threshold and must level with ground level. Electronic door is apt to suffer from power failure or breakdowns, making most of disabled people afraid of being locked inside.
- (2) The disabled toilet shall have a net turn-around space with a diameter of 150 cm to allow for a wheel chair to make a U-turn.
- (3) Disabled people sit on the wheelchair most of the time, so insufficient muscle movement often causes peristalsis of the intestines. Therefore, most suffer from excretion difficulties and constipation, they have to assist the feces out with their hands or use an enema, thus making both hands dirty and unable to wear trousers. Consequently, a small washbasin is needed to fix next to the wall beside the disabled water closet. (Photo 1)



Photo 1 - The disabled toilet with a backrest without water tank. A small washbasin next to it, the width of two handles is 70 cm and height of 65 cm. (228 Park in Taipei)

- (4) The water closet should provide a backrest without seat cover. The height of the water closet should be 40 cm.
- (5) Handles are to assist the disabled person in using the toilet, two handles beside the toilet seat give support for disabled people taking off their trousers, so the height should be 63~65 cm, and a width distance of 67~70 cm to facilitate use. One of the

- suspended handles should be moveable and easy to turn, the other sidewall's handle should be L-shaped (preferably length of each handle is 80 cm)
- (6) The disabled toilet does not need a water tank. It is better to provide a pressure flush with a flush button must not set behind the toilet seat, but instead placed it should be easy to reach and place on top of the small washbasin (height is 120 cm). Next to flush button, an emergency bell should be provided. Lastly, a toilet paper holder can be placed beside the small washbasin.
- (7) Because the disabled person sits on a wheelchair, they use urine pot or a catheter to urinate, so the sidewall next to L-shaped handle should provide another set of flushing buttons, toilet paper holder and emergency bell. (Figure 1). They can press the flush button while sitting in the wheelchair.

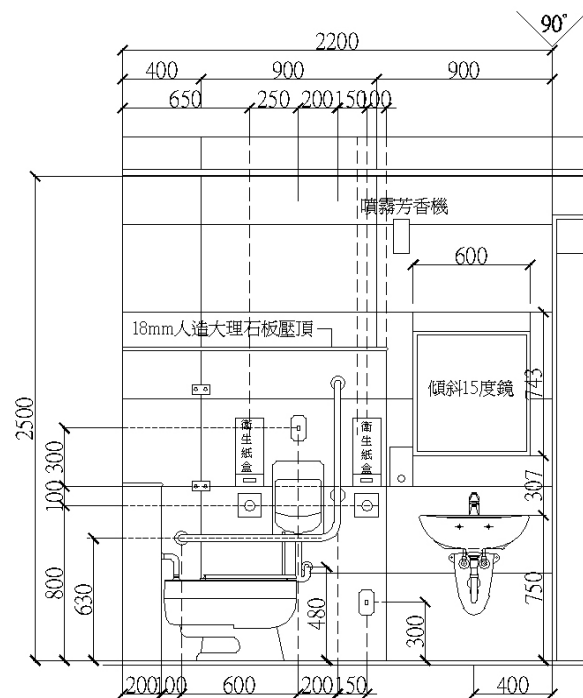


Figure 1 - A disabled toilet with small washbasin next to the water closet, 2 sets of flush button, emergency bell, and paper holders should be provided.

- (8) Minimum dimensions of the disabled toilet and its entrance-appliance relationship are detailed in figure 2. The required space for a disabled toilet varies with respect to manual and powered wheelchairs. The basic layout of the water closet and washbasin, and their relationship with the entrance shall be as indicated in figure 2.

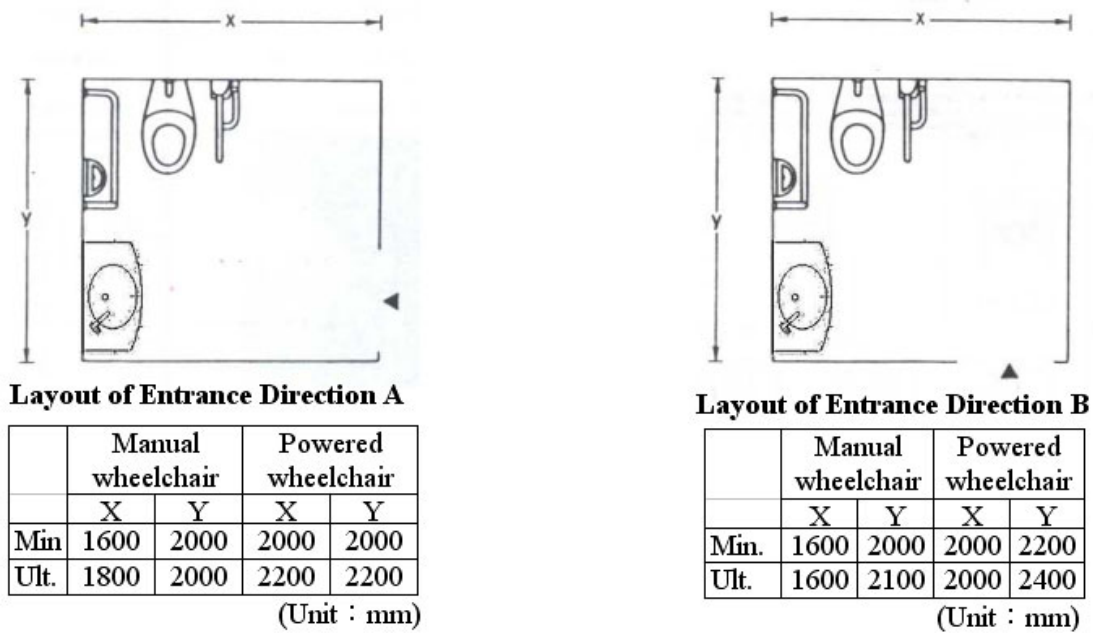


Figure 2 - Recommended dimensions for disabled toilet and its entrance-appliances relationship. All dimensions are net dimension. (Hiroyuki,1995)

3 Multi-functional disabled toilet

The facility and related costs of a disabled toilet are very high, yet the usage frequency of most disabled toilets is extremely low. Recently, in order to increase the disabled toilet usage frequency, there was an international trend of incorporating baby toilet, baby chairs, diaper tables, artificial-anus feces lavatories etc. into a disabled toilet so that it becomes multi-functional; it is no longer a disabled toilet only but a parent-child-toilet and an artificial-anus-toilet as well so that its usage is expanded. This configuration has been termed the “Multi-use Toilet” or “Universal Toilet”.

A disabled toilet can incorporate a variety of facilities to become a universal one:

- (1) Diaper Table (baby bed)
 - (2) Baby Chair.
 - (3) Child's water closet or urinal.
 - (4) Artificial anus feces lavatory – A feces lavatory can be added to a disabled toilet for the use of Ostomates or artificial bladder users; this lavatory is preferably fit with a detachable warm water rinse faucet on top of it. Additionally, there should be a flip-open trashcan for disposing used urinal bags. A dressing mirror and some hangers shall be installed on the wall. (Figure 4)
- With these 3 items installed, the disabled toilet is facilitated with Parent-Child toilet functions. (Figure 3)

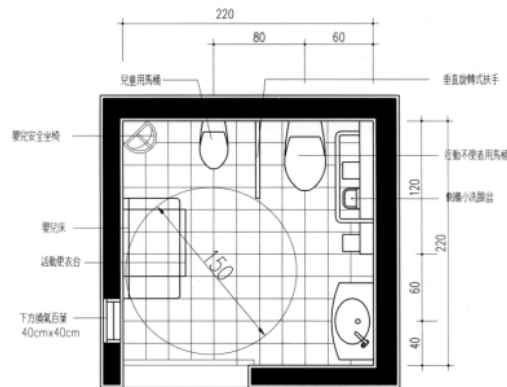


Figure 3 - Added with baby toilet, baby chair, and infant bed to become a family toilet

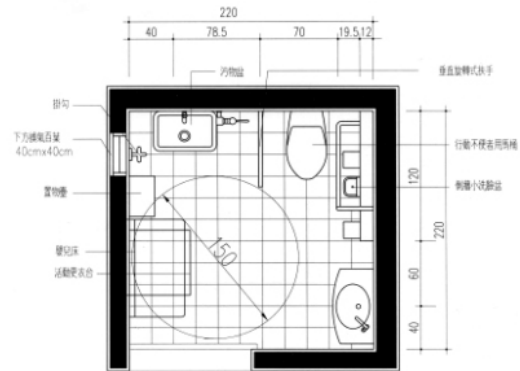


Figure 4 - A multi functional toilet with artificial anus feces lavatory

- (5) Dressing platform for women – if a women’s menstrual period comes when she is shopping in a department store or in a park, it is very inconvenient if they change their clothes in a water closet compartment. A detachable platform of size 60x60 cm on a wall (under Baby Bed) in a disabled toilet would be preferable for them to lock up the disable toilet door and change clothes privately. A specific changing room is equally preferable, but must be equipped with a basin. (Photo 2 & Figure 6)



Photo 2 - A disable toilet provides with dressing platform for ladies (228 Park in Taipei)

4 The design of squatting type toilets

Toilets can be separated into two main categories, “squatting” type toilet (also called Japanese toilet), and “sitting” type toilet (also called Western toilet). In the distribution

of toilets in the world we can take Turkey as a boundary. To the east of Turkey toilets are mainly of the squatting type. To the west of Turkey they are of the sitting type. The squatting type make up the great majority of public toilets in Taiwan, because of the general unsanitary feeling about direct contact with toilet seat, so most of them only provide one sitting toilet in public toilets. The design of squatting type toilets still has a lot of problems that need to be improved:

- (1) For the design layout of squatting type toilets, it is advisable to design them parallel level with the door. That is to say the door is on your right or left hand side while squatting. Most of people feel insecure if their buttocks are toward the door when someone knocks the door.
- (2) Squatting type water closet's dimension usually is 1 meter $\times$ 1 meter, due to cleaning consideration, it is advisable that the width should be more than 1 meter. The length is 1.10 ~ 1.20 meter.
- (3) In Taiwan, the general size of squatting type water closet is 50 cm, which is so short that the excrement can often be found outside of toilet basin, causing cleaning problems. Therefore, we have especially developed a long squatting type of 70 cm. (Photo 3) The 4 angels of the edge were made in square shape, it is much easier to fix with ceramic tiles into floor than the previous round shape, and is neat, and easy to clean.



Photo 3 - The inverted T-shaped handles and an extension squatting toilet

- (4) Using 70 cm extended squatting water closet, furnished with inverted T-shaped Handle as Photo 3. It can support the users not only to help maintain balance when squatting down or standing up, but also to help users to get in the right position to prevent excreting outside of the toilet basin.
- (5) Toilet basin into the floor deck, so it causes a 20 cm step difference between toilet and floor. The step barrier makes it easy for elderly people, children, and pregnant women to fall. It is more advisable to make the design flat without a step barrier. (Figure 5)

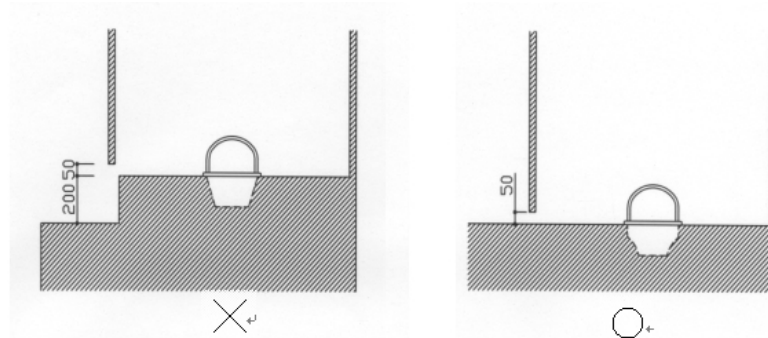


Figure 5 - Left with step barrier is dangerous. Right with flat level of floor is safe.

5 Adding Safety to ladies toilet's facilities

The first priority in design for ladies toilet is to ensure “safety” and “privacy.” The entrance should be designed as a curved walkway without a door, that can not be seen easily from outside. In recent years, the ladies toilets have been designed with more humanized consideration, such as :

- (1) The gap distance for squatting type toilet should be no more than 3~5 cm from the floor to toilet door to ensure privacy. The top of each toilet should be provided with a bright lamp and place with emergency bell to increase security.
- (2) The ladies toilets should be more spacious and additional powder/makeup corner.
(Photo 4)



Photo 4 - Powder corner of Idée department store in Taipei

- (3) It is preferable to provide a room with toilet, dressing platform and water basin.
(Figure 6) This will provide a private, safe room for women to change their underwear with ease during menstrual periods, and with a cleaning platform (movable), washbasin.

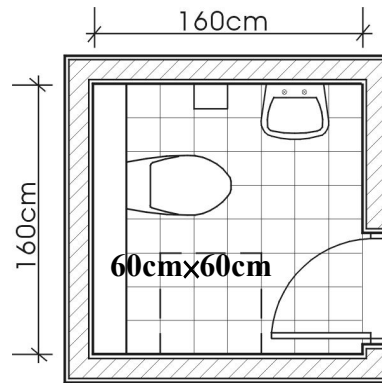


Figure 6 - A toilet layout with dressing platform.

- (4) The quantity problem of toilets for men and women, have long been neglected. Usually female require longer time than male in using toilet, according to the investigation of TOTO Technical Center, Japanese female's urinating duration in average is 90~93 sec whereas male's is about 30~35 sec, the proportion of time necessary between male and female are 3 times difference. In Taiwan, based on my study – most women are 70~73 sec, and men are 30~35 sec. Why Japanese women require longer time of toileting, because they are usually shy of their urinating noise being heard by others, they would flush water before use and flush again for actually urinating, so the actual urinating sound would be covered by water flush noise, then they would finally flush third time after putting their clothes back, totally take 90~93 sec. In Taiwan, the proportion of usage time for men and women are 1:2; basically when come to design of public toilet quantity, the female require one time more than male. But in place like schools, movie theatres, stations, concert halls, theatres and conference rooms where people rush to toilet during the “simultaneous” period, the number of male and female urinal sets should be “1:2” or “1:2.2.” However if there would not be a high probability of simultaneous use for toilets in park and department store, it would not be necessary to follow the proportion of “1:1.2” or “1:1.5.”(Table 1)

Table 1 - The comparison between Japan and Taiwan's usage in urinating time

	Gender	Time require for urinating	Ratio of time
Japan	Female	90 ~ 93 Sec	3
	Male	30 ~ 35 Sec	1
Taiwan	Female	70 ~ 73 Sec	2
	Male	30 ~ 35 Sec	1

Note : Japanese female waste too much water when urinating. TOTO has developed a device called "Otohime" (Imitation sound unit) that releases water flushing noise to replace actual flushing.

6 The Problem of Urine Residue on Men's Toilets

The most serious problem of keeping public toilets clean is the urine residue problem which cause the terrible smell under urine bowls in men's toilets, it is difficult to clean

urine drop on the floor. In the design plan, we tried to apply some countermeasures to prevent the problem. (Photo 5)



Photo 5 - Toilet in Taipei 228 Park.

T o p : The light & window view. Below : Paved a black granite stone, for easy cleaning.

- (1) Hanging type urinal sets should be installed (the floor type is not easy to clean), the height of urinal sets opening is 60~65 cm. In most European countries are 65~70 cm, Japan is 58 cm, a slightly increase in height will make urination into the urine set that much easier.
- (2) Place a fluorescent light above the urinal set will enable the users to get closer. If the lights are placed in middle of the room, our own reflecting shadow will cover the urinal set and cause vision to be somewhat blurred. This cause people to resist stepping closer to the urinal set and also are afraid of getting dirty on their pants.
- (3) Pave a 50 cm-wide black granite stone band right under the urinal sets, with 1 ~ 1.5 cm slightly higher than the floor for the user to stand on. This can reduce the problem of urine drop and be easy to clean. A large ceramic board can also be used. If using small size of floor tiles, dirt can easily hide in the cracks, causing a smelly problem.
- (4) There should be a piping wall for urinal sets with a thickness of 15~20 cm, height of 140 cm. Additionally, a marble stone should be placed on top of it, offering a place to put handbag or flower pots.
- (5) The distance between each urinal set should not be less than 80 cm. If users get too closer to urinal set, it will easily cause a dripping problem on the floor.
- (6) It is preferable to use the projecting window on top of urinal sets, it provides a good view for user to step closer and good ventilation.

7 Conclusion

Dealing with the treatment of excretion, different ethnicities have different methods of handling it. The public toilet in different locals such as mountains, rural areas, or beside rivers, all proceed with different ways of design. The above suggestions are designed for a developed city well equipped with water and electricity. Public toilet have always

been criticized as a scourge of society, they are dirty, dark, smelly, frightening and run-down. How to upgrade the standard of public toilets, and provide a bright, comfortable humanized toilet environment is everybody's concern.

Humanization is considered primarily when designing a public toilet. A thoughtful design will make the user feel comfortable and convenient. Certainly, it must also consider the ease of cleaning when determining size of space and material selection. Especially selecting suitable size of tiles to fit into the floor and wall at a toilet is very important. The floor tile must be easy to clean and nonslip. If using face tile as material, the tile pattern integration have to be made, for example we employed the face tile of 19.8 cm × 19.8 cm at the public toilet of 228 Park, so we can use 20 cm multiple space to avoid cutting on tiles, it can avert hiding the dirt on the joint. Finally, I am glad to have this opportunity to offer these few proposals for everybody's reference. Of course, there still remain a lot of problems that must be paid attention to, such as the ventilation, no door entrance, the tool room facilities, the establishment of septic tank, the maintenance problems and the measures of water & energy saving, etc. I wish to have a chance to discuss these more at some other time.

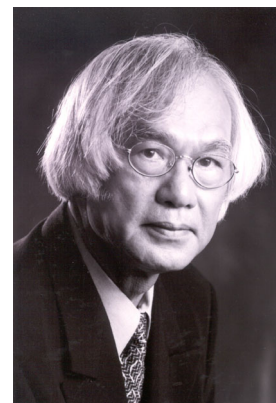
8 References

- Japan Toilet Association- *Reports on Toilet*, The 11th National Toilet Symposium, Japan Toilet Association, 1995
TOTO- *Barrier-Free Book (Barrier-Free Toilet Section)*, October 2001
Japan Toilet Association-*Sources from The 17th Toilet Symposium*, Japan Toilet Association, November 2001
Frank. M. H. Wu- *Design of Disabled Toilet*, Taiwan Architect magazine, Vol 343, July 2003, pp68-73
Frank. M. H. Wu- *Design of Humanized Toilet*, Taiwan Architect magazine, Vol 343, July 2003, pp74-81
Hiroyuki Kono- "Work for better barrier-free toilet", "Reports on Toilet, The 11th Japan Toilet Association National Toilet Symposium, 1995, pp40

9 Presentation of Author

Frank, Ming Hsiu Wu architect is the honorable chairman of Taiwan Toilet Association. He has been involved in studying, from architectural designing to architectural planning for more than four decades. He was appointed to the professor in the department of architecture of Kyushu Sangyo University, Japan, between 1991 and 1993.

More recently, he has been promoting to study the relationship of man and environment from the angle of environmental psychology, as well as designing humanized architectures and environment based on analysis of human behaviors.



1996- Awarded for second R.O.C Outstanding Architects Award

1999- Awarded for Far Eastern Architectural Design Award

2002- Designed the No. 1.2.3. public toilet of Yang-Min Mountain Park (Humanized toilets)

2004- Designed the public toilet of Taiwan History Museum. (At 228 Park)

2005- Designed and reformed ten toilets along Muzha Line in Taipei M.R.T