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Foreword

With the support of the International Council for Research and Innovation in Building and Construction (CIB) W062 commission members, the 34^{th} International Symposium on Water Supply and Drainage for Buildings (CIBW062 2008 Hong Kong) is held in The Hong Kong Polytechnic University in 8-10 September 2008. The symposium is partially financed from the Department of Building Services Engineering and supported by The Hong Kong Polytechnic University.

The forty-three papers contained in the proceedings illustrate current research areas in management and maintenance of water systems, commissioning, non destructive techniques, water conditioning, health aspects, sustainable construction, water conservation, rainwater and grey water reuse, hydraulics of water systems in high-rise buildings, influence of natural disaster, flooding, earthquakes, terrorism, durability, materials, historic buildings, standardisation, certification and drinking water regulations. These papers are organized and presented in eight plenary sessions.

We thank all authors for their participation in these sessions.

We would like to thank the organizing committee, international scientific committee and invited reviewers for reviewing all the abstracts and papers and for their advice in editing the conference proceedings.

We would also like to thank all the sponsors for their support to this conference.

Ling-tim WONG, Kwok-wai MUI, Shui-man LEUNG
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Protection of Drinking Water Quality in Hong Kong: From Source to Consumers

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Abstract

Based on information published by the Water Supplies Department, this paper reviews the current practices of water supplies in Hong Kong with particular reference to the approaches, strategies, programmes and measures of protecting water quality from source to taps. The outcomes and limitations are critically discussed with a view of ensuring long-term and environmentally sustainable supply of quality water to households.

Keywords

water resource, water safety, water quality, plumbs

1. Introduction

The challenges of potable water supply in Hong Kong include ensuring the sufficient amount of water being steadily distributed to domestic users and securing the quality of drinking water being safe and healthy to local citizens. Due to population increased, the reservoirs of Hong Kong are not able to support the full demand of water supply in Hong Kong. Since the 1960s, Hong Kong has made agreement with the government of Mainland China in abstracting water of Dongjiang (The East River) for supplementing local supplies (Guangdong and Hong Kong Water Supplies Department, 1996). Currently, 70-80% of the water supplies in Hong Kong are imported water from Dongjiang via a system of pumping stations, open and semi-open channels and aqua-ducts. Therefore, plans for protecting the quantity and quality of potable water supplies in Hong Kong should cover not only the local territory but also the catchment of Dongjiang with collaboration and joint-efforts of the Hong Kong and Mainland China governments (Feng 2002; Hills *et al* 2002).

Resulted from the increase in human population and the associated domestic, agricultural and industrial activities, the authority of Guangdong Province which manages the water supplies in the Pearl River Delta has also come across with challenges in maintaining the stable supply of quality water. Dongjiang, being as one of the tributaries of Pearl River, is the major source of water supplies for more than 20 millions of people living in the Guangdong Province. Concerns have been raised by various academics and professionals for the increase in domestic and industrial water demands in the Pearl River Delta and the progressive deterioration of water quality in Dongjiang (Ho and Hui 2001, Ho and Yau 2003; Ho *et al* 2003; Smil and Yushi 1998). Since 2005, an "enclosed-aqua-duct" which cost for more than 5 billion of RMB for construction has been commissioned to ensure the quality of water supplied by Dongjiang fulfilling the State Surface Water Environmental Standards (Class II) *i.e.* environmental quality parameters achieving the standard of potable uses after proper water treatment. Furthermore, the water treatment plants in both Hong Kong and Guangdong have been strengthened with facilities and processes in ensuring the quality of piped water achieving the World Health Organization (WHO) guideline values for drinking purposes. Numerous environmental measures have been implemented to remove pollution sources and protecting water catchment from further environmental deterioration.

2. Total Water Management

The total fresh water demand in Hong Kong was 951 million cubic metres (mcm) in 2007. Roughly estimated, the daily water consumption rate per capita is ~0.14 M^3. Out of the total water demand, about 35% is for domestic use and about 25% for commercial and industrial uses. Unfortunately, water mains leakage is a bit serious attributed to 23% of the total amount of water supply. Furthermore, fire-fighting flushing and other social consumptions consume the remaining 17% of total water supply ((Water supplies Department, 2002).

Due to population increase, it is estimated that by the year 2030 the then 8.4 million population in Hong Kong will require for 1,315 mcm. of freshwater supplies. Hence, it is necessary to have early and thoroughly survey and planning to meet the challenge of future water demand. The Government of Hong Kong Special Administrative Region (HKSAR) is committed and enthusiastic to ensure the sufficient supply of water for domestic, industrial and commercial usages. Hence, the Government of HKSAR pledged that for meeting the global challenge of protecting water resource, it was necessary to implement a Total Water Management (TWM) programme(The Chief Executive of HKSAR, 2003).. The TWM aims to enhance water conservation and protection and to explore new technology and other means for expanding water resources In 2005, the Water Supplies Department (WSD) commissioned a study on formulating TWM strategy to serve the long-term need of water supplies in Hong Kong (Water supplies Department, 2001, 2008).

While the raw water supplied from Dongjiang will be maintained at stable level in the coming years due to strong political support to HKSAR from the state government of China, the TWM recognized the collaborative and partnership relation between Hong Kong and Guangdong Province. The TWM also stated that it is necessary to adopt proactive management measures to meet the demand and supply of quality water in integrated, multi-sectoral and sustainable manners. Based on the theme of incorporating suitable integrated strategy for water resource management, the TWM will prepare Hong Kong for various uncertainties including global climate changes such that the projected water demand of different population growth scenarios in the coming two decades shall be well satisfied. Taking into consideration of the rapid development in Mainland China, the proposed TWM will also help Hong Kong to serve as a good partner of other municipalities in the Pearl River Delta for social, economic and environmental sustainability.

Specifically, the TWM includes the following approaches and measures:

2.1 Water conservation

The main measures currently employed by the Water Supplies Department include public education, active leakage control, widespread use of seawater for toilet flushing and a tiered tariff structure to encourage water saving.

With the use of TV and radio programmes, leaflets, seminars and exhibitions, the public education programmes focused on the younger generation which is the main stakeholder in the coming decades.

With regard to active leakage control, the Water Supplies department has implemented a pipe replacement and rehabilitation programme which costs for $15.7 billion Hong Kong dollars and will be completed in 2015. About 3,000 km of water mains will be subjected to renewed and repaired. Moreover, water mains will be installed with pressure-reducing valves and flow-meters to optimize pressure, reduce leakage and monitor irregularities.

Interestingly, the Water Supplies Department is considered implementing a “Water Efficiency Labeling Scheme” which is similar to the currently used Energy Efficiency Labeling Scheme. The Water Efficiency Labeling Scheme will cover plumbing fixtures and appliances used in toilet, kitchen, bathroom and laundry. However, it will only be implemented on a voluntary basis and will be implemented not earlier than 2009.

Currently, the use of seawater for toilet flushing covered ~80% of households in metropolitan areas and new towns. While the use of seawater for toilet flushing has saved 28% of the daily fresh water consumption, due to economical and geographical reasons this Scheme is extremely difficult to be further expanded although the Water Supplies Department is still planning and flighting for resources to extend the Scheme to other districts including Pokfulam, Yuen Long and Tin Shui Wai.

2.2 Water Reclamation and Recycling

The Water Supplies Department is enthusiastic to implement water reclamation which means the use of lower quality water (e.g. treated sewage effluents) to replace high quality water for non-potable usages including toilet flushing, irrigation and street cleaning. The tertiary sewage treatment plants in Ngong Ping and Shek Wu Hui were commissioned in 2006. As noted, reclaimed water were mainly used for toilet flushing,

gardening and landscaping. Due to the gut feelings of the general public, unfortunately, the Government and relevant corporations have no intention to apply reclaimed water for other household usages. Sanitary implications shall be specially studied and widely accepted by the general public after the disaster of SARS in 2003.
uses.

Harvesting of rainwater for water supplies is very costly. The Water Supplies Department estimated that the potential saving of water saved is only in the order of a few mcm per year. Therefore, the Government has low priority in doing this with only a few grey water and rainwater recycling projects being planned for schools and some community facilities.

2.3 Protection and Development of Water Resources

The Water Supplies Department has conducted a study to evaluate the water pollution risks in water gathering grounds. The study also aims to review the current philosophy, principles and practices for managing water gathering grounds and propose environmental impact assessment.

Water Supplies Department also recognizes the essence of proper maintenance of the catchwater systems and management of the slopes in the catchment and adjacent areas. It is project that by 2013, a total length of ~26 kilometres of existing catchwater systems will be maintained.

The Water Supplies Department has reviewed the possibility of expanding water gathering grounds and reservoir storage. As noted, expansion of water gathering ground will entail high costs because Hong Kong is a highly populated and urbanized city. Nevertheless, the Government found that the technologies of seawater desalination *e.g.* by reverse osmosis (RO), has been greatly advanced during the past decades. Therefore, the Water Supplies Department initiated a pilot desalination plant study using RO technology in Tuen Mun and Ap Lei Chau in 2003. According to survey results, RO can be technologically and economically applicable in Hong Kong. While the application of desalination in Hong Kong will impose high capital and energy costs, long-term application of desalination will meet the global expectation of development of new water resource. The major constraints include whether the general public is willing to afford the higher water charge and the physical and geographical limitations in developing the new water supplies network.

3. Water Safety Plan

The World Health Organization (WHO) has officially launched the third edition of Guidelines for Drinking-water Quality in 2004. The WHO urged for development and implementation of Water Safety Plan in each countries to allow citizens enjoying sufficient and high quality of drinking water supplies. The Water Supplies Department of Hong Kong echoed to the urges of WHO and started its implementation of the Water Safety Plan from 2006 (Water supplies Department, 2006-b).
Water Safety Plan is an effective means to provide a proactive mechanism to ensure the

quality of drinking water for the protection of public health. Through a systematical assessment mechanism, the risks come across by a drinking water supply system from the source through treatment to the customers' taps will be identified, controlled and closely monitored. Relevant action plan, if implemented, will minimize health and environmental risks proactively.

Details of the Water Safety Plan are shown below:

3.1 Organization and Management

To actualize the Water Safety Plan, a Working Group on the Development and Implementation of Water Safety Plan has been established by the Government of HKSAR. The Director of Water Supplies is the head of this Working Group with members from the Health Department, Environmental Protection Department, Food and Environmental Hygiene Department, Water Supplies Department and the Development Bureau. Regular meetings will be held to ensure the smooth operation and progress of the Water Safety Plan.

3.2 Full adoption of the Guidelines for Drinking-Water Quality published by the WHO as the drinking water quality standards in Hong Kong

On the basis of the Guidelines of WHO published in 1993, 12 water quality parameters which are less apparent to public health and safety were deleted from the list. However, there are 11 new additional chemical parameters, mainly related to trace organics, being added to the list. The Water Supplies Department will keep abreast the guideline values of individual parameters based on health significance and latest available scientific evidences provided by the WHO. The list of chemical parameters and the corresponding guideline values as recommended by WHO (2004) can be found in the website of the Water Supplies Department (http://www.wsd.gov.hk/en/html/water/index.htm).

The Chief Chemist in Water Science Division of the Water Supplies department is responsible for monitoring the various water quality parameters.

3.3 Development of Health-based Targets

Development of health-based targets is one of the essential components of the Water Safety Plan. The studies and development of health-based targets help to determine appropriate standards and relevant intervening measures for the delivery of safe and quality drinking water. With the close cooperation between the Water Supplies Department and the Health Department, various health-based targets and associated control measures such as source protection and treatment processes are considered. However, the Health Department found that the quality of treated water in HK has been maintained at a high quality level and there is low existing risk of serious waterborne disease in Hong Kong. Hence, it is concluded that the chemical parameters listed in the 3rd edition of Guidelines for Drinking-water Quality (WHO 2004) shall be adopted as the water quality targets in Hong Kong. With regard to microbiological quality of treated water, the two departments concluded that it is necessary to ensure the absence of “thermo-tolerant Coliform” and *E. coli* in 100 ml of treated water.

3.4 Prevention of contamination of source waters

The Water Safety Plan aims to prevent contaminants going into the potable water supply system during storage, distribution and handling stages. Furthermore, if slight contamination is unavoidable, these contaminants shall be properly removed through treatment processes.

On the basis of this, the Water Supplies Department is developing a multi-barrier approach and an integrated system of procedures and processes that allows government departments to prevent and reduce the risks of contamination of raw water. Generally, the quality of drinking water shall be safeguarded “from source to tap”.

3.5 Protection of the Dongjiang Water

While 70-80% of raw water in Hong Kong is supplied from the Dongjiang in the Guangdong Province, it is necessary to liaise closely with the Guangdong Authority to incorporate their efforts into the Water Safety Plan. The Government of HKSAR has brought up this issue in the meetings of cross-border cooperation on environmental protection and sustainable development. Favorable responses were received from the Environmental Protection Bureau and Provincial Department of Water Resources of Guangdong Province. The details of water safety plan including risk assessment, resource management and taking proactive measures of environmental control have been sincerely acknowledged by the Guangdong authorities. As noted, the various authorities of Guangdong Province are taking actions to actualize various details of the Water Safety Plan. This is a very good example of cross-border environmental cooperation and water resource management with regard to the policy of “one country, two systems” which has been actualized since July 1997.

3.6 Surveillance

Surveillance which involves a continuous and vigilant public health assessment and overview of the safety and acceptability of the drinking water supply have been continuously conducted by the Health Department with assistance from the Water Supplies Department. In addition to regular monitoring of water quality, the Water Supplies Department also investigates water quality in household in response to compliant from citizens. A Task Group has been established with regular meetings on health-related issues being held between the Department of Health and the Water Supplies Department on half-yearly and as-needed basis.

3.7 Transparency of Information

The Water Safety Plan urged for enhancing information transparency and the earliest dissemination of information to the general public. Therefore, the Water Supplies Department discloses the water quality analysis results to the general public regularly. Results of the Dongjiang water quality, as obtained from the Guangdong authorities and monitored at the Muk Wu Pumping Station (which is the entry point of Dongjiang water to Hong Kong) have also been posted up the website of Water Supplies Department at half yearly intervals.

4. Maintaining Water Quality in Plumbing System

While the quality of the treated water in Hong Kong, as monitored at the exits of water treatment works, is fully complied with the drinking standards recommended by the WHO, it is essential to ensure the quality of tapped water also suitable for drinking and other domestic uses. The Water Supplies Department (WSD) has established good systems and practices for cleansing of service reservoirs and flushing mains at regular intervals (Water supplies Department, 2001). Hence, the risks of having water quality problem in distribution system are normally low. However, problems arise when the water enters individual buildings through the connecting pipes and water tanks. Sometimes, the quality of tapped water is suffered from rust and other degraded materials when plumbs are not properly managed. Currently, maintenance of the plumbing systems in buildings and households rested to the owner of building or the building management company/corporations. For Hong Kong, buildings more than 30 years old are more susceptible to poor tapped water quality. Generally, buildings with plumbs installed after Dec 1995 should have already used corrosion-resistant pipe materials and are less problematic. It is however estimated by the Water Supplies Department that there are about 33,000 buildings in Hong Kong that shall be targeted for promoting better maintenance of plumbs and better management of water tanks (Water supplies Department, 2001, 2006-a).

To ensure that good water quality is maintained throughout the supply systems from sources to taps, and to deal increasing problems related to the maintenance and management practices of water plumbs, the Water Supplies Department launched the Fresh Water Plumbing Quality Maintenance Recognition Scheme in 2002.

Since the launching of the Fresh Water Plumbing Quality Maintenance Recognition Scheme in July 2002, up to March 2008, the Water Supplies Department have issued more than 3000 certificates including ~2000 for private and Home Ownership Scheme residential properties, ~650 for public rental properties and ~600 for commercial properties. More than 750,000 households have been benefited from this Quality Maintenance Recognition Scheme. The Scheme is regarded useful for improving the conditions of tap-water quality in buildings and to raise the general awareness of households for proper maintenance of plumbs and water tanks.

No matter whether the Fresh Water Plumbing Quality Maintenance Recognition Scheme is successful, the Water Supplies Department has strengthened its taskforce in supervising the maintenance of plumbing systems and conducting regular/on-complaint basis monitoring of water quality from taps. The Department will also continue its efforts on replacing and rehabilitating old water mains, especially those unlined galvanized steel sub-mains.

5. Customers Services, Public Participation and Education

The Water Supplies Department has given special attention to the openness of information. Spontaneity of reporting incidents of substandard water supply is a must to respect customers' right. Customer-services is another pillar for the Department to build up collaboration and partnership with the end-users. It is also an essential measure for building up the confidence of customers to the water supply system and the water authority. A "Telephone Enquiry Centre " which is equipped with staff of the necessary knowledge to give advices the public enquiries has been developed and provided services since the late 1990s.

The Government has established the Advisory Committee for the Quality of Water Supplies (ACQWS) since April 2000. This is an independent body comprising members from the public sectors including academics, district councilors, green advocates, professionals, and officials from related government departments and bureau. The terms of reference of the ACQWS is "to keep under review and to advise the Government of the Hong Kong Special Administrative Region through the Director of Water Supplies on matters relating to the quality of water supplies". Under the ACQWS, there are working groups including the Working Group on Publication of Water Quality Data, Working Group on Quality of Water in Buildings and Working Group on Public Education. These working groups meet frequently to share views and give advices to the Government on publicity, education and maintenance of plumbing systems. Every year, the ACQWS organizes a visit to the catchment of Dongjiang to progress the works of water abstraction and share views with the Guangdong officials on management of water resources and environmental quality. The Working Group on Public Education has also organized a lot of community and educational activities for the promotion of quality water supply.

6. Discussion

The environmental quality in the Pearl River Delta has been deteriorating since the early 1990s. This poses risk to the quality of water in Dongjiang which supplies Hong Kong for more than 70% of potable water. During the past years, the Hong Kong - Guangdong Environmental Protection and Sustainable Development Committee had done significant jobs in improving environmental quality and securing the quality of water resource. However, more collaborative work on the basis of the Water Safety Plan is anticipated to protect Dongjiang watershed and to avoid severe waterborne diseases. While the "enclosed aqua-duct" which costs for ~5.2 billion RMB is able to maintain water quality being acceptable in a short-term, long-term environmental works are essential for ensuring the quality of drinking water supplies in the Pearl River Delta including Hong Kong in the coming decades. Specifically, trace organics is a major concern in most drinking water supply systems in the world. Intensive monitoring and frequent reviewing of the list of water parameters in the Water Safety Plan are necessary to prevent the risks of carcinogenic diseases.

It is anticipated that by the year 2021, the annual freshwater demand in Hong Kong will increase to 1,050 mcm/year (Water Supplies Department, 2002). While officials of the Water Supplies Department of Hong Kong are confident that by then Hong Kong is still able to maintain a stable supply of freshwater by local abstraction of 295 mcm/year and importation of Dongjiang water of 1,100 mcm/year, the overall increase of water demand in the Pearl River Delta should not be overlooked. In fact, the Guangdong authority has anticipated simultaneous increase in water demand in the coming 20 years. Provision of sufficient amount of quality water in the coming decades is a big challenge. Early exploration of new water resources including the actualization desalination by new technology and recycling of treated effluents shall be serious considered. The use of market-mechanism e.g. by adjusting water price and imposing polluters pay' principle shall also be seriously considered for earliest implementation.

Promotion of the Fresh Water Plumbing Quality Maintenance Recognition Scheme is shown successful in raising public awareness and strengthening the management of plumbing system. With better education, more transparency in information and provision of high-class customer-services, the quality of water supplies in Hong Kong is able to be further upgraded in the coming decades. Anyway, experiences told us that water quality management strategy shall be implemented at a bottom-up approach, from source to consumers.

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8. Presentation of Author

Prof. K. C. Ho is the Dean of School of Science & Technology of the Open University of Hong Kong. Specialized in environmental studies, Prof. Ho serves as the Chairman of the Advisory Committee to the Quality of Water Supplies (ACQWS) of the Government of HKSAR. He is also the President of Green Power, a renowned green group in Hong Kong. In 2004, Prof. Ho was awarded the Bronze Bauhinia Star (BBS) badge by the Chief Executive of HKSAR to honour his outstanding contributions to environmental research and environmental protection.

A1) Residential water profile and internal end uses

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Abstract

This paper presents the results from a research Project about residential pattern water consumption and internal uses. The research was carried out in a sample of residences in the west zone of Sao Paulo, Brazil. Initially, was developed a bibliography review in order to get the state of art of monitoring techniques which supported the research methodology.

The results are presented in tables and graphics where can be identified the water profile and internal uses of sanitary appliances. Taking in account the total consumption, it was found out the individual consumption of the shower with 13,9%; followed by kitchen tap with 12,0%; clothes washing machine with 10,9%; tank tap with 9,2%; tank tap associated with clothes washing machine with 8,3%; water closet basin with 5,5%; clothes tank tap with 5,5%; and sink tap with 4,2%. It was found 30,6% as "another uses" which can be attached to external use, leaks etc. Also, it was carried out some additional analyses in order to find out the typical flow rate and frequency of use for sanitary appliances monitored. The results pointed out the appliances mean flow rate as well the dairy frequency of use where the shower with a mean flow rate of 4,1 L/min and dairy frequency of 6 uses; kitchen tap with 1,2 L/min and 80 uses; water closet basin with 3,8 L/min and 8 uses; clothes washing machine with 1,2 L/min and 10 uses; tank tap with 3,3 L/min and 7 uses; tank tap with clothes washing machine with 3,7 L/min and 12 uses; and finally the clothes tank with 2,3 L/min and 10 uses.

The research results allowed to advance in the field knowledge about the theme considering the methodologies applied to find out the water consumption profile and residential water end uses. Also the results came out to engineering field some news values about sanitary water consumption that can be used in design methods and water conservation programmes.

Keywords

Water consumption pattern; residential end uses of water; domestic water consumption; sanitary appliances water consumption; frequency of use.

1. Introduction

An important question nowadays understands how to use the water in homes, mainly in urban centres where, in recent decades and throughout the world there was a tendency of the population density and urbanization.

At the same extent as the city grew in size with streets and avenues also increased the demand for water, resulting in providing the infrastructure for the water supply and sewerage collection.

Moreover, there was the population density in cities, resulting from the effects of urbanization that caused a real rural exodus towards the cities. This density, in numerical terms, and the habits of people from other regions were shaping the consumption of water in cities, so that resulted in a mixture of different habits and customs that formed the profile of urban consumption of water.

In this scenario of changing the urban areas, the issue of water, which seemed enough, that is, the springs near the cities were sufficient or exceeded the demand. Thus the use of urban water is now managed by the demand, which is due to take control over the actions of demand as a way to relieve the pressure on the springs.

Thus, the knowledge of the profile of consumption and end uses of water becomes information for developing actions to control demand and also to rationalize the use of water in the urban scene.

This need led this search whose purpose was to define a profile of household water consumption of sanitary appliances by monitoring sanitary appliances on a sample of households. From the results, beyond the water profile and end use of water have also obtained the flow rates and the frequency of use of sanitary appliances.

2. Objective

This paper is to present the results of a research on surveying the water profile of residential consumption, end uses of water and frequency and mean flow rates in a sample of households located in the west side of the city of Sao Paulo. The consumption profile and final uses were obtained through the monitoring of water consumption in the entry of residences and withdraw points of use of water for domestic households. The frequency of use and flow rates were determined by processing the data collected where have been identified the flow rates of appliances, and their frequency of daily use.

3. Bibliographic review

In this paper only few authors are showed since a extensive list of papers about the subject were identified. One of the first researches that address the question of water consumption and usage of water was made final in 1971, when Thackray et all (1978) have made a daily reading of water meters installed along the supply of buildings, and simultaneously applied questionnaires to residents to identify the in daily use that referred to the use of appliances.

In Brazil, one of the early works was done in the 80 by the Institute for Technological Research (Montenegro, MHF, 1981 apud CIB, 1987). In this research, was developed equipment, which coupled with a meter installed in series with entry's water meter of a residence permitting the flow of household registration, whose only purpose was to identify the change in consumption throughout the day, without needing to know the internal consumption.

The search results encouraged an improvement, where Barreto (1990) raised various parameters on consumption of water in sanitary appliances, by means of equipment associated with a microcomputer and a program specially developed for the treatment of the data collected. The author obtained relevant data such as duration of use, range between uses, average volume and flow to all units monitored.

Rocha (1999) monitored the points of internal consumption of a single residence unit - family through the installation of flow meters at the point of use inside the residence. These transducers were monitored by a data acquisition system that allowed the surveying detailed volumes of water by various types of sanitary appliances to obtain the profile of consumption. The results of this survey showed that the shower had the highest consumption inside the residence, reflecting 55% of total consumption, followed by the kitchen sink, which showed a consumption of 18%. The clothes wash machine made the third largest consumer with 11% of the total, sink tap 8%, WC basin 5%, and tank 3%.

The profile of water consumption has been studied since the end of the 70. In terms of the most recent reference was a survey conducted in 1994 in the city of Heatherwood - Boulder in the U.S. state of Colorado (DeOREO, WB et all, 1996). The technique of measuring employed was not intrusive being used to find out the profile of consumption the technical of "flow trace analysis", which consist to identify, in a continuous graph, which are the flow rates of sanitary appliances that caused demand for water.

From June 1996 to March 1998, was conducted by the American Water Works Association - Research Foundation (DeOREO, 1999) a new research in twelve U.S. cities on the profile of water consumption, with the purpose of identify the end uses of water. In total 1188 homes have been monitored by "date-loggers", recording the flow rates every 10 seconds. The data were treated in specific software for computer (flow trace analysis) able to break down the profile of consumption in individual events of use of water such as a discharge of WC basin, a cycle of a clothes washing machine and so on. Figure 1 and Table, 1 below shows the results compiled in the two surveys, in terms of relative percentage compared with total consumed amount of water by the houses surveyed.

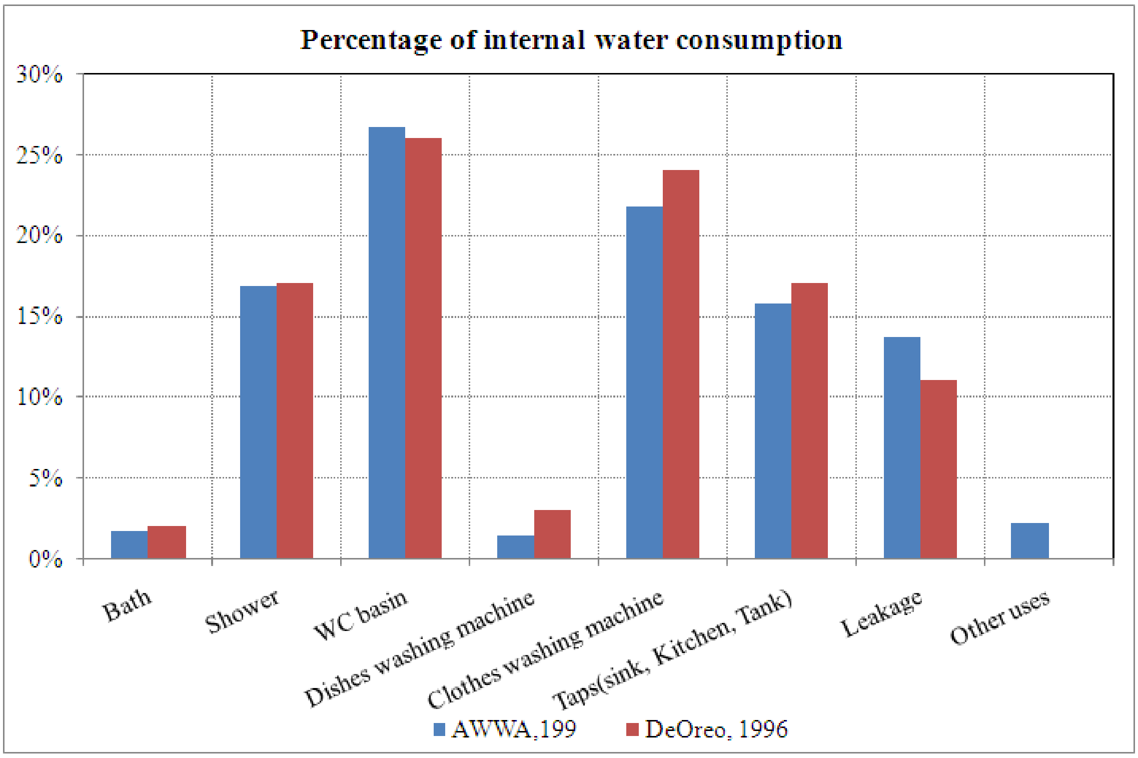

Figure 1 – End uses of water (percentage of total internal household consumption).

Table 1 – Typical domestic consumption of water (DeOreo, 1996 and AWWA,1999)

Wate use/sanitary appliance	Water profile Heatherwood -Boulder - Colorado – EUA (DeOreo,1996)		End uses (AWWA,1999)
	Internal and external	Internal	Internal
External uses	78,0%	-o-	-o-
Swimming pool	3,0%	-o-	-o-
Bath	0,4%	2,0%	1,7 %
Shower	3,2%	17,0%	16,8 %
WC pan with discharge tank	4,9%	26,0%	26,7 %
Dishes washing machine	0,6%	3,0%	1,4 %
Clothes washing machine	4,6%	24,0%	21,7 %
Taps	3,2%	17,0%	15,7 %
Leakage	2,1%	11,0%	13,7 %
Other uses	-o-	-o-	2,2 %

Of the results presented in Table 1, it can be seen that the search conducted in 1999 resulted in more accurate figures for domestic consumption, allowing the knowledge of the end uses of water in homes of 12 North American cities. Figure 2, below, shows the distribution of hourly end uses of water in terms volumes of water consumed (litres per hour).

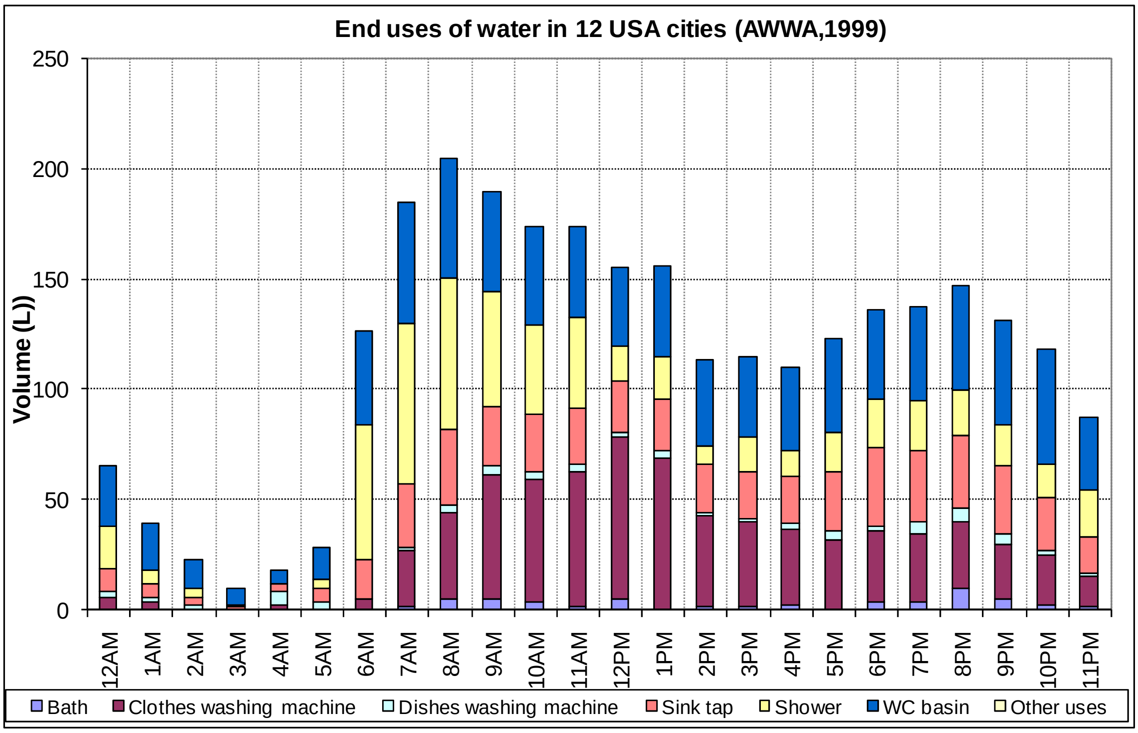

Figure 2 – End uses of water (daily volume) obtained for 12 U.S. cities (adapted from AWWA, 1999).

In Figure 2, the curve of the values recorded in the "x" axis represents the profile of water consumption. The values were segregated by sanitary appliances and mean their end uses. The results showed in same graphic shows the percentage of participation in the consumption of each sanitary appliance and in which day time is more used.

It is considered that the profile and the end use of water reflected the U.S. customs so that it can not be used for general application. But it might be considered as a model of breakdown of consumption that can be used as a reference to surveying the profile of the consumer and end use in the case of Brazil, whose search results are presented and discussed below.

Regarding the frequency of use of sanitary appliances, Barreto (1999) monitored the consumption of specific uses of two bathrooms, an office building, representing each one the combination of different types of sanitary appliances.

The researches cited encouraged the study so that if could identify the consumption, uses the finals and flow rates typical, medium and their frequency of use of sanitary appliances (withdraw points of use), to subsidize an evaluation of the parameters of the project premises land of cold water and water-saving programmes in buildings.

4. Methodology

To carry out this survey were selected households within the same cluster of consumers, in the west side of the city of Sao Paulo, which typical monthly water consumptions is in the range of 15 to 20 m^3/month.

Thus were set 100 addresses for which was provided for the installation of "data-loggers" along with an internal meter at the residence water entry (consumer's water meter). The data-logger has the function of storing data, which are then downloaded into microcomputer, for validation, conversion and standardization of a database allowing the appropriate treatment.

The surveying of the water profile of consumption was done by monitoring for seven consecutive days, seven homes located in the western region of Sao Paulo. With the data collected, and after due treatment, was achieved, beyond the consumption profile of the typical flow, as well as the frequency of use of appliances such internal sample of households. In short terms the methodology is detailed below:

• installation of equipment for internal monitoring in points and a sample of residence (water meters and "datalogger" in the residence entry and points of use);
• implementation of a questionnaire characterization of the building and socioeconomic profile of the residents;
• monitoring of total consumption and internal (individual points of use) for seven consecutive days to cover every day of the week;
• assistance to residents through telephone monitoring;
• removing of equipment and replenishment of the facility as original state;
• transfer of data collected by "datalogger" to the microcomputer;
• validation and analysis of the consistency of data collected;
• conversion of the values for units of volume and flow;
• calculation by means of routine electronic consumption and end uses;
• calculation through routine electron flow and the frequency of use;
• preparation of tables, charts and histograms.

From the data processing was possible to obtain a profile of water consumption for the sanitary appliances of homes monitored by determining the volume and timing of use of equipment, and consequently, the flow rates for each interval of use.

5. Results

The find outs of research results were summarized in tables and graphs based on daily intakes gathering information on the average daily consumption, percentage on the average daily consumption point for internal use and total monitored; internal consumption (by withdraw point of use monitored); percentage of participation in the consumption of each point of use and consumption time disaggregated by point of use. Table 3, below, shows the average daily consumption obtained after processing the data collected by the instrumentation in homes monitored.

Table 3 - Consumption daily average by type of device (litres per day)

House	Shower	Kitchen tap	Sink tap	clothes tank	tank tap	Clothes washing machine	WC basin	Tank tap associated with clothes washing machine	Other uses	Total
1	*	113	50	50	*	*	*	*	225	**438**
2	60	90	14	*	*	*	*	63	215	**442**
3	200	71	39	*	*	148	*	*	314	**772**
4	58	78	18	3	*	18	42	*	*	**217**
5	87	82	55		*	*	*	*	*	**224**
6	40	75	25	69	28	*	*	*	202	**439**
7	190	127	25	*	112	*	*	*	205	**659**
avge	**106**	**91**	**32**	**41**	**70**	**83**	**42**	**63**	**232**	**760**

* = withdraws point of use non evalluated

For purposes of analysis of consumption in all addresses monitored were a compilation, where it was taking in account the average total consumption and domestic consumption. Total consumption is the volume of water consumed and recorded by the meter bridge while domestic consumption is the sum of domestic consumption registered by water meter points of use. The difference is the share of consumption that has not been defined so far as other uses.

In the graph of Figure 3, below, it can be viewed the consumption for each week day of monitoring, and the Friday day as the higher consumption. Also, it appears that the body hygiene uses (sink, WC basin and shower) occur every day. Consumption in the kitchen sink is also daily while the washing machine and tank occur in certain days (Tuesday, Wednesday, Friday, Saturday and Sunday).

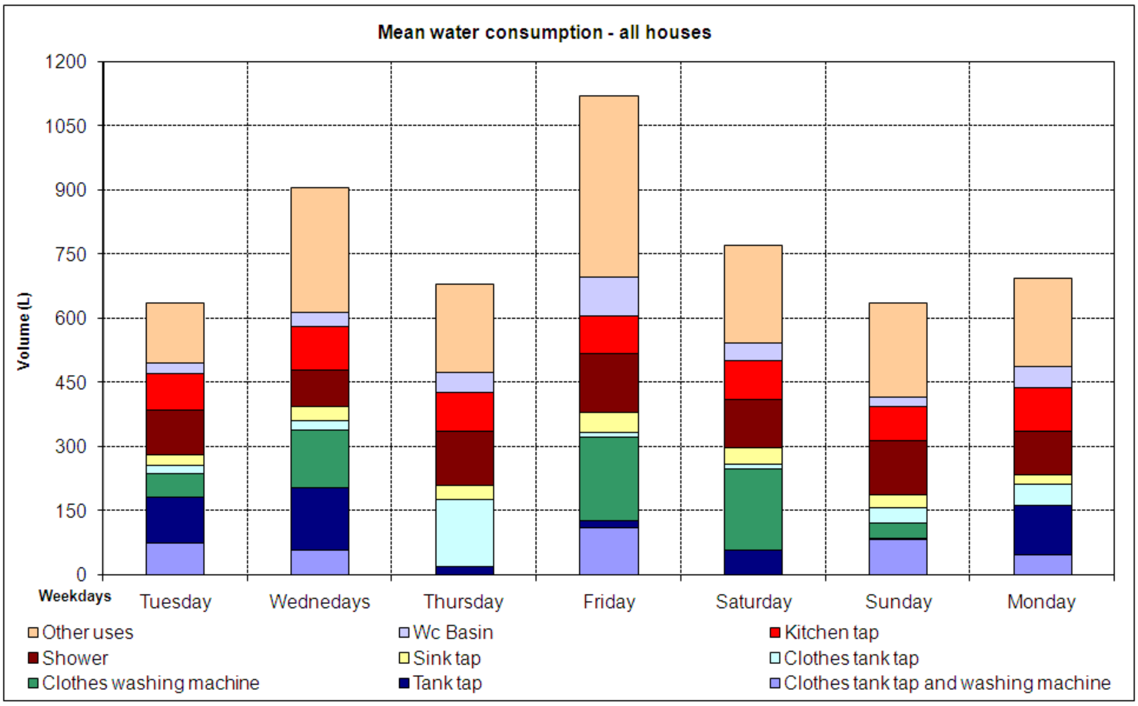

Figure 3 - Consumption broken by periods of use monitored.

Figure 4, below shows the percentage in terms of average consumption and final domestic uses of water among the homes studied. The percentages are calculated on the average consumption of each sanitary appliance.

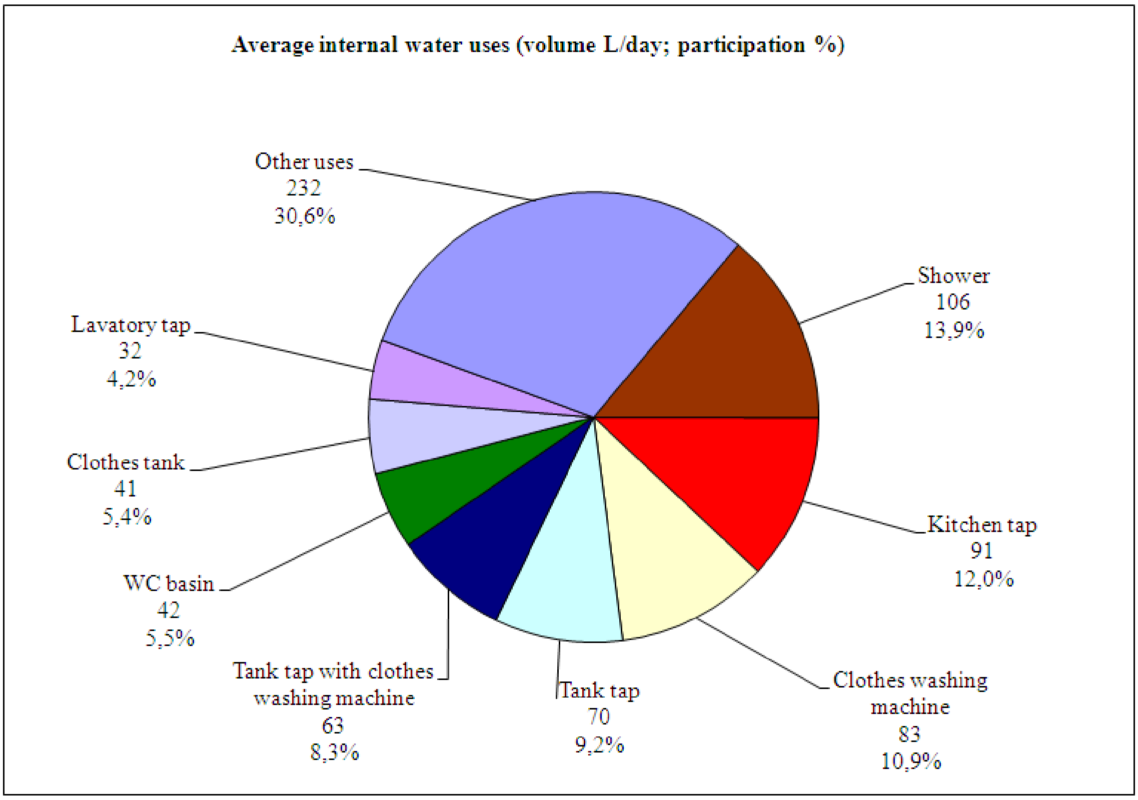

Figure 4 – Average volume and participation percentage of water consumed.

In terms of percentage shares in consumption, from figure 4 it can be commented that the point of consumption that showed greater use was the shower with 13.9% followed successively from the kitchen tap of 12.0%, a clothes washing machine 10.9%; tank tap 9.2%; tank tap with a washing machine 8.3%; WC basin 5.5%, 5.4% clothes tank, and sink tap, with 4.2%.

The other uses, which contain the share of consumption not measured, make up the rest with 30.6%. It should be noted that can not be directly involve the consumption presented, as it is a chart containing the average of all households, representing, on average, how much each resident spends each day through its residents by performing the tasks daily.

The research applied questionnaires to the householders and among the results were identified the average number of three residents by residence. From this number was raised the water consumption "per capita" related to the sample studied, for point of use per inhabitant. The “per capita” founded are shown in Table 4, below.

Table 4 – average daily consumption “per capita” in point of use per inhabitant.

Sanitary appliance	Participation (%)	Daily consumption (L/day)	Water consumption “per capita” (L/day/inhab.)
Shower	13,9%	105,8	35,3
Kitchen tap	12,0%	90,9	30,3
Clothes washing machine	10,9%	83,0	27,7
Tank tap	9,2%	70,0	23,3
Tank tap with clothes washing machine	8,3%	63,0	21,0
WC basin	5,5%	42,0	14,0
Clothes tank	5,4%	40,7	13,6
Sink tap	4,2%	32,3	10,8
Other uses	30,6%	232,2	77,4
Total	**100,0%**	**759,8**	**253,3**

The values of table 5 reflect the consumption "per capita" mean that the results were obtained from spreadsheets monitoring considering the consumption of items of use. Certainly we must consider a number of peculiarities, it is seen that in some addresses was not possible to track the WC basin, and others, are not monitored the tank, and so on.

The "per capita" raised, but expressed some figures within expectations, for example, one resident daily consumes 35.3 liters per day in the shower which is very close to the bath "pattern" of 40 liters, or a bath , 8 minutes with flow of 5 litres per minute. For the WC basin, the equivalent to 14.0 liters daily two discharges of 7.0 liters each, this is consistent with the values of prescribed standard for these sanitary appliances.

Also the other consumption may be within expectations, but a more extensive monitoring in order to get more accurately characterize water consumption of each withdraw point of use.

The graph in Figure 5, below shows the water consumption disaggregated and synthesize the average consumption during the entire day. This chart can allow the management of water demand and, moreover, also allows taking strategic decisions targeting the rational use of water. For example, it can assess the impact of the reduction of water consumption come from a programme of exchange of basins in a region of the city.

The results expressed in the chart also help to identify the house holders habits that can serve as an allowance for educational campaigns about the use of certain sanitary appliances of interest.

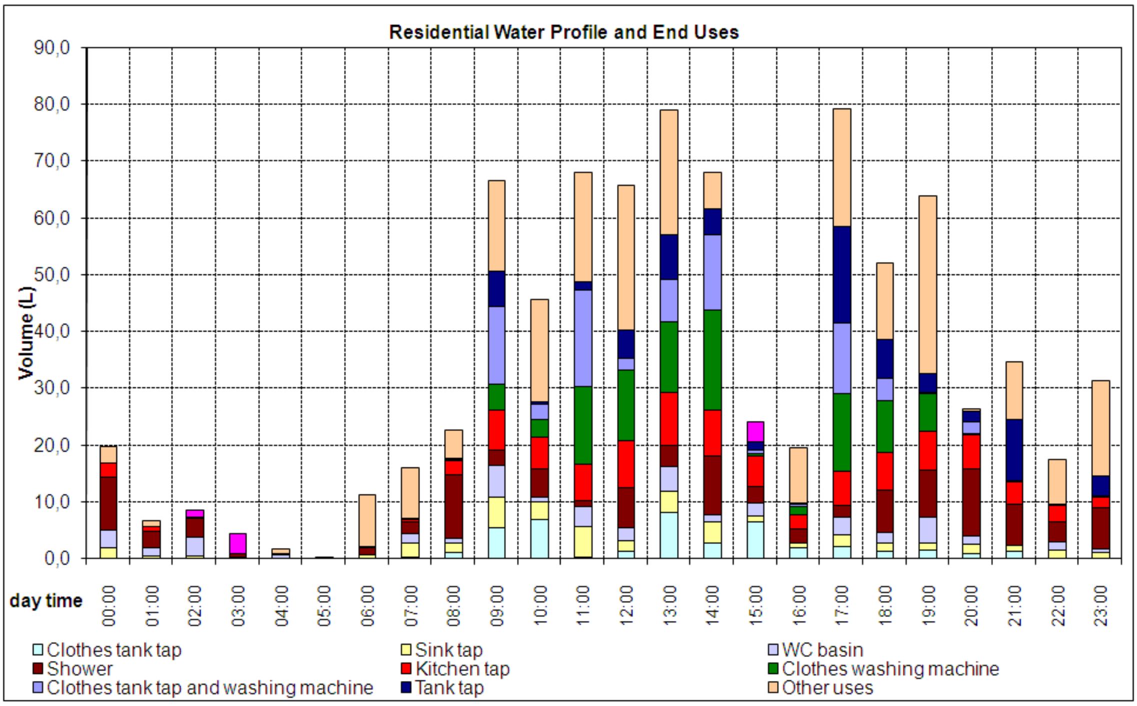

Figure 5 - Consumption time disaggregated by points of use.

From the results were determined for each of the sanitary appliances the values of average flow rate and average standard deviation, the mean flow and frequency of daily use. Table 5, then presents the results considering all the events recorded in all of addresses searched.

Table 5 – Average flow rates, and typical frequency of daily use of sanitary appliances.

Sanitary appliance	Mean flowrate		Standard deviation	Daily frequency (Uses per day)
	(L/min)	(L/sec)	(L/min)	
Shower	4,1	0,07	1,7	6
WC basin	3,8	0,06	0,5	8
Tank tap and clothes washing machine	3,7	0,06	2,8	12
Tank tap	3,3	0,06	2,9	7
Clothes tank	2,3	0,04	2,0	10
Sink tap	1,4	0,02	1,0	25
Kitchen tap	1,2	0,02	0,9	80
Clothes washing machine	1,2	0,02	2,1	10

The average flow of the sink tap, the tap for cooking and the washing machine clothing was the order of 1.2 L/min, while the shower of 4.1 L/min and the WC basin 3.8 L/min. Note that up to the taps of the sink and the kitchen and a washing machine for the typical flow was also small, so the higher the frequency of use lower the flow and vice versa.

There is still, as for the tap tank, washing machine and tank the standard deviation was high indicating a wide dispersion of results. The clothes washing machine also presented a standard deviation higher, which indicates different cycles of the machine as mentioned above. The shower, a kitchen tap, tap of the sink and housing coupled showed lower standard deviations, reflecting a smaller dispersion of flow rates.

It may be noted that the kitchen tap has the highest frequency of use and shower the lower frequency. On the average flow rate recorded in the period of monitoring, it is observed that the shower has the largest flow to the lower frequency of use. The taps and the kitchen sink and a clothes washing machine have the lowest average flow rates, but the highest frequencies of use.

6. Remarks and general comments

In terms of existing data on the profile of consumption and end uses of water it was found by the survey that not many data and that few entities are devoted to research on the subject, such as AWWA.

It can be commented that the survey is at the moment in Brazil, an advance in knowledge on the subject, and that the results would represent new benchmarks, apart from presenting themselves as unpublished data.

The results presented, even if they have not been surveyed all the households in the sample, show that the work helped to enlarge the knowledge about the needs and methods applied in surveying the profile of the consumer and end use of water providing the technical means, update the profile of the values of consumption and end uses of water in homes, and the flow rates and frequencies of sanitary appliances.

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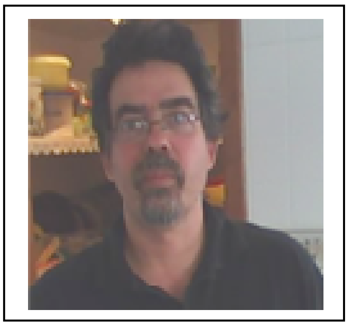
8. Presentation of author



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A2) Calculation Method for Loads of Hot Water Demand with the Hot Water Storage Tank System in Houses

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Abstract

The purpose of this study is to suggest the calculation method for loads of hot water consumption based on the hot water usage with the hot water storage tank system in houses. In the previous studies, there were some papers about the calculation method for hot water consumption. Though, the generalized calculation methods have not been developed. Especially, current houses with the hot water storage tank system have various functions, which are automatic filling up bathtub, automatic keeping the bathtub's water warm, reheating the bathtub's water. Therefore, it is supposed that the dwellers have various styles on hot water usage and behavioral patterns.
In this paper, we try to set the calculation models that are applied to various hot water usages and behavioral pattern with hot water storage tank system in houses. First, we carried out questionnaires and field measurements on the hot water usage and the performance for the CO_2 heat pump water heater in 14 houses through a year from December 2005. Based on the results of questionnaires and measurements in summer and winter, the behavior of hot water usage and the loads of hot water consumption are analyzed. Especially, frequency, duration time and discharge flow rate, etc. in each hot water usage are shown. From these analyses, the calculation models which are divided into some levels for hot water usage are prepared. Finally, we suggest the calculation method for the loads of hot water consumption in households which have various styles on hot water usage.

Keywords

Hot Water Supply Demands, Storage Tank, CO_2 Heat Pump,
Hot Water Usage, Calculation Method, Houses

1. Introduction

In recent years, the high efficiency hot water heaters, such as latent heat recovering hot water heater, CO_2 heat pump hot water heater, cogeneration system, etc., have been developed in Japan. It has become popular to equip CO_2 heat pump hot water heater with hot water storage tank system in houses because of expectations of energy conservation. As for the CO_2 heat pump hot water heater, we carried out the measurements of hot water consumption in 14 houses. As the results, we analyzed the fluctuation and tendency for the loads of hot water consumption in each house [1]. Additionally, we analyzed the characteristics of hot water usage in details. Specifically, the dweller's behavior at bathroom and the loads of hot water, which were consumed by reheating a bathwater, were studied in each house [2].

In this paper, we analyze the dweller's behavior for hot water usage with the use of the measurement data and the questionnaire data. We suggest the calculation method for loads of hot water consumption in households which have various styles on hot water usage.

2. Outline of the investigation

The measurements of hot water consumption in houses with the hot water storage tank were carried out in 14 houses located at the regions of different climates in Japan. Figure 1 shows the distribution diagram of hot water supply system and the measurement points. We measured mainly cold and hot water temperatures, flow rates and consumption of electricity at each point in the system. These points were the same in all houses except the surface temperatures of hot water storage tank depended on the tank capacity. These values were recorded automatically every two or three seconds through a year. Hot water was supplied to a bathtub and other uses by each pipeline. In addition, this system had the function to reheat water in the bathtub by the circuit of pipe putting the heat exchanger inside the storage tank. The measurement in each house was started between December, 2005 and January, 2006.

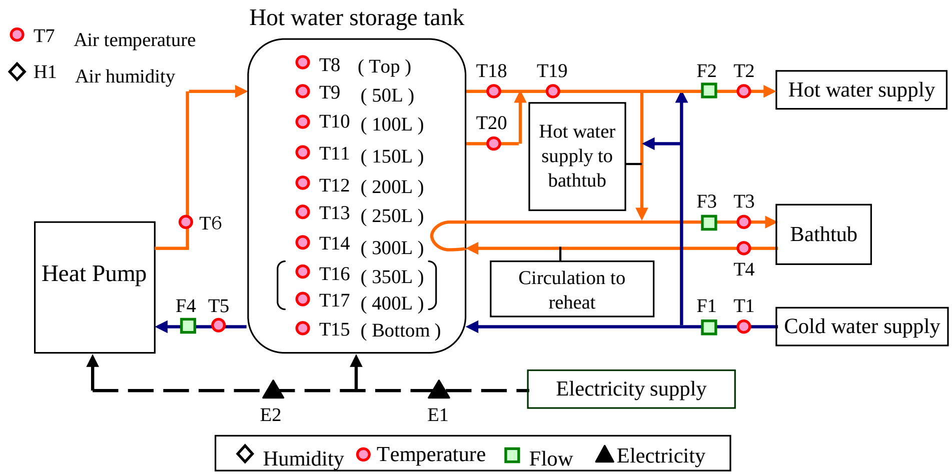


Figure 1 – Distribution diagram of hot water supply system and measurement

We carried out two kinds of questionnaires every season in order to grasp the characteristics of household, hot water usage for household and individual, and so on. The questionnaire survey period was five days on Tuesday from Friday in each season on the basis of the consideration to the difference of lifestyle between weekday and weekend. Table 1 shows the contents of the questionnaires. One of the Questionnaires includes items on the hot water usage for whole of the household as Questionnaire A sheets. Another includes items on the individual about hour being at home and behavior of hot water usage as Questionnaire B sheets.

Table 1 - Contents of questionnaires

A	Respondent		Relationship between the householder, Sex, Age, Occupation
	Characteristics of housing		Scale, Structure
	Hot water usage	Kitchen	With or without dishwasher, Frequency of dishwasher usage
		Bath	How to take a bath, Frequency of changing bathwater
		Laundry	Frequency of washing, Use or nonuse of hot water
		Consciousness	Sense of using
B	Bath		How to fill bathtub with hot water, Time for filling bathtub with hot water
	Dish care		Use or nonuse of dishwasher
			Time for washing dish, Number of dishes
	Laundry		Use or nonuse of washing machine, Time for washing clothes
			Use or nonuse of hot water
	Living hour		Time of taking a meal, Time for going out from house
			Time of taking a bath, How to take a bath or a shower

3. Calculation method of hot water consumption loads

We aim to calculate the hot water consumption for simulation of the running condition and the efficiency of the CO_2 heat pump water heater. As a time series simulation, it is possible to apply the calculation method with the Monte Carlo Simulation technique, which had presented in previous paper [3,4].

At the beginning of the calculation, it is very important to grasp the characteristics of household. The number of family composition living in a household, frequency of hot water usage, duration time of water usage and discharge flow rate on each hot water usage, will be required as the basic data for the calculation. Therefore, we have to set up the calculation model with the frequency of hot water usage in each period through a day, and average values and the distributions of the duration time, the flow rate, etc. The calculation of hot water consumption loads can be carried out according to the procedure shown in Figure 2. We generate the pseudo-random numbers by using personal computer. And the generated random numbers are applied to calculate the occurrence time interval of water usage, the duration time and the flow rate. In this paper, we consider the hot water as 40 ºC hot water consumption on each usage, but "Reheating" and "Keeping warm" for bathtub's water are models converted to the value of heat loads. The simulation is carried out with repetition until we can get the stability for the calculating results. The time interval of simulation is one minutes. The simulation is checking the contradiction of the time-zone for hot water usage, for example, someone take a bath with bathtub which is not filled a hot water, and the reheating starts before the hot water is filled in the bathtub. From these results, we can get the fluctuation patterns of hot water consumption in the time series through a day.

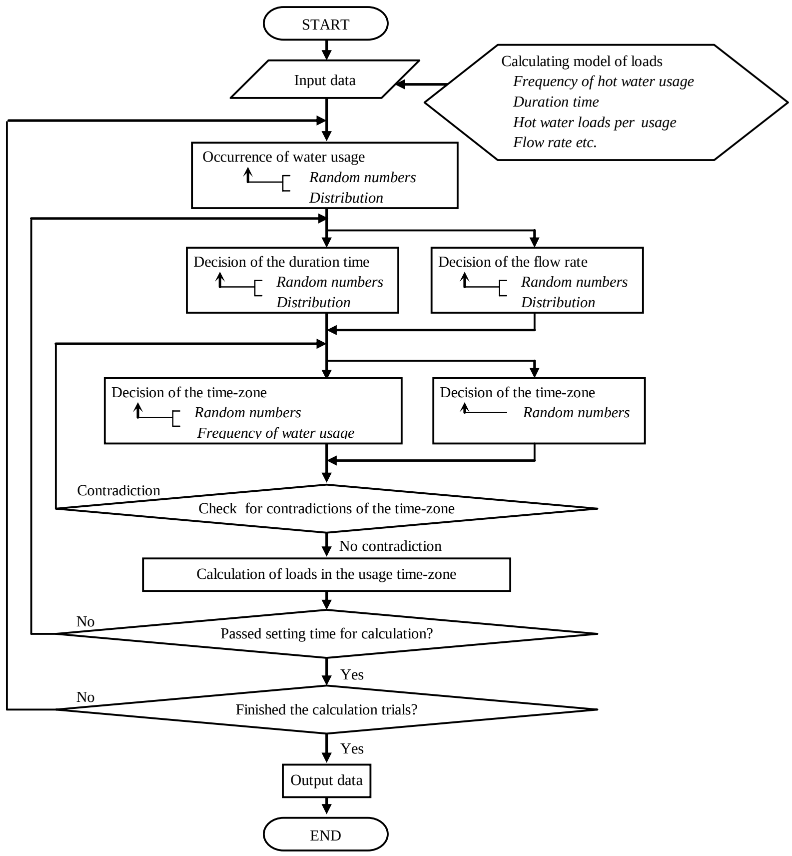


Figure 2 - Procedure for calculation of hot water consumption loads

4. Investigation of the calculation model

4.1 Extraction of loads of hot water consumption

From the results of questionnaire survey and measurement data, we tried to grasp the characteristics of hot water usage in each dweller. Figure 3 shows the image of checking

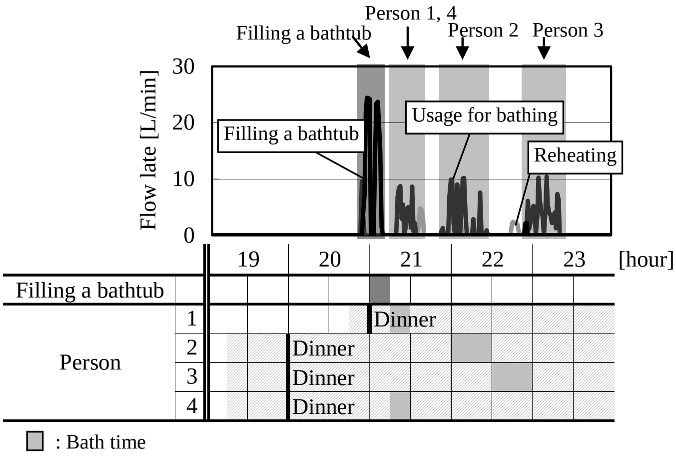


Figure 3- The image of checking the dwellers' behavior for hot water usage

the dwellers' behavior, which is gotten from questionnaire survey against the measurement data of hot water consumption in the same time zones. Similarly, the characteristics of hot water usage are analyzed from questionnaire survey and measurement data.

4.2 Setting up the calculation model in an investigated house (Chugoku-2)

As an example, we set up the calculation model of Chugoku-2 in winter. The family size of Chugoku-2 is a family of four persons; father, mother, daughter, and grandmother. As for the bathing style of Chugoku-2, they are taking a bath every day. The number of days of filling a bathtub and the number of days of reheating are almost in the same. Father and grandmother are taking a shower everyday even if the bathtub is filled with hot water. Figure 4 shows the ratio of frequency of hot water usage. "Filling a bathtub" and "Reheating" occurred religiously at the 18 o'clock time zone. A time zone of "Shower" is later than that of "Usage for bathing", and a time zone of "Keeping warm" is almost the same as that of "Usage for bathing". The peak ratio of "Kitchen etc." occurs between the 7 o'clock and 9 o'clock in the morning and at the 18 o'clock time zone in the evening. Table 2 shows the calculation model. The hot water usages for handling fixture are classified into four categories; "Kitchen etc.", "Usage for bathing", "Shower", and "Filling a bathtub". On the other hand, the loads of hot water for using the function of reheating are classified into two categories, "Reheating", and "Keeping warm". In each hot water usage, we decided the frequency of usage per day and per household, duration time per frequency, and loads per unit of time from the measurement data. As for the "Reheating", the duration time and loads per unit of time had the negative correlation. Therefore, we use the model of the heat load per frequency and loads per unit of time, and we calculate the duration time from the two parameters.

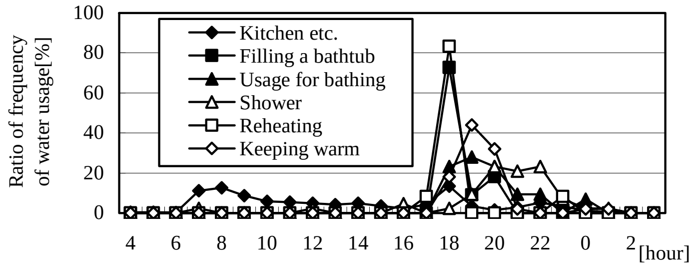


Figure 4 - Ratio of frequency of hot water usage (Chugoku-2, winter)

Table 2 - Calculation model for a house (Chugoku-2, winter)

		Hot water usage for handling fixtures				Loads of hot water for using the function of reheating		
		Kitchen etc.	Usage for bathing	Shower	Filling a bathtub	Keeping warm	Reheating*2	Keeping warm
Frequency of usage [frequency/house/day]	Average	86.5	2 x 0.84	2 x 0.84	1.0	3.4	1.0	1.6
	Distribution	Erl.K=15				Erl.K=06		Erl.K=06
Duration time per frequency [min/frequency]	Average	1.0	25.4	13.4	9.6	4.2	*3	4.2
	Distribution		Erl.K=04	Erl.K=05	Erl.K=100	Erl.K=03		Erl.K=03
Loads per unit of time [L/min], [kJ/min]*1	Average	2.2	5.2	7.0	14.7	348.8	496.3	348.8
	Distribution	Hyp.K=100	Erl.K=08	Erl.K=08	Erl.K=100	Erl.K=08	Erl.K=50	Erl.K=08

Note: *1 [kJ/min]: Unit of "Reheating" and "Keeping warm"

*2 As for a heat load per frequency on "Reheating", the average is "14.6[MJ]" and the distribution is "Erl. K=30".

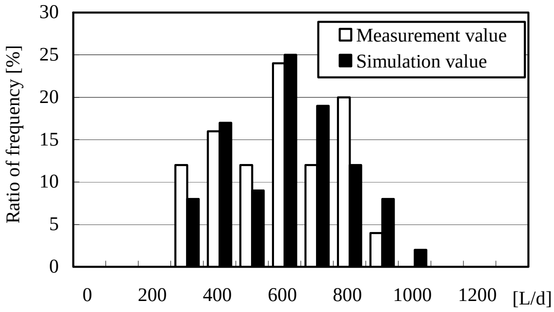
*3 A duration time per frequency on "Reheating" is calculated from a heat load per frequency and loads per unit of time.

4.3 Calculation results for the loads of hot water consumption (Chugoku-2)

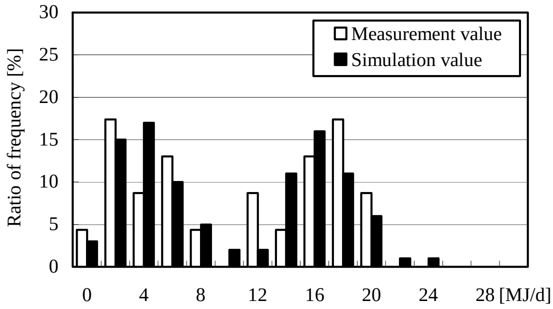
We calculated the loads of hot water consumption with the calculation model of Chugoku-2 by using the personal computer. The simulation was carried out in every one second through a day. The number of trials is one hundred in each hour. As for the “Filling a bathtub” and “Reheating”, the number of trails was fifty in each. From the simulation data of one second interval, we analyzed the fluctuation of the daily and hourly loads of hot water consumption.

The frequency distributions of hot water consumption per household and per day are shown in Figure 5. The numbers of samples for “Measurement value” and “Simulation value” are twenty five days and one hundred days respectively. The average values, standard deviations, maximum values and minimum values as the volume of hot water consumption are shown in Table 3. Both Figure 5 and Table 3 show the volume of hot water consumption and the volume of heat loads separately.

The simulation results show the reproducibility of the fluctuation of daily loads, although the measurement values are widely distributed. The range from maximum value to minimum value of the simulation values is a little wider than that of measurement values. It is thought to be causally related to the number of samples.



a) Hot water consumption



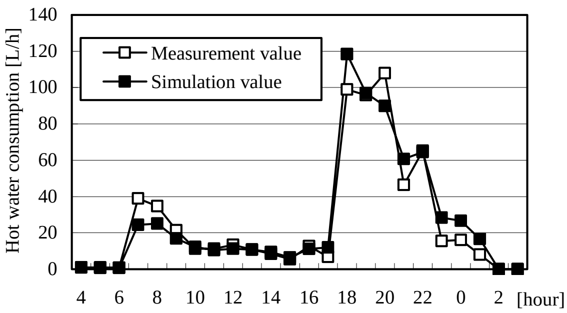
b) Heat loads for reheating

Figure 5 - Daily loads of hot water consumption

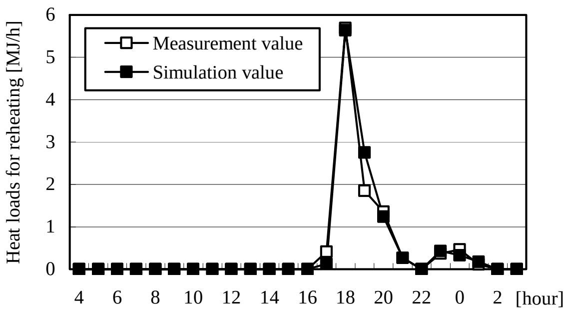
Table 3 – Statistics of daily loads of hot water consumption

	Hot water consumption [L/d]		Heat loads for reheating [MJ/d]	
	Measurement value	Simulation value	Measurement value	Simulation value
Average	632	649	11.49	11.22
S.D.	180	175	6.80	6.68
Maximum	961	1020	21.36	24.98
Minimum	327	306	0.97	1.19

Figure 6 shows the fluctuation of hourly loads of hot water consumption and heat loads of reheating a bathwater. According to the Figure, there is not so much difference between “Measurement value” and “Simulation value”. Therefore, the accuracy of this calculation method is confirmed. Table 4 shows the maximum values of hourly and instantaneous loads of hot water consumption. As for the maximum values of hot water consumption, simulation values are larger than measurement values. It is considered that the usage for bathing in the while of filling the bathtub affects the difference of volume of hot water consumption. In the measurement data, the usage for bathing in the while of filling the bathtub did not occur in Chugoku-2, however we considered that such usage might occur in the other household. As for the heat loads for reheating, there is not so much difference between “Measurement value” and “Simulation value”. It is possible to calculate the loads of hot water consumption by using this calculation method.



a) Hot water consumption



b) Heat loads for reheating

Figure 6 - Hourly loads of hot water consumption

Table 4 - Maximum values of hourly and instantaneous loads of hot water consumption

	Hot water consumption [L/h], [L/min]		Heat loads for reheating [MJ/h], [MJ/min]	
	Measurement value	Simulation value	Measurement value	Simulation value
1hour value	291.4	374.6	18.17	18.63
1 minute value	22.6	25.3	1.19	1.12

5. Calculation model for various hot water usage in houses

5.1 Setting up the calculation model in consideration of levels for hot water usage

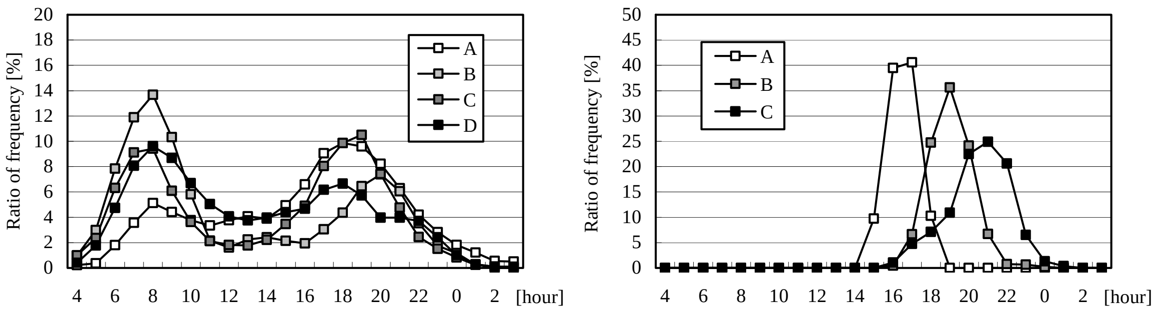
We analyzed the characteristics of hot water usage from questionnaire survey and measurement data in each house. Specifically, the frequency of hot water usage per day, the volume of loads per frequency, loads per unit of time, duration times were calculated from the data on February as a winter season and on July and August as a summer season. As the results, the hot water usage of individual showed various styles. Therefore, the characteristics of hot water usage were classified into some levels by the cluster analysis. Table 5 shows the calculation model for houses, and Figure 7 shows the ratio of frequency of hot water usage as an example of "Kitchen etc." and "Filling a bathtub and Reheating" in winter. We can set up an ideal model by combining the parameter of hot water usage in various levels.

Table 5 - Calculation model for houses

			Filling a bathtub	Reheating	Usage for bathing					Shower			
Level					1	2	3	4	5	1	2	3	4
Frequency per day [frequency/house/day]					Frequency of bathing per week [frequency/house/week]					Frequency of shower per week [frequency/house/week]			
Loads per frequency [L/frequency], [MJ/frequency]	Winter	Average	*1	12.7	35.6	54.3	80.8	115.7	177.3		36.1	57.1	107.3
		Distribution	Erl.K=100	Erl.K=10	Erl.K=02	Erl.K=03	Erl.K=03	Erl.K=05	Erl.K=30		Erl.K=04	Erl.K=05	Erl.K=05
	Middle	Average	*1	8.7	33.1	55.4	81.0	114.4			39.9	61.3	107.8
		Distribution	Erl.K=100	Erl.K=08	Erl.K=02	Erl.K=06	Erl.K=05	Erl.K=05			Erl.K=05	Erl.K=10	Erl.K=05
	Summer	Average	*1	4.6	30.6	56.4	81.2	113.1		27.1	43.6	65.5	108.3
		Distribution	Erl.K=100	Erl.K=06	Erl.K=03	Erl.K=10	Erl.K=08	Erl.K=05		Erl.K=09	Erl.K=06	Erl.K=15	Erl.K=05
Loads per unit of time [L/min], [kJ/min]	Winter	Average	15.0	519.4	5.6						7.4		
		Distribution	Erl.K=50	Erl.K=15	Erl.K=04						Erl.K=10		
	Middle	Average	14.1	397.5	5.5						6.1		
		Distribution	Erl.K=50	Erl.K=12	Erl.K=04						Erl.K=07		
	Summer	Average	13.2	275.7	5.5					4.8			
		Distribution	Erl.K=50	Erl.K=10	Erl.K=05					Erl.K=05			

Note: *1 The volume of hot water consumption for filling a bathtub depend on the size of bathtub.

			Kitchen				Keeping warm	
	Level		1	2	3	4	1	2
Frequency per day [frequency/house/day]	Winter	Average	21.9	45.9	89.8	130.4	1.8	5.4
		Distribution	Erl.K=02	Erl.K=09	Erl.K=20	Erl.K=30	Erl.K=05	Erl.K=05
	Middle	Average	15.5	32.3	70.1		1.6	3.7
		Distribution	Exp.	Erl.K=06	Erl.K=12		Erl.K=07	Erl.K=05
	Summer	Average	9.2	18.8	50.4		1.3	1.9
		Distribution	Hyp.K=100	Erl.K=03	Erl.K=04		Erl.K=10	Erl.K=05
Duration time per frequency [min/frequency]	Winter	Average	1.0				4.1	8.2
		Distribution					Erl.K=03	Erl.K=03
	Middle	Average	1.0				3.4	7.1
		Distribution					Erl.K=03	Erl.K=04
	Summer	Average	1.0				2.8	6.0
		Distribution					Erl.K=03	Erl.K=05
Loads per unit of time [L/min], [kJ/min]	Winter	Average	1.7				194.8	295.1
		Distribution	Hyp.K=02				Erl.K=06	Erl.K=03
	Middle	Average	1.7				176.3	282.7
		Distribution	Hyp.K=02				Erl.K=06	Erl.K=06
	Summer	Average	1.7				157.7	270.3
		Distribution	Hyp.K=02				Erl.K=06	Erl.K=10



a) Kitchen etc. b) Filling a bathtub, Reheating

Figure 7 - Ratio of hourly frequency of hot water usage as an example of winter

5.2 Levels of hot water demands and patterns of bathing styles

The simulation of hot water usage was done in a family of four persons. Levels of hot water demands in the household are shown in Table 6. The levels are set up by assuming two levels. One level is “Large model” which uses a large amount of hot water, and another level is “Small level” which uses a small amount of hot water. Pattern of usage in Table 6 means the model of hourly frequency of hot water usage, which was shown in Figure 7. Pattern of usage in the Kitchen etc. is adapted to the pattern D, the other usage is adapted to the pattern B which is average pattern. Bathing styles have a strong influence to the volume of hot water consumption in the household. We set up the model patterns of bathing styles from the high possibility of occurrence based on the measurement data, which is shown in Table 7. Case-1 has the filling a bathtub everyday. Case-2 has alternating styles of filling a bathtub and reheating every second day. Case-3 has the taking a shower mainly. Case-4 has filling a bathtub in four days and not taking a bath in three days per week. As for the method of occurrence for the bathing styles, we produce the bathing behavior according to the ratio of frequency by generating the random numbers for the case-3 and case-4.

Table 6 - Levels of hot water demands in a family of four persons

<table>
<tr><td colspan="2" rowspan="2"></td><td rowspan="2"></td><td colspan="2">Large model</td><td colspan="2">Small model</td></tr>
<tr><td>Level</td><td>Pattern of usage</td><td>Level</td><td>Pattern of usage</td></tr>
<tr><td>Kitchen etc.</td><td>Frequency per day</td><td>Winter
Summer</td><td>Level 3</td><td>D</td><td>Level 1</td><td>D</td></tr>
<tr><td rowspan="2">Shower</td><td rowspan="2">Loads per frequency</td><td>Winter</td><td rowspan="4">Level 3 x 2
Level 4 x 2</td><td rowspan="4">B</td><td>Level 2 x 4</td><td rowspan="4">B</td></tr>
<tr><td>Summer</td><td rowspan="3">Level 1 x 2
Level 2 x 2</td></tr>
<tr><td rowspan="2">Usage for bathing</td><td rowspan="2">Loads per frequency</td><td>Winter</td></tr>
<tr><td>Summer</td></tr>
<tr><td>Filling a bathtub</td><td>Loads per frequency</td><td>Winter
Summer</td><td>200L</td><td>B</td><td>160L</td><td>B</td></tr>
<tr><td rowspan="3">Keeping warm</td><td>Frequency per day</td><td>Winter
Summer</td><td>Level 3
Level 2</td><td rowspan="3">B</td><td>Level 1</td><td rowspan="3">B</td></tr>
<tr><td>Duration time per frequency</td><td>Winter
Summer</td><td>Level 1</td><td>Level 1</td></tr>
<tr><td>Loads per unit of time</td><td>Winter
Summer</td><td>Level 1</td><td>Level 1</td></tr>
</table>

Table 7 - Patterns of bathing styles

		Filling a bathtub	Reheating	Shower	No person take a bath
case-1		7			
case-2		3.5	3.5		
case-3	Winter	3.5		3.5	
	Summer			7	
case-4		4			3

Note : The value shows the frequency of usage per week.

5.3 Calculation results for the loads of hot water consumption

We calculated the loads of hot water consumption in each pattern. The simulation was carried out at one hundred trials. As for the conditions, cold water temperature is 7.7 ºC on February and 27.3 ºC on August at Hiroshima city. As the simulation results, Figure 8 shows the fluctuation of daily loads of hot water consumption in a family of four persons in “Large model” on February and August. These data are randomly selected for one month from one hundred data of simulation results. In each bathing style, the simulation method shows reproducible results in the fluctuation of daily loads.

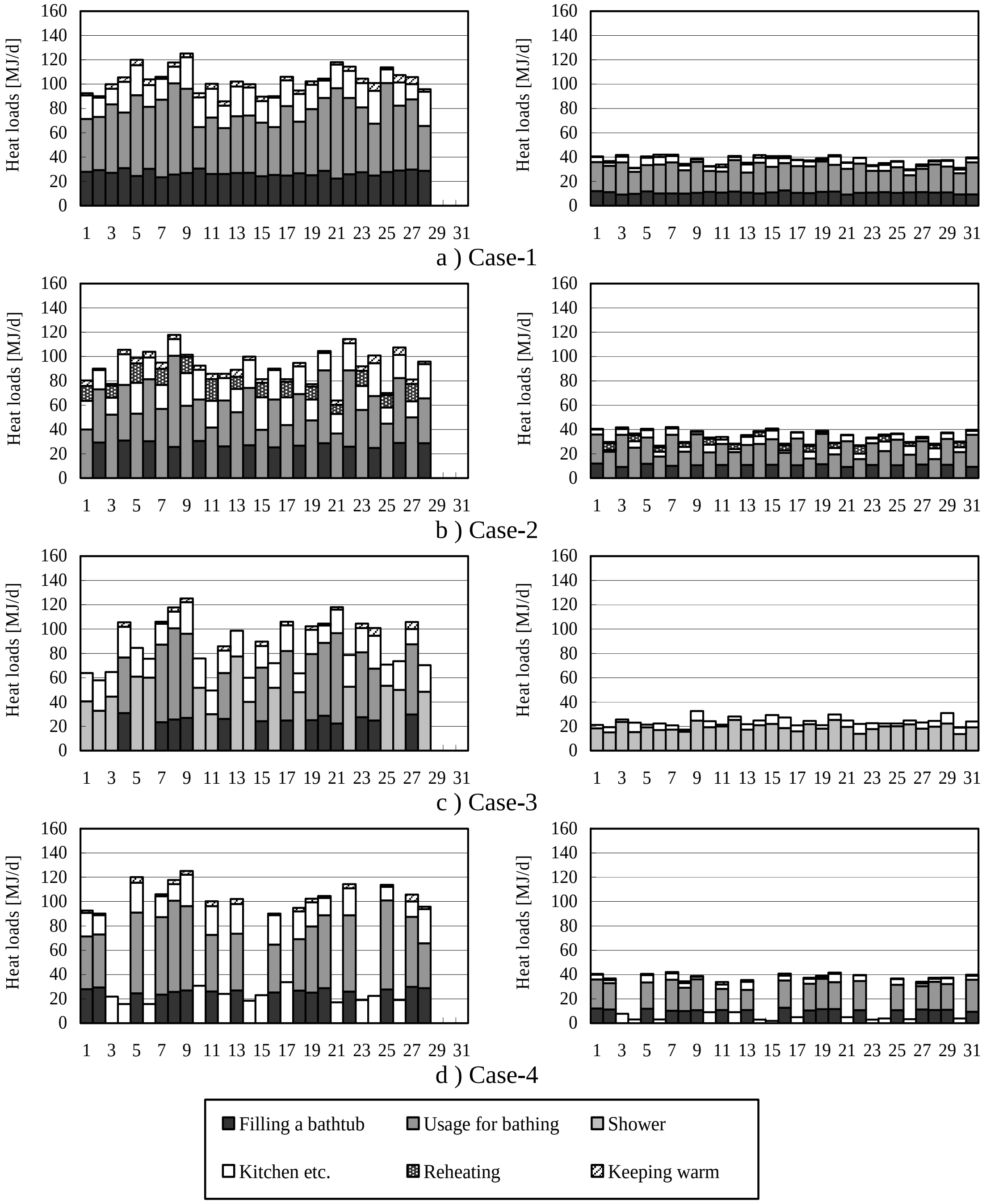


Figure 8 - Daily heat loads of hot water consumption (left: February, right: August)

Figure 9 shows the fluctuation of hourly loads of hot water consumption in a family of four persons in each bathing style; filling a bathtub, reheating, and taking a shower. The simulation values could recreate the fluctuation of hourly loads without contradiction of time-zone for hot water usage, as dwellers took a bath after filling a bathtub with hot water or reheating water. Considering the simulation results of the daily and hourly loads, the simulation method is useful to calculate the loads of hot water consumption in the houses with the hot water storage tank system.

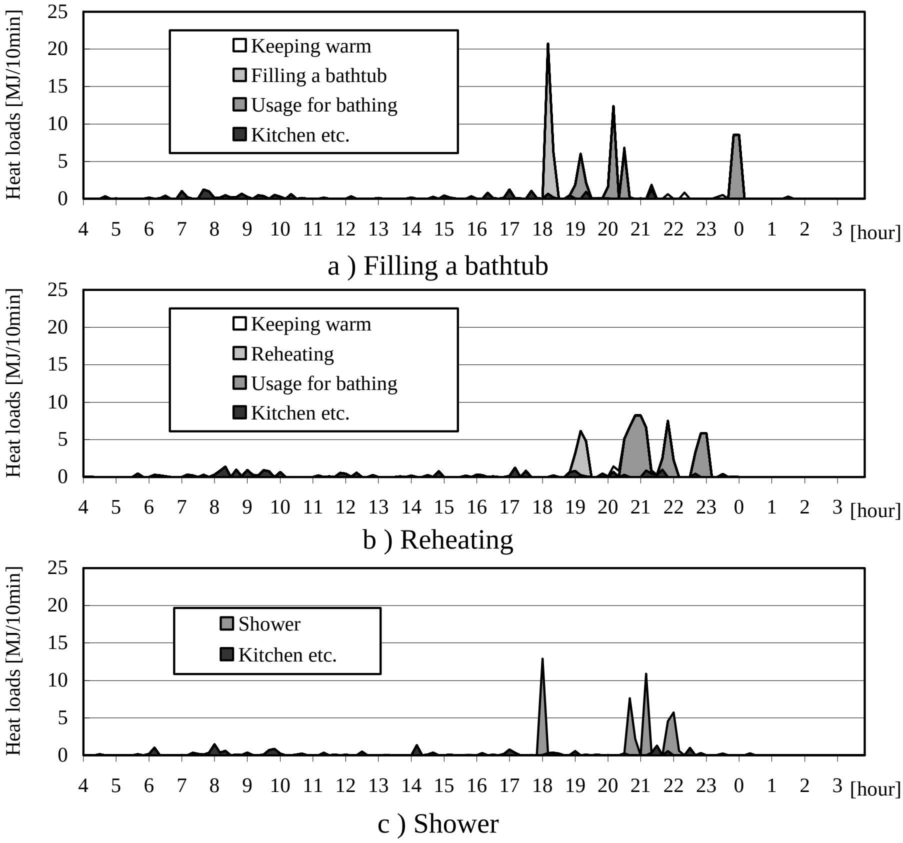


Figure 9 - Hourly heat loads of hot water consumption

6. Conclusion

In this paper, we suggested a calculation method for loads of hot water consumption based on the hot water usage in houses with the hot water storage tank system by using the Monte Carlo Simulation technique.

We carried out questionnaires and field measurements of hot water consumption in 14 houses located at the regions of different climates in Japan.

From the results of questionnaire and measurement data, we grasped the characteristics of hot water usage in each dweller. The characteristics of hot water usage were classified into some levels by the cluster analysis. On the basis of these data, the calculation model was set up to estimate the load of hot water consumption and the heat loads of reheating in each usage. Furthermore, we proposed the levels of hot water demands and the model patterns of bathing styles in the household to apply the calculation of various hot water usage styles.

The simulation results in each case of bathing styles were shown. It was clarified that the calculation technique was able to apply the estimation for the loads of hot water consumption in the houses with the hot water storage tank system.

Acknowledgments

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A3) Design flow rate simulation of cold water supply in residential buildings by means of open probabilistic model

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Abstract

The main objective of this paper is to present the results of performed simulations by means of an open probabilistic model in order to determine the design flow rate for cold water in building systems comparing the obtained results to the results of empirical method applied in the Brazilian Standard. For this simulation following values were required: flush duration, design flow rate, number of uses per capita for each plumbing fixture during the peak period and duration of the peak period obtained by means of a questionnaire filled by engineers and architects specially trained in the design process and in the management of installation and maintenance of building water supply systems. The statistic treatment given to the survey data produced values that can subsidize the input parameters of the model. The simulation outcomes showed big differences in both methods estimated design flow rates. The probabilistic model enables the design professional to adjust the parameters in order to better reproduce the actual building systems flow rate according to different conditions. Thus, its use appears to be more beneficial than the empirical method, mainly concerning submetering systems where the specification with adequately dimensioned meters especially when better accuracy is required.

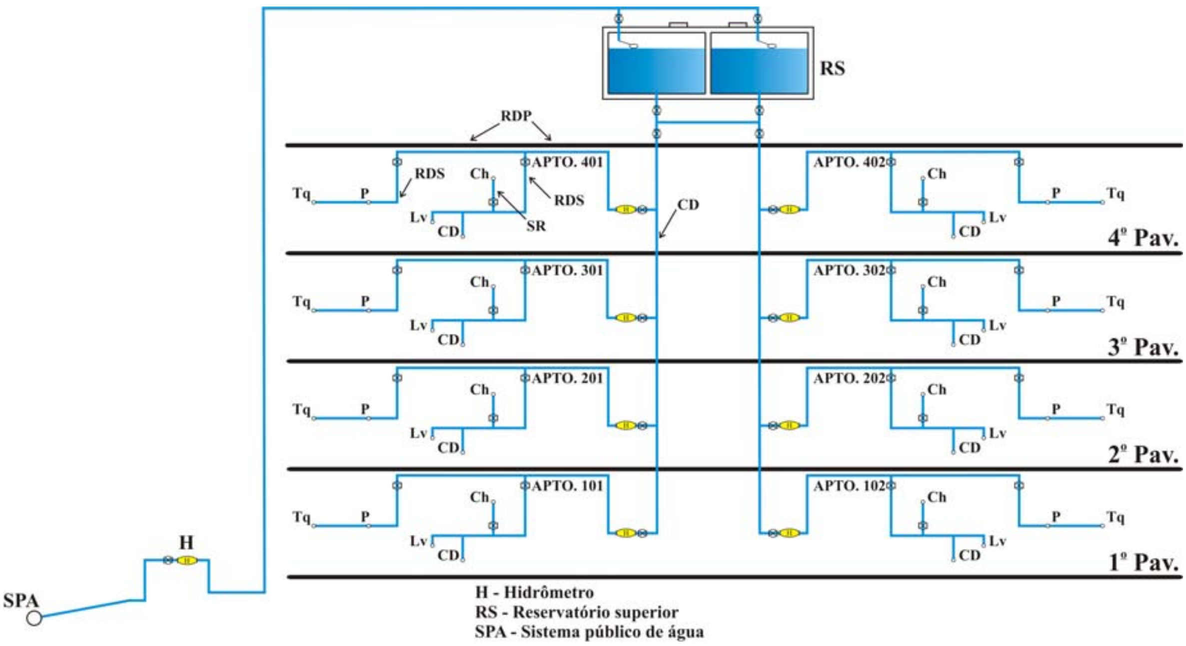
1. Introduction

There are some years the users of multifamily buildings have come requesting water sub metering systems as occurs with the gas and energy systems. One of the factors that they justify this claim is the increase of the awareness of that the water sub metering system allows to the management of the water consumption contributing for the reduction of water wastage and, consequently, the billing of the water effectively consumed in the activities carried through in the dwelling.

Water submetering system is the individualization of the water consumption with the installation of at least one water meter in each dwelling, so that is possible to measure the consumed volume of water.

Basically, the elements of the Water sub metering, proposed by PERES (2006), are described to follow and presented in Figure 1.

Riser (CD) – section that feeds the water meters when it has origin in the roof tank.
Supply branch (RA) – section between the riser and the upstream of the water meter(s).
Principal distribution branch (RDP) – section downstream of the water meter without ramification.
Secondary distribution branch (RDS) - section that feeds two or more taps.
Sub-branch (MR.) - section that feeds only one tap.



Ch – eletric shower (Sh) ; Lv – wash basin (WB); CD – close-coupled water closet (WC) ; P – sink (S) ; Tq – sink laundry (LS); H – water meter; RS – roof tank; SPA – public water supply system

Figure 1 – Elements of water sub metering system, PERES (2006)

The sizing and the specification of the water collective metering system have been task of the water utilities in Brazil. Due to this, in general, is verified an unaware of the water supply systems designers on the different involved aspects in this task (PEREIRA, 2007).

Water meters inadequately dimensioned can result in the submetering of the water consumption and it occurs when the flow rates in the feeding branch are, in its majority, lower to the minimum flow rate of the water meters and, therefore not detected.

This situation is very frequent in indirect systems of water supply of buildings, where the control of the water supply for the reservoir is done by a float valve. The flow rates caused for the displacement of the float valve are, at some moments, extremely low, not detected for the water meter usually used (PEREIRA, 2007).

On the other hand, in case that the flows rates in the feeding branches are, in its majority, next to the maximum flow rate of the water meter used, the main problem is the consuming suffered for this equipment, reducing its useful life.

In the case of a water sub metering system, the sizing of the water meter depends on the estimate of the design flow rates that will go to occur in the feeding branch of the dwellings, where the taps are supplied directly. It is important to highlight that in this in case that the sanitary rooms with different periods of use, such as bathrooms, kitchen and laundry room are supplied by one same piping, being this the main difference in the establishment of the flow rates, comparing itself with the water collective metering systems, where is usual the use of risers to supply sanitary rooms with similar standards of use.

So that the system presents the necessary efficiency is essential the adequate election of the water meters to be used, in order to minimize the errors in the accounting of the consumptions effectively occurred. Thus, the correct establishment of the design flow rates is one of the premises for the attendance to the performance requirement "trustworthiness" of the water sub metering system.

Some works developed by the authors of this paper evidence the necessity of adjusted models not only for the sizing of the individual water meters, but for the sizing of the water supply system (OLIVEIRA, 2007; OLIVEIRA et al., 2007a; OLIVEIRA et al., 2007b)
Although developed probabilistic methods already in Brazil in the decade of 1980 to exist, such as the model proposed by Gonçalves (1986), NBR 5626 (ABNT, 1998) still recommends the use of a deterministic method - method of the "fixture units" - for the establishment of the design flow rates in the cold water supply system, whose expression is presented by equation 1:

$$Q = 0{,}3\sqrt{\sum P} \quad (1)$$

Where:
Q is the design flow rate in the considered pipe section, L/s.
$\sum P$ is the sum of the relative "fixture units" of all the fixtures, installed downstream of the given pipe section.

This method, however, is not adequate, therefore it does not consider that the design flow rates depend on the activities of the users who, in turn, are function of the type of the building and the characteristics of the user; of the characteristics of the building, defined for the amount and the distribution of the population and, still, of the characteristics, flow rates and intensity of use of the sanitary appliances.

The classic probabilistic model was developed by Roy B. Hunter in the 30's and is widely used until today. The proposed binomial model considers that the probability of that sanitary appliance **r** or more appliances is in simultaneous use in a group of **n** installed appliances of one same type (n ≥ r) is given by the following expression:

$$P(x \geq r) = \sum_{x=r}^{n} \binom{n}{x} p^x (1-p)^{n-x} \qquad (4)$$

Where:
p is the usage probability of a sanitary appliance.

Considering a failure factor ε equal to the 0.01, that is, P (x ≥ r) < ε, Hunter constructed curves based on the probabilities of each type of appliance (p_i), determining the number of appliances (r_i) in simultaneous usage and respective design flow rates. From these curves it developed the concept of "fixture units", associated to each type of sanitary appliance and, thus, simplifying the attainment of the design flow rates (Q_p).

Hunter's model was the base for other similar models had been developed. Updated models had been proposed by WEBSTER (1972), using the binomial distribution generalized and by COURTNEY (1976), using the multinomial distribution.

GONÇALVES (1986) model presents an application the results of the use of these deterministic and probabilistic models, considering the same hypotheses of their use, resulting in great variability of values, depending on the model, having the calculated design flow rate vary between 1.2 L/s and 30.2 L/s for one single value of total design flow rate.

It was observed, in the majority of the studied models, a search of simple procedures, based on theoretical considerations or not, not usually represent the complexity of the problem. One common practice of the authors is to formulate closed models of universal character, nor always adjusted to the particularities of each project situation, not providing the engineers the necessary conditions for the decision taking.

Thus, the related author proposed "an open" model for the determination of water demands in water supply systems that could represent the real conditions of each design situation. A detailed description of the related model was presented in Oliveira et al. (2007 b).

The occurrence of flow rates in water supply system depends on the interaction between the user and the sanitary fixtures, in the taps, according to the following factors: activities of the users and characteristics of the set of sanitary appliances. The intervening variables that consider the above mentioned factors, influencing the flow rates in the systems, are grouped in the model as follows: intensity of use of the set of sanitary appliances; unitary flow rates of each type of sanitary appliance.

The intensity of use of the set of sanitary appliances is represented in the model by the following variables: duration of the discharge of a sanitary appliance, denoted by **t**; time interval between consecutive discharges of a sanitary appliance, denoted by **T** (depends on the number of usages per person during the peak period, the served population, and the number of sanitary appliances available) and of the number of installed sanitary appliances downstream of the pipe section, denoted by **n**.

The unitary flow rate of one determined type of sanitary appliance is denoted by **q**. As in the case of the variable **t**, the reduction of the figures of **q** is proposed in water conservation programs.

In this model, all these variables are open and can be treated as deterministic or random. The random variables **t** and **T** are represented by the Erlang type or exponential function density of probability, and **q** is represented by the Gamma type function density of probability. It was considered in the model that the values of mean and standard deviation of these variables could be obtained by the method of estimate for three characteristic points, provided by the experience of the designer or by field survey.
Similarly, the unitary flow rate of each appliance (q) can also be determined by means of field surveys, calculating of the mean and the variance or by the three points estimative method.

In the case of the WC cistern, the flow rates depend mainly on the characteristics of this device and the available hydraulic pressure, not being defined for the users. In the case of WC with conventional discharge valves, the flow rate is regulated previously and, depending on the hydraulic pressure, constant at each drive, being that the drive time is defined by the user. Already in the WC with fixed cycle, the control of the time not depends of the user.

The mean and the variance of the interval between two consecutive uses of a sanitary appliance in the period of peak can be determined by the following equations 2 and 3.

$$\mu_T = \frac{n \, . \, t_p}{P} \left(\frac{1}{\mu_u} + \frac{\sigma^2{}_u}{\mu^3{}_u} \right) \tag{2}$$

$$\sigma^2{}_T = \left(\frac{n \, . \, t_P}{P} \right)^2 \frac{\sigma^2{}_u}{\mu^4{}_u} \tag{3}$$

Therefore, the flow rate in the system can be determined by the equation 4.

$$Q = \sum_i r_i \, q_i \tag{4}$$

Where:
r_i is the number of appliances of type i, in simultaneous usage, which follows a beta-binomial distribution, presented in equation 10, with parameters a_i, bi, and dependents of pi i, where:

$$r_i \overset{d}{=} B - B(a_i, b_i, n_i) \tag{5}$$

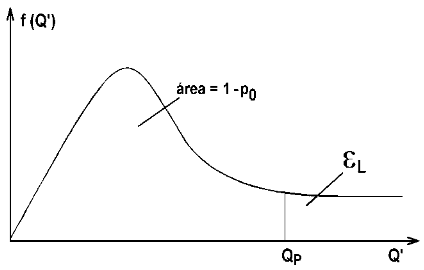
$$p_i = t_i \,/\, T_i \tag{6}$$

q_i, the unitary flow rate of the appliance of type i.

The values of the mean and standard deviation of Q (μ_Q, δ_Q) make it possible to determine the values of the mean and standard deviation of the variable Q' ($\mu_{Q'}$, $\delta_{Q'}$) that represents the not null values ($Q/Q \neq 0$) of the flow rate, in the peak period. The function density of probabilities that represents the variable Q' (Q/Q ≠ 0) is of Gamma type, as shown in Figure 2.

$$f(Q') = \frac{\lambda_Q^{r_Q}}{\Gamma_{(r_Q)}} . Q'^{r_Q - 1} . e^{Q'} , \lambda_Q > 0 \qquad (7)$$

where
$r_Q > 0$



p_0 - probability of the occurrence of null flow rates during the peak period
ε_L - local failure factor

Figure 2 - Function density of probabilities of Gamma type

Considering the local failure factor and the approach of Johnston for the Gamma function, it is possible to calculate value z and, consequently, the design flow rate of Q_p can be determined using the equation 8:

$$Q_p = \mu_{Q'} + z\sigma_{Q'} \qquad (8)$$

Maximum local factor **(**ε_G**)** is the probability of design flow rate is exceeded during the peak period considered. It states the failure admitted in the system. Thus, if the desired one is that the design flow rate calculated for the section is not exceeded more than 1% of the time, the global factor will have to be 1/100=0,01.

Maximum local factor, $\varepsilon_{LMÁX}$ is the probability of design flow rate is exceeded, considering only the time intervals at which flow rates occur in the pipe section during the peak period considered. Thus, if the desired one is that the design flow rate calculated for the section is not exceeded more than 1% of the time, the global factor will have to be 1/100=0,01.

A Queuing Theory model was developed (type M/M/C), allowing determining the necessary number of sanitary appliances that must be installed and the values of the mean standard deviation of the random variable T in the model, based on performance criteria, as presented in Gonçalves (1988). This model of Queuing Theory was used as reference by the Professor Thomas P. Konen of the Stevens Institute of Technology (United States) for the definition of the model of determination of sanitary appliances in sanitary of offices, elaborated for the ASPE - American Society of Plumbing Engineers.

The open character of the demand model, in which all the entry variables can be modified for different design conditions, was explored in three applications presented in Gonçalves (1989). In this work the variations of the water demands in residential building were verified, in function not only of the variation of the number of users served by the same bathroom, but also by the regional and climatic conditions as well as the variation of different times of the day.

It is observed that the empirical method, presented previously (equation 1), does not consider the presented variables previously and treats in the same way buildings with different characteristics as, for example, a residential building with apartments with one bathroom and population of two people and another one with one bathroom and five people. This consideration results in different design flow rates.

In the case of the water sub metering systems, the regimen of use of the appliances, considered by the NBR 5626 method, does not occur in residential buildings since it considers the same peak period for all the appliances. This regimen is verified in conventional systems, with one riser for each sanitary room, where the biggest intensity of use of the sanitary appliances in general occurs in the same period as, for example, the use of showers and water closets at the beginning of the morning.

In the case of the water sub metering systems the pipe sections of the water piping, where the meters are installed, cover different types of sanitary rooms such as: kitchens, bathrooms and laundry rooms. It is important to highlight that the peak period of use in these rooms do not coincide, therefore is not the same of social bathroom e, thus, for other sanitary rooms.

Therefore, in a city like São Paulo, a water meter installed in a section of pipe of cold water system, can simultaneously serve bathrooms, with peak periods from 6:00am to 8:00am and from 6:00pm to 8:00pm, and kitchens with peak period from 11:00am to 2:00pm and sometimes from 6:00p, to 8:00pm. In worst of cases the peak period will occur from 6:00pm to 8:00pm with the simultaneous use of some sanitary appliances of the bathroom and of the kitchen.

It is still observed, that, for conventional systems as for water sub metering systems, the use of WC discharge valve, as NBR 5626 (ABNT, 1998), requires an exclusive riser. In the case of water sub metering systems the main reason of not using WC discharge valve is that in function of the great difference of flow rate of the valve of discharge as compared as to the other sanitary appliances the water meter sized for the flow rate of the WC discharge valve would be over sized for the flow rates of the other sanitary appliances, what would result the sub metering.

In the article published in the CIB W62 - 2007 the differences cited, using for in such a way data of entrance for the probabilistic model, proceeding from carried through surveys pilot in field and the experience of the authors had been evidenced. In the present study they are presented new resulted of simulation with the methods empirical and probabilistic, using itself for in such a way data raised for professionals who act in the area of water sub metering systems, participants of a qualification course that comes being developed by means of an accord between the local water utility (SABESP) and the University of São Paulo.

3. Metodology

The comparative evaluation of the design flow rate values, gotten from the empirical method recommended by NBR 5626 (ABNT, 1998) and by the opened probabilistic method (GONÇALVES, 1986), was developed by the activities described as follow:

- definition of the typology of residential buildings to be studied;
- definition of the entrance parameters for the simulations;
- accomplishment of the simulations and analyses.

3.1 Definition of the typology of residential buildings to be studied

Some residential buildings typologies had been considered, which are: 1 dormitory and 1 bathroom (1D/1B) for a population of 2 people; 2 dormitories and 1 bathroom (2D/1B) for a population of 5 people; 2 dormitory and 2 bathroom (2D/2B) for a population of 5 people. Each apartment has one kitchen and one laundry room.

In each apartment the following sanitary appliances had been considered:

- Bathroom (social or master): one close-coupled toilet with nominal volume of discharge of 6 liters (WC), a wash basin (WB) and one electric shower (Sh);
- Kitchen: one sink (S);
- Laundry room: one washing machine (Ws) and one sink laundry (LS).

3.2 Definition of the entrance parameters for the simulations

As presented in item 2, in the case of the simulations with the empirical method, the entrance data if relate to the "fixture units" of the sanitary appliances, being considered the constant values in NBR 5626/98, which is reproduced in Table 1.

Table 1 – "Fixture units" and flow rates used in the simulation of the method recommended by NBR 5626 (ABNT, 1998)

Sanitary appliance	Fixture unit	Flow rate (L/s)
Wb	0,3	0,15
WC	0,3	0,15
Sh	0,1	0,1
S	0,7	0,25
Ws	1,0	0,3
LS	0,7	0,25

For the open probabilistic method, beyond the unitary flow rates of the appliances, it must be estimated: the mean duration of the discharge and the mean number of uses for user of each type of sanitary appliance in the peak period; the duration of the peak period; the number of people taken care of for sanitary rooms where if they find the sanitary appliances to be supplied in each pipe section of the system and the of local and global factors.

The mean duration of the discharge and the mean number of uses for person of the bathroom devices (electric shower, close-coupled water closet and wash basin) in the peak period had been determined from the pilot survey, carried through for professionals who work with plumbing systems. For other devices, it was used the same parameters considered by Oliveira et al. (2007b). Figure 3 shows the distribution of the period of the peak. Tables 2 and 3 present the values considered for these parameters.

The same values of the mean unitary flow rate and the mean duration time of the discharge of each appliance for the social bathroom had been considered. As cited previously, electric shower in both bathrooms was considered (individual heating, in the proper tap), which, to guarantee an acceptable heating, operate to a flow rate lower of what the used one in central hot water systems.

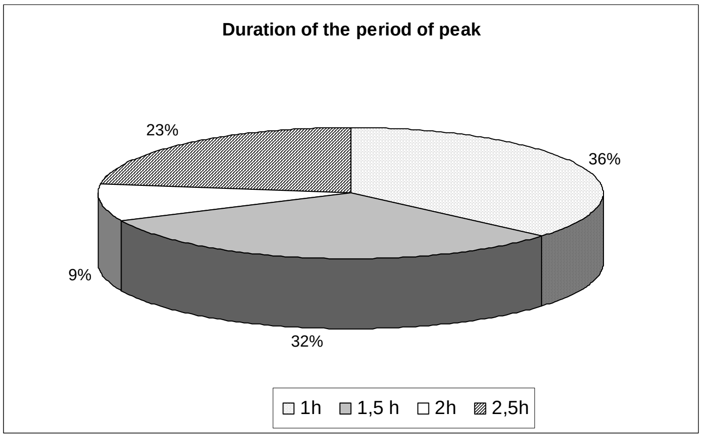


Figure 3 – Distribution of the duration of the peak flow – field data

Table 2 - Values of duration of discharges (for user and use) and of flow rate of sanitary appliances for the probabilistic model

Sanitary appliance	Duration of the discharges (s)		Flow rate (L/s)	
	Mean	Variance	Mean	Variance
WB	50	2407	0,09	0,0096
WC	66	4138	0,14	0,0001
Sh	608	38533	0,08	0,0003
S	33	81	0,13	0,0004
Ws	720	9216	0,14	0,00032
LS	30	16	0,15	0,0004

Table 3 - Number of uses *per capita* used in the simulation of the probabilistic model

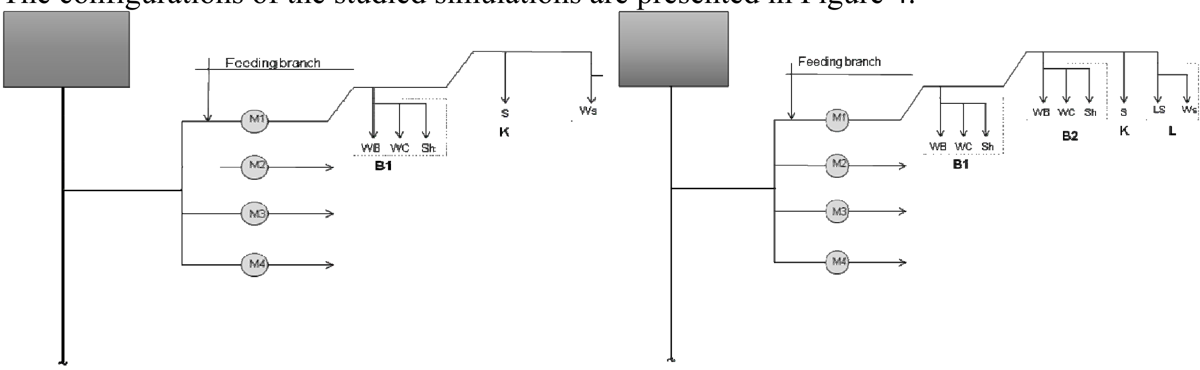
Sanitary appliance	Number of uses per person in the peak flow	
	Mean	Variance
WB	1,77	0,5762
WC	1,47	0,8725
Sh	0,96	0,083
S	4,2	0,36
Ws	1,0	0,16
LS	0,8	0,04

The definition of the duration of the period of peak also was effected in function of the results gotten in the field investigation, being considered three values of this parameter, to make possible a comparative of the gotten results: 1 h, 1h and 30 min and 2 h and 30 min.

The following values had been considered for the population of each sanitary room, as the simulated case:

- Simulation A: master bathroom: 2 people; kitchen: 1 person and laundry room: 1 person.
- Simulation B: social bathroom: 5 people; kitchen: 1 person and laundry room: 1 person.
- Simulation C: social bathroom: 3 people; couple bathroom: 2 people; kitchen: 1 person and laundry room: 1 person.

The configurations of the studied simulations are presented in Figure 4.



(a) (b)

Figure 4 – Cold water system for one bathroom (a) and two bathrooms apartments (b)

Finally, it was considered that the design flow rate calculated for section pipe in study would not have exceeded more than 1% of the time, of what results in the definition of a global factor of 0,01. For the local factor, the value proposed by Gonçalves (1986), was considered, that is, 0,05.

3.3 Simulations and analyses

The determination of the design flow rates using probabilistic method was done with the aid of a developed computational program for this end, called ProAcqua, which calculates the probable maximum flow rate in each pipe section of the system, considering the specified failure factors. The simulated conditions of project are presented in Table 4.

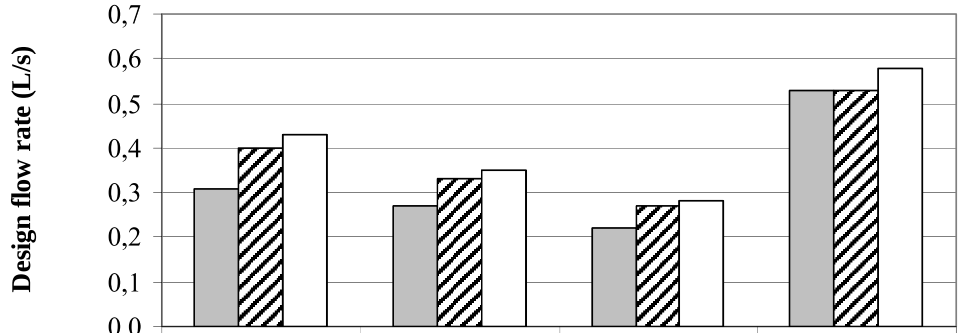
Table 4 - Conditions of project in the simulations

Simulation	Tipology	Population	Peak period (h)	Master Bathroom	Social Bathroom	kitchen	Laundry room
A	1D/1B	2	1:00	1	---	1	1
			1:30				
			2:30				
B	2D/1B	5	1:00	---	1	1	1
			1:30				
			2:30				
C	2D/2B	5	1:00	1	1	1	1
			1:30				
			2:30				

From the results obtained from the simulations using probabilistic method the additions (or decreases) of design flow rates, when compared to the values obtained with the empirical method recommended by NBR 5626/1998, had been determined.

4. Results and Discusses

The results obtained by the probabilistic method indicate value of design flow rate inversely proportional to values of peak period, what it does not occur with the method recommended by NBR 5626/1998, whose resulted does not depend on the peak period, as presented in Figure 3.



	Probabilistic (1h)	Probabilistic (1h30min)	Probabilistic (2,5h)	NBR 5626
Sim. A	0,31	0,27	0,22	0,53
Sim. B	0,40	0,33	0,27	0,53
Sim. C	0,43	0,35	0,28	0,58

Figure 2 – Design flow rate in the feeding branch gotten by the probabilistic method and by NBR 5626/1998

In the supply branches the open probabilistic method have resulted in values of flow rate with a range of 0,22 to 0,43 L/s, i.e, an 32% increase when the period of peak reduces of 2,5 h for 1 h, whereas the value obtained for 0,53 NBR 5626/98 was of 0,53 L/s for the simulations A and B and 0,58 L/s for simulation C.

These results demonstrate that the method recommended for the Brazilian Standard can result in upper values of design flow rates in the feeding branches of systems of water sub metering system. It is also important to say that the value of flow rate that will be used in the sizing of the water meter in the simulation C, for the most critical condition considered in the probabilistic method, period of peak of 1 hour, reaches in the method of NBR 5626 a value of 0,58 L/s, that is, about 35% above of the maximum value obtained for the probabilistic method, 0,43 L/s.

Considering that the basic parameters for the selection of water meters are the hydraulic pressure and the flow rate, it is observed by the results obtained in the simulations that the head loss of the calculated water meter as equation 9 would be bigger for the value of flow rate obtained by NBR 5626/1998. This would imply in the choice of water meters with bigger values of nominal flow rate, which could result in sub metering. Table 5 illustrates this fact.

$$\Delta h = (36 \times Q)^2 \times (Q_{máx.})^{-2} \qquad (9)$$

Where:
Δh is the head loss in the water meter, kPa;
Q is the maximum flow rate specified for water meter, m^3/h.

Table 5 - Comparison of the head losses values, as equation of NBR 5626 (ABNT, 1998), obtained in function of the flows rates in the feeding branch for the peak period of 1 h, gotten for the opened probabilistic method and the method of NBR 5626/1998.

Simulation	Flow rate obtained for the probabilistic method for peak period of 1 h (L/s)	Flow rate obtained for the NBR 5626/1998 method (L/s)	Head loss (kPa) Qmax of the water meter: 1,5 m^3/h	
			Flow rate of the probabilistic method	Flow rate of the NBR 5626/1998 method
A	0,31	0,53	55,4	161,8
B	0,40	0,53	92,2	161,8
C	0,43	0,58	106,5	193,8

With the head losses values resulted of the flow rates of the probabilistic method it could be possible specify water meters with maximum flow rate of 1,5 m^3/h in the worst of the hypotheses for the floors with bigger hydrostatic load, whereas for the values of flow rate obtained by the method of NBR 5626/1998, it would not be possible.

5. Conclusion

It can be observed that the probabilistic method offers a suitable tool for the design process, making possible the calculation of the design flow rates of the system considering:

- the behavior of the users in relation to water usage;
- the compatible peak periods with the carried activities;
- the duration of usage of the sanitary appliances and time interval between usages, in different types of buildings;
- the range of the water flow rates of each type of sanitary appliance.

Therefore, one concludes that the probabilistic method is more suitable to determine the design flow rates to dimensioning the water sub metering systems than the empirical method, therefore it is possible to consider the operational real conditions of the system.

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A4) Analysis on Cold and Hot Water Usage of Students in Each Dwelling

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Abstract

It is necessary to analyze in detail based on the actual dimensions of cold and hot water usage in order to develop a calculation method of cold and hot water consumption. The authors are developing Monte Carlo Simulation technique based on the usage of cold and hot water in various buildings. The purpose of this paper is to improve the accuracy of the simulation method.

The authors focused on dwellings of university students and analyzed their usage of cold and hot water and life styles. Investigations were carried out in winter and summer of 2002. Each usage of cold and hot water of respondents is divided into 7 categories, which are toilet, wash-basin, laundry, kitchen, usage for bathing, shower, and filling a bathtub. The calculation models which are composed of duration discharge time, flow rate, temperature and frequency par hour are made based on the investigation of life styles. Time series loads, such as daily, hourly and instantaneous demands are calculated by the Monte Carlo Simulation techniques with the calculation models on personal computer. We estimate the cold and hot water consumption by using the calculation method and compare the results of measurement and simulation.

Keywords

Cold water consumption; Hot water consumption; Life style; Measurement;
Monte Carlo Simulation.

1. Introduction

This paper presents analysis of cold and hot water usage of university students and comparison result of actual measurement value and simulation result by the Monte

Carlo Simulation technique. In recent years, importance of conserving energy has been rising along with global warming. In architecture field, it is necessary to improve building equipment system which consumes energy less than now in order to construct sustainable use. Accuracy enhancement of calculation method of cold and hot water demands is needed in order to reduce waste of energy consumption.

It is known that a calculation method for cold and hot water demands in the different types of buildings by the Monte Carlo Simulation technique has been studied by S. Murakawa. Consumption structure of cold and hot water in residential buildings, hotel, office building and restaurant were already reported. However, there is little information available on water usage of university students in their dwellings, although wide spectrum of data is needed for accuracy improvement. The purpose of this study is to accumulate of basic data about water usage of university students to use for calculation method. In this paper, trend of cold and hot water usage of university students is analyzed and simulation results are shown.

2. Outline of the investigations

Table 1 shows outline of the investigations which was conducted in winter and summer in 2002. The investigations consist of two parts. Investigation 1 is to consult lifestyle of university students. Each student noted their behavior every 15 minutes while they were at their home. The period of the investigation 1 had both of weekdays and holidays. Investigation 2 is to measure the amount and temperature of cold and hot water in each usage in order to clarify the features of cold and hot water consumption circumstantially. Bar thermometers were used to measure operating temperature and water flow meters were used to measure water consumption. The students took notes of instrument readings at after and before each water usage. In this paper, hot water indicates consumption in usage side not in supply side. Fundamentally, hot water supply based on heat quantity should be analysis for planning of hot water supply system. However in this paper, we defined hot water as mixed water of hot water supplied and cold water supplied because temperature of hot water supplied was unclear and records of operating temperature were not enough to analyze.

Table 1 – Outline of the investigations

	Period of the investigation	The number of object person	Total number of investigated days	
			Investigation 1	investigation 2
Winter	2002/2/26-2002/3/9	9 (Male:5) (Female:4)	34 (Weekday:20) (Holiday:14)	55 (Weekday:38) (Holiday:17)
Summer	2002/9/7-2002/9/29	11 (Male:6) (Female:5)	43 (Weekday:20) (Holiday:23)	80 (Weekday:47) (Holiday:33)

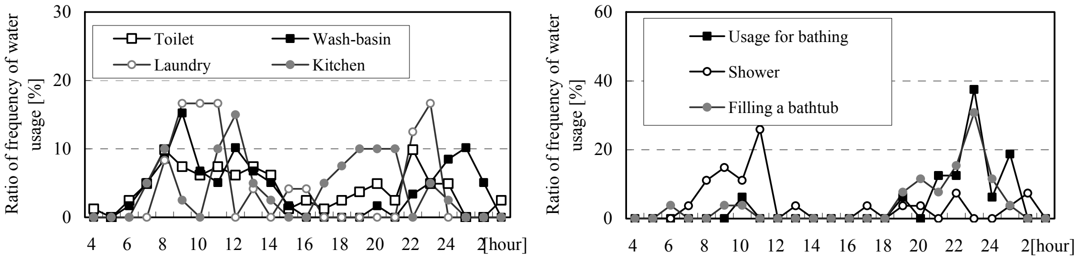
3. Analysis of hot and cold water usage of university students

Cold and hot water usage consists of seven behaviors; “toilet”, “wash-basin”, “laundry”, “kitchen”, “usage for bathing”, “shower”, and “filling a bathtub”. Contents of the seven behaviors are shown in Table 2. These behaviors were configured in consideration of result of the investigation 1.

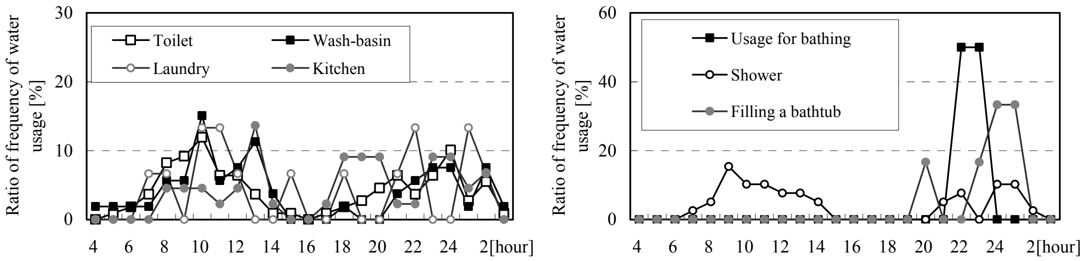
Table 2 – Contents of seven behaviors

Categories	Contents
Toilet	Flush a toilet with cold water
Wash-basin	Washing hands and face etc. at wash-basin
Laundry	Using water for clothes by washing machine
Kitchen	Using water for cooking and washing dishes at kitchen
Usage for bathing	Hot water usage at bathroom except for "Shower" and "Filling a bathtub"
Shower	Taking a shower without using a bathtub
Filling a bathtub	Filling the empty bathtub with hot water

Figure 1 shows the ratio of the hourly frequency of usage to the daily frequency of usage. Usage for toilet and wash-basin show shallow curves because their total frequencies are large and are dispersed at nearly all time. According to this Figure, at the time zone of 8:00~14:00 and 18:00~3:00 have a high percentage of frequency of water usage. This trend shifts about two hours behind comparing peak value with common lifestyle. By contrast, usage for bathing and filling a bathtub concentrate at the time zone of 20:00~1:00 with a high rate. Filling a bathtub occurs at about the same time each day. In winter, usage for bathing and filling a bathtub have low percentages in morning. Shower occurs in the morning and evening in contrast to usage for bathing and filling a bathtub. The result shows that the ratio of frequency of water in winter and summer doesn’t have large distinction.



a) Winter



b) Summer

Figure 1 - Ratio of the hourly frequency of usage

4. Analysis of hot and cold water consumption

The results of cold and hot water consumption per day and its standard deviation in each student are plotted in Figure 2. The results of respondents K and P are excluded because the number of investigated days was not enough. From the measurement results, it is found that there are large differences between individuals. It can be thought that water usage with a large amount of water such as laundry and filling a bathtub is not conducted daily. The number of times of filling a bathtub or laundry in a period of the investigations affects the results of cold and hot water consumption and the standard deviation.

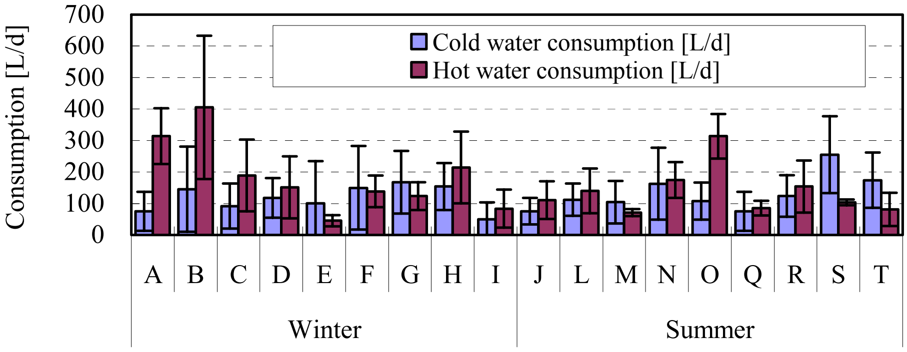
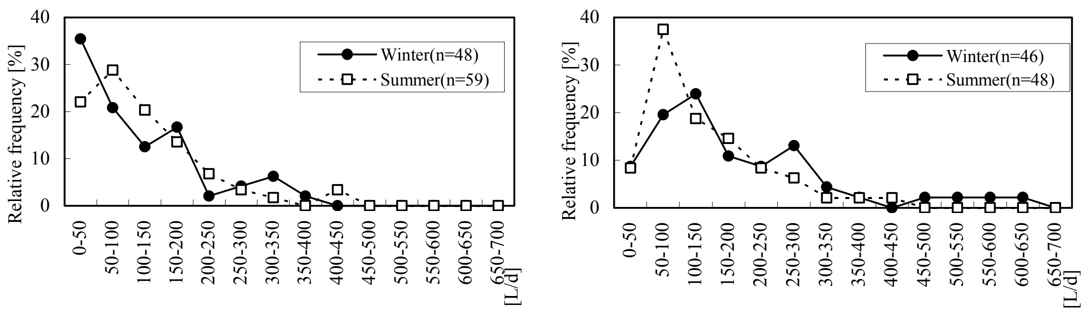


Figure 2 - Cold and hot water consumption per day

Figure 3 shows the relative frequency distributions of cold and hot water consumption per day. Mode values of cold water consumption are 0-50 litters in winter and 50- 100 litters in summer. They have a similar distribution. On the other hand, mode values of hot water consumption are 100-150 in winter and 50-100 in summer. The most-distinguishing feature of the results is that breadth of the distribution in winter is larger in width than the distribution in summer.



a) **Cold water** b) **Hot water**

Figure 3 – Relative frequency distributions of cold and hot water consumption per day

Table 3 shows the statistics of cold and hot water consumption per day. Average values of cold water consumption in the both seasons almost correspond. As for the hot water consumption, average value of winter is larger than summer by about 50 litters.

Table 3 – Statistics of cold and hot water consumption per day

	Cold water consumption [L/d]		Hot water consumption(40ºC)[L/d]	
	Winter	Summer	Winter	Summer
Average	115.6	123.9	189.6	138.5
Max	383.4	416.7	625.2	405.0
Min	9.0	24.3	17.1	7.2
Standard deviation	96.9	89.4	144.2	89.2
The number of sample [day]	48	59	46	48

5. Simulation of hot and cold water consumption

5.1 Calculation model

Cold and hot water consumption were calculated by the Monte Carlo Simulation technique. Calculation model shown in Table 4 was made based on the investigation 2. The model consists of average values and approximate distributions by Erlang or Exponential distribution in each behavior and item. Seven behaviors: “toilet”, “wash-basin”, “laundry”, “kitchen”, “usage for bathing”, “shower”, and “filling a bathtub” were set. As for “wash-basin” and “kitchen”, two cases of cold water usage and hot water usage were considered. Frequency of water usage, duration time, flow rate and operating temperature were analyzed for each behavior of seven items.

Table 4 – Calculation model for students in a dwelling

		Usage for bathing	Filling a bathtub	Shower	Wash-basin		Kitchen		Toilet	Laundry
					Hot	Cold	Hot	Cold		
Frequency of water usage [frequency/day]	Winter	0.27	0.45	0.70	0.39	2.16	0.34	1.09	3.07	0.41
	Summer	0.07	0.14	0.71	0.09	3.02	0.00	1.55	3.34	0.38
Duration time [sec./frequency]	Winter	168.4 Erl.K=6	710.7 Erl.K=50	859.3 Hyp.K=100	114.5 Hyp.K=100	34.8 Hyp.K=2	308.9 Hyp.K=100	91.8 Hyp.K=2	70.3 Erl.K=3	720.0
	Summer	120.0 Erl.K=100	761.1 Erl.K=50	645.4 Hyp.K=100	225.4 Erl.K=5	43.3 Erl.K=2	0	114.0 Hyp.K=2	60.9 Erl.K=3	720.0
Flow rate [L/min]	Winter	8.6 Erl.K=2	9.4 Erl.K=20	11.9 Erl.K=2	7.2 Erl.K=6	7.7 Hyp.K=100	6.8 Erl.K=2	7.5 Hyp.K=10	12.1 Erl.K=2	10.0
	Summer	12.7 Erl.K=10	9.8 Erl.K=100	11.5 Erl.K=10	5.8 Erl.K=20	6.5 Erl.K=2	0	6.9 Erl.K=3	12.0 Erl.K=3	10.0
Operating temperature [deg C]	Winter	41.8 Erl.K=100	43.0 Erl.K=100	41.5 Erl.K=100	34.0 Erl.K=30	11.8	36.1 Hyp.K=100	11.8	11.8	11.8
	Summer	38.8 Erl.K=100	39.8 Erl.K=100	39.5 Erl.K=100	34.8 Erl.K=30	26.0	—	26.0	26.0	26.0

5.2 Results of the calculation

On the basis of the usage models as shown in Figure 1 and Table 4, the simulation was carried out 100 times with repetition to get the stability for the calculation. From these results, we grasped the fluctuation patterns of cold and hot water demands in the time series through a day. And by using the statistical analysis, hourly values and daily values of cold and hot water consumption were calculated.

Figure 4 shows relative frequency distributions of cold and hot water consumption per day calculated by the simulation method. And the statistics of the results were shown in Table 5. From the relationship of the daily values, the calculation technique is able to apply to estimate of cold and hot water consumption and the simulation method is useful to estimate the loads of hot water demands in dwellings.

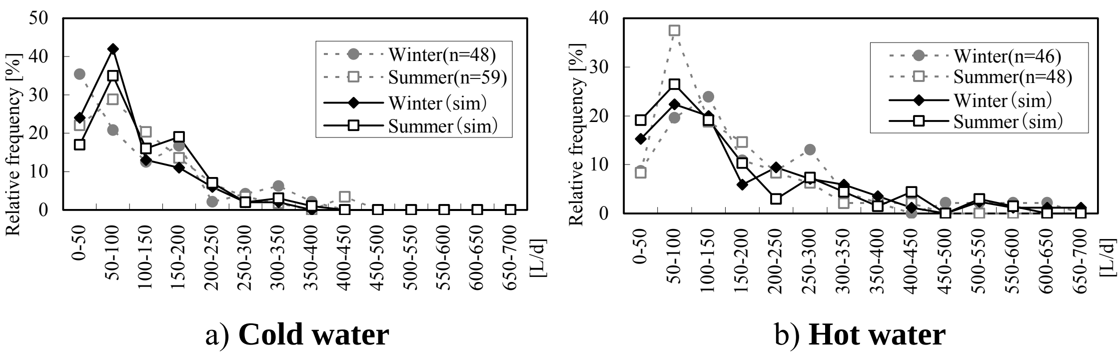


Figure 4 - Relative frequency distributions of cold and hot water consumption per day calculated by the simulation method

Table 5 - Statistics of the simulation results

	Cold water consumption [L/d]		Hot water consumption(40ºC)[L/d]	
	Winter	Summer	Winter	Summer
Average	100.1	116.7	201.6	159.1
Max	327.3	355.6	990.5	596.0
Min	2.4	10.0	4.5	8.3
Standard deviation	70.4	75.6	200.5	134.2
The number of sample [day]	100	100	85	68

Figure 5 shows the hourly fluctuation of cold and hot water consumption. The time zone of occurrence of cold and hot water consumption is found to be in agreement with the ratio of the hourly frequency of cold and hot water usage. Accordingly, the simulation method can recapture the cold and hot water consumption.

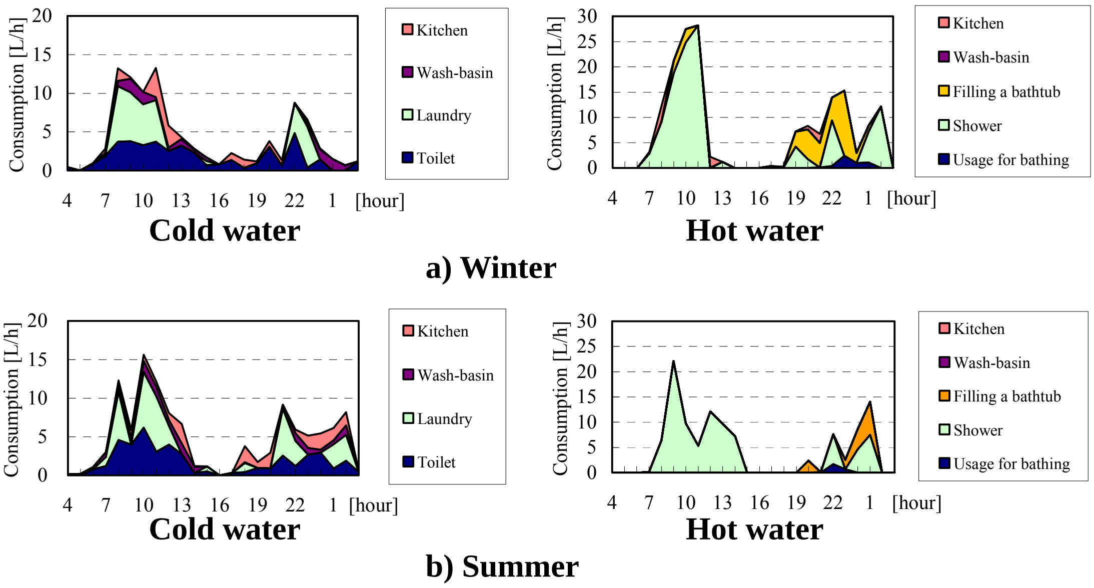


Figure 5 – Hourly fluctuation of cold and hot water consumption

6. Conclusions

In this paper, the trend of cold and hot water usage of university students and simulation result were analyzed to accumulate the basic data about water usage of university students. From the results, we can conclude following items.

(1) Cold water usage occurs frequently at the time zone of 8:00~14:00 and 18:00~3:00. This trend is late about two hours in comparison with the common life style.

(2) As for cold and hot water consumption per day, there were large differences between individuals. Average of hot water consumption in winter was larger than in summer by 50 litters even though cold water consumption in the each season has little differences.

(3) By making models for estimation of the loads based on the investigations, cold and hot water consumption were calculated by the Monte Carlo Simulation technique. In comparison with the simulation value and the measurement value, it could be found that the calculation technique was useful for estimation of cold and hot water consumption.

Acknowledgments

The study descried in this paper was promoted by the subsidy of science research from the Ministry of Education, Culture, Sports, Science and Technology (Project number 19560595, Head investigator: Saburo Murakawa). We wish to express gratitude for the great cooperation of the university students.

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2. S. Murakawa and H. Takata: Development of the Calculating Method for the Loads of Cold and Hot Water Consumption in the Apartment Houses; Proceedings of the CIB/W62 International Symposium on Water Supply and Drainage for Buildings (Ankara), pp.281-295 (2003)
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8. Presentation of Author

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A5) "Hunter" Fixture Units Development

Lawrence S. Galowin
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Consultant

Abstract

"Hunter Fixture Units" appear tabulated and referenced in worldwide variations for plumbing design for pipe sizing and capacity determinations. Dr. Hunter applied binomial probability theory in application to simultaneous events of water usages and drainage discharge events for design parameters of building plumbing systems. His publications presented graphs/tabulations for pipe sizing. The derived basis from binomial theory frequency analyses of usages resulted in tabulations that provided a means for selecting pipe sizes for adequacy/functions. From limited actual building usage patterns, data, and extended laboratory research the necessary piping requirements for both supply and discharge emerged in tabulations and design curves.

Dr. Hunter at National Bureau of Standards undertook plumbing research 1921 to his demise in 1943.
The planned identified future reports were not undertaken.

Keywords

Plumbing design, building drainage, potable water systems; building pipe sizing; plumbing codes; waste and water plumbing; plumbing detain methods; fixture units

1. Introduction

Plumbing systems actuations occur randomly and intermittently with variable magnitudes (probability for such events). Dr. Hunter introduced binomial probability theory for simultaneous events for water pipe supply and drainage systems that set sizing requirements. Improved procedures for loading tables were recognized as a need by the Coordinating Committee for a National Plumbing Code. Codification resulted from '**fixture units'** (dimensionless) for probable instances in building pipe sizing for water supply and drainage design. The water supply and drainage loading tables in plumbing design applications were based upon loads in 'dimensionless fixture units' as created from probability of simultaneous events introduced for water supply and drainage design as applied in model codes and handbooks. Prolonged illness and subsequent death of Dr. Hunter left barren the detailed descriptions applied in preparing the technical paper on pipe sizes determinations/computation.

Design to codes for water supply and drainage requirements follow procedures with tabulated "Hunter Fixture Units". From mid-last century into this era, the uncertainty factors in engineered systems sizing requirements demand for variations inherent to design loading results from determinations for unknowns with variability determinations from probability principals**.** Recent engineered sizing by adaptation of probability determinations adapted from post-1940 plumbing systems loadings variability concepts by Dr. Hunter found application to central air operations for hood/air duct loads/power needs of station/plant loads with great uncertainty of demand functions (2). That probability application of uncertainties drew on a referral to Dr. Roy Hunters' applications to plumbing systems' fixtures user loadings (1). Similarities for random events probability theory to engineered systems for sizing water and waste piping systems relied on uncertainties from usage variations in applications that led to a probability basis a means of quantifying a probable 'not to exceed' failure rate. Uncertainty impacts from incalculable variables in many engineering methods require probability - as developed for plumbing systems system sizing parameters design approximations.

Dr. Hunter in BMS 65 stated:

“**INTRODUCTION” -** ***Simplification and standardization must comply with accepted health regulations and minimum requirements for plumbing, which in turn should be based on scientific principles,***
The report deals with one of the factors, on which minimum requirements should be based, the maximum load to be provided for in plumbing systems. Other reports are planned dealing with water supply and water distribution systems in buildings, principles of building drainage, and principles of venting.
“PURPOSE” - ***Purpose of this series of papers is to collect in organized manner information obtained by the author over a number of years (from 1921 to research of 1937-1940) on plumbing, together with results from research (1937 - 1940) on plumbing with intervening experiments and interpreting results in a form suitable for direct and practical applications. It hoped that this series of papers will supply logical answers to questions pertaining to pipe sizes and design of plumbing construction.***

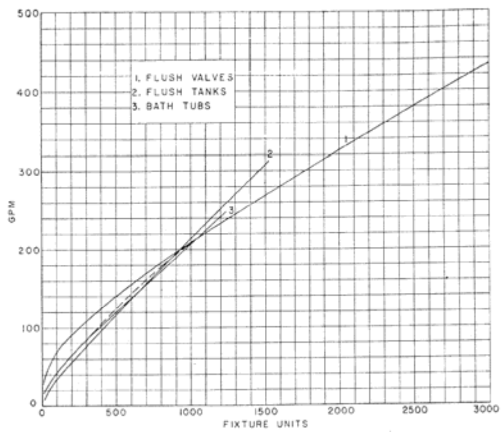


FIGURE 4.—*Relation of demand to fixture units.*

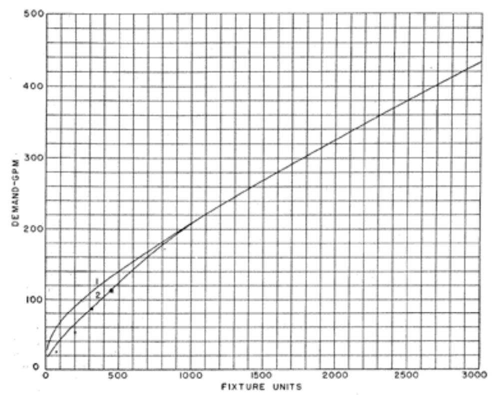


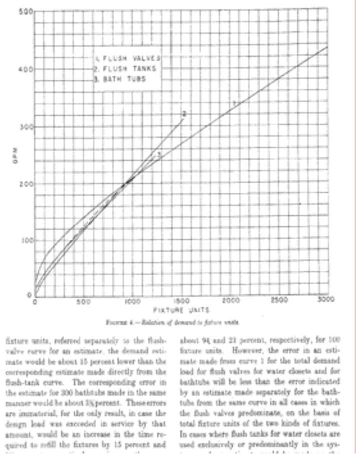
FIGURE 5.—*Estimate curve for design purposes.*

fixture units, referred separately to the flush-valve curve for an estimate, the demand estimate would be about 15 percent lower than the corresponding estimate made directly from the flush-tank curve. The corresponding error in the estimate for 300 bathtubs made in the same manner would be about 3½ percent. These errors are immaterial, for the only result, in case the design load was exceeded in service by that amount, would be an increase in the time required to refill the fixtures by 15 percent and about 94 and 23 percent, respectively, for 100 fixture units. However, the error in an estimate made from curve 1 for the total demand load for flush valves for water closets and for bathtubs will be less than the error indicated by an estimate made separately for the bathtubs from the same curve in all cases in which the flush valves predominate, on the basis of total fixture units of the two kinds of fixtures. In cases where flush tanks for water closets are used exclusively or predominantly in the sys-

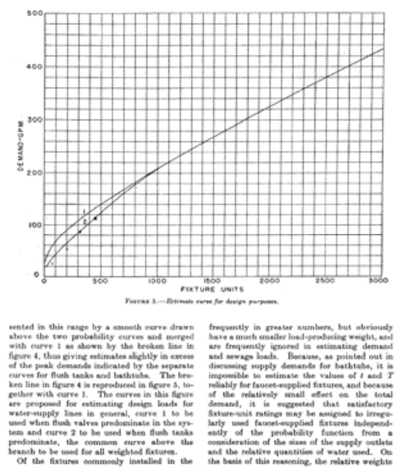
sented in this range by a smooth curve drawn above the two probability curves and merged with curve 1 as shown by the broken line in figure 4, thus giving estimates slightly in excess of the peak demands indicated by the separate curves for flush tanks and bathtubs. The broken line in figure 4 is reproduced in figure 5, together with curve 1. The curves in this figure are proposed for estimating design loads for water-supply lines in general, curve 1 to be used when flush valves predominate in the system and curve 2 to be used when flush tanks predominate, the common curve above the branch to be used for all weighted fixtures.
Of the fixtures commonly installed in the frequently in greater numbers, but obviously have a much smaller load-producing weight, and are frequently ignored in estimating demand and sewage loads. Because, as pointed out in discussing supply demands for bathtubs, it is impossible to estimate the values of t and T reliably for faucet-supplied fixtures, and because of the relatively small effect on the total demand, it is suggested that satisfactory fixture-unit ratings may be assigned to irregularly used faucet-supplied fixtures independently of the probability function from a consideration of the sizes of the supply outlets and the relative quantities of water used. On the basis of this reasoning, the relative weights

Primary source documents (1, 3) present graphical (illustrated) and tabulated loads results from probability theory applied to plumbing systems design requirements by

Dr. Roy Hunter. His research extended over more than two decades. His detailed research/analyses and introduction from binomial probability theory applied to specific fixtures functions/user demands. Currently details developed for pipe sizing in plumbing remains applicable with modified details.



The "fixture units" terminology appears for pipe sizing of plumbing systems design and regulatory information in "Hoover Code(s)" (5, 6, 7) with different definition from the 1940 probability concept. Use of the terminology applied to both design and regulatory requirements.



Observations (members of the committee) regarding use of water closets in public places resulted in definition "… *intent established rate of discharge of ordinary wash basin at* ***..about 7.5 gpm, so near to one cubic foot minute that it was taken as the definition of one fixture unit...*** in the initial usages**.** Terminology code changes occurred after the research applications adopted from probability principles analyses based upon actual fixture usages (supply or discharge) from defined user functions.

1.2 Secretary of Commerce - Herbert Hoover Recognition - 1924 (4)

Three sequenced reports (4, 5, 6) - recommendation of Dept. of Commerce Building Code Committee. Reports - BH2, BH 13 – (same title – '24, '28, '32 - known as "Hoover Codes") were initially requested by Secretary of Commerce Herbert Hoover (later 31st President). Statement from the 1924 code "…*Actual practice has been*


U. S. DEPARTMENT OF COMMERCE
R. P. LAMONT, Secretary
BUREAU OF STANDARDS
GEORGE K. BURGESS, Director

Elimination of Waste Series

RECOMMENDED MINIMUM REQUIREMENTS FOR PLUMBING

(With Supplement Containing Progress Revision to May, 1931)

REPORT OF SUBCOMMITTEE ON PLUMBING OF THE BUILDING CODE COMMITTEE

REVISED AUGUST 30, 1928
[Supplementary revision issued March 8, 1932]

GEORGE C. WHIPPLE, Chairman
HARRY Y. CARSON — AUGUST E. HANSEN
WILLIAM C. GROENIGER — J. L. MURPHY

JOHN M. GRIES, Chief, Division of Building and Housing
GEORGE N. THOMPSON, Secretary
R. B. HUNTER, In Charge of Tests

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON: 1932

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $1.25


48 RECOMMENDED PLUMBING REQUIREMENTS

In view of the importance of corrosion as an element in the longevity of plumbing systems, one of the members of the committee has prepared a memorandum on this subject, which will be found in the appendix. Another experimental study bearing on the subject of corrosion was made in the Sanitary Engineering Laboratory of Harvard University, under the direction of the chairman of the committee, by Dana E. Kepner and Warren E. Howland. It concerned the movements of air and gases in horizontal branch waste-pipes, especially long branches. Mr. Howland's memorandum, to be found in the appendix, describes only a few of the many experiments conducted during a period of about six months.

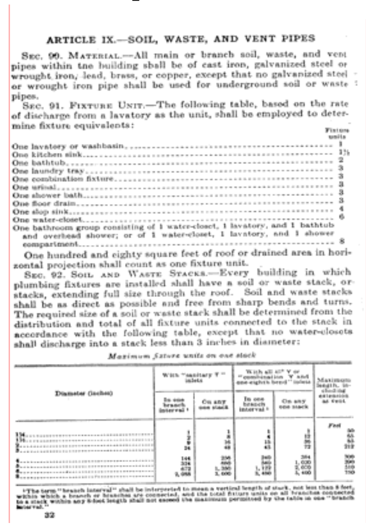
Doctor Hunter's original report (see ch. 6) will speak for itself, but because of its length and its technical character the committee wishes to call attention to some of its salient features and to express its own views on certain matters pertinent to the investigation.

UNIT OF FIXTURE DISCHARGE

In order to study the capacity of house drainage systems, it was found desirable to establish a unit of fixture discharge—a unit involving both volume and time; that is, rate. The rate of discharge of an ordinary washbasin having a nominal 1¼-inch outlet, trap, and waste was found to be about 7.5 gallons per minute, a figure so near to 1 cubic foot per minute that the latter was taken as the definition of one fixture unit. The maximum rate of discharge of other fixtures may be expressed in terms of this unit. For example, it will be seen from Table 1 that a sink with a 1½-inch outlet is equivalent to 1½ units; a bathtub with a 1½-inch outlet, to 2 units; and a water-closet, to 6 units. Fixtures differ a great deal, however, and minor details of design may considerably affect the rate of discharge. It would be useful in designing plumbing systems to know the unit value of each of the common fixtures on the market. No attempt was made to collect this information, although a dozen or more fixtures were studied with reference to their rates of discharge.

WATER-CLOSETS

Doctor Hunter devised an ingenious apparatus for determining the rates of discharge of water-closets by means of an autographic record. This showed the advantage of siphonic action in flushing. While no attempt was made to set definite limits for the rate of flush or for the volume of water required, it may be said that for "wash-down closets" efficient flushing was obtained by using rates of 27 to 33 gallons per minute, or 3.6 to 4.4 units; for siphon-jet closets, 3.2 to 4.8 units, the average value being about 30 gallons per minute, or 4 fixture units. If the rate of discharge is too low, the closet may not be properly cleansed; if it is too high, flushing will be less efficient


ARTICLE IX.—SOIL, WASTE, AND VENT PIPES

SEC. 90. MATERIAL.—All main or branch soil, waste, and vent pipes within the building shall be of cast iron, galvanized steel or wrought iron, lead, brass, or copper, except that no galvanized steel or wrought iron pipe shall be used for underground soil or waste pipes.

SEC. 91. FIXTURE UNIT.—The following table, based on the rate of discharge from a lavatory as the unit, shall be employed to determine fixture equivalents:

	Fixture units
One lavatory or washbasin	1
One kitchen sink	1½
One bathtub	2
One laundry tray	3
One combination fixture	3
One urinal	3
One shower bath	3
One floor drain	3
One slop sink	4
One water-closet	6
One bathroom group consisting of 1 water-closet, 1 lavatory, and 1 bathtub and overhead shower; or of 1 water-closet, 1 lavatory, and 1 shower compartment	8

One hundred and eighty square feet of roof or drained area in horizontal projection shall count as one fixture unit.

SEC. 92. SOIL AND WASTE STACKS.—Every building in which plumbing fixtures are installed shall have a soil or waste stack, or stacks, extending full size through the roof. Soil and waste stacks shall be as direct as possible and free from sharp bends and turns. The required size of a soil or waste stack shall be determined from the distribution and total of all fixture units connected to the stack in accordance with the following table, except that no water-closets shall discharge into a stack less than 3 inches in diameter:

Maximum fixture units on one stack

Diameter (inches)	With "sanitary T" inlets: In one branch interval[1]	With "sanitary T" inlets: On any one stack	With all 45° Y or "combination Y and one-eighth bend" inlets: In one branch interval[1]	With all 45° Y or "combination Y and one-eighth bend" inlets: On any one stack	Maximum length, including extension as vent
					Feet
[illegible]	1	1	1	1	[illegible]
[illegible]	2	8	4	12	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	24	[illegible]	[illegible]	72	[illegible]
4	144	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[1] The term "branch interval" shall be interpreted to mean a vertical length of stack, not less than 8 feet, within which a branch or branches are connected, and the total fixture units on all branches connected to a stack within any 8-foot length shall not exceed the maximum permitted by the table as one "branch interval."

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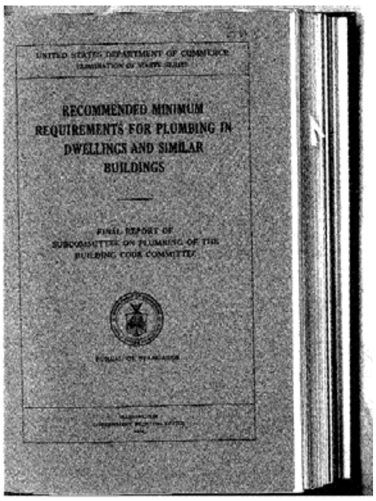
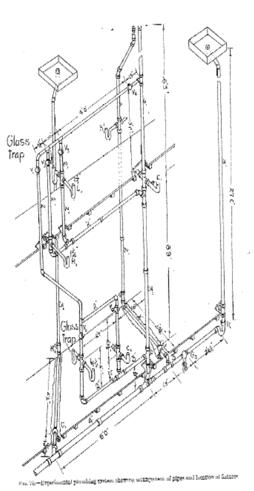
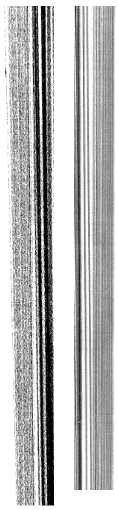
governed by opinions and guesswork, often involving needless costly precautions which many families could ill afford. The lack of generalized principles is responsible to a certain extent for the contradictory plumbing regulations in different localities …". Illustrations are shown (1931) and cited elements made for continued research at NBS were noted with identification for the historically significance from NBS plumbing research by Dr. R. B. Hunter (he was a leader in plumbing research at National Bureau of Standards from 1921 to 1943). The acknowledgment stated ***"Especial commendation should be given to Dr. R. B. Hunter for his ingenious and accurate physical investigations of the hydraulics and pneumatics of drainage systems under various conditions of use***" (Chapter 7 extended contents on "Sizes of Soil, Vent and Waste").

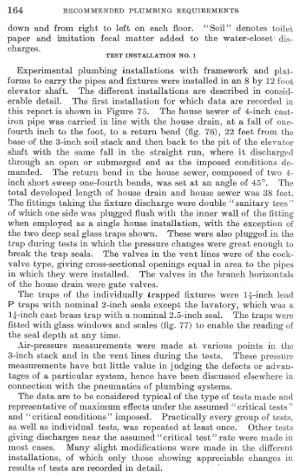
1.2 Earlier Competence - Back to 1924

Initial documentation published in 1924 from developments of team efforts established a new Plumbing Code; examples form that initial report are illustrated.









164 RECOMMENDED PLUMBING REQUIREMENTS

down and from right to left on each floor. "Soil" denotes toilet paper and imitation fecal matter added to the water-closet discharges.

TEST INSTALLATION NO. 1

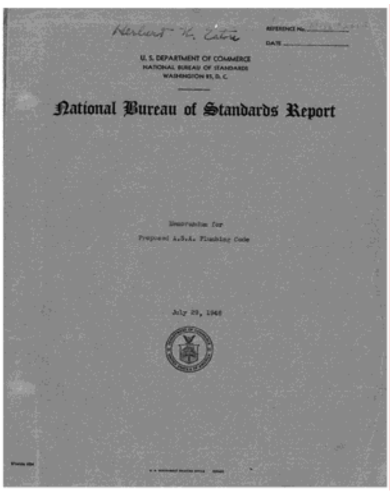
Experimental plumbing installations with framework and platforms to carry the pipes and fixtures were installed in an 8 by 12 foot elevator shaft. The different installations are described in considerable detail. The first installation for which data are recorded in this report is shown in Figure 75. The house sewer of 4-inch cast-iron pipe was carried in line with the house drain, at a fall of one-fourth inch to the foot, to a return bend (fig. 76), 22 feet from the base of the 3-inch soil stack and then back to the pit of the elevator shaft with the same fall in the straight run, where it discharged through an open or submerged end as the imposed conditions demanded. The return bend in the house sewer, composed of two 4-inch short sweep one-fourth bends, was set at an angle of 45°. The total developed length of house drain and house sewer was 38 feet. The fittings taking the fixture discharge were double "sanitary tees" of which one side was plugged flush with the inner wall of the fitting when employed as a single house installation, with the exception of the two deep seal glass traps shown. These were also plugged in the trap during tests in which the pressure changes were great enough to break the trap seals. The valves in the vent lines were of the cock-valve type, giving cross-sectional openings equal in area to the pipes in which they were installed. The valves in the branch horizontals of the house drain were gate valves.

The traps of the individually trapped fixtures were 1½-inch lead P traps with nominal 2-inch seals except the lavatory, which was a 1¼-inch cast brass trap with a nominal 2.5-inch seal. The traps were fitted with glass windows and scales (fig. 77) to enable the reading of the seal depth at any time.

Air-pressure measurements were made at various points in the 3-inch stack and in the vent lines during the tests. These pressure measurements have but little value in judging the defects or advantages of a particular system, hence have been discussed elsewhere in connection with the pneumatics of plumbing systems.

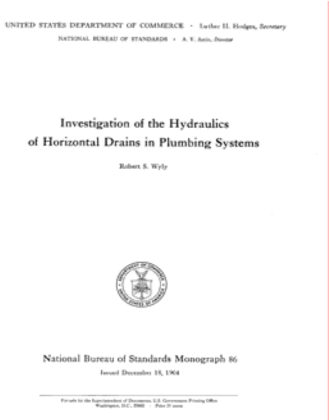
The data are to be considered typical of the type of tests made and representative of maximum effects under the assumed "critical tests" and "critical conditions" imposed. Practically every group of tests, as well as individual tests, was repeated at least once. Other tests giving discharges near the assumed "critical test" rate were made in most cases. Many slight modifications were made in the different installations, of which only those showing appreciable changes in results of tests are recorded in detail.

1.3 Supplementary Information



The prolonged illness and death of Dr. Hunter left barren details/descriptions applied in preparing the report for fixture units based upon binomial probability of simultaneous events. A July 29, 1946 draft report (following WWII) by John French (7) undertaken to investigate Dr. Hunters' files provided indications of source materials but was not published. Selected information for sources and basis of formulation of fixture units as developed and published were sought as set in a directive "... examining Dr. Hunter's files" dated. Selected materials for information/suppositions from records/assumptions attempted to establish the origins/resources and applications in Dr. Hunter's developments. The primary focus of the task was ".. to reconcile requirements of "A.S.A Plumbing Code and Plumbing Manual BMS 66". That apparently was not resolved although conclusion stated was not to support the ASA version based upon differences between the methods form that study. {Note - **ASA – American Standards Association** refers to a Standards Committee (AESC) - AESC became the **American Standards Association (ASA)** in 1928. **ASA** was reorganized (1966); in 1969 became United States of America Standards Institute (USASI) and now ANSI.

R. Wyly (8) comments related Fixture Units background developments and sources that noted aspects of Dr. Hunter investigations. Comments provided limited indications of tests that Hunter had previously conducted and selected testing results. The research efforts enlarged the database from testing and gave newer design data for larger and complex plumbing drainage system configurations not previously evaluated and data tables presented in the report. Extension of fixture units sizing for capacities of drainage systems was proposed for needs future efforts for applications to larger drainage systems.


UNITED STATES DEPARTMENT OF COMMERCE • Luther H. Hodges, Secretary
NATIONAL BUREAU OF STANDARDS • A. V. Astin, Director

Investigation of the Hydraulics of Horizontal Drains in Plumbing Systems

Robert S. Wyly

National Bureau of Standards Monograph 86

Issued December 18, 1964


4. Field Study

4.1. Test methods and Apparatus

Hunter installed gages on the building drains of several large buildings by tapping the top and bottom of each drain. Two types of gage were used. The first was an external glass tube connected to the top and the bottom of the drain, and the second was a simple piezometer tube connected to the bottom of the drain near the same point as was the first gage, the upper end being open to the atmosphere. Under conditions of steady flow, the elevation of the water surface in the closed gage was the same as that within the drain, and the elevation of the water surface in the open gage indicated the sum of the pneumatic and hydrostatic pressures at the drain invert. The difference between the indications of the two gages was the penumatic pressure within the drain.

A modified form of the closed gage was used for determining maximum water depths in building drains over a period of days. Small water traps were connected to the gage tube at vertical intervals of ½ in. The elevation of the inlet connection of the highest trap in which water was collected indicated the highest elevation, within ½ in., reached by the water in the tube.

Observations were made by the use of the gages both in occupied buildings with normal use of fixtures and in unoccupied buildings with manual test flushing of fixtures. Descriptive information on the buildings in which observations were made is given in table 1.

TABLE 1. *Buildings investigated in field study of flow in building drains*

Building No.	Location	Type	Height	Occupancy	Drains observed
1	Washington, D.C.	Office and laboratory	4-story and basement	Occupied	[illegible] primary and [illegible] secondary branches.
2	Washington D.C.	Office	[illegible]-story and basement	Unoccupied (new)	[illegible] branch.
3	New York, N.Y.	Office, storage, and laboratory.	[illegible]-story and basement	Occupied	Two [illegible] main drains a.
[illegible]	New York, N.Y.	Apartment	[illegible]-story	Unoccupied (new)	Various primary and secondary branches.
[illegible]	New York, N.Y.	Hotel-apartment		Unoccupied (new)	[illegible] and 10-in. primary branches.
7	New York, N.Y.	Office	[illegible]-story	Occupied	[illegible] secondary branch b (combined storm and sanitary).

4.2. Results

A brief summary of the field observations will be given, since this information was later utilized in the design of apparatus and in establishing hydraulic conditions for laboratory experimentation.

The results of flushing a single water closet, as observed from gages attached to the drains in the manner described in section 4.1, were as follows: (1) the water level in open and closed gages rose rapidly to the same height in both, then gradually receded with fluctuations to approximately the same level in both gages; and (2) the time interval required for the stream to pass an observation point varied from two to twelve times the duration of flow at the fixture. In general, the interval increased with length of drain between the fixture and the observation point.

The results of flushing a number of water closets either in rapid succession or simultaneously were: (1) for moderate rates of flow, the water levels in the open and the closed gages rose with fluctuations to approximately the same elevation in both and receded as described for the flow from a single closet, with the exception that time durations of flow and maximum indicated water depths were greater; (2) for rates of flow sufficient to fill the drain greater than approximately one-fourth the drain diameter at the observation point, the gages indicated the existence of fluctuating positive pneumatic pressures the magnitude of which increased with water depth; and (3) for rates of flow sufficient to produce indicated water depths in excess of half the drain diameter, large pneumatic-pressure fluctuations were observed, indicating that intermittently the crests of surges of water may have filled the drain at one or more cross sections and produced excessive pneumatic pressures.

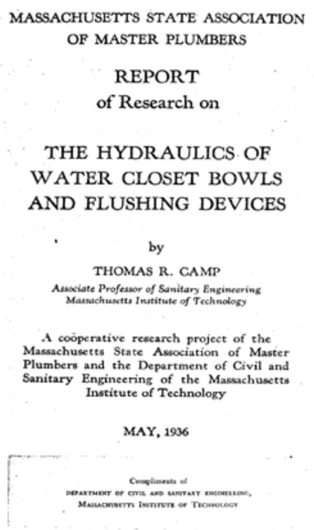
The gages equipped with miniature traps indicated that normal use of fixtures during the periods of observation did not cause the drains to flow full at the stations where the gages were located.

Flushing of fixtures in buildings, either manually or through normal use, proved to be an unsatisfactory method of producing hydraulic loadings

7

1.4 Other Research

Researchers at other U.S. and worldwide plumbing testing facilities were underway (illustrated) but it is unknown to what extent collaborative undertakings were undertaken. U.S. specialists shared inputs and were involved in the evolution of the "Hoover Codes". Referrals to the studies of such investigations appear in the Hoover code outcomes. Later efforts by Dr. Hunter from continuing research


MASSACHUSETTS STATE ASSOCIATION OF MASTER PLUMBERS

REPORT of Research on

THE HYDRAULICS OF WATER CLOSET BOWLS AND FLUSHING DEVICES

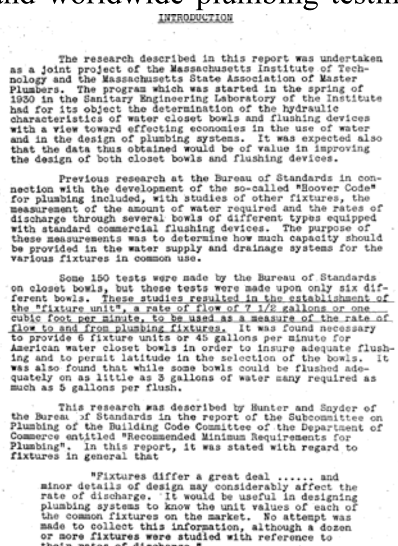
by

THOMAS R. CAMP
Associate Professor of Sanitary Engineering
Massachusetts Institute of Technology

A coöperative research project of the Massachusetts State Association of Master Plumbers and the Department of Civil and Sanitary Engineering of the Massachusetts Institute of Technology

MAY, 1936

Compliments of
DEPARTMENT OF CIVIL AND SANITARY ENGINEERING,
MASSACHUSETTS INSTITUTE OF TECHNOLOGY


INTRODUCTION

The research described in this report was undertaken as a joint project of the Massachusetts Institute of Technology and the Massachusetts State Association of Master Plumbers. The program which was started in the spring of 1930 in the Sanitary Engineering Laboratory of the Institute had for its object the determination of the hydraulic characteristics of water closet bowls and flushing devices with a view toward effecting economies in the use of water and in the design of plumbing systems. It was expected also that the data thus obtained would be of value in improving the design of both closet bowls and flushing devices.

Previous research at the Bureau of Standards in connection with the development of the so-called "Hoover Code" for plumbing included, with studies of other fixtures, the measurement of the amount of water required and the rates of discharge through several bowls of different types equipped with standard commercial flushing devices. The purpose of these measurements was to determine how much capacity should be provided in the water supply and drainage systems for the various fixtures in common use.

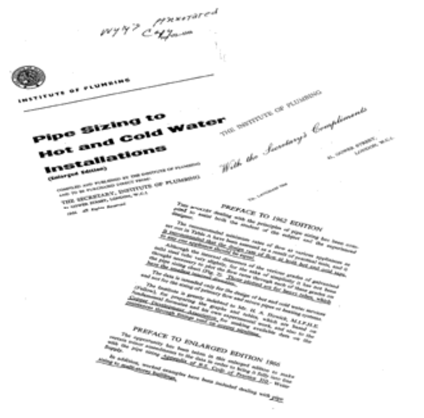
Some 150 tests were made by the Bureau of Standards on closet bowls, but these tests were made upon only six different bowls. These studies resulted in the establishment of the "fixture unit", a rate of flow of 7 1/2 gallons or one cubic foot per minute, to be used as a measure of the rate of flow to and from plumbing fixtures. It was found necessary to provide 6 fixture units or 45 gallons per minute for American water closet bowls in order to insure adequate flushing and to permit latitude in the selection of the bowls. It was also found that while some bowls could be flushed adequately on as little as 3 gallons of water many required as much as 5 gallons per flush.

This research was described by Hunter and Snyder of the Bureau of Standards in the report of the Subcommittee on Plumbing of the Building Code Committee of the Department of Commerce entitled "Recommended Minimum Requirements for Plumbing". In this report, it was stated with regard to fixtures in general that

"Fixtures differ a great deal ...... and minor details of design may considerably affect the rate of discharge. It would be useful in designing plumbing systems to know the unit values of each of the common fixtures on the market. No attempt was made to collect this information, although a dozen or more fixtures were studied with reference to their rates of discharge."

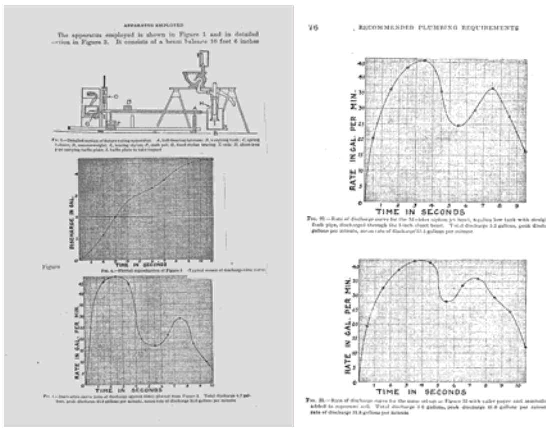
apparently led to advances for **FIXTURE UNITS concepts** developments with probability basis from continuity of research activities on an independent path.

Elsewhere, plumbing systems applications for varied design methods continued. An example from a 1962 report from Great Britain, twenty years following Hunter's report, maintained pipe-sizing methods from earlier basis of flow designations that applied to pipe sizing design as recommended practice.



2. Publications Noted

Background - Information preceding the 1940 Hunter report directed for pipe sizing designs for plumbing systems based upon "Hoover Code(s)" (4, 5, 6). Sample illustrations shown indicate source basis applied to establishment of plumbing requirements for designers' purposes. Methods for plumbing system design for system services capacities buildings resulted from collaborative efforts. Implementation to regulatory purposes established systems' requirements in locales for regulatory acceptances (where codes applied). Hoover Code terminology applied "Fixture Unit" terminology but not as Hunter later established as integral with probability concept usage.

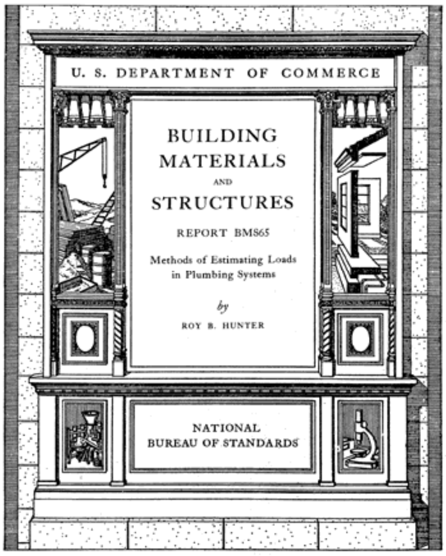


The water closets served as a basis for fixture of supply and drainage parameters that required detailed data input from test data for fixture discharge profiles (quite varied). Sample illustration indicates use of a tracing technique for recording time varying water closets' discharges into a collection chamber that provided measurement records noted in the figure. A test configuration balance (also shown) had provision for elimination of water discharge loading impacts. Data for collected volumes as function of discharge time indicated many profiles with multi-peaked outflow profiles (formatted as flow rate vs. time).

Over time Hunter Fixture Units modifications occurred but with few detailed study reports or detailed analyses/evaluations as codes/manuals adopted newer requirements. Recent investigators applied probability Monte Carlo event computer methods to random loadings, some for multistory buildings (reported at CIB W62 Symposia). Such concerns need address. Extensive data sources reported by researchers to CIB W62 on usages applicable to design requirements have been on diverse user-required capacities and consumption in restaurants, exercise facilities, hot tubs/bath-houses and tall buildings. Simultaneity usage patterns concerns from very recent water conservation actions (significantly less duration times) may result in limitations for simultaneous event history with reductions of ‘overlapping’ simultaneous events/functions.

3. Target Documents

Subsequently the model codes adopted Dr. Hunter procedures that also appears in handbooks for domestic and worldwide usages (often locally altered tabulations). Current U.S. codes include similar tabulations but now modified and altered for water conservation needs, and appear in reference handbooks by plumbing and water utility sources. Frequent referral and terminology identification to “Hunter” persists in current times. Tabulated ‘fixture units’ for water supply and drainage design for fixture loads remain a primary dimensionless system for established code applications requirements for pipe sizing in buildings[1].



From the report**:** The Foreword by Lyman J. Briggs, Director of NBS, states: “… ***additive reports in the Building Materials and Structures series will be written”. “This report deals with one of the factors which must be considered in the selection of adequate yet economical sizes of pipes for plumbing systems – namely, the load to be expected from a given number and kind of plumbing fixtures”……“This report deals … in the selection of adequate yet economical sizes of pipes for plumbing systems – namely, the load to be expected from a given number of fixtures and kind of plumbing fixtures… ‘….. “…estimating loads …, it will be understood that such numerical values, when not the actual results of Bureau tests or experiments, represent the author’s judgment in regard to the most suitable factor to use in the application of the method, and that these are not to be regarded as standard values, unless after approved as such by a representative and authoritative body.”***

The author’s Abstract stated: ***“.. that a method of estimating the demand and sewage loads for which the provision should be made in designing plumbing systems in order that the service may be satisfactory. … The relative load producing values of different kinds of commonly used plumbing fixtures are analyzed, and a table is developed giving relative load weights in terms of a load factor called the ‘fixture unit. An estimate curve developed by the means of the probability function is given, and its use in conjunction with the table of fixture units is illustrated.”***

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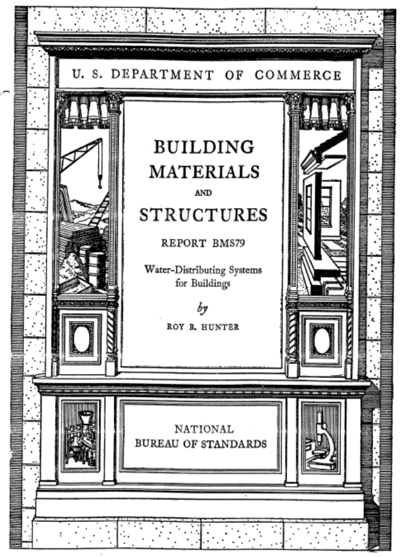
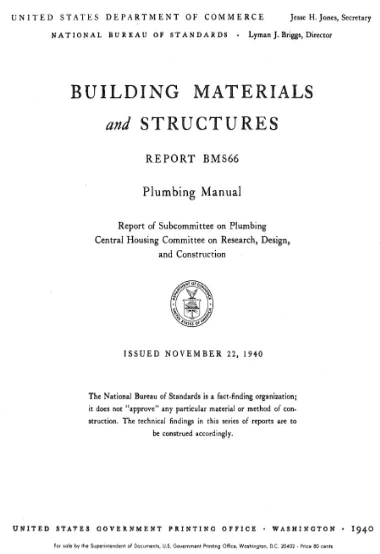
[1] Decades later “DRAINET” developed by Prof. Swaffield provides computer numerical solutions for transient partially filled drainpipe attenuated drain flow dynamics (9) with solid(s) waste transport.

Section II - effort extent in "Purpose" provides:"…organized from the mass of information obtained by the author over a number of years, beginning with the investigation in 1921 of plumbing of small dwellings, and including……. current research (1937-40) on plumbing for low cost housing, together with the results of intervening experiments related to plumbing requirements, and to interpret the results of these investigations in a form suitable for direct and piratical application. …"

3.1 Associated Reports

Dr. Hunter provided application based utilizations based on Fixture Units descriptive usages. Few reports show publication date sequences that vary, possibly due to Institute required review procedures (3, 10). Example of the Plumbing Manual applications specific to water distribution systems provides fixture water supply application for sizing demonstrates that noted differences from existing methods (at the time) for new Fixture Units utilization of Hunter method.




UNITED STATES DEPARTMENT OF COMMERCE · Jesse H. Jones, Secretary

NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

BUILDING MATERIALS
and STRUCTURES

REPORT BMS66

Plumbing Manual

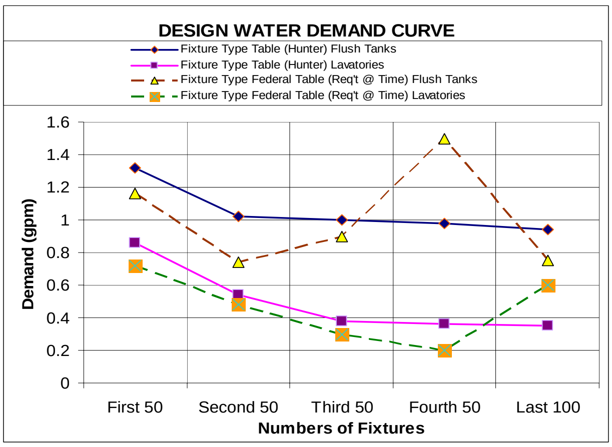
Report of Subcommittee on Plumbing
Central Housing Committee on Research, Design, and Construction

ISSUED NOVEMBER 22, 1940

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

UNITED STATES GOVERNMENT PRINTING OFFICE · WASHINGTON · 1940

The figure compares demand estimates in *gpm* usage from the so-called probability function in manual of 1923 with new mode. There, demand cited in gallons per minute directly for several fixtures shows indicated estimated irregularities cited as erroneous since ".. the estimates for given increments in numbers of fixtures should gradually approach a constant minimum as the total number increases.". The discussion suggested "… tendency to oversize supply pipes does not lie in any inherent fault in the probability function, but in the method …. but a table which does not provide for the probability, or rather the improbability, of overlapping between or among two or more groups of different kinds" (3).

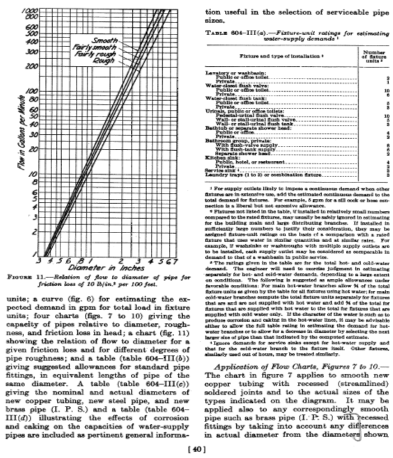


Tabulated ‘fixture units’ for water supply and drainage design remained a primary system established in code requirements (modified over time) as changes developed for altered required fixture capacities.

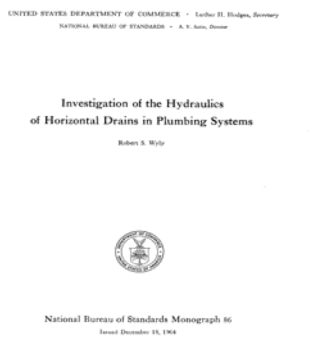
4. Requirements - Loadings - References

Many design and code examples appeared for required sizing practices in the tabulated listings of Hoover codes. From the ’32 version tabulated required drains and stacks loadings of drainage elements from fixture units (definition of that time) examples are shown. Later Hunter developments from probable loading developed listings based upon probability of simultaneous event conditions differed substantially.

Fixture Unit applications of the method in plumbing systems design were necessary for implementations with explanatory introductions and details/explanations to water supply and drainage systems. Differences cited needs for achieving descriptive documentation for design and use in regulatory applications with requirements and rules illustrated for applications to demonstrating compliance. Even in the “Plumbing Manual” (3) there appears “…still a marked lack



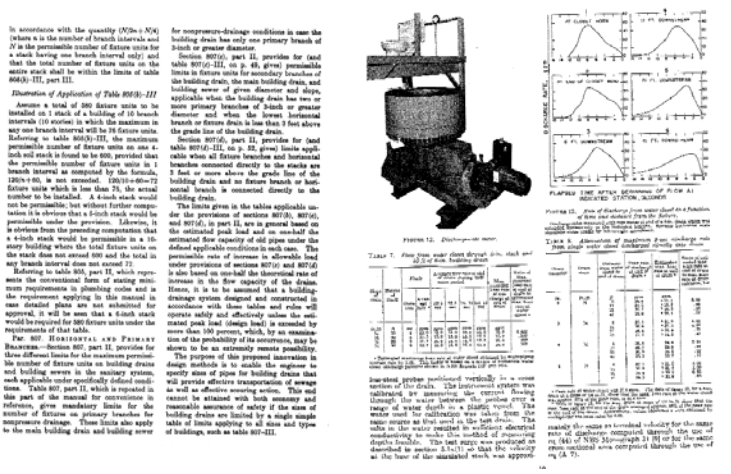
of agreement among recommended plumbing requirements” and also the purpose indicated that “.. intended to serve as a guide in their own work and as recommended procedure where local codes do not govern.”



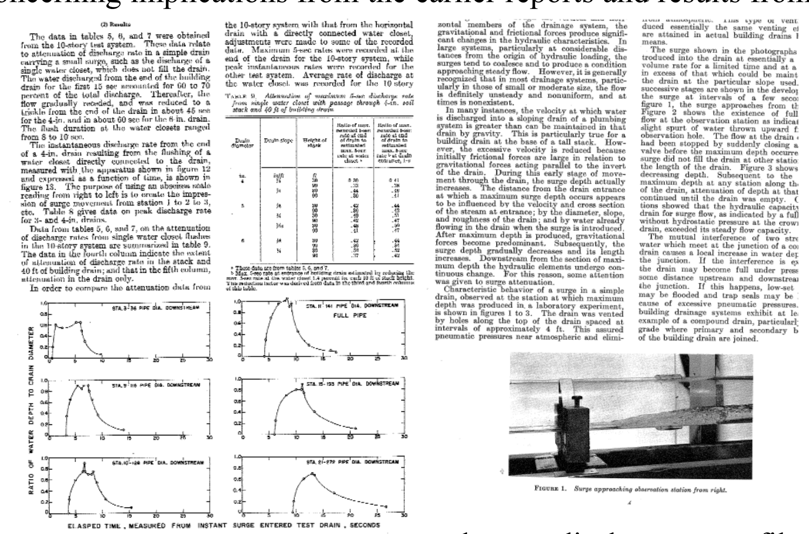
The undertaking by J. French (7) was an attempt to seek greater knowledge of the basis for Hunter's published reports.

4.1 Perspectives

Indicated research aspects noted on Dr. Hunter investigations by R. Wyly (..) in related materials on Fixture Units developments are to the point of the topic.

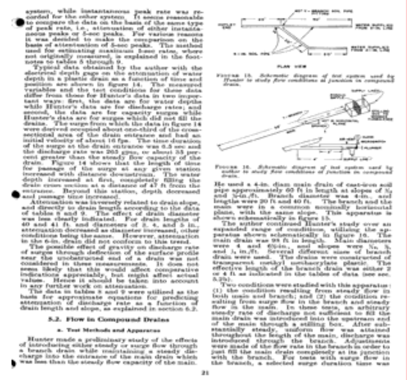


Comments in the report provided test series limitations or indications from certain historic parts of past testing methods. Report applications to water demand pipe system sizing from tabulated fixture units were described and special concerns indicated in table footnotes. For drainage systems utilization of Fixture Units ratings concerning implications from the earlier reports and results from additional test series introduced later interpretations for drain loadings as derived from detailed testing series and results/conclusions.



From earlier Hunter test efforts rather unique experimental developments were noted and indicated test experimental illustrations. Water closet discharge profiles and drain connected indicated attenuation of flows were determined.

That prior research demonstrated surge attenuation from water closets interacting with other pipe flows. The attenuation of surge waves combined with other essentially steady fixture outflows (washbasins, showers, and baths) had become an aspect of needed data applied to developments in tabulated correlations developed for fixture units. Newly measured distributions of attenuated water closet surges also were developed but shown as



normalized water depth to drain diameter but substantiated earlier measured data forms. Extensions for tabulated loadings results to design applications for allowed loadings in determining allowable total drainage discharges (not in Fixture Units) for design purposes was not made. The methods extended scope of tables to buildings greater than three stories or more in height and for systems with relatively small horizontal branches. The Wyly study showed tabulated results that indicated the extent of capacity increases in drains when surges occurred. As stated: "capacities for hydraulics in steady gravity driven flows are constant" and "of limited value in solution of problems of surge flow". Further, for surge flows "hydraulic elements vary both with distance and time at any cross-section". The tabulated test indications ranged over values from two to five times the capacity for steady flow conditions. Expanded series of tests for branch drain discharges into main drain (few varied conditions) with unsteady flow from branch loadings were undertaken. Compilations into broad tabular data listings for applications to branch installation designs resulted.

TABLE 2. *Surge capacities of initially empty, sloping, simple drains*

(Data on cast-iron soil pipe obtained under Hunter's direction, using measurements of [illegible] shaped jet, long-sweep stack-base fitting, and open condition at lower end of drain)

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Drain diameter	Drain slope	Capacity a for steady flow	Ratio of initial area of stream b to area of drain	Time duration of surge	Capacity c for surge flow	Ratio of initial velocity to stack terminal velocity d	Ratio of capacity for surge flow to capacity for steady flow
in.	in./ft	gpm		sec	gpm		
e 3.00	1/16	32.8	0.042	30	42.0	3.22	1.28
			.042	30	42.0	3.22	1.28
			.042	20	42.0	3.22	1.28
			.042	20	42.0	3.22	1.28
			.042	20	42.0	3.22	1.28
			.055	15	51.8	4.55	1.58
			.055	15	51.8	4.55	1.58
			.055	15	51.8	4.55	1.58
			.075	10	66.8	3.90	2.04
			.075	10	66.8	3.90	2.04
			.075	10	66.8	3.90	2.04
			.116	5	99.5	3.20	3.03
			.116	5	99.5	3.20	3.03
			.116	5	99.5	3.20	3.03
	1/8	46.8	0.061	40	54.5	4.25	1.17
			.061	30	54.5	4.25	1.17
			.064	20	59.3	4.27	1.27
			.071	15	63.4	4.00	1.36
			.086	10	74.3	3.61	1.59
			.124	5	104	3.06	2.22
	1/4	66.7	0.083	40	72.5	3.69	1.09
			.085	30	74.3	3.61	1.11
			.089	20	76.7	3.37	1.15
			.093	15	77.6	3.54	1.16
			.095	10	81.8	3.49	1.23
			.134	5	112	2.97	1.68
3.90	1/16	64.1	0.054	40	79.5	3.98	1.24
			.054	30	79.5	3.98	1.24
			.055	20	80.9	3.90	1.26
			.068	15	97.0	3.54	1.51
			.093	10	132	3.03	2.06
			.149	5	193	2.44	3.01
	1/8	91.2	0.071	30	102	3.48	1.12
			.073	25	107	3.38	1.17
			.079	20	111	3.31	1.22
			.098	15	130	3.05	1.43
			.113	10	151	2.86	1.66
			.165	5	207	2.29	2.27
	1/4	130	0.103	30	142	2.93	1.09
			.108	30	146	2.89	1.12
			.109	30	146	2.87	1.12
			.108	20	149	2.88	1.15
			.109	20	149	2.86	1.15
			.109	15	150	2.86	1.15
			.110	15	152	2.85	1.17
			.123	10	167	2.67	1.28
			.126	10	169	2.67	1.30
			.175	5	215	2.21	1.65
			.176	5	216	2.21	1.66

a Values given for steady flow capacity were derived by applying corrections in accordance with the rational pipe-flow formula to laboratory measurements of apparent steady flow capacities in drains 20 ft long discharging to atmosphere at the lower, open end (see sec. 9.2).
b Based on area of opening through gate valve which was used to control stream introduced through sweep fitting at drain entrance.
c Values given for surge flow capacity were derived from laboratory data giving degree of opening of control valve and a calibration curve showing rate of discharge as a function of degree of opening.
d Computed from eq (A-7) and from values in columns 1, 4, and 6. Equal stack and drain diameters were assumed. A value of absolute roughness of 0.00083 ft for the stack was used in the computations. This value was derived from resistance measurements on cast-iron soil pipe [9].
e Nominal diameter. The laboratory notes do not indicate the exact diameter of this drain.

cross sections indicated by the values in column 4 of table 2 assuming stack and drain diameter to be the same. The initial experimental velocities used in the author's tests reported in table 3 covered a more restricted range from a little less than 0.5 to about 1.3 times theoretical stack terminal velocity. This range of velocities is reasonable at the bases of drainage stacks in service.

Table 3 gives, among other information, the distances along the drains at which the full-conduit condition was observed. In the case of Hunter's data, shown in table 2, this distance is is not given, but was less than 20 ft from the drain entrance in all cases. The capacities of the test drains under conditions approaching steady, uniform flow are given in table 4.

Perhaps the most significant observations with reference to surge flow were:

1. For a given time duration of surge, actual surge-flow capacity increased with drain slope but relative capacity decreased,

2. for a given drain, capacity decreased with increasing surge-duration time, approaching as a lower limit the steady flow capacity of the drain, and

3. entrance velocity, initial area and shape of surge cross section, and drain roughness appeared to have small effect on relative capacity.

Detailed discussion of the experimental results appears in section 6.1.

b. Surge Attenuation

(1) Test Methods and Apparatus

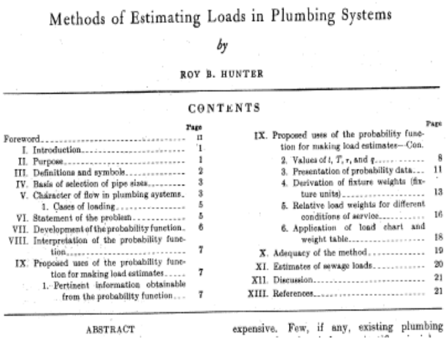
The attenuation of discharge rates of surges was investigated by Hunter. He first utilized a 4-in. drainage stack 10 stories in height with a building drain extending laterally 40 ft from the base of the stack. Building-drain diameters of 4, 5, and 6 in. at slopes of 1/8 and 1/4 in./ft were used. For the 5-in. drain, a slope of 1/16 in./ft was also used. The drains were constructed of 5-ft lengths of cast-iron soil pipe. Single water closets were discharged into 4-in. branch drains at either the fourth or the tenth floor. The average rates at which the water closets discharged water into the branch drains were measured, and the cumulative discharges from the end of the building drain were measured volumetrically in a collecting tank for three consecutive 5-sec intervals after the water reached the end of the drain.

At another time, Hunter used the apparatus shown in figure 12 to measure instantaneous rate of flow at the discharge end of a horizontal drain produced by a water closet discharged directly into the upstream end without the use of an intervening vertical drain. The 60 radial compartments moved transversely beneath the discharge end of the drain at a constant angular velocity adjusted so that the full volume of a single operation of the water closet was discharged from the end of the drain in one revolution. The approximate instantaneous rate of discharge was computed as a function of time from the measurements of volume of water caught in successive compartments and of angular velocity. Drain diameters of 3 and 4 in., and lengths of 0, 1, 6, 11, 21, and 41 ft at a slope of 1/8 in./ft were used successively. The drains were constructed of 5-ft lengths of cast-iron soil pipe.

10

5. Hunter BMS 65 (1)

The report Foreword by the Director L.J. Briggs, states "This report deals with one of the factors which must be considered in the selection of adequate yet economical sizes of pipes for plumbing systems – namely, the load to be expected from a given number and kind of plumbing fixtures. Also, "..it will be followed by other reports in the Building and Materials and Structures series dealing with other aspects of plumbing problems".



Methods of Estimating Loads in Plumbing Systems

by

ROY B. HUNTER

CONTENTS

ABSTRACT

expensive. Few, if any, existing plumbing

From the authors' Introduction "Simplification and standardization must comply with accepted health regulations and minimum requirements for plumbing, which in turn should be based on scientific principles, The report deals with one of the factors, on which minimum requirements should be based, the maximum load to be provided for in plumbing systems. Other reports are planned dealing with water supply and water distribution systems in buildings, principles of building drainage, and principles of venting." And in the "Purpose' there appears " this series of papers is to collect in organized manner information obtained by the author over a number of years (from 1921 to research of 1937-1940) on plumbing, together with results from research (1937 - 1940) on plumbing with intervening experiments and interpreting results in a form suitable for direct and practical application. It is hoped that this series of papers will supply logical answers to questions pertaining to pipe sizes and design of plumbing construction".

Selected report materials indicate Fixture Units developments for the adopted technique and methodical procedure adopted. Developed materials apparently resulted

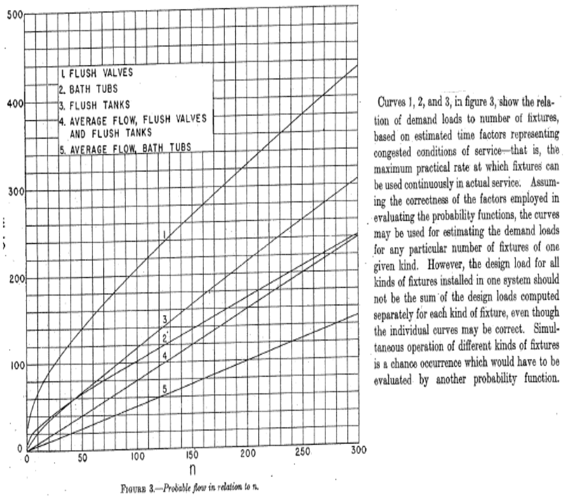


FIGURE 3.—*Probable flow in relation to n.*

Curves 1, 2, and 3, in figure 3, show the relation of demand loads to number of fixtures, based on estimated time factors representing congested conditions of service—that is, the maximum practical rate at which fixtures can be used continuously in actual service. Assuming the correctness of the factors employed in evaluating the probability functions, the curves may be used for estimating the demand loads for any particular number of fixtures of one given kind. However, the design load for all kinds of fixtures installed in one system should not be the sum of the design loads computed separately for each kind of fixture, even though the individual curves may be correct. Simultaneous operation of different kinds of fixtures is a chance occurrence which would have to be evaluated by another probability function.

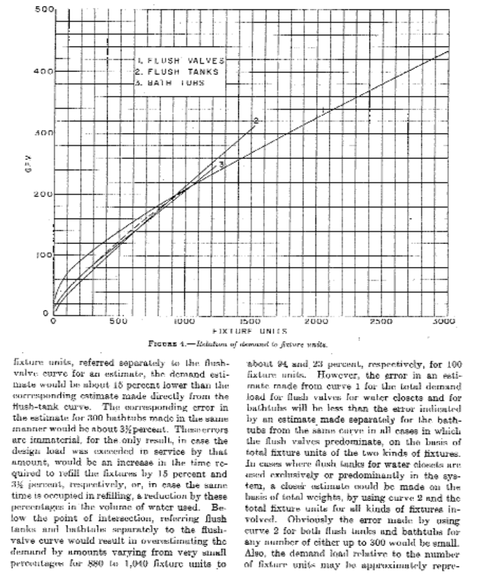


FIGURE 4.—*Relation of demand to fixture units.*

fixture units, referred separately to the flush-valve curve for an estimate, the demand estimate would be about 15 percent lower than the corresponding estimate made directly from the flush-tank curve. The corresponding error in the estimate for 300 bathtubs made in the same manner would be about 3½ percent. These errors are immaterial, for the only result, in case the design load was exceeded in service by that amount, would be an increase in the time required to refill the fixtures by 15 percent and 3½ percent, respectively, or, in case the same time is occupied in refilling, a reduction by these percentages in the volume of water used. Below the point of intersection, referring flush tanks and bathtubs separately to the flush-valve curve would result in overestimating the demand by amounts varying from very small percentages for 880 to 1,040 fixture units to about 94 and 23 percent, respectively, for 100 fixture units. However, the error in an estimate made from curve 1 for the total demand load for flush valves for water closets and for bathtubs will be less than the error indicated by an estimate made separately for the bathtubs from the same curve in all cases in which the flush valves predominate, on the basis of total fixture units of the two kinds of fixtures. In cases where flush tanks for water closets are used exclusively or predominantly in the system, a closer estimate could be made on the basis of total weights, by using curve 2 and the total fixture units for all kinds of fixtures involved. Obviously the error made by using curve 2 for both flush tanks and bathtubs for any number of either up to 300 would be small. Also, the demand load relative to the number of fixture units may be approximately repre-

from the depths of efforts from prior studies,
acquisition of vast amounts of test data,
analytical determinations and organized compilations of comprehensive sets of data from many prior years of research.

Selection of minimum pipe size requires accurate flow capacities for conditions to be used for load and to know accurately the

It is necessary to define the expression, "operating simultaneously," in order to completely define a particular event of "r fixtures operating simultaneously." In the following development of the theory, this event will be considered as occurring when r, and only r, fixtures are found flowing at the instant of observation; and hence the r fixtures found flowing will include all those, and only those, which began their operation during the t-second interval immediately preceding the instant of observation.

VII. DEVELOPMENT OF THE PROBABILITY FUNCTION

By the generally accepted concept of probability, the probability that a particular fixture out of a number, n, will be found operating at any arbitrarily chosen instant of observation is t/T, where t has been defined as the duration of each operation and T as the time between operations of each fixture. In the same manner, the probability that the particular fixture will not be in operation at the instant of observation is 1−t/T or (T−t)/T.

A law of combinations that applies to the composite event of which the probability is sought in this problem may be stated as follows: The number of ways in which two or more independent events can occur together is the product of the ways each can occur separately. A similar law of probability may be stated as follows: The probability of two or more independent events occurring together, in this case at the same instant, is the product of the probabilities of their separate occurrence.

By the law of combinations, the probability that none of the remaining n−1 fixtures will be operating at the instant of observation is

[illegible] (3)

Equation 3 is equivalent to the binomial expansion of $\left(\frac{t}{T}+\frac{T-t}{T}\right)^n=1$ and is the conventional expression for certainty, since either no fixtures, r=0, or some number of fixtures from r=1 to r=n must be operating at the instant of observation.[3]

VIII. INTERPRETATION OF THE PROBABILITY FUNCTION

As previously stated, the probability function, p_r^n, eq 2, gives the probability that exactly r fixtures out of a total of n will be found operating at an arbitrary instant of observation, provided that all n fixtures are in continuous use at the assumed rate. The probability, p_r^n, may also be interpreted as the percentage or fraction of the time in the long run that r flows will occur in the manner defined, since the fraction

$$\frac{\text{time of } r \text{ fixtures operating}}{\text{total time}}$$

is also the probability of the occurrence. Hence for any given values of n and r, if the probability function as developed is multiplied by a time τ in seconds such that

$$\tau p_r^n = \tau C_r^n \left(\frac{t}{T}\right)^r \left(\frac{T-t}{T}\right)^{n-r} = 1 \text{ second}, \ldots \quad (4)$$

or

$$C_r^n \left(\frac{t}{T}\right)^r \left(\frac{T-t}{T}\right)^{n-r} = \frac{1}{\tau}$$

the equation signifies that r fixtures will be in simultaneous operation for an aggregate of 1 second out of every τ seconds that all n fixtures are in use at the assumed rate. Likewise, the condition that a chosen design factor, r=m, will not be exceeded more than a given fraction of the time 1/τ, is expressed by

[illegible] (5)

Equations 4 and 5 are based on the assumption that all n fixtures will be in continuous use over the entire time τ at the average rate of once in T seconds. The time τ may be reduced to days or years on the basis of the daily period of peak use, by assuming or determining this period and computing on the basis of a day of that length.

IX. PROPOSED USES OF THE PROBABILITY FUNCTION FOR MAKING LOAD ESTIMATES

1. PERTINENT INFORMATION OBTAINABLE FROM THE PROBABILITY FUNCTION

It may be helpful in judging the reasonableness of the proposed application of the probability function to summarize the information obtainable from the probability function before proceeding with the selection of the time factors applicable to practical cases.

The following pertinent information can be obtained from the equations developed:

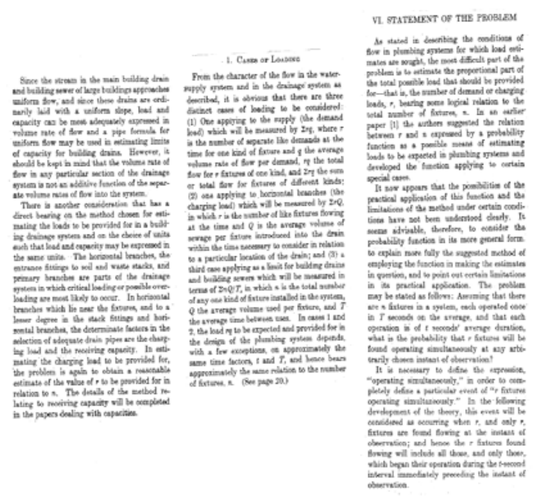
(a) The probability that a given number of fixtures, m, out of a total of n, will be operating at an arbitrary instant of observation, determined by eq 2.

(b) The fraction of the time that m and only m fixtures will be operating at the same instant, a second interpretation of eq 2.

(c) The fraction of the total time that any number of fixtures greater than the design number, m, will be operating at the same instant, determined by eq 5.

(d) The ratio of any two successive terms in the series of eq 2; for example, the ratio of the fraction of the time r+1 to the fraction of the time r fixtures will be operating at the same instant, determined by

$$C_{r+1}^n\left(\frac{t}{T}\right)^{r+1}\left(\frac{T-t}{T}\right)^{n-r-1} \div C_r^n\left(\frac{t}{T}\right)^r\left(\frac{T-t}{T}\right)^{n-r} = \frac{n-r}{r+1}\times\frac{t}{T-t} \quad (6)$$



Since the stream in the main building drain and building sewer of large buildings approaches uniform flow, and since these drains are ordinarily laid with a uniform slope, load and capacity can be most adequately expressed in volume rate of flow and a pipe formula for uniform flow may be used in estimating limits of capacity for building drains. However, it should be kept in mind that the volume rate of flow in any particular section of the drainage system is not an additive function of the separate volume rates of flow into the system.

There is another consideration that has a direct bearing on the method chosen for estimating the loads to be provided for in a building drainage system and on the choice of units such that load and capacity may be expressed in the same units. The horizontal branches, the entrance fittings to soil and waste stacks, and primary branches are parts of the drainage system in which critical loading or possible overloading are most likely to occur. In horizontal branches which lie near the fixtures, and to a lesser degree in the stack fittings and horizontal branches, the determinate factors in the selection of adequate drain pipes are the charging load and the receiving capacity. In estimating the charging load to be provided for, the problem is again to obtain a reasonable estimate of the value of r to be provided for in relation to n. The details of the method relating to receiving capacity will be completed in the papers dealing with capacities.

1. CASES OF LOADING

From the character of the flow in the water-supply system and in the drainage system as described, it is obvious that there are three distinct cases of loading to be considered: (1) One applying to the supply (the demand load) which will be measured by Σrq, where r is the number of separate like demands at the time for one kind of fixture and q the average volume rate of flow per demand, rq the total flow for r fixtures of one kind, and Σrq the sum or total flow for fixtures of different kinds; (2) one applying to horizontal branches (the charging load) which will be measured by ΣrQ, in which r is the number of like fixtures flowing at the time and Q is the average volume of sewage per fixture introduced into the drain within the time necessary to consider in relation to a particular location of the drain; and (3) a third case applying as a limit for building drains and building sewers which will be measured in terms of ΣnQ/T, in which n is the total number of any one kind of fixture installed in the system, Q the average volume used per fixture, and T the average time between uses. In cases 1 and 2, the load rq to be expected and provided for in the design of the plumbing system depends, with a few exceptions, on approximately the same time factors, t and T, and hence bears approximately the same relation to the number of fixtures, n. (See page 20.)

VI. STATEMENT OF THE PROBLEM

As stated in describing the conditions of flow in plumbing systems for which load estimates are sought, the most difficult part of the problem is to estimate the proportional part of the total possible load that should be provided for—that is, the number of demand or charging loads, r, bearing some logical relation to the total number of fixtures, n. In an earlier paper [1] the authors suggested the relation between r and n expressed by a probability function as a possible means of estimating loads to be expected in plumbing systems and developed the function applying to certain special cases.

It now appears that the possibilities of the practical application of this function and the limitations of the method under certain conditions have not been understood clearly. It seems advisable, therefore, to consider the probability function in its more general form, to explain more fully the suggested method of employing the function in making the estimates in question, and to point out certain limitations in its practical application. The problem may be stated as follows: Assuming that there are n fixtures in a system, each operated once in T seconds on the average, and that each operation is of t seconds' average duration, what is the probability that r fixtures will be found operating simultaneously at any arbitrarily chosen instant of observation?

It is necessary to define the expression, "operating simultaneously," in order to completely define a particular event of "r fixtures operating simultaneously." In the following development of the theory, this event will be considered as occurring when r, and only r, fixtures are found flowing at the instant of observation; and hence the r fixtures found flowing will include all those, and only those, which began their operation during the t-second interval immediately preceding the instant of observation.

load the pipe will be called upon to carry. Pipe flow formulae (usual means of estimating pipe capacities of pipes) expressions are based upon dynamic equilibrium and applies only to the irregular and intermittent flows that occurs in plumbing systems during that time (usually very short) and in that section of the pipe in which the variable factors involved (velocity or volume rate of flow, pressure, or hydraulic gradient, and hydraulic radius) are constant[2] and applies only to the particular conditions – namely, condition of uniform continuous flow in the pipe. Hence, conventional pipe formulae applies to irregular and intermittent flows that occur in plumbing systems only during that time (usually very short) and in sections which the variables involved (velocity or volume rate of flow, pressure, or hydraulic gradient, and hydraulic radius) are constant. ***That descriptive explanation was an attempted explanation for conditions of "steady state approximations" utilization.***

6. Manual Report BMS 66 (4)

Applications of Fixture Units for practical implementation procedures were provided in the Manual (3). Anticipated benefits from newly developed procedures and applications were indicated to be:

ABSTRACT

A manual of recommended plumbing practice is presented by a committee composed of representatives of Federal agencies most concerned with the subject. The committee has taken into consideration available recommendations of other bodies and results of research performed at the National Bureau of Standards. Part I consists of an introduction explaining the origin of the work. Part II contains recommendations regarding necessary sizes of piping, precautions against pollution of water supply, permissible types of venting, and other matters customarily covered in plumbing codes. Part III contains information useful in applying the recommendations, including illustrative interpretations of the specific requirements in part II. The recommendations are presented as suitable for adoption by Federal agencies engaged in actual plumbing work or in passing upon plans of structures containing plumbing.

CONTENTS

- Especially for large buildings;
- Better sewage transport
- More satisfactory operation
- More economical construction.

2. Values of t, T, τ, and q

In applying the probability function for estimating the design load mq, it is necessary to select values of t, T, and τ from which to compute the value of m and to select a value of q, the factors excepting τ pertaining to a particular kind of fixture and service. The actual values selected in any case are largely a matter of engineering judgment. In this connection, it is to be understood that in the following development and illustrative examples, the values selected represent the author's judgment in regard to the appropriate values for producing satisfactory service and are based on the author's interpretation of the information available.

For the purposes of this discussion *satisfactory service* is defined in a relative sense as that in which interruption in service because of controllable factors, such as the sizes and arrangement of pipes, is infrequent and is of sufficiently short duration to cause no inconvenience in the use of fixtures or any unsanitary condition in the plumbing system. Attainment of satisfactory service will depend on the selection of the design factor m, or more specifically on the value of τ from which the value of m is computed. The value of τ selected for illustrating the proposed application is 100 seconds, which provides for wholly satisfactory service 99 percent of the time and for reasonably satisfactory service all of the time if the design load mq gpm is not greatly exceeded. In this connection, it will be observed that if m is exceeded in actual service it is most likely to be exceeded by one fixture only and is progressively less likely to be exceeded by two, by three, or more.

Obviously t and q bear a direct relation to Q in respect to the values necessary to provide satisfactory service if m fixtures are in operation simultaneously. Since there is a considerable range in the values of t and Q on which the value of q depends for any particular fixture, it will be very helpful to the engineer in determining reasonable values to be used for a particular kind of fixture to consider the charac-

It is a characteristic of water closets that they will operate more or less effectively under any average rate of supply from about 15 gpm up to rates of about 30 gpm or more delivered in any time ranging from about 6 seconds up. For each type and design of water-closet bowl there is an intermediate smaller range of average rate of supply within which there is no detectable difference in the effectiveness of the flush in emptying the bowl of its contents. There is likewise a range in time of flow within

Table 7 gives the fixture weights suggested in accordance with the use to which the fixtures are subjected and the manner in which they are installed. The term "public" refers to fixtures which are individually open for use at all times when the building is open, as in public toilets or general toilets in office buildings. "Private" refers to fixtures installed in groups in such a manner that the entire group may be and generally is confined to the use of one person at a time, as in residences or private baths of hotels. "Total" refers to hot and cold supply combined. "Hot or cold" refers to hot or cold water supply only.

Table 7.—*Demand weights of plumbing fixtures*

Fixture or group	Occupancy	Type of supply	Weight per fixture or group in fixture units
Water closet	Public	Flush valve	10
Do	do	Flush tank	5
Pedestal urinal	do	Flush valve	10
Stall or wall urinal	do	do	5
Do	do	Flush tank	3
Lavatory	do	Total	2
Do	do	Hot or cold	1.5
Bathtubs	do	Total	4
Do	do	Hot or cold	3
Shower head	do	Total	4
Do	do	Hot or cold	3
Bathroom group	Private	Flush valve (total)	8
Do	do	Flush valve (cold only)	6
Do	do	Flush tank (total)	6
Do	do	Flush tank (cold only)	4
Do	do	Hot water only	3
Bathroom group with separate shower.	do	Add to corresponding group above for total, 2; for cold or hot	1.5

The report background had past committee actions with input or reviews for the new document. It is divided into two parts -
(1) General and basic requirements; Subject matter not likely to need frequent revision, and
(2) Matter likely to need revision to keep abreast of current standards when revision is advisable.

manual. It is intended to serve as a guide in their own work and as recommended procedure where local codes do not govern. It is also offered as a contribution to efforts toward greater uniformity in plumbing requirements. Particular emphasis is placed upon its usefulness in connection with low-cost housing, where there is special need to take advantage of all legitimate economies. The field of the manual, however, is not restricted to housing, since the same fundamental principles apply in any structure.

In developing the manual, close attention has been paid to previous recommendations prepared by the Subcommittee on Plumbing of the Department of Commerce Building Code Committee and issued under the title "Recommended Minimum Requirements for Plumbing" by the National Bureau of Standards. Similar recommendations prepared by nongovernmental bodies have also been consulted. The results of research extending over a long period at the National Bureau of Standards have been made available to the committee, including results of experiments that have been completed since the committee started its work. In addition, the members of the committee have brought to the work an experience with plumbing extending over many years. The manual represents the consensus of the committee and is recommended as suitable for use throughout the Federal Government service.

The subject matter of the manual is divided into two parts, as follows: part II, containing general and basic requirements concisely stated; and part III containing many illustrated interpretations, specific citations of applicable accepted standards, rules for applying exceptions to general or basic requirements as stated in part II, and much other information considered valuable to the builder in complying with the requirements and to the authorities in determining compliance. Part III also contains illustrations of simple plumbing lay-outs permissible under the requirements of part II and applicable to low-cost housing. (See par. 1008 and figs. 16 to 20, pt. III.)

Several innovations or departures from the usual form of presenting plumbing requirements have been made, to a few of which particular attention is invited. These changes from conventional methods of presenting minimum requirements apply principally to required sizes of soil and waste stacks and of building drains and building sewers and to permissible methods of venting. The changes have been made for the purpose of permitting the engineer to design, and the builder to install, plumbing systems more in accord with the actual demands of particular buildings than can be done under tables that make no distinction for buildings of different sizes and types other than the total number of fixtures. The results to be expected from applying the proposed methods, especially in relation to large buildings, are (1) better transportation of sewage, (2) safer and more satisfactory operation in the long run, and (3) more economical construction than can be obtained under the old methods.

The arrangement of the manual in two main parts, one containing subject matter not likely to need frequent revision or additions and the other containing the subject matter likely to need revision to keep abreast of current standards, will facilitate revision as experience and new developments make such revision advisable. It is also to be expected that new data and other information of value to the engineer or builder will be added to part III with each revision.

Acknowledgment is made to Martin Goerl for assistance in preparing the report, to Theodora C. Bailey for editorial review, and to E. A. Ledwith for assistance in preparation of the illustrations.

Detailed sample to both water supply and drainage applications illustrate use of Fixture Units. No distinctions or differentiation for utilizations of Fixture Units separately or for needs of adjustments from initial developments. The BMS 65, where the origins and

[2] Early recognition for dynamics' essential details were not readily established at that time of his research

source indications were provided, the supply/discharge seemingly appear commingled for further applications. ***That issue of whether there exists a need to distinguish or utilize the aspects together or separately remains open and the subject requires further considerations. Are there any limitations or assumed utilizations to both aspects of piped plumbing applications? Scrutiny of those developed bases/descriptions for developed and recommended Fixture Units from probability of simultaneous events requires further study since of implied generalities to both water supply and drainage does not appear or specifically addressed in published discussion of the earlier developments as applied directly in BMS 66.***

Report applications provide illustrative examples with discussion of usages to applications for many aspects of plumbed systems in small and large buildings and extension to roof drainage applications/combinations with drains and storm systems. However, the examples do not discuss the aspects of load simultaneity of the system but imply such states. Sample from the report indicates the breadth.

only 2 inches per hour is to be provided for, the allowable roof areas may be doubled; and if a rate of 6 inches per hour is to be provided for, the allowable roof area would become 2/3 of the values given in the tables.

Par. 903(*d*). ALLOWANCE FOR PROJECTING WALLS.—In case a wall projects above a roof in such a manner that storm water drains from the wall onto the roof, the following allowances to be added to the roof area are suggested:

(1) For total roof area applied to a leader or storm drain receiving total flow from the roof:

a. For one wall only, add 50 percent of the wall area;

b. For two adjacent walls only, add 35 percent of the sum of the wall areas if both are of the same height. If the two adjacent walls are of different heights, allow 35 percent of the combined wall area below and 50 percent of the wall area above the top of the lower wall;

c. For two opposite walls only, make no allowance if both are of the same height. Add 50 percent of the wall area extending above the lower wall if the two are of different heights;

d. For walls on three sides, add 50 percent of the area of that part of the inner wall that lies below the lowest of the three walls, and allow for the portions of the two walls extending above the lowest, as in b if the walls are adjacent, or as in c if the walls are opposite;

e. For walls on four sides, ignore all wall areas lying below the top of the lowest wall, and add for those extending above it according to whether they fall under a, b, or d.

(2) For application to leaders or storm drains receiving only part of the roof drainage:

a. Determine the portion and dimensions of the roof area drained into each leader connection;

b. Compute allowance for projecting walls separately for each leader connection, as for total allowance to be added, ignoring walls not directly adjoining and extending above the section of the roof drained into the leader for which the computation is being made.

(3) For application to the main building drain and building sewer:

a. Ignore walls not extending above the building;

b. For one wall only extending above the building, ignore the wall area if it is less than that of the roof, or add 50 percent of the difference if it is greater than the roof area;

c. For two adjacent walls only, ignore the combined wall area if less than that of the roof, or add 35 percent of the difference if it is greater than the roof area;

d. For two opposite walls only, ignore wall area if the area of that portion of the higher wall above the top of the lower is less than the roof area, or add 50 percent of the difference if it is greater;

e. For three walls extending above the building, ignore wall area below the top of the lowest wall and then apply c or d above according to whether the walls extending higher are adjacent or opposite.

In all cases, the importance of applying an allowance for walls extending above the building and draining onto its roof depends largely on the relative areas of the extending walls and the roof. If the roof area is large relative to the total area or to that part of the total area for which allowance would be made under the preceding rules, the matter is not likely to be of great importance. It may be very important to make an allowance for wall area if a low building is built at the side of a tall one or into an angle formed by two tall buildings, or if a low-roofed portion of a building has a similar relation to different wings. It will be of less importance in any case if the leaders and storm drains required by the regulations for roof area alone are more than ample than if they are near the limit in capacity.

The allowances given in the preceding rules were selected to provide for a driving rain at an angle of 30° with the vertical. Regardless of the angle at which the rain falls, the portions of projecting roofs ignored under the rules given can be safely ignored in regard to their effects on the building storm sewer.

Par. 904. SEPARATE AND COMBINED DRAINS.—The provisions of section 904(*a*), part II, are intended to require separate sanitary and storm systems until they can be conveniently connected at grade. The sanitary system should be collected into one sanitary drain and the storm system into one storm drain, and the two connected at grade, if it can be conveniently done without crossing over. If the preceding

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is not convenient or economical, the sanitary and storm drains on each side of the combined sewer of the building may be joined at grade as described and the two combined drains thus formed connected to the building sewer. Connections should not be made through double-wye branches. If the street sewer is subject to overcharging or submergence, there will be less likelihood of detrimental effects to the sanitary system if the storm drainage and sanitary drainage are carried separately to the street sewer.

TABLE 904-III.—*Required diameters for combined building drains and sewers according to number of fixture units*

FOR DRAINS AND SEWERS HAVING ⅛-INCH FALL PER FOOT

Roof area \ Fixture units	0	225	425	450	675	880	1,350	1,400	2,450	3,300	4,000	4,900	6,000
sq ft	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
0	.....	4	4	4	5	5	6	8	8	8	10	10	12
775	4	4	5	5	6	6	8	8	8	10	10	10	12
1,330	4	5	5	6	6	6	8	8	10	10	10	10	12
1,550	4	5	5	6	6	8	8	8	10	10	10	12	12
2,100	5	6	6	6	6	8	8	8	10	10	10	12	12
2,700	5	6	6	6	8	8	8	8	10	10	12	12	12
4,300	6	6	6	8	8	8	8	8	10	10	12	12	12
4,350	6	6	8	8	8	8	8	8	10	10	12	12	15
7,800	8	8	10	10	10	10	10	10	10	12	12	12	15
8,700	8	8	10	10	10	10	10	10	12	12	12	12	15
12,400	10	10	10	10	10	10	12	12	12	12	12	15	15
15,300	10	12	12	12	12	12	12	12	12	15	15	15	15
24,500	12	12	12	12	12	12	12	12	15	15	15	15	15

FOR DRAINS AND SEWERS HAVING ¼-INCH FALL PER FOOT

Roof area \ Fixture units	0	315	590	680	960	1,190	1,900	1,950	3,400	3,900	5,650	6,800	11,300
sq ft	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
0	.....	4	4	4	5	5	6	8	8	8	10	10	12
1,075	4	4	5	5	6	6	8	8	8	10	10	12	12
1,300	4	5	5	6	6	6	8	8	10	10	10	12	12
2,150	4	5	6	6	6	6	8	8	10	10	10	12	12
3,000	5	6	6	6	6	8	8	8	10	10	10	12	12
3,600	5	6	6	6	8	8	8	8	10	10	12	12	15
5,950	6	6	6	6	8	8	8	8	10	10	12	12	15
6,000	6	6	8	8	8	8	8	10	10	10	12	12	15
9,300	8	8	8	8	10	10	10	10	10	12	12	12	15
11,900	8	10	10	10	10	10	10	10	12	12	12	15	15
15,900	10	10	10	10	10	10	12	12	12	12	12	15	15
19,600	10	10	12	12	12	12	12	12	12	12	15	15	15
31,300	12	12	12	12	12	15	15	15	15	15	15	15	15

FOR DRAINS AND SEWERS HAVING ½-INCH FALL PER FOOT

Roof area \ Fixture units	0	450	830	900	1,350	1,700	2,700	2,800	4,900	5,800	7,800	9,300	16,000
sq ft	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*	*in.*
0	.....	4	4	4	5	5	6	8	8	8	10	10	12
1,550	4	4	5	5	6	6	8	8	8	8	10	10	12
2,700	4	5	5	6	6	6	8	8	10	10	10	10	12
3,100	4	5	6	6	6	8	8	8	10	10	10	12	12
4,200	5	6	6	6	6	8	8	8	10	10	10	12	12
5,400	5	6	6	6	8	8	8	8	10	10	10	12	15
8,400	6	6	6	6	8	8	8	8	10	10	12	12	15
9,700	6	6	8	8	8	8	8	8	10	10	12	12	15
13,300	8	8	10	10	10	10	10	10	10	12	12	15	15
17,400	8	10	10	10	10	10	10	10	12	12	12	15	15
24,700	10	10	10	10	10	10	12	12	12	12	12	15	15
30,400	10	10	10	12	12	12	12	12	12	12	15	15	15
49,400	12	12	12	12	12	15	15	15	15	15	15	15	15

long vertical vents to wash out rust or other products of corrosion. Fixtures discharging greasy or other waste water likely to congeal and deposit and fixtures in excess of the limits set in section 1012 should not be so connected.

Par. 1101. INDIRECT CONNECTIONS.—Any indirect connection whereby the continuity of the

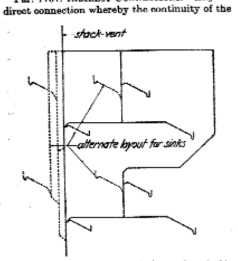

FIGURE 19.—*Piping lay-out for bathrooms in each of two stories.*

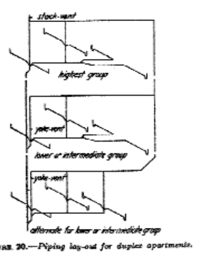

FIGURE 20.—*Piping lay-out for duplex apartments.*

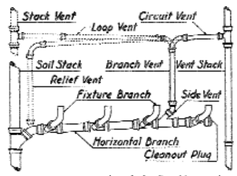

FIGURE 21.—*Illustration of circuit-and-loop vents.*

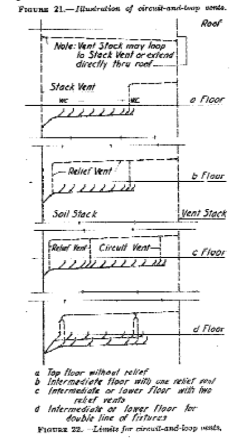

FIGURE 22.—*Limits for circuit-and-loop vents.*

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7. J. FRENCH 1946 Report (7)

The task of researching Dr. Hunter's files following WW II was an attempt to establish aspects from research and developments in setting the new method of Fixture units into applications that had indicated differences from the then accepted standard. The draft report was not published; several aspects from a copy are indicated from materials assembled for the report.

A few examples are reproduced from that study to illustrate selected report findings. That source indicated the limited extent of information found (or determined) from the files and records and limited resource materials found. The study specific "Conclusions" (shown in the reproduction) indicates "recommending that the Bureau (NBS) should not concur in publication of the proposed (at the time) code". Several additional findings reported that newer considerations by Hunter after the initial reports (BMS 65 & 66) publication seemed likely. Other selected indications are provided in the copied materials.

Memorandum for Mr. G. N. Thompson

From: John L. French

Subject: Proposed A.S.A. Plumbing Code

I. Introduction

About the first of the year, you requested that an effort be made to reconcile the requirements of the proposed A.S.A. plumbing code with Plumbing Manual BMS66, and where important differences existed to examine, insofar as possible, the merits of the two codes in the light of accepted hydraulic theory.

It was discovered early that any satisfactory comparison of the two codes would require much more time than had at first been anticipated, and your patience on this point has been fully appreciated.

The major portion of the discussion which follows consists of a derivation of the tables of BMS66. This has been difficult for several reasons, the most important, of course, being Dr. Hunter's death in 1944, and the confusion in his files resulting in part from the fact that it was necessary to move them from the Hydraulic Building, along with other hydraulic files, during the war. Certain limited data relating to the requirements of BMS66 have been found in Dr. Hunter's files and have been used in the comments which follow. Additional data were found which may or may not have direct application to BMS66, but which were not analyzed because of lack of time. Certain other data, known to have been obtained under Dr. Hunter's direction, and having important application to BMS66, have not as yet been located.

not prove to be warranted by future data, or by experimental results which may be discovered in Dr. Hunter's files. These assumptions, as will be seen later, were made on what is believed to be a conservative basis.

The principles on which the following discussion are based are all due entirely to Dr. Hunter, and are either described in his published works, or have been implied in the data obtained under his direction. However, none of the detailed computation sheets, or any direct description of the data or methods used by Dr. Hunter in deriving BMS66, have been found. We are, therefore, not justified in assuming that the derivation of the tables in BMS66 in the following discussion follows in precise detail the methods used by Dr. Hunter.

On the last page of this memorandum a table of contents is provided.

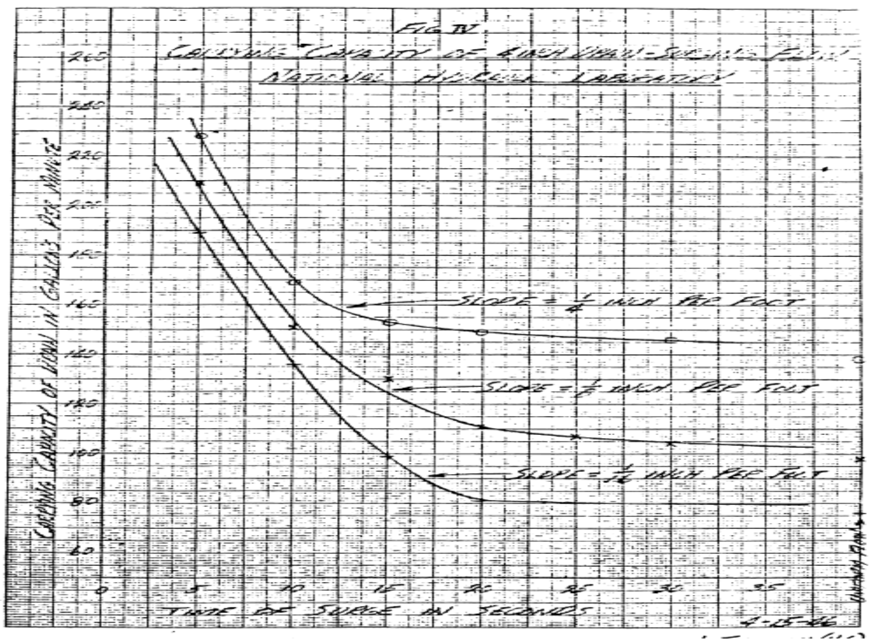
II Scope of this Analysis

Because of limited time, only portions of those sections in the two codes relating to horizontal drains have been examined. Those sections dealing with pressure drains, combined drains, stacks and vents have not been analyzed. The derivation of BMS66 on these points will be carried forward as rapidly as time and available data will permit.

III Derivation of Tables in BMS66

A) Probable Drainage-Load Curve

The probable flow from water closets, bath tubs, and lavatories; i.e., the load imposed on the drainage system by these fixtures, has been plotted in Figure I. These curves were obtained as follows:



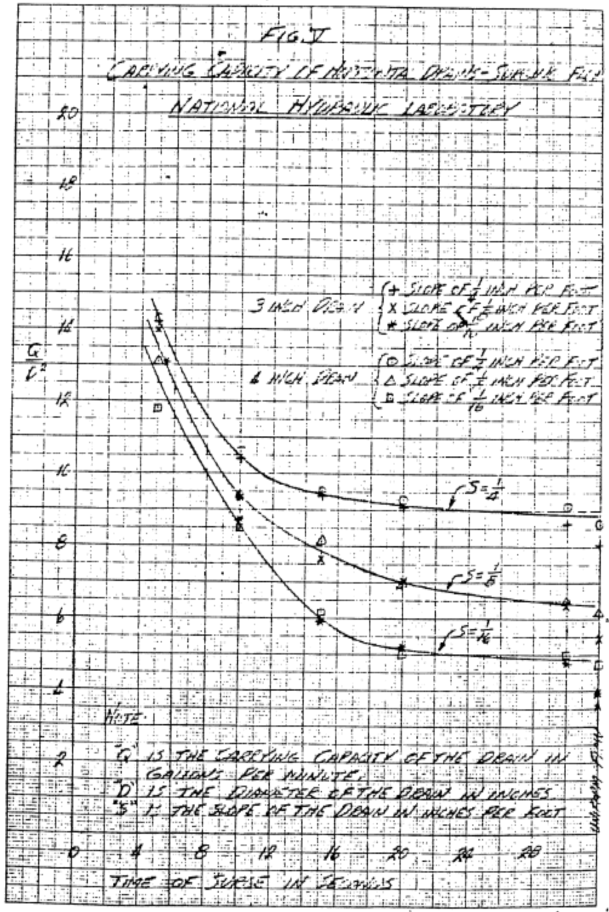


FIG. V
NATIONAL HYDRAULIC LABORATORY
3 INCH DRAIN
6 INCH DRAIN
S = 1/4
S = 1/8
S = 1/16
NOTE:
TIME OF SURGE IN SECONDS
J. FRENCH (46)

10

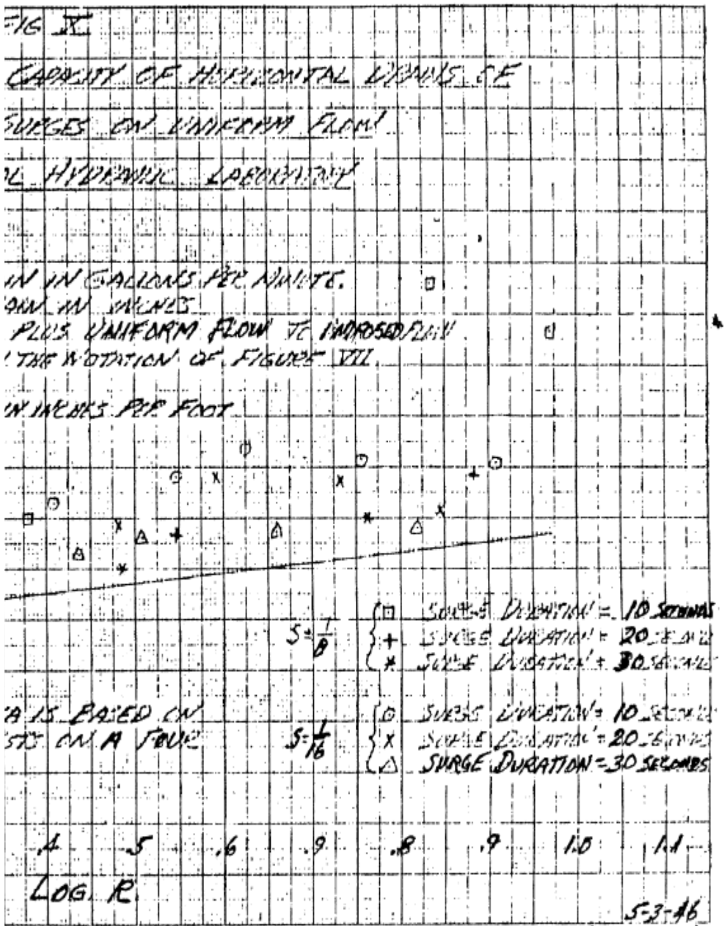


FIG X
PLUS UNIFORM FLOW TO IMPOSED FLOW
S = 1/8
S = 1/16
SURGE DURATION = 10 SECONDS
SURGE DURATION = 30 SECONDS
LOG. R
5-3-46
(J. FRENCH)

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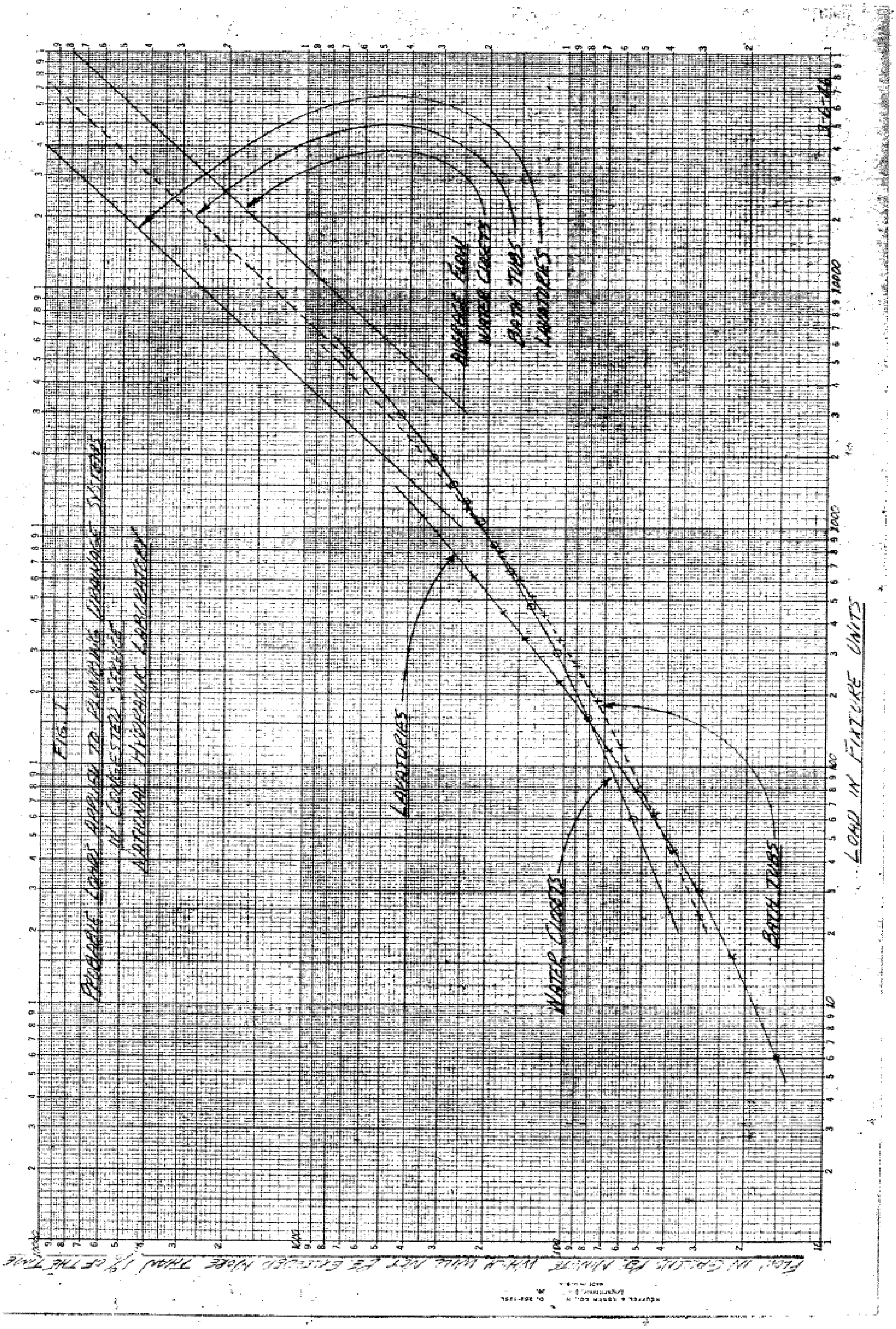

FIG. I
AVERAGE FLOW
WATER CLOSETS
BATH TUBS
LAVATORIES
LAVATORIES
WATER CLOSETS
BATH TUBS
LOAD IN FIXTURE UNITS

Probable Proposed Revision of BMS66

Permissible Loadings Found in Dr. Hunter's Files

Appendix I.

Sec. 807. Sloping Drains and Sewers (Sanitary Only).

(a) Horizontal Branches – The maximum number of fixture units installed on a horizontal branch of a given diameter shall not exceed the values given in Column (2) of Table X.

(b) Primary Branches – The maximum number of fixture units drained into a primary branch of given diameter and slope shall not exceed the values given in Columns (3) to (6) of Table X, except as provided for in paragraph of this section for pressure drainage conditions.

(c) Secondary Branches and Main Building Drain; (Sanitary System only). If the Building Drain has one primary branch only, or not more than one primary branch of 3-inch diameter or larger, the main building drain shall be of the diameter required by Table X for primary branches, except as provided by paragraph c of this section for pressure drainage conditions. If the building drain has two or more primary branches of 3-inch diameter or greater, the number of fixture units drained into the main building drain and its secondary branches may be increased by 10 percent, of the number permitted for a primary branch of the same diameter and slope, for each primary branch upstream from the secondary branch or main in question within the limits given in Table Y, provided:

(1) that the building drain and its secondary branches are laid at a uniform slope;

(2) that all connections are made by means of single-Y fittings; and

(3) that no primary branch which extends less than 15 feet in length at grade before connecting to the main or a secondary branch shall be counted in applying this rule. The provisions of paragraph (c) shall not apply except when construction plans showing the sizes,

(d) Pressure Drainage Conditions. In case no horizontal branch or other trapped drain connects to the sanitary drainage system within 3 feet above the grade line of the building drain (sewage ejectors excepted), the permissible number of fixture units as given by Table Y for primary branches and computed under paragraph c for secondary branch and main building drain may be increased by the factor (1 + 1/2 H/h) within the limits given in Table X, where h is the total fall in feet in the building drain including its longest branch and H is the elevation in feet of the lowest horizontal branch above the horizontal plane through the end of the main building drain. The provisions of this paragraph shall not apply except when construction plans as required for the application of paragraph c showing in addition the elevation of the lowest horizontal branches on all stacks in the system and details relating to any other proposed connections such as a sewage ejector, are submitted to and approved by the authority having jurisdiction.

(e) Building sewer. The building sewer, if laid at the same slope as the main building drain or at a greater slope, shall be of the same diameter as the main building drain.

If for any reason it is necessary to decrease the slope of the building sewer below that of the building drain, the diameter of the building sewer shall be such that its capacity for non-pressure drainage (paragraph c), as given by Table X (columns (6) to (9)) for Main building drains for the slope to be installed, is equal to or greater than the number of fixture units to be carried; and the diameter of the building sewer for pressure drainage (paragraph d) shall be such that building drains for the slope to be installed, is equal to or greater than the number of fixture units to be carried; and the diameter of the

Table X (807)

Capacities of Horizontal Branches and

Primary Branches of Building Drains

Diameter of pipe inches	Maximum permissible number of fixture units				
	Horizontal(1) branch	Primary branch			
		1/16 in. fall per foot	1/8 in. fall per foot	1/4 in. fall per foot	1/2 in. fall per foot
(1)	(2)	(3)	(4)	(5)	(6)
1-1/4	1	-	-	2	2
1-1/2	3	-	-	5	7
2	6	-	-	21	26
3	32	-	36	42	50
3	20	-	24	27	36
4	160	-	180	216	250
5	360	-	390	480	575
6	620	-	700	840	1000
8	1400	1400	1600	1920	2300
10	2500	2500	2900	3500	4200
12	3900	3900	4650	5600	6700
15	7000	7000	8300	10000	12000

(1) Slope of horizontal branches may be equal to or greater than the minimum slope for given diameters.

Table Y (807c)

Limits in Capacities of Building Drains for Non-Pressure

Drainage Conditions (Sanitary only).

Diameter of pipe inches	Primary branch				Secondary branch or main			
	1/16" fall per foot	1/8" fall per foot	1/4" fall per foot	1/2" fall per foot	1/16" fall per foot	1/8" fall per foot	1/4" fall per foot	1/2" fall per foot
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2	-	-	21	26	-	-	-	-
3	-	36	42	50	-	85	125	170
4	-	180	216	250	-	440	625	880
5	-	390	480	575	-	820	1100	1640
6	-	700	840	1000	-	1410	2000	2920
8	1400	1600	1920	2300	1950	2750	3900	5500
10	2500	2900	3500	4200	4375	6200	8750	12400
12	3900	4600	5600	6700	7500	10600	15000	21800
15	7000	8300	10000	12000	11900	16800	23800	33700

VI Conclusions

The following conclusions are believed warranted:

A) The proper concept of flow conditions in a drainage system is of highly fluctuating flow obtaining in the horizontal branches, with gradual reduction in the intensity of surging as the flow passes through the stacks to the primary branches, and further reduction in the secondary branches.

B) The data presented in the foregoing discussion are limited, and many important points of the drainage concept in (A) above are not covered by any quantitative data: hence the analysis and use of the available data should be made in a conservative manner. It follows that no substantial increase in the permissible loads of BMS66 for horizontal drains is believed warranted until such time as additional experimental evidence warranting such an increase is available.

C) The probable-load curve derived in BMS65 for supply loads is directly applicable to drainage problems.

D) The probable-load curve of the proposed A.S.A. code appears to be overly conservative, although the methods by which it was derived are not known to me.

E) The use of the Manning formula for uniform flow to compute carrying capacities of horizontal and primary branches is entirely unwarranted by the data available at this time and may lead to serious overloading of drains.

F) The effect of slope on the carrying capacity of horizontal and primary branches is substantially less than that indicated in the proposed A.S.A. code.

G) The concept of fixture unit used in the A.S.A. code is antiquated and leads to cumbersome and illogical handling of the problem of public and private use of plumbing fixtures.

The proposed A.S.A. code is admirable in many respects and in no few instances offers distinct improvements over BMS66. This is particularly the case with the appendix which is to show in some detail the methods used in obtaining the tables of permissible loads. It may be pointed out here that the data on surging flow used by Dr. Hunter in preparing the tables of BMS66 have not been published and, hence were not available to the A.S.A. committee. The difficulties confronting the committee in assigning carrying capacities to the various drains are therefore perfectly understandable.

There are two basic and fundamental differences between the two codes. First is the magnitude of the load likely to be imposed on a drainage system by a given number of plumbing fixtures. The magnitude of this difference is shown in Figure XV, and since Dr. Hunter's curve has been well substantiated by the analysis of BMS65, no other alternativ exists but to accept it until it is shown to be false. The second basic difference is in the concept of the type of flow for which drains should be designed. If the carrying capacity of the drains is not based on the type of flow to which they are subjected, it appears obvious that the computed carrying capacities will not necessarily bear any relation to their actual carrying capacities. On the one point alone of the use of the Manning formula for computing the carrying capacity of horizontal and primary branches, it is believed that the rejection of the proposed A.S.A. code by the Bureau is fully warranted.

For the above reasons, and because of conclusions A to G above, it is not believed that the concurrence of this Bureau in the publication of the proposed A.S.A. code is justified.

July 29, 1948.

8. Conclusions & Recommendations

The review provides an historical perspective for insights on methods developed that introduced "Hunter Fixture Units" into practices for plumbing systems and continues as a means for plumbing engineers/designers and as applied in adopted local authorities' applications for plumbing code requirements.

Considerations for further study involving probability analyses have broadly expanded by computer numerical methods applications of Monte Carlo and other techniques applicable to random event(s) theory and interpretations. Extensive field usage data from CIB W62 colleagues' presentations to W62 provide resources that offer opportunities to generalize and further evaluate statistical loadings/simultaneity aspects. Those efforts could contribute greatly to current thrusts for water conservation.

Function times for water closets have decreased to about four seconds for water closet discharges for new reductions of water consumption - down to about four or five liters, or 1.28 gallons, that vastly alters probable simultaneous event overlaps. With that factor for probable simultaneity a decrease of probable t/T value occurs (about 250 %) and then simultaneity for concurrent events in usages may not correlate with the fixture unit value of six as adopted in the Hunter curves/report.

Direct computational designs based upon numerical methods of solution for the governing dynamic equations for flow in partially filled pipes (also full bore flow techniques) also provides means for plumbing system designs (as advanced by Prof. Swaffield and Heriot-Watt team with several others). This alternate method avoids tabulated listings and provides great flexibility with competency for individual design basis of many building applications and usage(s) for specifics applied to conventional and individualistic design applications. Detailed study comparisons would be a useful evaluation for decisions on applications from conventional tabulated values to more exact method for plumbing systems designs.

9. Presentation of Author

Dr. Lawrence Galowin is a consultant, formerly a National Institute of Standards and Technology (NIST) leader in plumbing research; now retired but serves as Guest Researcher. Consultant in: desalination developments by wave energy pumping for RO methods & potable water relief by Slow Sand Filtering. He also serves on ASME national plumbing standards committees, and continues performance parameters research.

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11. Appendix

I. From Section III Definitions and Symbols (1): Clarity of special defined elements**:** A number of terms employed in the plumbing industry, and a few that are now introduced for the first time, are defined in the sense to be used in this (and later papers) of this series. Included are following listed elements and others in the report:

plumbing system	horizontal branch
building main	building drain
water distributing system	building sewer
sanitary system	primary branch; secondary branch
plumbing fixture	vent or vent pipe
drain	vent stack or main vent
fixture drain	Demand load; Sewage load
waste pipe	Charging load
soil pipe	Receiving capacity
stack	Terminal velocity

Design factor m is the particular value of r out of n fixtures that will be found in operation a selected fraction of the time under the assumed conditions of use.
Fixture unit, or load fact, is a numerical factor which measures on some arbitrary scale the load producing effect of a single plumbing fixture of a given kind. The use of the fixture unit makes it possible to reduce the load-producing characteristics to a common basis.
Specific symbols follow:
n = the total number of fixtures or supply openings of a given kind in the system.
r = the number of fixtures out of a total of n which at any given instant of observation are found operating to impose a demand load on the supply system, or a sewage load on the drainage system.
m = the design factor (definition above)
q = the average volume rate of flow, in gallons per minute, to or from a plumbing fixture during actual operation. Q = the total volume of water in gallons that flows or is discharged by a fixture at each use.
t = average duration of flow in seconds for a given kind of fixture for one use
T = average time in seconds between successive operations of any given fixture of a particular kind
τ = time interval in seconds such that the event in question (for example, exactly r fixtures will be found operating will occur for an aggregate off 1 second
C_r^n = number of combinations of n things taken r at a time
p_r^n = probability of exactly r fixtures out of a total of n fixtures being found in operation at an arbitrary instant of observation
$\sum_{r=m}^{r=n} p_r^n$ = the probability that some number of fixtures between $r=m$ and $r=n$, inclusive, will be found operating at an arbitrary instant of observation

II. From (8) the Reference List provides some insights into topics that were of interest in a selected number of plumbing research efforts following WW II.

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B1) Environment Conscious Residential Energy Use by Fuel Cell CHP Technology

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Abstract

The paper presents the world first Home CHP (Combined Heat and Power) System development, using the Polymer Electrolyte Fuel Cell (PEFC) Technology. PEFC Home CHP system has been studied and the Large Scale Field Testing Project has been conducted over 3000 sites until 2009. The paper uses 205 sites data for the system validation. The testing shows the promising result and the Home CHP system is about to merge in the Japanese market in early 2009.

The recent Environment Policy in Japan is seriously considering the considerable energy efficiency promotion program. Despite the historical effort in energy efficiency in industrial sectors, the energy demand in residential and small commercial sectors has been steadily growing. Hot Water demand and Electricity demand are the two major energy demands in residential. Application of Combined Heat and Power Technology has been long studied in residential sector. PEFC has advantage to the other conventional CHP systems, in its low operating temperature, the light weight of system and high energy efficiency with power generation efficiency of 33% and heat recovery efficiency of 45%. The challenges of Home CHP system are the initial capacity choice and the optimum operation control. The electricity demand and hot water demand vary by houses and seasons. In order to make the maximum use of exhausted heat upon power generation, Home CHP system should be in operation as long as the hot water supply is used (or stored in the hot water tank). The intelligent operation control should make the good forecast of the next day electricity demand and the hot water demand. The Large Scale Field Testing has been conducted with more than 3000 sites across the nation. The data shows that Home CHP system can deliver a good energy efficiency and primary energy saving, despite the variation of electricity demand and hot water demand ratio by houses and seasons.

Keywords

Polymer Electrolyte Fuel Cell (PEFC); Home CHP System; hot water demand; electricity demand; primary energy saving; Large Scale Field Testing Project

1. Introduction

1.1 Energy Demand Growth in Japan

Despite the historical effort in energy efficiency in industrial sectors, the overall energy demand in Japan has been constantly growing, mainly due to the demand growth in residential and commercial sectors.

The increase in the electricity use in the residential sector is the primary driver of such growth. Fig.1 shows that both the growth in the energy use per household and the increase of number of houses have resulted that the total energy use in residential sector in 2005 has increased by 230% compared with 1973.

The same trend in the increase of CO_2 emission is shown in Fig.2. The residential sector is now responsible as much as 14% of total CO_2 emission in 2005. It is now the common understanding that the energy efficiency and CO_2 emission reduction in residential and commercial sectors is the key issue in the Environmental Policy in Japan.

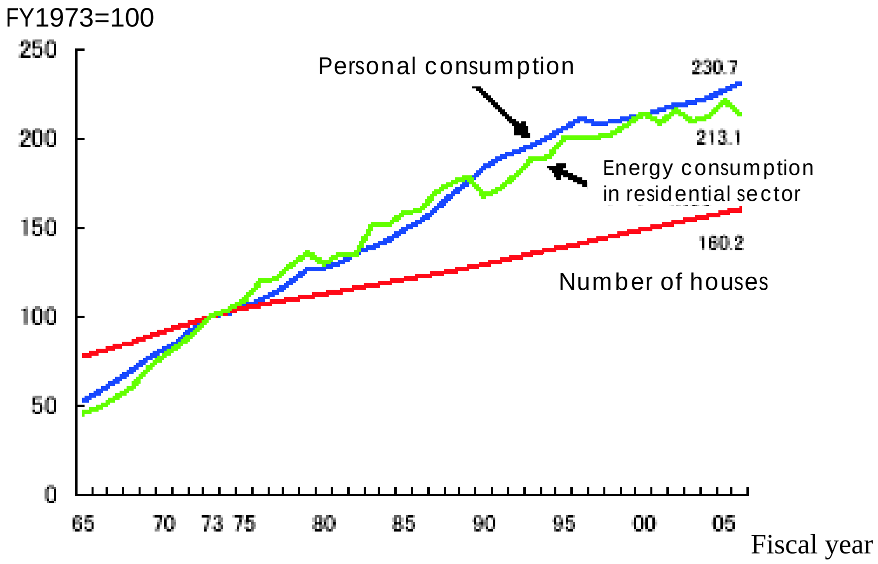

Figure 1 – Trend of Energy Consumption in Residential Sector in Japan[1)]

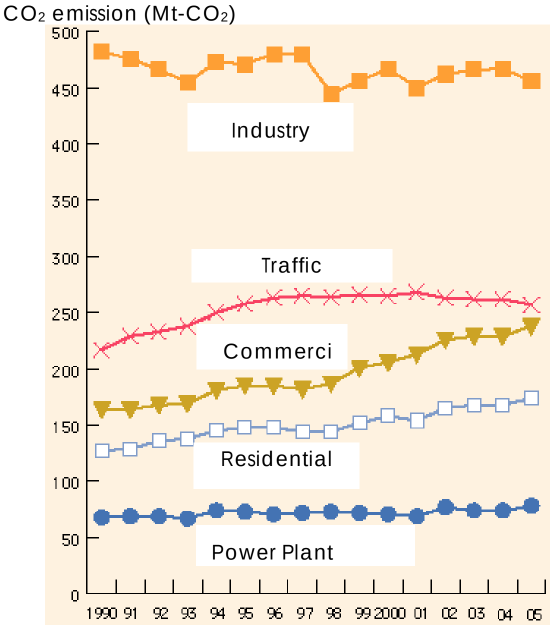

Figure 2 – CO2 Emission from Each Sector in Japan[2)]

1.2 The Role of Combined Heat & Power (CHP) in Japan

Combined Heat & Power (CHP) technology has been widely used in the industrial sector since late 1980s in Japan. CHP is the onsite energy efficiency technology, utilizing the exhausted heat during power generation. The maximum use of exhausted heat should achieve better efficiency compared with conventional power supply from the grid and the use of conventional boilers. Due to the relatively large scale of the power generation plant, either by engines or turbines, the CHP has been scarcely applicable to the residential and small commercial sectors. During 1990s, a new CHP technology, Fuel Cell has been introduced. There are four types of fuel cells (as shown in Table 1) and the new Fuel Cell technology, Polymer Membrane Electrolyte Fuel Cell (PEFC) is expected to enable the development of "Home CHP" (Residential CHP) system, due to the low operating temperature and the light weight of the system. The application of PEFC is already know in the use of automobile industry, as Fuel Cell Vehicle in 2002. An expectation to see the next application of PEFC in the stationary Home CHP system has been growing.

Table 1 – Types of Fuel Cell[3)]

	PAFC	MCFC	SOFC	PEFC
Electrolyte	Phosphoric Acid	Molten carbonate	Ceramics	Polymer Electrolyte
Operation temperature	200℃	650～700℃	750～1000℃	Normal temperature ～90℃
Generation Efficiency （HHV)	36～38%	40～50% (Normal pressure） Over 50%（combined）	40～50% (Normal pressure) Over50%（combined）	30～37%
Number installed				 
Status	Practical use	Practical use started	Under development	Practical use started
Purpose of Use	Industrial / Commercial	Industrial / Commercial	Industrial / Commercial / Residential	Residential / FC Vehicle / Portable telephone
Capacity	100～200kW	250kW～1MW	1kW～1MW	1kW class

2. Development of Home CHP System

2.1 The Concept of Home CHP System

The concept of Home CHP system is similar to the industrial CHP system, trying to make the maximum use of exhausted heat during power generation. The following three points have been considered in the initial design of the system:

Point 1: Maximum use of the exhausted heat for hot water supply

The demand of hot water supply in Japanese residences is relatively large due to the historical hot-water bathing lifestyle as well as recent floor-heating popularity. The Home CHP system should use the maximum exhausted heat for hot water supply.

Point 2: Optimum choice of power generation capacity and Intelligent Operation Control

In order to achieve the maximum energy efficiency, the Home CHP system power generation capacity should be carefully designed in order to match the electricity demand and hot water demand balance. It is also important that Home CHP system should operate by learning the hot water /electricity demand for the installed household in order to achieve the maximum energy efficiency.

Point 3: Low operating temperature and Easy Daily Start/Stop function

The change of the weather is relatively large in Japan. The hot water demand and electricity demand may vary seasonally. The demand is also variable according to the number of families, residence type and lifestyle. The intelligent operation control may require frequent Start/Stop function.

2.2 Operation Control

As described in the previous chapter, the operation control, with the balance of electricity demand and hot water demand is the most important studies in Home CHP system development. The operation control should learn the optimum load forecast.

- The Home CHP system should be in operation as long as the hot water is not wasted. The hot water can be stored in the storage tank, so it is not necessarily instantly consumed upon power generation, but the system will be cease in operation when the stored hot water becomes full.

- The Home CHP system will forecast the next day's electricity demand and the hot water demand by learning the historical consumption data during the past 12 weeks. The system operation control has a calendar function and it will make the forecast of next 24 hours demand from the last two sets of data of the same date of a week.

- The energy demand forecast is made for the next 24 hours.

- The Japan Electricity Regulation Act does not require electricity utilities to buy out the surplus of onsite power generation. Therefore, the surplus power is simply lost, which will result in the efficiency decrease. Fig.3 shows a schematic illustration of the optimum operation control of the Home CHP system. The maximum hot water demand is expected during 7PM-10PM by the hot water bathing use. Electricity demand is expected to develop from 7AM till midnight. The system will calculate the hot water demand from 7PM till 9PM and the demand in the following morning. Then it will calculate how many hours does the system need to store the hot water in order to meet such demand. Please note that the electricity is substantially supplied from the grid when the electricity demand exceeds the Home CHP generation. Fig 4 shows a typical daily operation chart from the Home CHP system field testing. In this example, Home CHP system is in operation for 24 hours, storing hot water from 0AM till 6AM, consuming some hot water between 6AM and 8AM, storing again from 8AM till 6PM and the hot water consumption is developed from 6PM, with the maximum use with bathing at 9PM. For the electricity supply, the CHP supplies good portion of electricity demand between 0AM and 6AM, receiving large electricity from the grid between 6AM and 8AM, CHP again supplies good portion of the demand between 10AM and 6PM and the large electricity use is developed after 6PM, when the grid power supply is necessary.

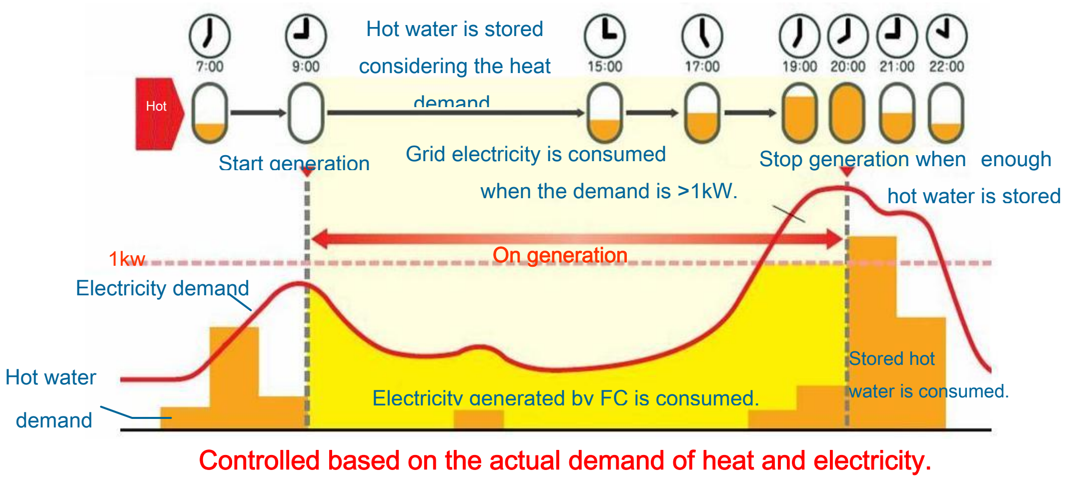

Figure 3 – Image of the Optimum Operating Control

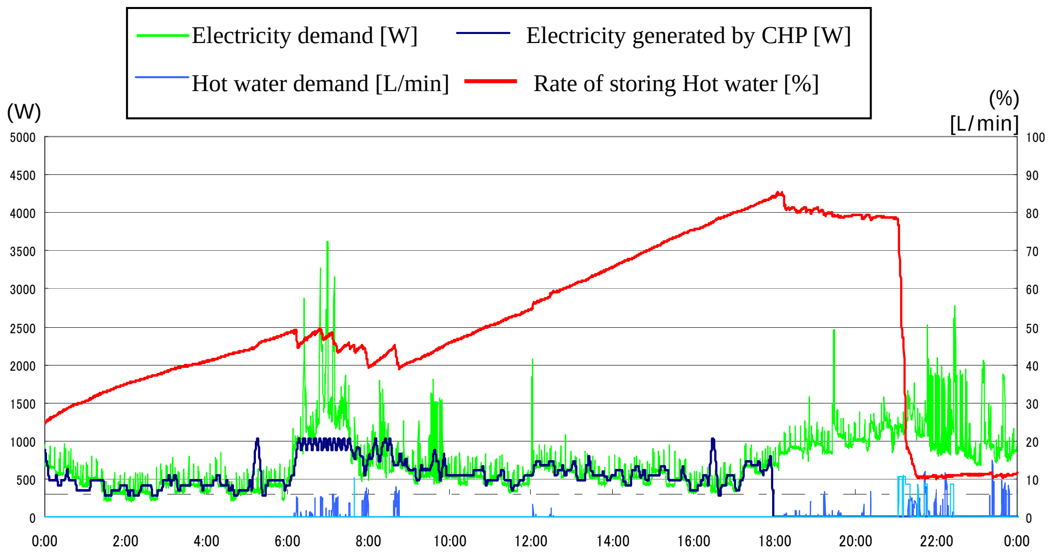

Figure 4 – Example of the Optimum Operating Control

2.3 System Configuration

Fig.5 shows the Home CHP system configuration. The system is comprised from two units, Fuel Cell Power Generation Unit and the Hot Water Storage Unit.

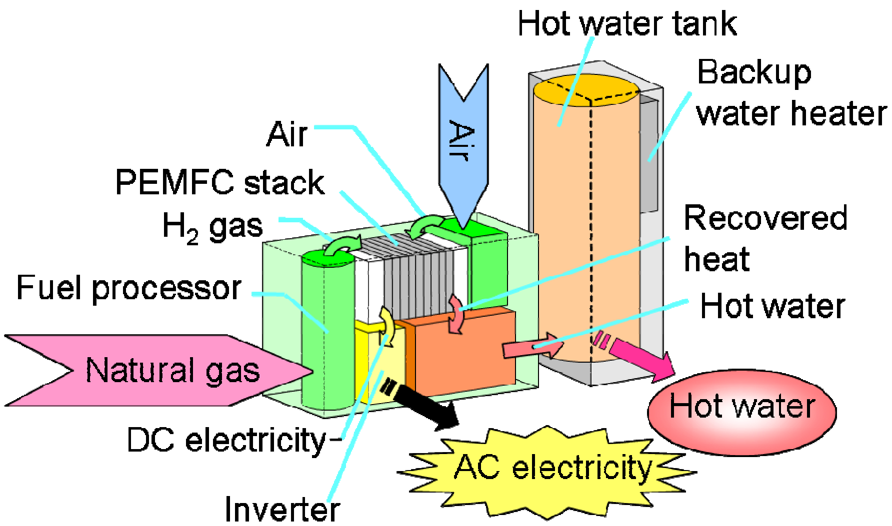

Figure 5 – Components of Home CHP system

The Fuel Cell Power Generation Unit is consisted from Desulfuriser Unit, Fuel Processor, Fuel Cell Stack and DC-AC Converter.

- Desulfuriser Unit: Remove sulfur component from fuel gas. Sulfur is included in the gas odorant.
- Fuel Gas Processor: H2 (hydrogen) gas is processed from fuel gas by steam reforming technology.
- PEFC Cell Stack: The core unit of the system, generating power from H2 and O2.
- DC-AC Converter

The Hot Water Storage Unit is consisted from Storage Tank and the Backup Boiler.

- Storage Tank: in order to meet average household daily hot water demand, the standard storage tank size was chosen as 200 litre.
- Backup Boiler: the backup boiler will supply the shortage of hot water, when the demand exceeds the stored hot water. The backup boiler use condensing heat recovery function.

Table 2 and Fig. 6 show the first two models of Home CHP system. They were subjected to the Large Scale Field Testing Project funded by the government during 2006-2009.

Table 2 – Specifications

		(a) Ebara Ballard	(b) Matsushita
Fuel cell unit	Max. output	1.0 kW	
	Min. output	0.3 kW	
	Electric efficiency	37 % LHV, 33 % HHV (at 1 kW)	
	Heat efficiency	50 % LHV, 45 % HHV (at 1 kW)	
	Heat recovery temperature	> 60 ˚C	
	Fuel	City gas (natural gas based)	
	Dimensions	W 800 D 350 H 1000 mm	W 800 D 375 H 900 mm
	Dry weight	153 kg	175 kg
Hot water tank unit	Dimensions	W 850 D 530 H 1850 mm	W 850 D 510 H 1900 mm
	Dry weight	153 kg	140 kg
	Tank capacity	200 L	
	Backup water heater	41.9 kW	

Figure 6 – External Appearance

3. Validation of Home CHP System by Large Scale Field Testing Project

3.1 Large Scale Field Testing Project

The government, New Energy Industrial Technology Development Organization (NEDO) and New Energy Foundation (NEF) have jointly conducting the Large Scale Field Testing Project on Home CHP during 2006 and 2009.

More than 2100 units have been installed and tested across the nation. 900 units with the fuel supply by Natural Gas, 1000 with Liquefied Petroleum Gas (LPG) and 200 with Light Diesel. More than 3000 units will be tested by the end of the project.

3.2 Validation of Home CHP system using Natural Gas

The Home CHP system data from first 205 sites using natural gas have been validated in this paper.

Fig 7 shows the distribution of electricity demand and hot water supply demand balance (E/H Ratio) across 205 test sites. The plot represents the E/H Ratio (annual use) per site. The graph shows the project has intentionally chosen the variety of E/H Ratio, in order to prevent the biased data collection.

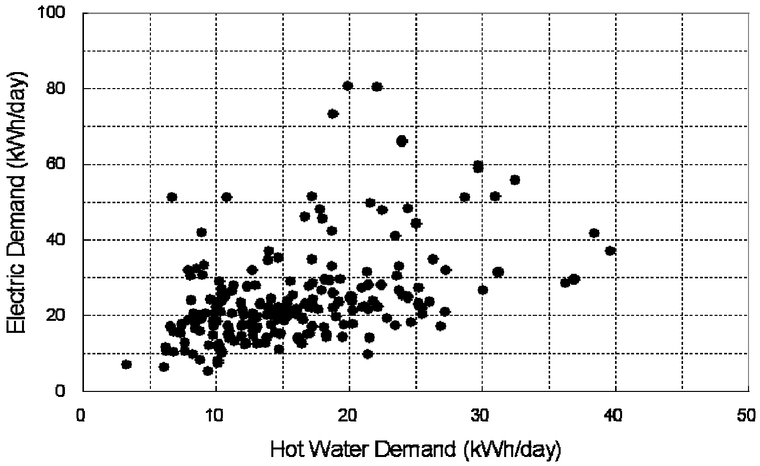

Figure 7 – Electric and Hot Water Demand (Annual)

Fig 8 shows the annual change of electricity demand and hot water demand. The plot represents a monthly averaged daily demand from 205 test sites, between October 2006 and September 2007. While the hot water demand shows winter-peak demand, with the least demand in summer, the electricity demand has two peaks with space cooling air conditioning use in summer and space heating air conditioning use in winter.

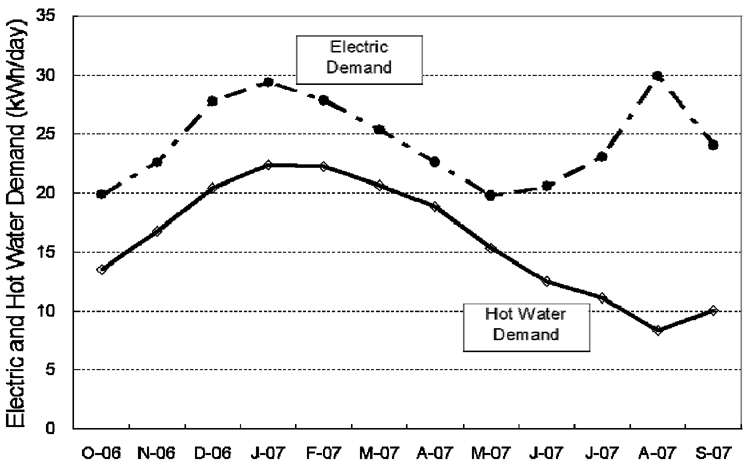

Figure 8 – Electric and Hot Water Demand (Monthly)

Fig 8 shows that E/H Ratio changes seasonally, and this is the technical challenge for Home CHP system operation control learning algorithm. It is expected that Home CHP system should achieve the best efficiency in winter, when the hot water demand is big enough to encourage the continuous operation, while the system may achieve less efficiency in summer when the hot water demand becomes small, discouraged the operation when the hot water supply unnecessary.

Fig.9, Fig 10 and Fig 11 show the typical testing site weekly operation data. Fig 9 shows the data with average hot water demand, Fig 10 with less hot water demand and Fig 11 with larger hot water demand.
Fig 9 and Fig 10 show that the most of the hot water demand have been met by the Home CHP system with limited backup boiler operation.
Fig 11 shows that the installed 1kw Home CHP capacity was too small. There have been considerable amount electricity supply from the grid and the hot water supply by backup boiler.

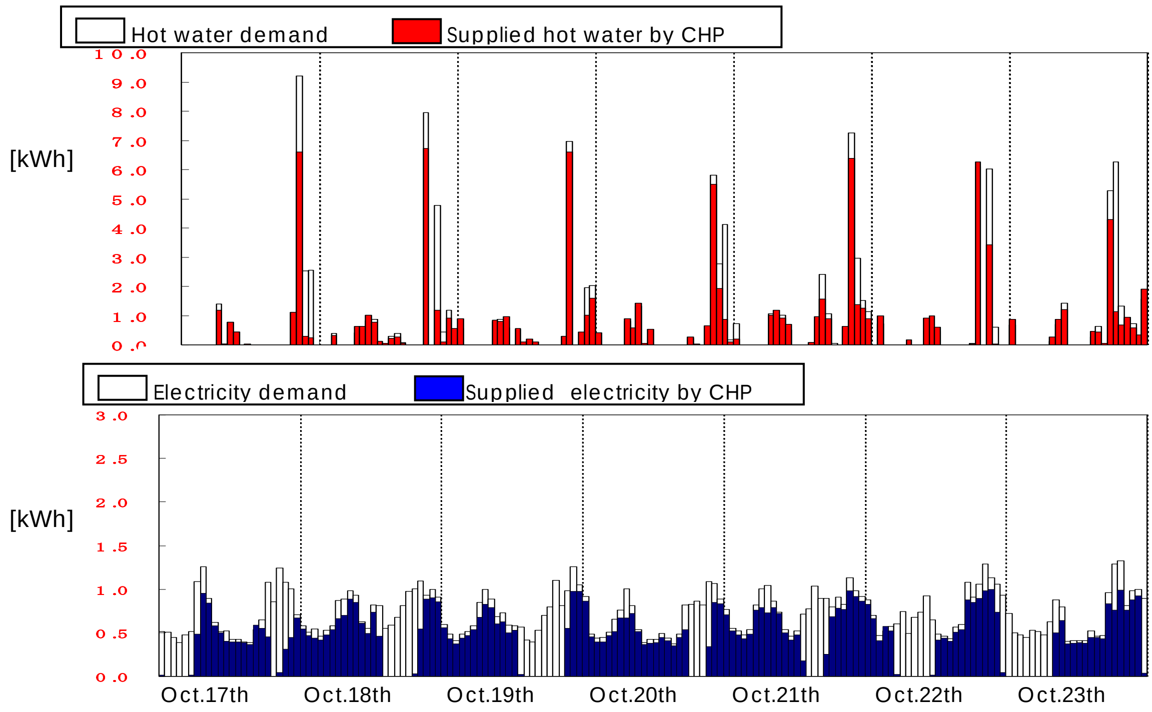

Figure 9 – Weekly Operation Data (average hot water demand)

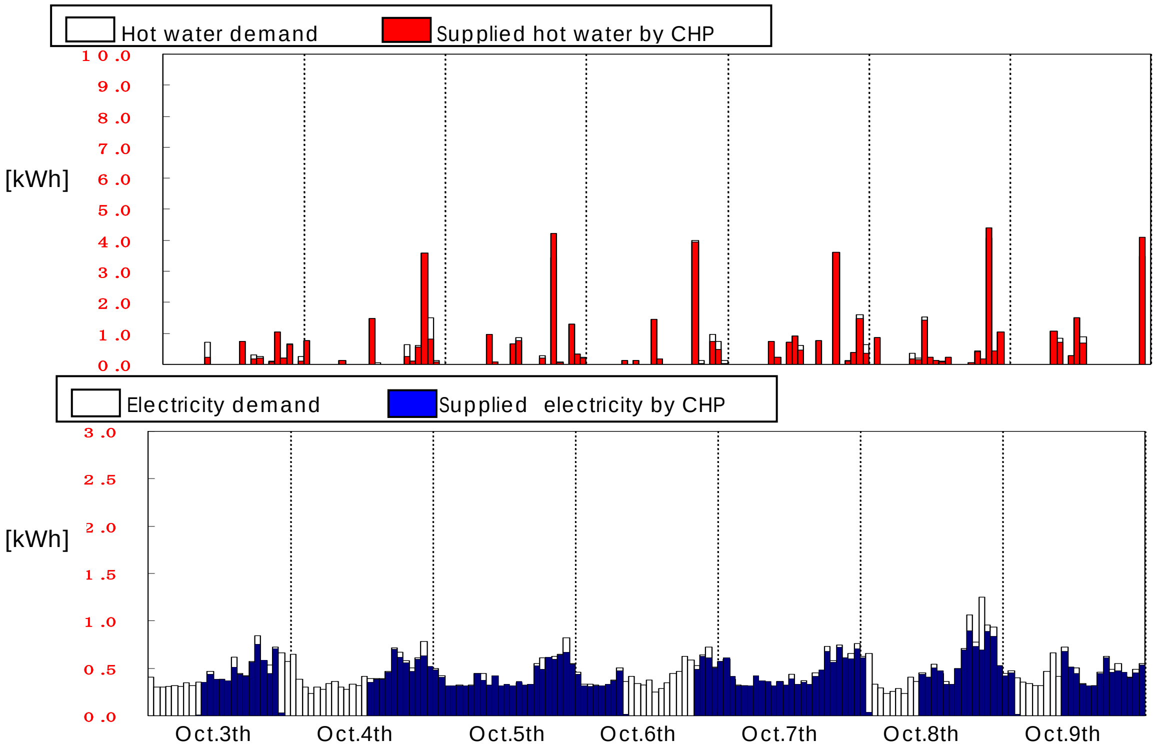

Figure 10 – Weekly Operation Data (less hot water demand)

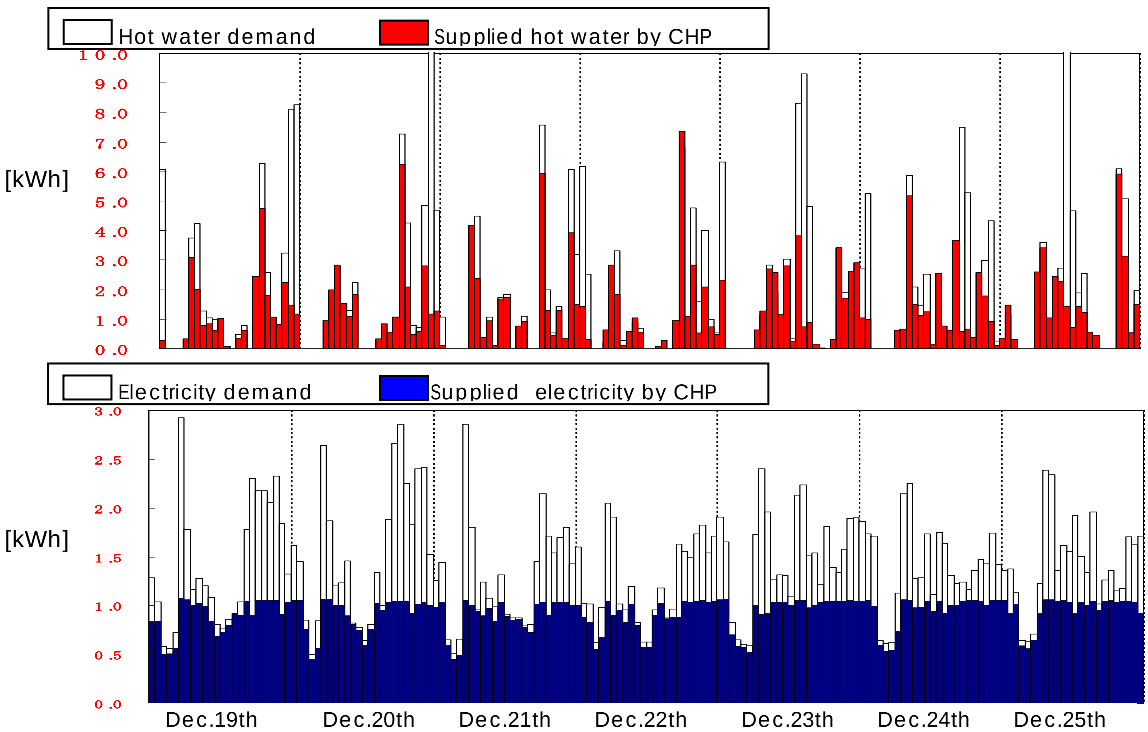

Figure 11 – Weekly Operation Data (lager hot water demand)

Fig 12 shows the annual change of Home CHP system running time, avaearge running time of 205 sites. The average running time during winter (November – March) exceeds 14 hours per day. This data shows that Home CHP system performed good efficiency in winter season when the hot water demand matches the Home CHP capacity.

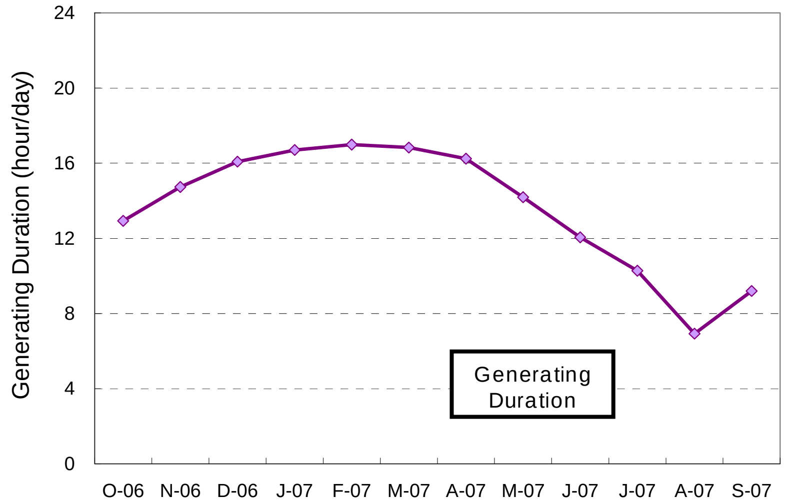

Figure 12 – Generating Duration and Start-up/Shutdown

3.3 Efficiency Change in Partial Operation

It is widely known that the CHP system efficiency will be degraded when the system is running under partial capacity load. Fig 13 shows that the total efficiency (power generation and heat recovery) distribution across 205 test sites. The capacity of this first Home CHP system was 1kW. Fig 13 shows that the despite the variation in average power generation, from 0.4kW to 1kW, the system achieve constant performance with the total efficiency of 78% and the power efficiency of 39%, Unlike conventional engines/turbines CHP system, PEFC CHP system can achieve a good efficiency even under partial operating load. This will encourage the choice of system capacity by using the maximum heat demand in winter.

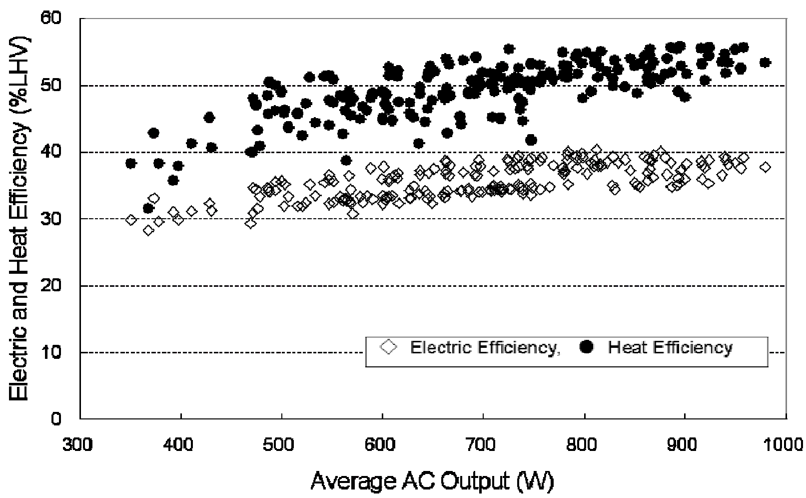

Figure 13 – Electric and Heat Efficiency

3.4 Primary Energy Saving

Also the validation was made for the primary energy savings by the Home CHP system. Fig 14 shows the annual change of average daily energy saving across 205 sites. The graph shows the identical trend of Fig 12. When the Home CHP system is in operation, primary energy saving becomes large. Fig 15 also shows the distribution of energy saving across 205 sites, the more primary energy saving is achieved when the hot water demand is larger.

Table 3 – Specific energy consumption indexes

Conventional sysytem	index
Grid power electric efficiency (at the receiving end)	36.9 %(HHV)
Gas boiler heat efficiency	78 %(HHV)

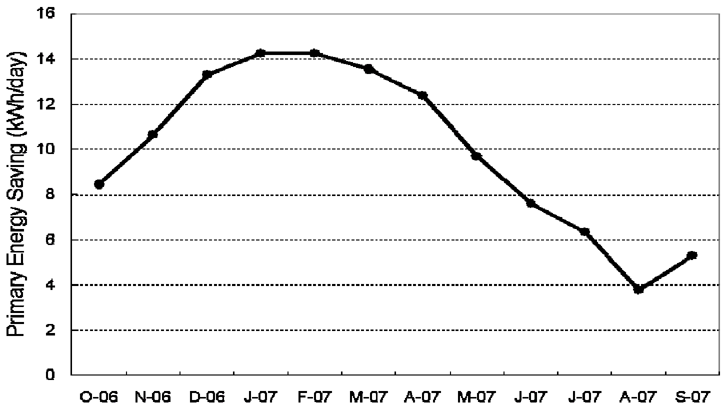

Figure 14 – Primary energy saving (Monthly)

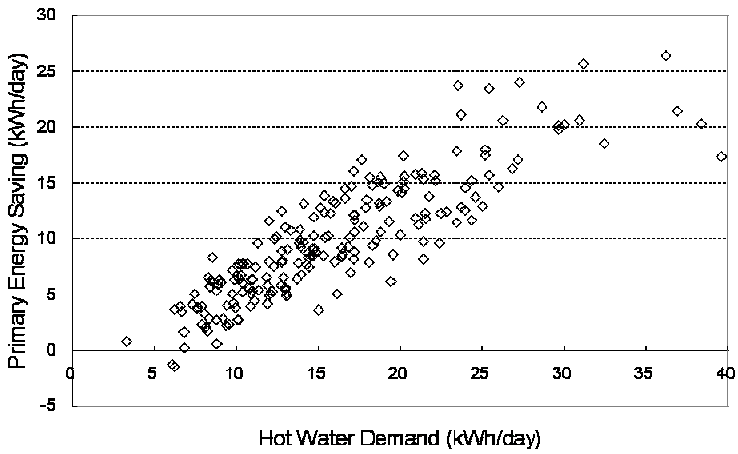

Figure 15 – Primary energy saving (vs. hot water demand)

3.5 Summary of the Field Testing

Table 4 shows the summary of the Home CHP System Large Scale Field Testing Project result during October 2006 and September 2007.

- Average System Power Generation: 8.4kWh/Day
  (Accounts 34% of the average electricity daily demand)
- Average Primary Energy Savings: 9.9kWh/Day
  (Account 25% saving from conventional energy use 40.0kWh/Day)

Table 4 – Operation results

		Total	Average(/day)
Generating duration		1,025,928h	13.6h
Generated electricity		702MWh	9.4kWh
Supplied electricity	Amount	629MWh	8.4kWh
	Contribution ratio	34 %	
Supplied heat	Amount	937MWh	12.5kWh
	Contribution ratio	78 %	
Primary energy saving	Amount	743MWh	9.9kWh
	Ratio	25%	

4. Conclusion and Further Development

The Large Scale Field Testing is scheduled to continue until March 2009, with total 3000 test sites including 450 Natural Gas fueled sites. Through the Large Scale Field Testing, the Home CHP energy efficiency has been validated, and it will be consolidated towards the conclusion of the Project. The Project also aims at the Home CHP System reliability and long term integrity, also supported by the continuous improvement from laboratory testing. The series of such testing have indicated promising results, and we are confident that the world first commercial Home CHP System market is about to emerge in early 2009.

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B2) Experimental study regarding a method for saving cold/hot water using single-lever kitchen faucets

Survey on the awareness of lever operation during washing-up

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Abstract

In supporting the prevention of global warming, highly energy efficient cold/hot water-saving equipment has been developed and it has been increasingly introduced in houses. Especially, when it comes to the hot-water supply equipment in Japan, which takes up 30[%] of total domestic energy consumption per household, cold/hot-water saving with single-lever faucets, which very much relies on how individuals use such faucets, is put to the test.

Keywords

Single-Lever Faucet, Dishwashing, Cold and Hot Water saving, Questionnaire survey

1. Background

In Japan, the reduction of residential energy consumption is one of the challenges for the prevention of global warming. In particular, as illustrated in **Fig. 1**, the percentage of energy used for hot-water supply is as high as about 33[%] out of the total energy used for household equipment. Therefore, reduction of energy consumption for hot-water supply is an objective to be achieved. Accordingly, in order to improve energy saving effects, the efficiency of hot-water supply equipment is intended to be improved. Moreover, various types of sanitary appliances such as cold/hot-water saving equipment have been developed.

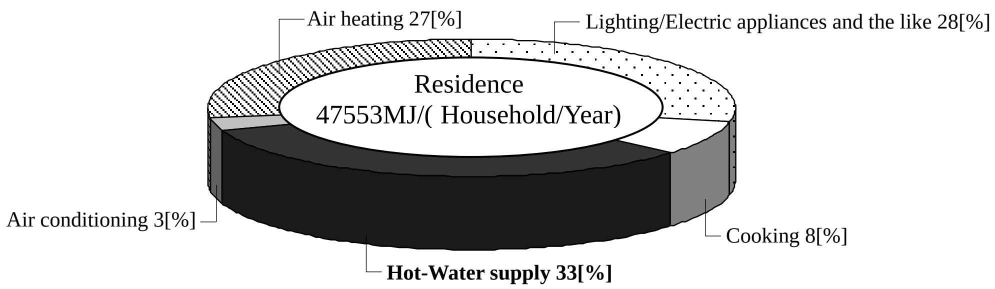


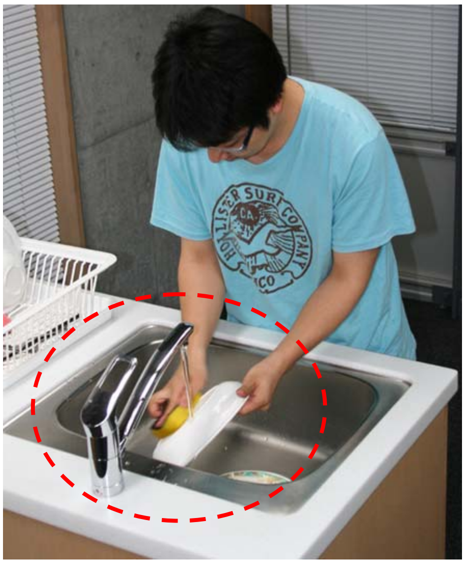
Fig.1 – Example of breakdown of energy consumption in residences

2. Purpose

As described above in paragraph **1**, reducing the amount of hot water used is the most efficient way to reduce the amount of energy used for hot-water supply. Household hot-water supply actions are roughly classified into two categories. One is the action of long-time use for “filling the bathtub with hot water” and for “taking a shower in the bathroom”. The other is the action of short-time use in “the kitchen” and in “the lavatory”. Cold/hot-water saving effects have already been examined for the long-time use for “filling the bathtub with hot water” and for “taking a shower in the bathroom”, and the data for the amount of cold/hot water which was saved has been presented. However, the actual conditions of use of a single-lever faucet in the kitchen where the short-time use actions are most frequently performed are still unknown. In particular, when a single-lever faucet is used in the kitchen, a lot of people perform ON/OFF operations of the lever unwarily while washing dishes as illustrated in **Pic. 1** and **Fig. 2.** It has been noted that unnecessary hot-water supply or gas ignition is likely to be caused by such unintentional lever operation[2)].

Furthermore, **Fig. 3** illustrates the opening of the single-lever faucet and the range of hot-water supply. The single-lever faucet in the range from (I) to (II) dispenses “hot water”. The single-lever faucet in the center position (III) dispenses “a mixture of hot and cold water”, and the single-lever faucet in the range from (IV) to (V) dispenses “cold water”. However, it has also been noted that a lot of users do not know the center position (III) in the drawing is for dispensing “the mixture of hot and cold water”[1)].

Therefore, the purpose of this study is to examine the points described above using a dishwashing experiment taken by test subjects and a Web questionnaire survey using a personal computer.
Specifically, we have examined the following points:
1) Lever operation state during dishwashing in each period; and
2) Awareness of lever operation of the single-lever faucet.



Pic.1 – Experiment condition

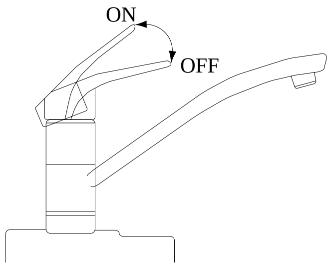


Fig.2 – Lever operation

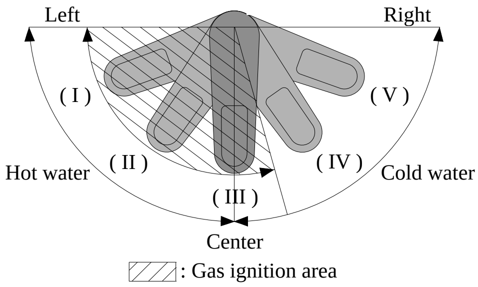


Fig.3 – Single-Lever faucet (Conventional type)

3. Experimental overview

3.1 Experimental methodology and measurement items

The experiment is carried out in the kitchen sink installed in the experimental facility of Kanto Gakuin University. **Pic. 2** shows the external appearance of a single-lever faucet (hereinafter, referred to as the "conventional type") used in the experiment, and **Pic. 3** shows the external appearance of the kitchen sink used in the experiment. **Table 1** shows the experimental overview, whereas **Table 2** shows the measurement items of an experiment system illustrated in **Fig. 4**.

Pic.2 – Experimental faucet

Pic.3 – Experimental kitchen sink

Table 1 – Experimental overview

Period	Summer period		Intermediate period		Winter period	
Experimental period	June 12 to July 20, 2007		November 7 to 15, 2007		December 14 to 20, 2007	
Average outside air temperature in period	26.4[°C]		18.5[°C]		11.7[°C]	
Average room temperature in period	26.0[°C]		24.1[°C]		23.8[°C]	
Test subjects	Housewives: 6 [person]	Students: 4 [person]	Housewives: 6 [person]	Students: 4 [person]	Housewives: 6 [person]	Students: 4 [person]
Average age	45.0 [years old]	18.8 [years old]	45.2 [years old]	21.3 [years old]	41.6 [years old]	23.3 [years old]
Number of experiments	One dishwashing cycle for four persons (six [dishes/person]; in total 24 dishes)					
Room condition	Set room temperature to about 26[°C]		Set room temperature to about 24[°C]			

Table 2 – Measurement items

Symbol	No	Items	Measurement interval
M	1	Cold water flow rate [L/min]	1[sec]
	2	Hot water flow rate [L/min]	
	3	Hot water flow rate at outlet of hot-water supply equipment [L/min]	
G	1	Gas flow rate [m^3]	
T	1	Temperature of supplied cold water [°C]	
	2	Temperature of supplied hot water [°C]	
	3	Temperature of supplied hot water at outlet of hot-water supply equipment[°C]	
	4	Faucet temperature [°C]	
	5	Room temperature [°C]	10[min]

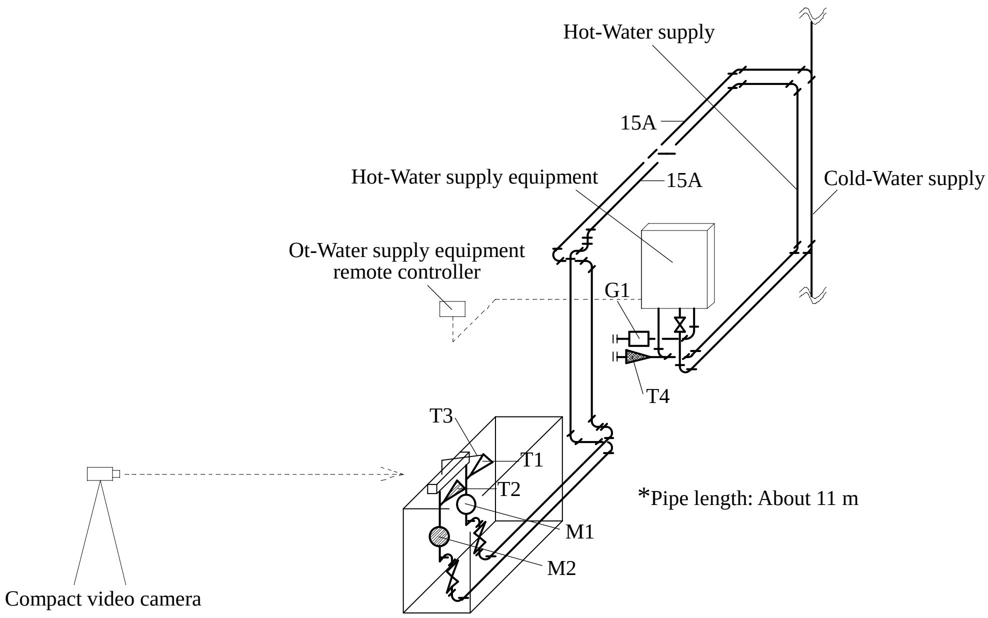


Fig.4 – Experimental system

3.2 Dishwashing experimental conditions

The dishwashing experiment was carried out in each of the summer period, the intermediate period (autumn), and the winter period during the year. In each period, of the ten test subjects, six were housewives and the remaining four were students. After the experiment, an interview survey and a questionnaire survey were conducted. The number of dishes washed in a single dishwashing cycle was for four persons with the number of dishes per person being six[2)] (including small utensils such as a glass and chopsticks). The test subjects were instructed to wash dishes as they would usually do. The following three conditions are the conditions before the start of the experiment.

(1) The initial position is the center position (III) shown in **Fig. 3**.
(2) The temperature of the hot-water supply equipment is set by a remote controller to 40[°C] in the initial state. The temperature can be arbitrarily changed by the test subject.
(3) A hot-water supply pipe is filled with "cold water" before the start of the experiment.In order to verify the lever operation performed by the test subject, a compact video camera was also used to film the experiment.

3.3 Web questionnaire survey

Table 3 shows the overview of the Web questionnaire survey. The Web questionnaire survey is conducted on the Internet using a personal computer. We entrusted the distribution and the collection of the questionnaires to a private research institute, but tabulated (simple tabulation and cross-tabulation) and organized the data by ourselves. The questionnaire survey was carried out in the winter period in which hot water is most frequently used. One thousand and thirty women (married) from all over Japan were surveyed.

The percentage of each area where the respondents resided was about 43[%] for the Kanto area and about 16[%] for each of the Kinki area and the Chubu area. As the distribution of ages, about 47[%] of the respondents were in the age range of 30 to 39 which represents half of all the respondents, followed by the age range of 40 to 49 which represents about 25[%]. About 57[%] of the respondents were housewives. Also, it was shown that about 77[%] of the respondents used the conventional type illustrated in **Fig. 3**. The remaining about 23[%] used either a single-lever faucet (10[%]) or a double-valve faucet (13[%]) illustrated in **Pic. 4**.

Table 3 – Web questionnaire survey overview

	Questionnaire items	Respondents	N number
Attributes	Age	All respondents	1,030
	Area		
	Number of people in household		
	Occupation		
	Type of faucet		
For single-lever faucet	Awareness of lever operation position	Single-lever faucet users	789
	State of use of lever operation position in each period		

(1) Single-Lever faucet (2) Double-Valve faucet

Pic.5 – Type of faucet

4. Experimental result and considerations

4.1 Test subject experiment

4.1.1 Example of waveforms of the dishwashing experiment conducted on test subjects

Fig. 5 shows an example of the results of measurements in the experiment conducted on test subjects. **Fig. 5** shows: (A) temperature of supplied cold water; (B) temperature of supplied hot water; (C) temperature at a hot-water outlet of the hot-water supply equipment; (D) a faucet temperature; (E) a flow rate (cold water); (F) a flow rate (hot water); (G) the amount of gas consumed; and (H) gas ignition timing. In **Fig. 5**, a change in the flow rate of cold/hot water and the like, which is caused by a different lever operation position shown in **Fig. 3**, can be seen. The numerals (I) to (III) on the waveforms indicate the respective lever operation positions shown in **Fig. 3**. The minimum operation flow rate for gas ignition was 2.8 to 3.0 [L/min].

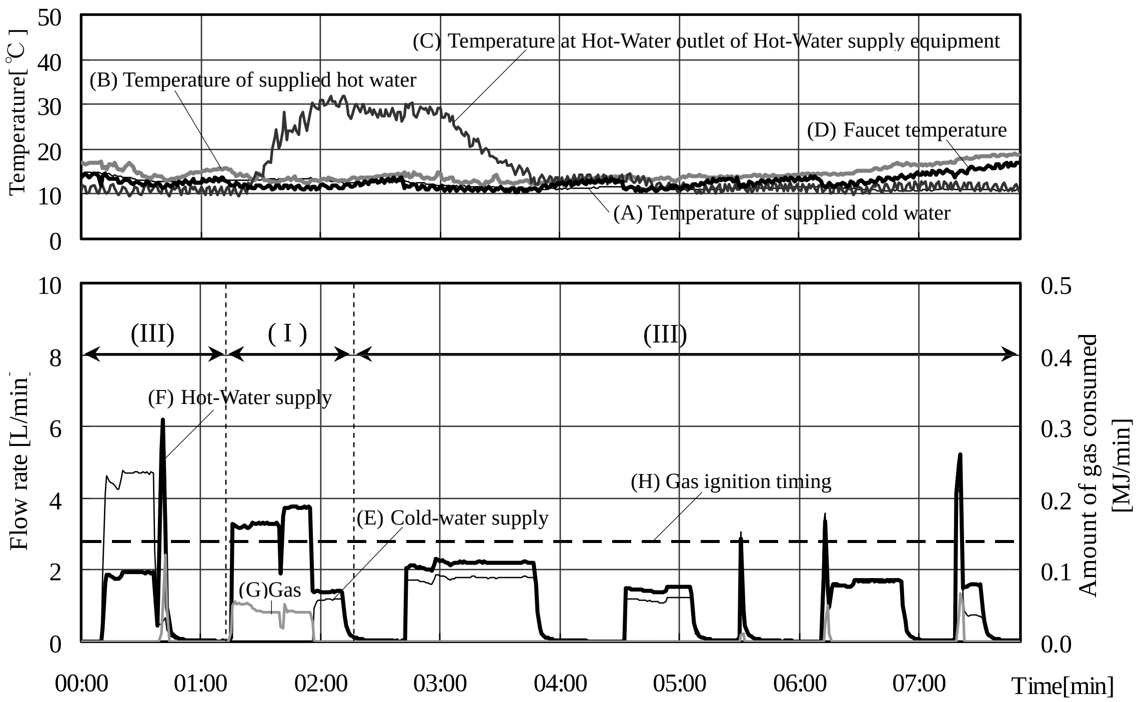


Fig.5 –Example of experimental waveforms of test subject X (winter period)

4.1.2 Lever operation position in dishwashing conducted on the test subjects

Fig. 6 is established by the collation of the results of measurements conducted on the test subjects shown in **Fig. 5**, the video filmed during the experiment, and the results of the questionnaire. In **Fig. 6,** the percentage of the use of each lever operation position is obtained from the number of times the lever operation is used (ON/OFF) in the single dishwashing cycle in each of the periods (the summer period, the intermediate period, and the winter period) based on **Fig. 5**.

In the summer period and the intermediate period, the percentage of use of the lever in the center position (III) was about 60[%] in all the operations (ON/OFF) by the test subjects. Since all the test subjects answered in the interview survey that the temperature of water was suitable for washing dishes, we can infer that the test subjects did not perform the lever operation intentionally.

In the winter period, since three of the ten test subjects used the center position (III), the results revealed that the lever was frequently used in the center position (III) about 43[%] of the time. However, the other test subjects were aware of their use of "hot water" when washing dishes. Moreover, based on the results of the interview survey, many test subjects answered that the temperature of the water was too "cold" for dishwashing.

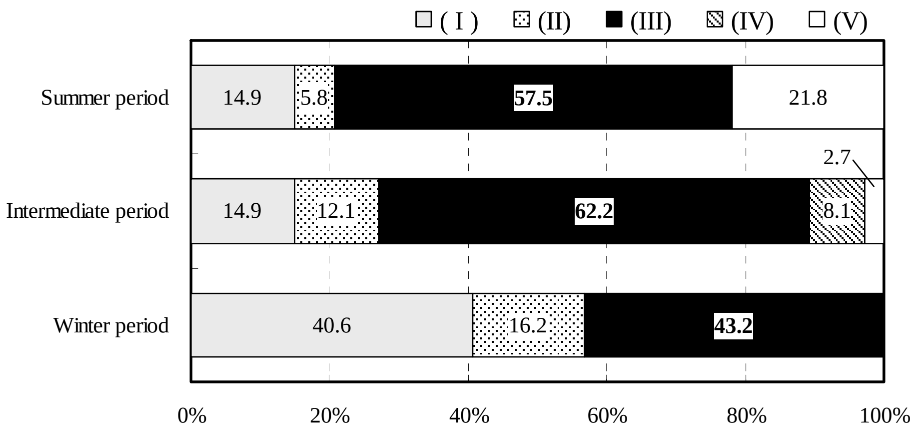


Fig.6 –Lever operation position in each period (Test subjects N=30)

4.1.3 Results of the questionnaire survey taken by test subjects

After the experiment, the questionnaire survey for awareness of the water supply in the lever operation positions shown in **Fig. 3** was carried out. The results are shown in **Fig. 7**. In the experiment on the test subjects, the awareness was surveyed for three lever operation positions (I), (III), and (V). About 88[%] of the test subjects knew that the lever operation position (I) was for hot-water supply and the position (V) was for cold-water supply. However, the results revealed that about 47[%] of the test subjects did not clearly know that the center position (III) was for "hot/cold water mixture supply". If the test subjects believe that the faucet in the center position (III) does not dispense hot water, we can infer that the test subjects are likely to unintentionally ignite the gas or cause the hot water to be dispensed.

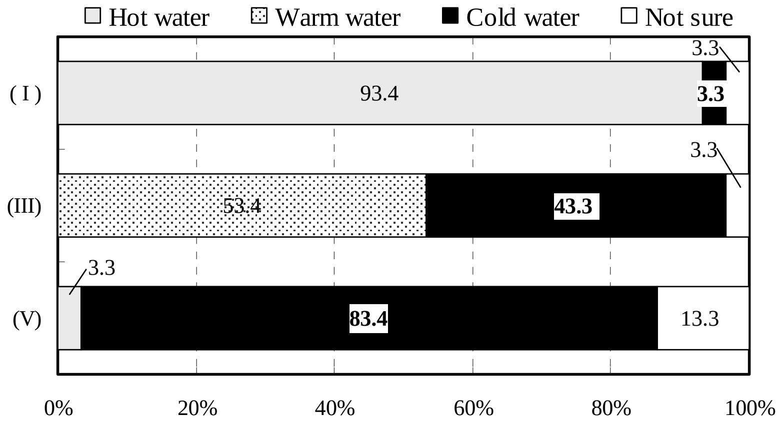


Fig.7 –Awareness of Lever position (Test subjects N=30)

4.2 Results of Web questionnaire survey

4.2.1 Awareness of the center lever position (III)

Fig. 8 shows the awareness of the water supply condition with the lever being in the center position (III) by age bracket when the hot-water supply equipment remote controller is always ON and when the hot-water supply equipment remote controller is turned ON only for use. From **Fig. 8**, about 46[%] of the respondents answered “cold water” or “not sure” both when the hot-water supply equipment remote controller is always ON and when the hot-water supply equipment remote controller is turned ON only for use. It is understood that the respondents used the center position (III) without knowing that the mixture of “hot/cold water” is supplied in this position.

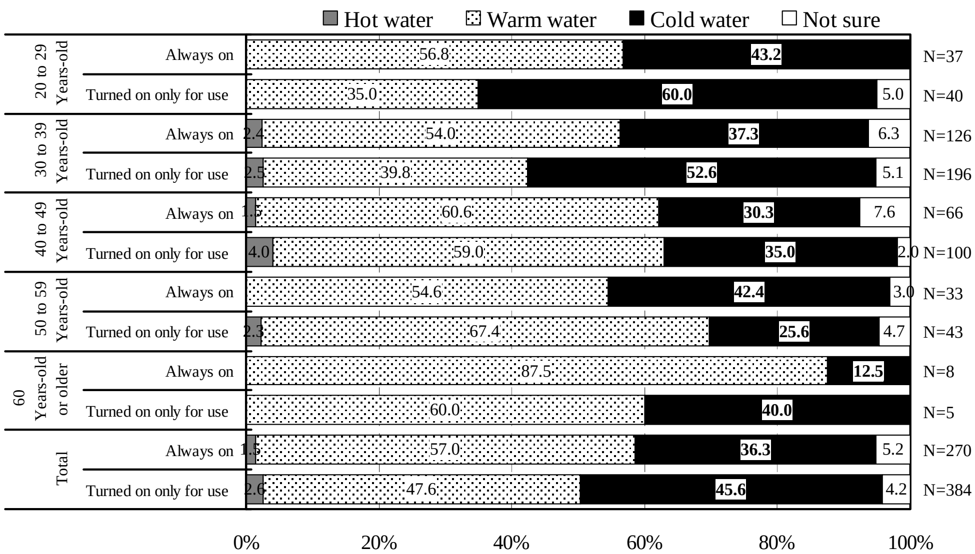
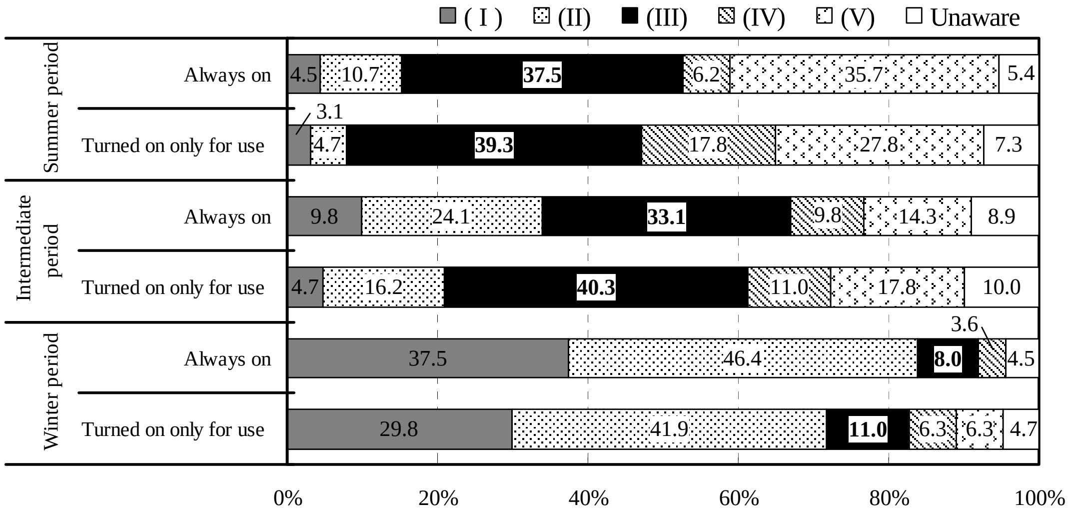


Fig.8 –Awareness of center position (Web N=654)

4.2.2 Lever operation position in the summer period, the intermediate period, and the winter period

Fig. 9 shows the results of the questionnaire about the lever operation position in each period. **Fig. 9** shows the results of the housewives who answered that the center position (III) is for supplying “cold water” in **Fig. 8**. In order to understand the details of the lever operation positions shown in **Fig. 3,** five lever operation positions were surveyed in the Web questionnaire. **Fig. 9** shows the results of the housewives who answered that the center position (III) is for supplying “cold water”. In the summer period and the intermediate period, about 81[%] of the respondents used the lever in positions (III) to (V) and were aware of the use of cold-water supply. Of the 81[%], however, about 38[%] used the lever in the position (III). If they use the lever position without knowing that the center position (III) is for “hot/cold water” mixture supply, we can infer there is a high possibility that hot water is supplied unintentionally and the gas is ignited needlessly.



*Housewives answering center position (III) is for “Cold-Water supply” both when Hot-Water supply equipment remote controller is always on (N=112) and when Hot-Water supply equipment remote controller is turned on only for use (N=191)

Fig.9 – Lever operation position in each period（Web N=303）

5. Consideration

From the results of the experiment on the test subjects and the Web questionnaire survey, the following findings are obtained.

1) About 47[%] of the test subjects and 46[%] of the respondents in the Web questionnaire did not clearly know about the water supply when the conventional type faucet illustrated in Fig. 3 is in the center position (III). Therefore, the results show that about half of the test subjects and the respondents did not know about the water supply in the center position (III).

2) The center position (III) corresponding to the initial position is more frequently used unaware in the summer period and the intermediate period in which cold water is used more frequently than in the winter period in which hot water is used more

frequently. We can thus infer that the individuals supply hot water unaware and therefore ignite the gas needlessly.

3) From the results in 1) and 2), we can infer that hot water is frequently supplied with the lever in the center position (III) which ignites the gas needlessly. Therefore, we point out the necessity of development of an improved energy-saving faucet which does not ignite the gas even when the lever is operated ON/OFF in the center position (III) illustrated in Fig. 10.

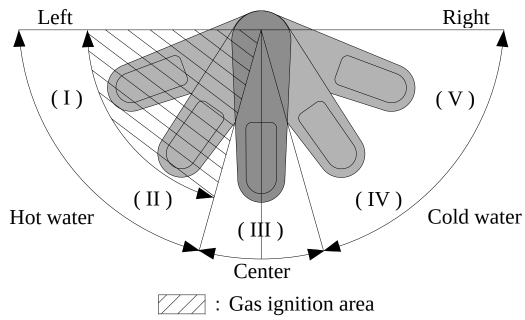


Fig.10 –Single-Lever faucet (Improved type)

6. Acknowledgements

This study was conducted in part under Grant-in-Aid for Scientific Research of the Ministry of Education, Culture, Sports, Science and Technology in 2007 as Basic Research B: “Development and Study of Comprehensive Evaluation Approach for Water-saving Effects of Household Sanitary Equipment” (representative researcher; Masayuki Otsuka). This study was also supported by “Strategic Development and Study of Environmental Symbiosis Technology for Urban/Building Stock Renewal” (Kanto Gakuin University) selected as the Academic Frontier Promotion Project of the Ministry of Education, Culture, Sports, Science and Technology in 2004.

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8. Presentation of Authors

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(2) Masayuki Otsuka is a professor at the Department of Architectural Environmental Engineering, 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), His current research interests are the performances of plumbing systems, drainage systems with drainage piping systems for SI (support and infill) housing.

B3) Study on the Running Condition of Residential Gas Engine Co-Generation System

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Abstract

Recently in Japan, the energy consumption in house is increasing. Especially, energy consumption of hot water supply accounts for about 1/3 of all utilization in a house. Therefore, it is very important to reduce the energy consumption for hot water usage.

Under such situation, it has become popular to set up the residential Gas Engine Co-Generation System (GECGS) in recent years. GECGS has spread about fifty thousand units from the year 2003 when the system brought to the market.

The electricity is generated by the engine used natural gas as fuel, and also the discharged heat from the machine is used for the demands of hot water supply system, etc. This system is expected as equipment for hot water supply to save the energy consumption in houses.

However, the efficiency of performance of GECGS is affected by the hot water and electric consumption depended on the life styles of dwellers. Therefore, it is important to grasp the data of operating this system accurately.

This study is aimed to obtain the basic data on the design for GECGS. We carried out the field measurements for performance of this system in four houses located in the regions of different climates of Japan.

This paper presents the outlines of the subject households, equipped facilities and

methods of the measurement, etc. In addition, characteristic of the hot water and electric consumption, running condition of the GECGS and efficiency are shown in each season.

Keywords

Co-Generation System ; Gas Engine ; Houses ; Hot Water Supply System

1. Introduction

Recently in Japan, it has become popular to set up the residential Gas Engine Co-Generation System (GECGS). GECGS has spread about fifty thousand units from the year 2003 when the system brought to the market. This system is expected as equipment for hot water supply to reduce the energy consumption in house. However, the efficiency of performance of this system is affected by the hot water and electric consumption depended on the life styles of dwellers. Therefore, it is important to grasp the data of operating this system accurately.

This study is aimed to obtain the basic data on the design for GECGS. We carried out the field measurements for performance of this system in four houses located in the regions of different climates of Japan.

This paper presents the outlines of the subject households, equipped facilities, methods of the measurement, etc. In addition, the characteristic of the hot water and electric consumption, running condition of the GECGS and efficiency are shown in each season.

2. Outline of investigation

2.1 Outline of investigated houses

Four detached houses were selected for the investigation from the typical areas in Japan, on the basis of the climate conditions and the characteristics of household, scale of houses, total floor area, etc. Table 1 shows the characteristics of household investigated. We selected the standard houses about household. The family size of the household is composed of three to five persons.

Table 2 shows the outline of the houses, the electric equipments and heating systems using hot water generated by GECGS. It is composed of two-story in each house, and total floor area is from $100m^2$ to $145m^2$. Characteristically, there is no air-conditioner in Hokkaido. In order to evaluate the performance of GECGS, we set up the new system to replace the existing system in all houses. Floor heating system is connected to the GECGS in each house. In Hokkaido, the area of floor heating is larger than the others.

Table 1 – Characteristics of household investigated in each area

Investigated house	Composition of family	Sex	Age	Occupation	Investigated house	Composition of family	Sex	Age	Occupation
Hokkaido	house holder	M	30〜39	office worker	Kanto	house holder	M	60〜69	without occupation
	wife	F	30〜39	office worker		wife	F	50〜59	housewife
	firstborn son	M	0〜9	kindergartner		firstborn daughter	F	20〜29	office worker
Hokuriku	house holder	M	30〜39	office worker	Chugoku	house holder	M	40〜49	office worker
	wife	F	30〜39	housewife		wife	F	40〜49	housewife
	firstborn daughter	F	10〜19	elementary school		second son	M	0〜9	elementary school
	second daughter	F	0〜9	elementary school					
	third dauter	F	0〜9	preschooler					

Table 2 – Outline of houses, electric equipments and GECGS in investigated houses

Investigated house	Years since construction	Scale	Total floor area	Number of television	Number of air-conditioner	GECGS	
						Hot water storage capadity	Heating system
Hokkaido	two-years	two-story	120m^2	2	0	150L	Floor heating（50m^2） Buthroom heating and drying（3.3kW）
Hokuriku	three-years	two-story	145m^2	1	3	150L	Floor heating（17.5m^2）
Kanto	twenty-years	two-story	100m^2	2	3	137L	Floor heating（9m^2） Buthroom heating and drying（3.3kW）
Chugoku	eleven-years	two-story	130m^2	2	2	137L	Floor heating（13.2m^2） Buthroom heating and drying（3.3kW）

2.2 Outline of hot water supply system and measurement

Figure 1 shows the distribution diagram of the hot water supply system and the measurement points. This system consists of Gas-engine unit and Tank unit. Generated electricity from Gas-engine is 1[kW], and exhaust heat is 2.8[kW]. Energetic efficiency of generated electricity is 20.3[% (HHV)], and energetic efficiency of exhaust heat is 56.9 [% (HHV)]. Meanwhile, there are two types about hot water storage capacity; 137[L] or 150[L], due to the difference of manufactures. Temperature of hot water storage of 137[L] is set up relatively higher than another.

The electricity is generated by an engine used natural gas or LPG as fuel, and the discharged heat from the machine is used for the demands of hot water supply system, etc. Electricity provided by power company covers shortfall of electric demand in house. Surplus electricity generated by Gas-engine is converted to heat energy with the recovery heater in Gas-engine unit. Furthermore, this system has a learning function for driving. It predicts the demand for hot water and electric consumption on the basis of the previous loads compiled according to a day of the week. GECGS operates at the best time of energy conservation by comparing predicted loads with actual loads of the house.

Basically, this system purveys electric loads and heat loads in the house by the exhausted heat from Gas-engine unit. However, when heat quantity runs short only by the exhausted heat, a Backup boiler installed in the Tank unit responds to the required loads.

We measured mainly cold and hot water temperature, flow rate, electricity and consumption of natural gas at each point in the system. These values were recorded automatically every two seconds. Hot water was supplied to bathtub and other uses by each pipeline. In addition, this system has the functions to reheat water in the bathtub and to heat water for floor heating in the living room, etc. The measurement in each house was started from August, 2007. We have planning to continue the measurement until July, 2008.

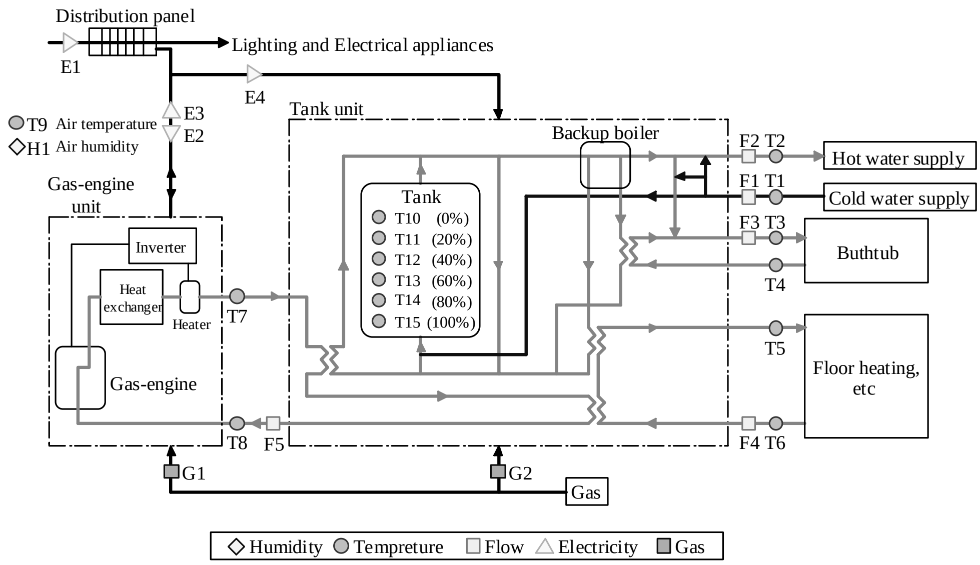


Figure 1 – Distribution diagram of the system and measurement points

3. Measurement results of hot water consumption

The distributions of average volume of hot water consumption in each house are shown in Figure 2. This Figure shows the result in October as an example. It is also shown the “Revised M1-MODE” which signifies as one standard value for hot water consumption in Japan. The mean value of hot water consumption in Hokuriku was larger than those in other houses although the standard deviation was relatively small. In Chugoku, it was indicated that standard behavior about hot water usage was done, because the sample of Chugoku was plotted at near the “Revised M1-MODE”.

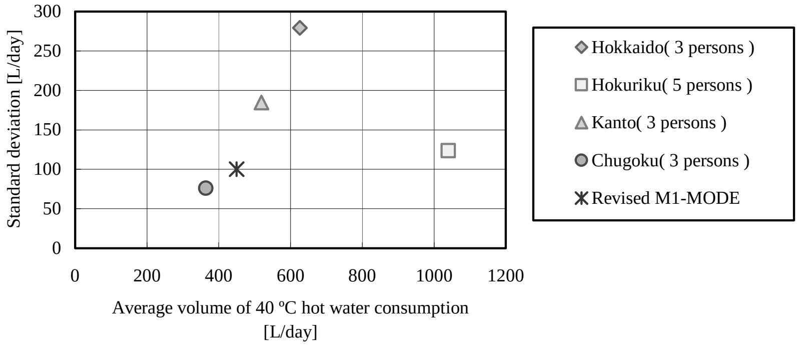


Figure 2 – Distribution of the volume of hot water consumption in each house

4. Energetic demands and running conditions of the equipment

4.1 Monthly fluctuation

Figure 3 shows the monthly heat loads of hot water consumption, electric loads and outdoor air temperature. We calculated the electric loads by summation “E1” and “E3” as shown in Figure 1. As for the Hokkaido and Hokuriku, the heat loads of hot water usage showed larger than those of other houses in each month. Because the air temperature was lower, the hot water consumption was larger. The floor heating loads showed a tendency to be large in autumn and winter. Especially in Hokkaido, the percentage of floor heating loads to the total heat loads was highest. However in Kanto, it was supposed that the indoor heating was used by other equipments excepting the floor heating system because the floor heating loads in this house were very little.

Figure 4 shows monthly gas consumption and operating time of the Gas-engine and the Backup boiler. The gas consumption was increasing in response to the total heat loads because this system operated basis on the heat loads in houses. In Hokkaido and Hokuriku, the operating time of the Gas-engine was approximately 16[h/day] in winter. On the other hand, in Kanto and Chugoku, the operating time was comparatively small, however it was increasing from summer to winter.

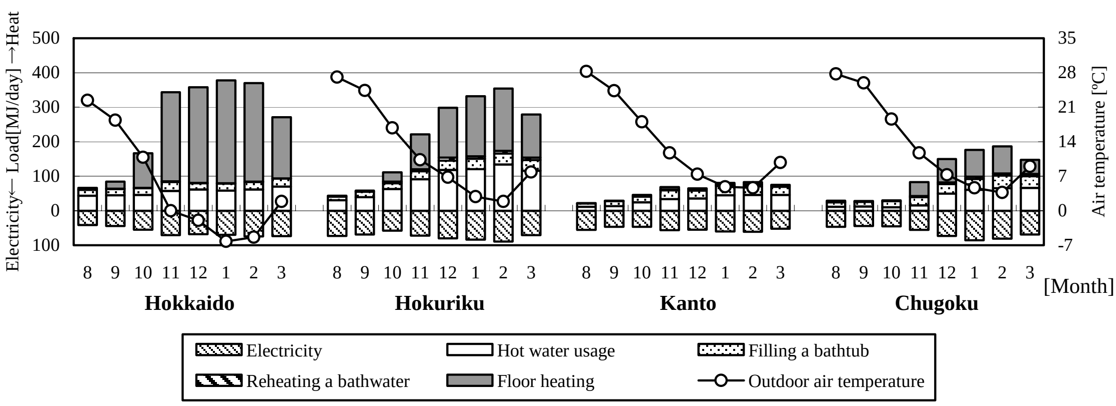


Figure 3 – Monthly heat loads and electric loads in each house

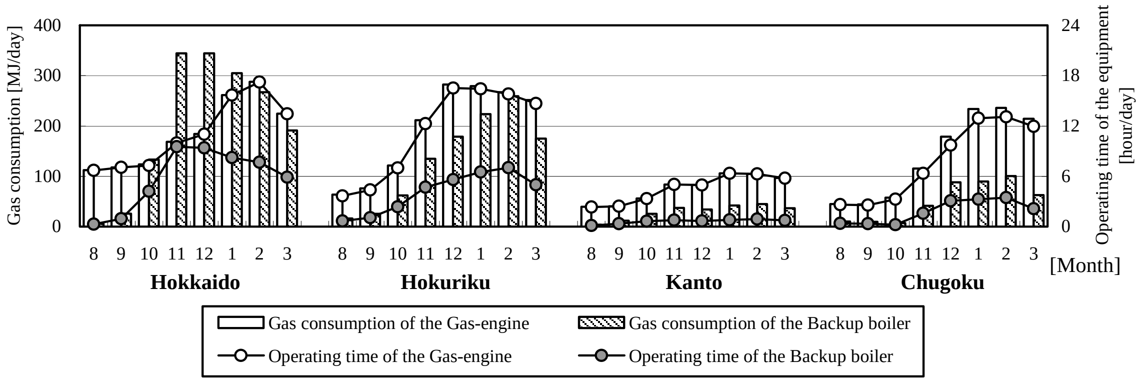


Figure 4 – Monthly gas consumption and operating time of the equipment

4.2 Relationships between floor heating loads and air temperature

Figure 5 shows the relationships between floor heating loads and air temperature in each house. In each house except Kanto, the floor heating loads were shown in the range not over about 20[℃], and it had a tendency to increase with decrease of air temperature. On the other hand, in Kanto, the floor heating loads were very little because of no uses for the floor heating system. Meanwhile, the maximum floor heating load was about 350[MJ/day] in Hokkaido.

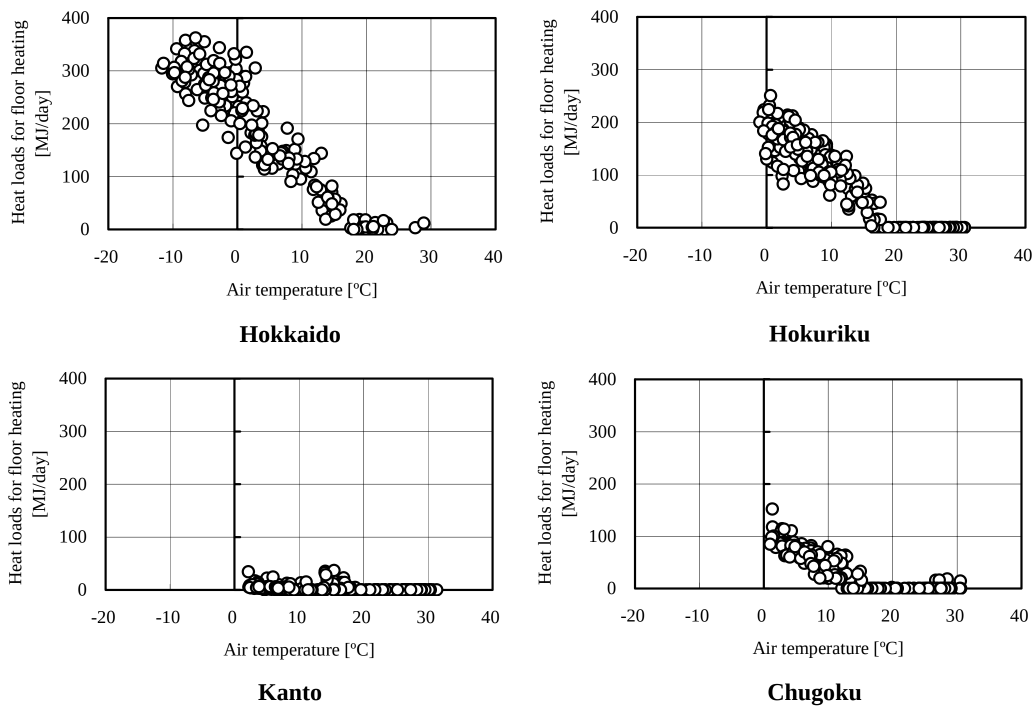
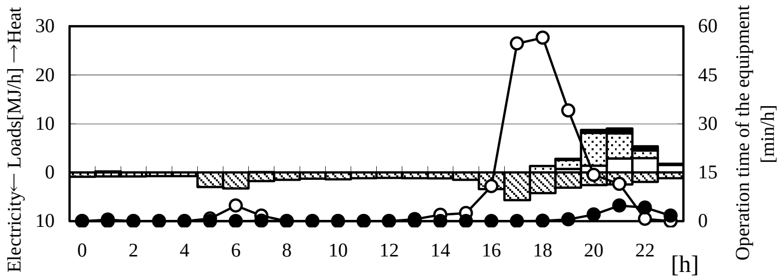


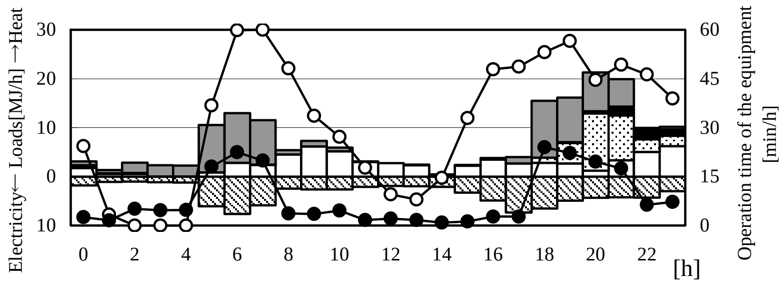
Figure 5 – Relationships between floor heating loads and air temperature

4.3 Hourly fluctuation

We analyzed the differences of the hourly running condition in each season. Figure 6 shows the hourly energetic loads and operating time of the equipment in Chugoku as an example. This figure shows the average values in each hour on weekdays in October and January. In October, the heat loads occurred intensively at only night. On the other hand, the peak time-zone of electric loads appeared from 16:00 to 20:00 before the peak time-zone of total heat loads. The Gas-engine operated frequently at the time-zone from 17:00 to 20:00, so the running pattern of the Gas-engine was roughly constant. The Backup boiler almost didn’t run in each hour. In January, the heat loads for hot water usage and floor heating occurred in the morning in addition to the occurrence in the night. Both the Gas-engine and the Backup boiler were running for the heat loads in the morning and night. The electric loads in the morning were comparatively larger, so the Gas-engine ran notably at the same time-zone.



a) October



b) January

Figure 6 – Hourly energetic loads and operating time of the equipment in Chugoku

5. Efficiency and contributing rate of the equipment

5.1 Monthly energetic efficiencies of the Gas-engine unit and system

We define the each energetic efficiency on the equipment with (1) ~ (4). About G1, G2 and E3, these symbols are shown in the Figure 1.

$$E_e[\%] = \frac{E3}{G1} \times 100 \quad (1)$$

$$E_h[\%] = \frac{H_g}{G1} \times 100 \quad (2)$$

$$E_t[\%] = (1) + (2) \quad (3)$$

$$E_c[\%] = \frac{E3 + H_t}{G1 + G2} \times 100 \quad (4)$$

E_e : Efficiency of electricity for the Gas-engine unit
E_h : Efficiency of heat quantity for the Gas-engine unit
E_t : Total efficiency for the Gas-engine unit
E_c : Comprehensive energy efficiency
H_g : Heat quantity from the Gas-engine unit
H_t : Total heat loads

"H_g" includes heat quantity from both the Gas-engine and the heater to recover surplus electricity.

Figure 7 and Figure 8 show monthly energetic efficiencies of the equipment in each house. According to the Figure 7, "E_e" of Hokkaido in August showed lower than 20.3[%](HHV) as specification because the electric loads were comparatively small. Therefore, it was considered that the heater in Gas-engine unit transformed surplus electricity into a form of heat quantity. In Kanto and Chugoku, the values of "E_e" in winter were smaller than others. The total efficiency for the Gas-engine unit; "Et" showed the values from 74.7[%](HHV) to 83.0[%](HHV) in each house. Therefore, it was satisfied the value of 77.2[%](HHV) as the capability of specification.

According to the Figure 8, in the investigated houses at Hokkaido and Hokuriku which had large total heat loads, "E_c" was comparatively larger, and it showed to increase in winter. On the other hand, "E_c" showed smaller in Kanto and Chugoku which had small total heat loads. Meanwhile, the minimum of "E_c" was 62.4[%](HHV) on October in Chugoku, and the maximum was 76.9[%](HHV) on February in Hokuriku.

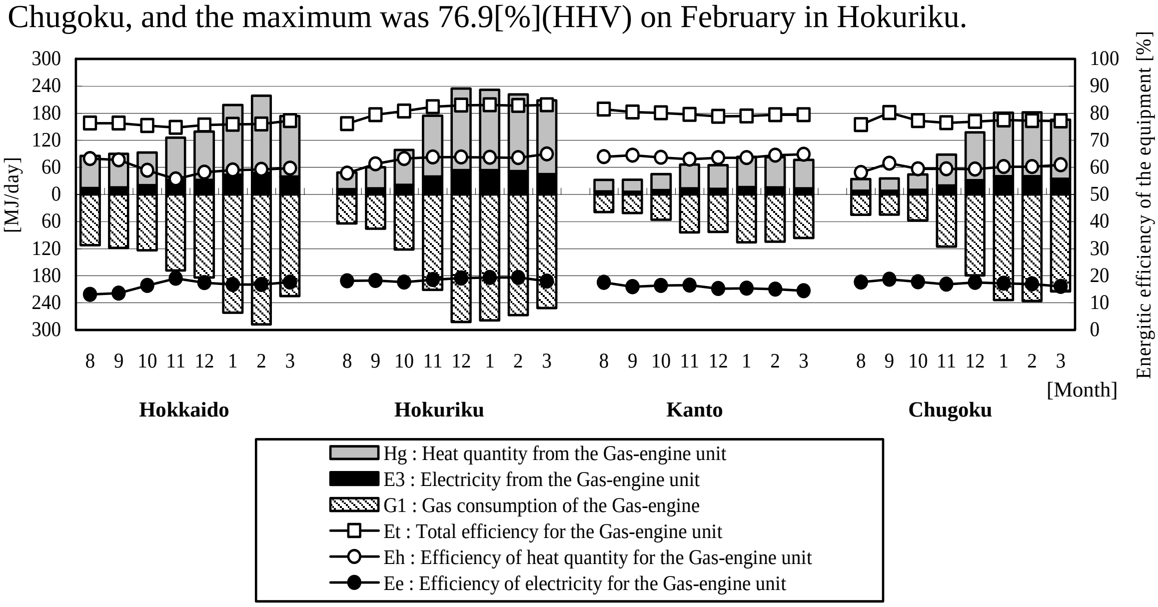


Figure 7 – Monthly energetic efficiencies of the equipment

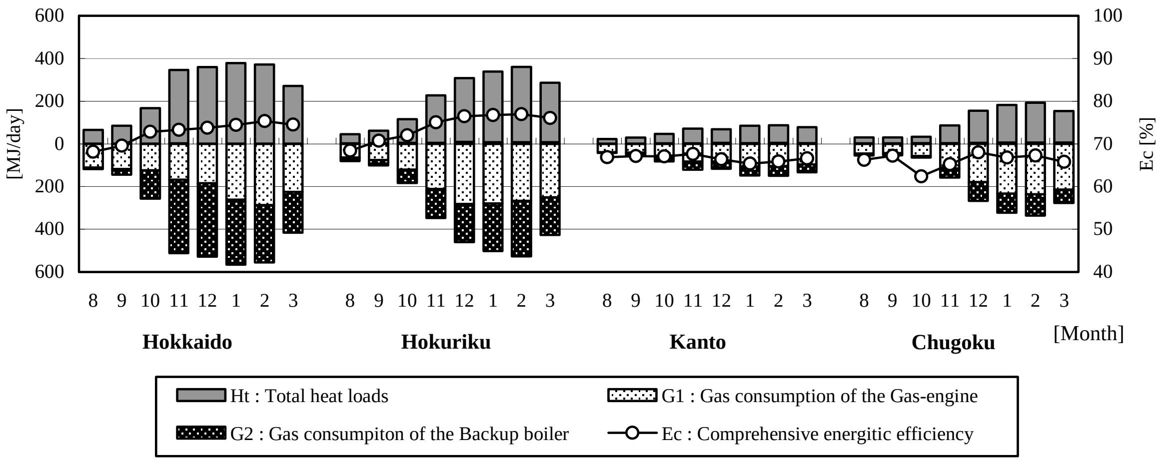


Figure 8 – Monthly energetic efficiency of the system

5.2 Contributing rate of the Gas-engine unit

We define the contributing rate on the GECGS with (5) and (6).

$$C_e\,[\%] = \frac{E3}{E1+E3} \times 100 \qquad (5)$$

$$C_h\,[\%] = \frac{H_g}{H_t} \times 100 \qquad (6)$$

C_e : Contributing rate of electricity for the Gas-engine unit
C_h : Contributing rate of heat quantity for the Gas-engine unit

Figure 9 shows monthly values of “C_e”. According to this Figure, “C_e” was increasing from summer to winter because the operating time of the Gas-engine was increasing to winter. In Hokuriku, the difference of “C_e” between summer and winter was remarkable. On the other hand, in Kanto, it didn’t exceed 30[%] in each month. The maximum value in every house and every month was 67.3[%] on December in Hokuriku.

The distribution of daily total heat loads and electric loads in each house is shown in Figure 10. We classified the samples according to the values of “C_e”. The samples less than 30[%] were shown intensively in the range that the total heat loads were small. On the other hand, in the range that the total heat loads were more than 100[MJ/day], the samples more than 30[%] were found despite the values of electric loads. Therefore, in the house which has demands more than 100[MJ/day] of total heat loads, it is possible that this system purveys more than 30[%] of electric consumption in a house.

Figure 11 shows the monthly values of “C_h”. In summer, it showed more than 80[%] in each house. Therefore, the heat quantity from the Gas-engine unit successfully purveyed most of the total heat loads connected to the GECGS. The values of “C_h” tended to decrease from summer to winter because the total heat loads in winter were larger than those in summer. However in Kanto and Chugoku, “C_h” showed relatively large values in each month. According to the result of Figure 9 and Figure 11, the large values of both “C_e” and “C_h” in winter of Chugoku were grasped.

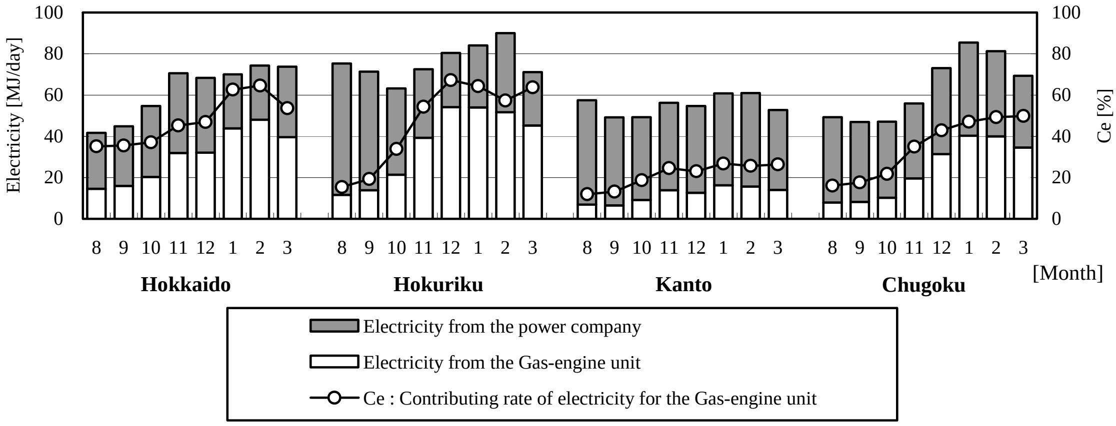


Figure 9 – Monthly Contributing rate of electricity for the Gas-engine unit

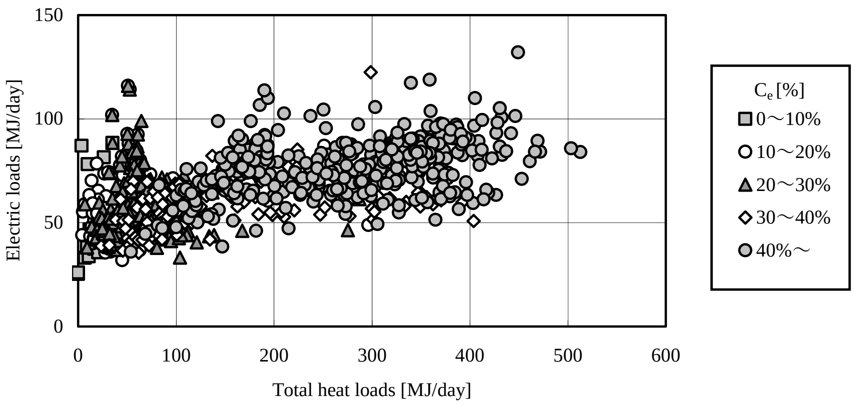


Figure 10 – Distribution of daily total heat loads and electric loads

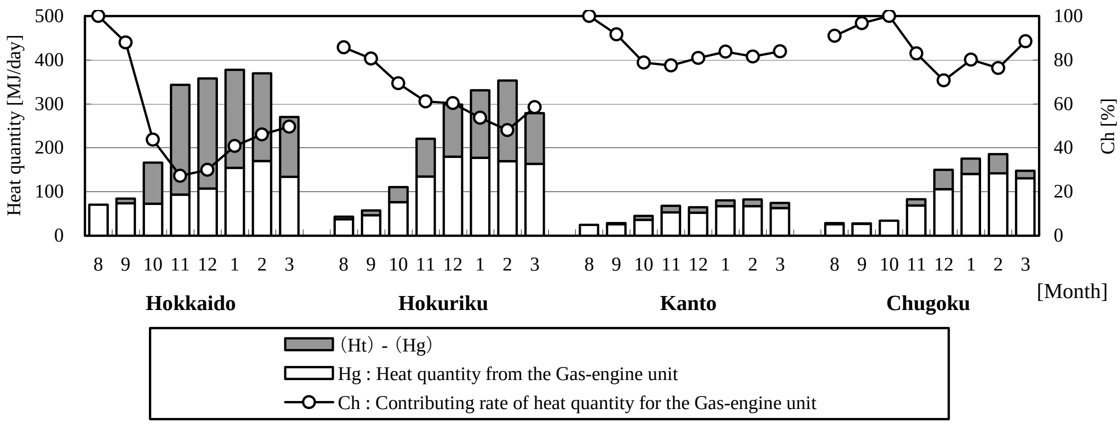


Figure 11 – Monthly contributing rate of heat quantity for the Gas-engine unit

6. Conclusion

We carried out the field measurements in four houses to clarify the performance of GECGS. At first, this paper presented the outlines of the subject households, equipped facilities, methods of the measurement, etc. Also characteristic of the hot water and electric consumption, running condition of the GECGS and efficiencies were shown in each season.

By the results of measurements, we showed monthly fluctuation of electric loads and heat loads for hot water consumption. The heat loads for hot water consumption in each house showed different tendency. Especially, the floor heating loads were extremely different among the regions.

Also, we showed the energetic efficiencies of this system in each season. We clarified that the comprehensive energy efficiency; "E_c" was slightly different among the houses. According to the analysis of the contributing rate of electricity for the Gas-engine unit; "Ce" in the house which had large demands of total heat loads, we clarified that the GECGS could purveys electricity more than 30[%] to the total electric demands. Therefore, it is very important to know that the efficiencies and contributing rates of GECGS have the different tendency according to the heat loads and electric loads in each house.

Acknowledgments

This study is conducted by Center for Better Living in Japan. We wish to express gratitude for the great cooperation of the participants.

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8. Presentation of Author

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B4) A Study of the Leveling Hot Water Supply Demands and the Reduction for Equipment Capacity in Complex Buildings

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Abstract

We have advanced the development of calculation method for hot and cold water demands 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 calculation method is applied by the Monte Carlo Simulation technique. So far in the CIB-W62 symposium, we had proposed the calculation method that was applied to apartment houses, office buildings, restaurants, city hotel and so on. We had confirmed the accuracy of simulation results compared with the measurement results. The calculation method with the utilization of personal computer has flexibility of changing for the conditions of simulation models such as the number of users and the specific types of fixtures like the type of saving water.

In this paper, we rearrange the calculation models for apartment houses, restaurants, and guest rooms of city hotel based on the last data. And we compare the results for the capacities of storage tank and heating power that are calculated with the hot water supply demands hourly between the total values in each type of building and the combined values as a complex building. We clarify the reduction effect for the capacities of storage tank and heating power by the leveling of hot water supply demands as a central hot water supply system planned in a complex building.

Keywords

Hot Water Supply Demand, Storage Tank, Heating Power,
Calculation Method, Monte Carlo Simulation, Complex Building

1. Introduction

Concern for the increase of the global mean temperature is growing now in the world. From the view point of global environment, we are required to reduce the emissions of greenhouse gases, such as carbon dioxide, nitrous oxide, methane, chlorofluorocarbons (CFCs), etc. Therefore, it is very important to save energy consumed in buildings on the basis of suitable scale design for building equipments.

In the buildings such as houses, restaurants, hotels, etc., the energy consumption for hot water supply has very high ratio to the total energy consumption in the buildings. Therefore, the suitable design for the capacity of storage tank and heating power in the hot water supply system is required on the basis of the high accuracy estimation of hot water demands in each type of building.

We have developed the calculation method for cold and hot water demands in the various types of building [1- 8]. The method is to estimate the demands in the time series such as daily, hourly and instantaneous loads by using the Monte Carlo Simulation technique.

At CIB-W62 Symposium in the last year, 2007 [Brno, Czech Republic], we showed the cold and hot water demands in the guest rooms of a city hotel, and analyzed the relationships between the heating power and the minimum capacity of storage tank on the basis of the calculation results in the time series through a day; one minute interval[9].

In this paper, we choose the three types of building as a case study; apartment houses, restaurants, and guest rooms of city hotel, from the investigated data on the past years. In addition we compare the two results for capacity of storage tank and heating power that are calculated by each type of building and complex building composed of three types. We clarify the reduction effect for the capacity of storage tank and heating power by the leveling of hot water demands as a central hot water supply system in the complex building.

2. Calculation models in each type of building and setting scale of complex building

As for the simulation models on the hot water usage in each type of building, we apply the hot water calculation models that have been proposed by our analyzed measurement data. The outlines of the calculation models, and the setting scale of complex building as a case study are as follows.

2.1 Calculation model for apartment houses

Table 1 and Figure 1 show the calculation model of hot water demands in each fixture usage of apartment houses. In this study, we suppose the common family uses. Therefore, the models of family size shown in Table 1 have three or four persons. Also, Table 1 shows as an example of weekday in winter season. In this Table, the frequency of usage per day means the total operating times in each fixture usage through a day. The hourly frequency in each fixture usage can be calculated by the hourly ratio to the frequency through a day on the basis of Figure 1.

In the right column in Table 1, the consumption per day and per flat at the conversion temperature of the 60°C can be calculated by the daily frequency and the average values of hot water demand per one operating fixture usage which are multiplied by the discharge flow rate and duration time. The values of hot water consumption in the hotel and restaurants described later are calculated by the same way.

In this model of apartment houses, we apply the bath water supply system without a reheating function. The “Ratio of hot water usage” in Table 1 is considered to have occurrence of the nonuse of hot water by being away from home, etc. The “Filling bathtub” is set with the value of 0.85, and other uses are set with the value of 1.00. Also, we apply the decrease ratio for more than the number of ten flats as building scale. The ratio is calculated with the following equation, which was introduced by the measurements of apartment houses [S. Murakawa et. al , CIB62, 1989].

$$\text{Decrease ratio } Y = 0.964\,X^{0.957} / 0.873X$$

However, X = the number of flats [$X>=10$]

The temperature of hot water usage in each fixture is set with the fixed value.

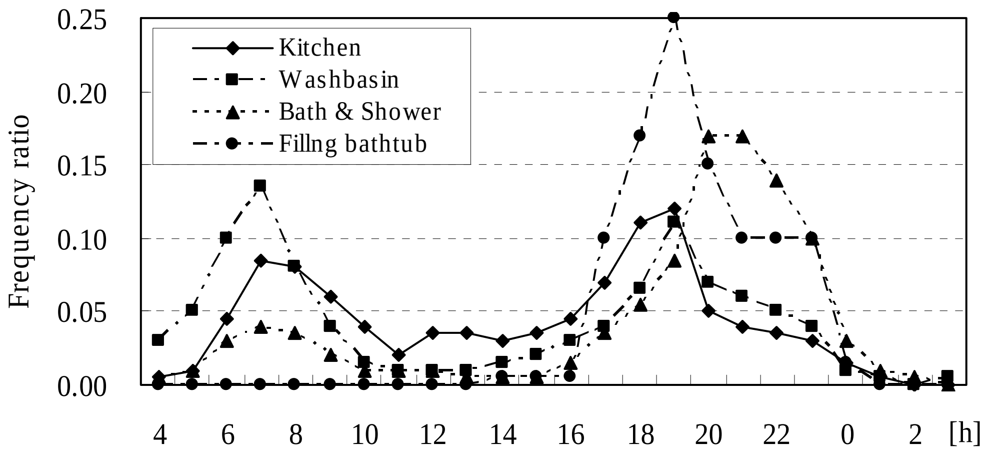

Figure 1 – Average frequency of hot water usage (Apartment houses)

Table 1 - Simulation model in each fixture usage of apartment houses

Fixture usage	Frequency of usage [frequency/flat/day]		Duration time of discharge[sec]		Flow rate[L/min]		Utilized temperature [°C]	Ratio of hot water usage	Hot water consumption [L/flat/day] (as 60°C)	
	Family of three persons	Family of four persons	Set up mean value	Distribution	Set up mean value	Distribution			Family of three persons	Family of four persons
Kitchen	24.0	28.0	50.0	Hyp.K=2	8.0	Erl.K=15	38.0	1.00	92.3	107.7
Washbasin	3.0	6.0	40.0	Exp.	7.0	Erl.K=10	37.0	1.00	7.8	15.6
Bath & Shower	6.0	7.0	120.0	Exp.	8.0	Erl.K= 7	40.0	1.00	59.1	68.9
Fillng bathtub	1.0	1.0	1200.0	Erl.K=15	8.0	Erl.K=20	58.0	0.85	153.8	130.8
Total	−	−	−	−	−	−	−	−	313.0	323.0

*1) Cold water temperature 8°C, supply hot water temperature 60°C in Winter
2) This model has no reheating system.
3) Exp, Hyp and Erl mean exponential distribution, hyper exponential distribution and Erlang distribution respectively in the column of [Distribution]

2.2 Calculation model for guest rooms of city hotel

Table 2 and Figure 2 show the calculation model of hot water demands in the guest rooms of city hotel. At the CIB-W62 Symposium in 2007 [Brno], we presented a paper on the calculation for cold and hot water demands in the guest rooms of a city hotel. On the basis of those results, in this paper we apply the highest demand of “Level 1” with two persons in a guest room.

The peak hours of taking bath appear at late period of night time in comparison with that of apartment houses. The utilization of “Bathtub” gives the highest influence to the total of hot water supply loads in the guest rooms.

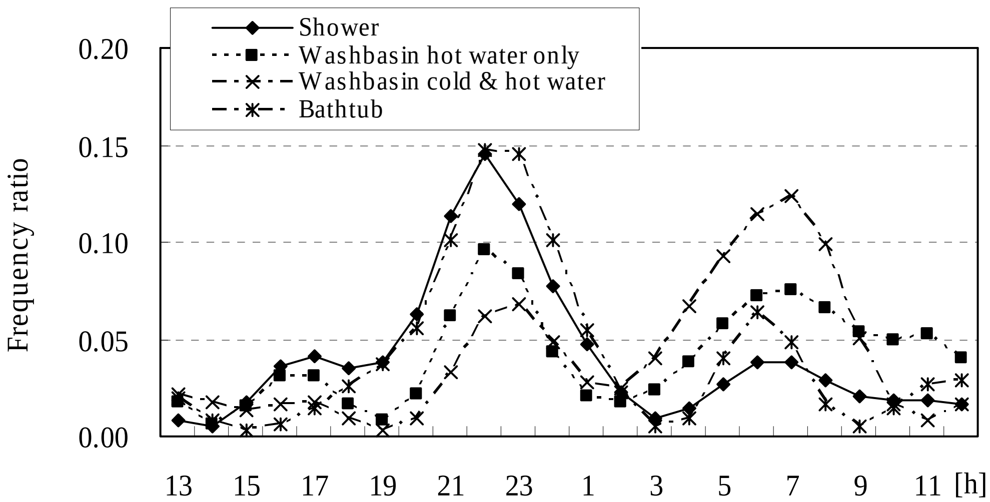

Figure 2 - Average frequency of hot water usage (Guest rooms of city hotel)

Table 2 - Simulation model in each fixture usage of guest rooms of city hotel

Fixture usage		Frequency of usage [frequency/room/day]	Duration time of discharge[sec]		Flow rate[L/min]		Temperature[°C]		Hot water consumption [L/room/day] (as 60°C)
			Set up mean value	Distribution	Set up mean value	Distribution	Set up mean value	Distribution	
Shower	cold & hot	5.6	160.0	Erl.K= 2	10.0	Erl.K=10	41.5	Erl.K=100	95.9
Washbasin	hot	3.9	35.0	Erl.K= 3	2.5	Erl.K= 2	60.0	const.	5.7
	cold & hot	4.3	70.0	Erl.K= 5	5.0	Erl.K=10	37.0	Erl.K= 20	14.0
Bathtub	cold & hot	3.2	315.0	Exp.	26.0	Erl.K= 6	42.0	Erl.K= 50	281.3
Total		—	—	—	—	—	—	—	396.9

*1) Cold water temperature 8°C, hot water supply temperature 60°C in Winter

2) Exp, Hyp and Erl mean exponential distribution, hyper exponential distribution and Erlang distribution respectively in the column of [Distribution]

2.3 Calculation model for restaurants

Table 3 and Figure 3 show the calculation models of hot water demands in restaurants. We had presented the two papers on the calculation methods of hot and cold water demands in the restaurants [4, 7]. In the papers, we suggested the technique for making model which was set up as a unit of water usage because it was very intricate to make calculation models for each fixture in the kitchen of a restaurant.

On the basis of the measurement results for six restaurants, the hourly average ratio of hot water usage through a day [from 7:00 to 24:00] was clustered with three patterns shown in Figure 3. In each pattern, the peak demands of hot water appear in daytime and nighttime. The pattern A shows higher peak in daytime than nighttime. The pattern B shows the converse pattern of the A. The pattern C shows three peaks in the morning, noontime and nighttime.

In case of two instantaneous water heaters installed in a kitchen, we have two hot supply lines except main line for making model.

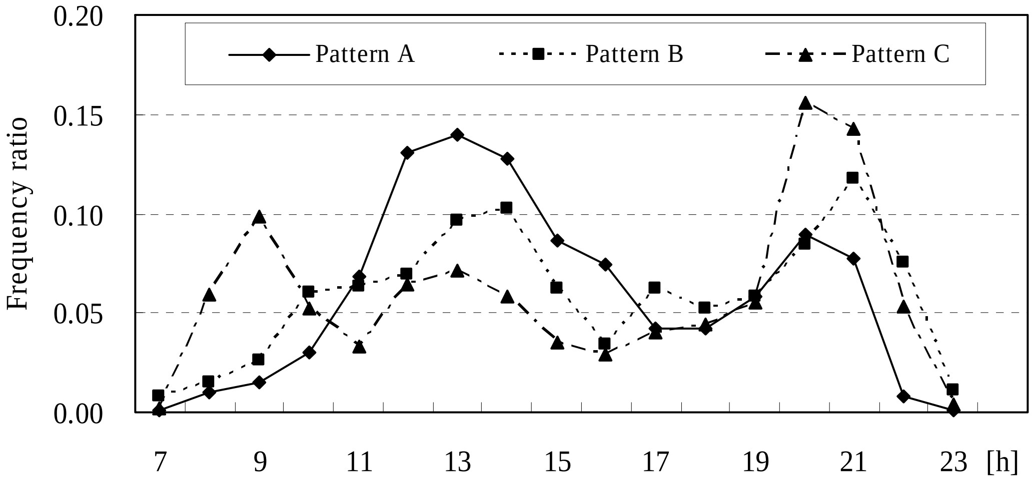

Figure 3 - Average frequency of hot water usage (Restaurants)

Table 3 - Simulation model in each kitchen of restaurants

Restaurant	Frequency of usage [frequency/day]	Duration time of discharge[sec]		Flow rate[L/min]		Hot water consumption [L/day] (as 60°C)	Hourly fluctuation pattern of frequency
		Average value	Distribution	Average value	Distribution		
Restaurant C	368.2	74.0	Hyp.K=10	6.1	Erl. K= 5	2754	B
Restaurant D	409	29.0	Exp.	5.4	Erl. K=10	1052	A
Restaurant F	306	142.0	Hyp.K= 2	4.6	Erl. K= 5	3308	C
Water heater F1	90	74.0	Hyp.K= 2	7.5	Erl. K=15	827	
Water heater F2	195	165.0	Hyp.K= 2	4.6	Erl. K=10	2481	
Restaurant I	184	142.0	Hyp.K= 3	7.8	Erl. K= 5	3412	A
Water heater I1	141	102.0	Hyp.K= 2	8.6	Erl. K=20	2062	
Water heater I2	179	107.0	Erl. K= 5	4.2	Erl. K=40	1350	
Restaurant J	429	52.0	Hyp.K= 2	7.5	Erl. K= 5	2812	B
Water heater J1	134	20.0	Erl. K=20	9.9	Erl. K=15	450	
Water heater J2	399	61.0	Hyp.K= 2	5.9	Erl. K=10	2363	
Restaurant K	133	70.0	Hyp.K= 3	7.0	Erl. K=20	1084	B

*1) Cold water temperature 8°C, supply hot water temperature 60°C in Winter

2) Exp, Hyp and Erl mean exponential distribution, hyper exponential distribution and Erlang distribution respectively in the column of [Distribution]

2.4 Setting model for complex building

As an example of calculation, we set up the imaged scale of a complex building shown in Table 4. In this case study, we set up 300 flats which are composed of three persons and four persons for a family size. The city hotel has 200 guest rooms with twin beds as a middle scale supposed. The six restaurants analyzed in the measurement are imaged to place in the complex building.

Table 4 – Setting scale of complex building

Building usage	Model & Scale	Average hot water consumption[L/day]	Hot water consumption[L/hour]			Peak time zone
			Average	Peak	Peak rate	
Dwelling house	100 families of three persons	26470.7	1102.9	4576.9	4.1	19
Dwelling house	200 families of four persons	57204.5	2383.5	9402.1	3.9	19
Hotel	200 twin rooms (Level 1)	80670.3	3361.3	11528.4	3.4	22
Restaurant	Total (C,D,F,I,J,K)	14801.3	616.7	1643.8	2.7	21
Total		179146.8	870.7	1643.8	1.9	22

The main usage to affect for hot water supply loads will be estimated by apartment houses and a city hotel. These two types of the building have different peak time zones for hot water demands. Therefore, the total hot water supply demands will appear in hourly leveling when the each type of building is composed with a complex building.

3. Calculation of hot water demands and equipment capacity

3.1 Process for calculation

According to the calculation models for hot water demands and the supposed scale of a complex building, we carry out the calculation of hot water demands by using the Monte Carlo Simulation technique. The simulation is carried out 100 times with repetition to get the stability for calculation. We get the fluctuation patterns of hot water demands in the time series through a day. By using the statistical analysis, we can calculate the instantaneous maximum flow rates, hourly peak values and daily values of hot water demands.

However, we need to apply the fluctuation patterns of hot water demands in the time series, when we analyze the relationships between the heating power and the capacity of hot water storage tank. The basic process for calculation of the suitable equipment capacity is shown in Figure 4.

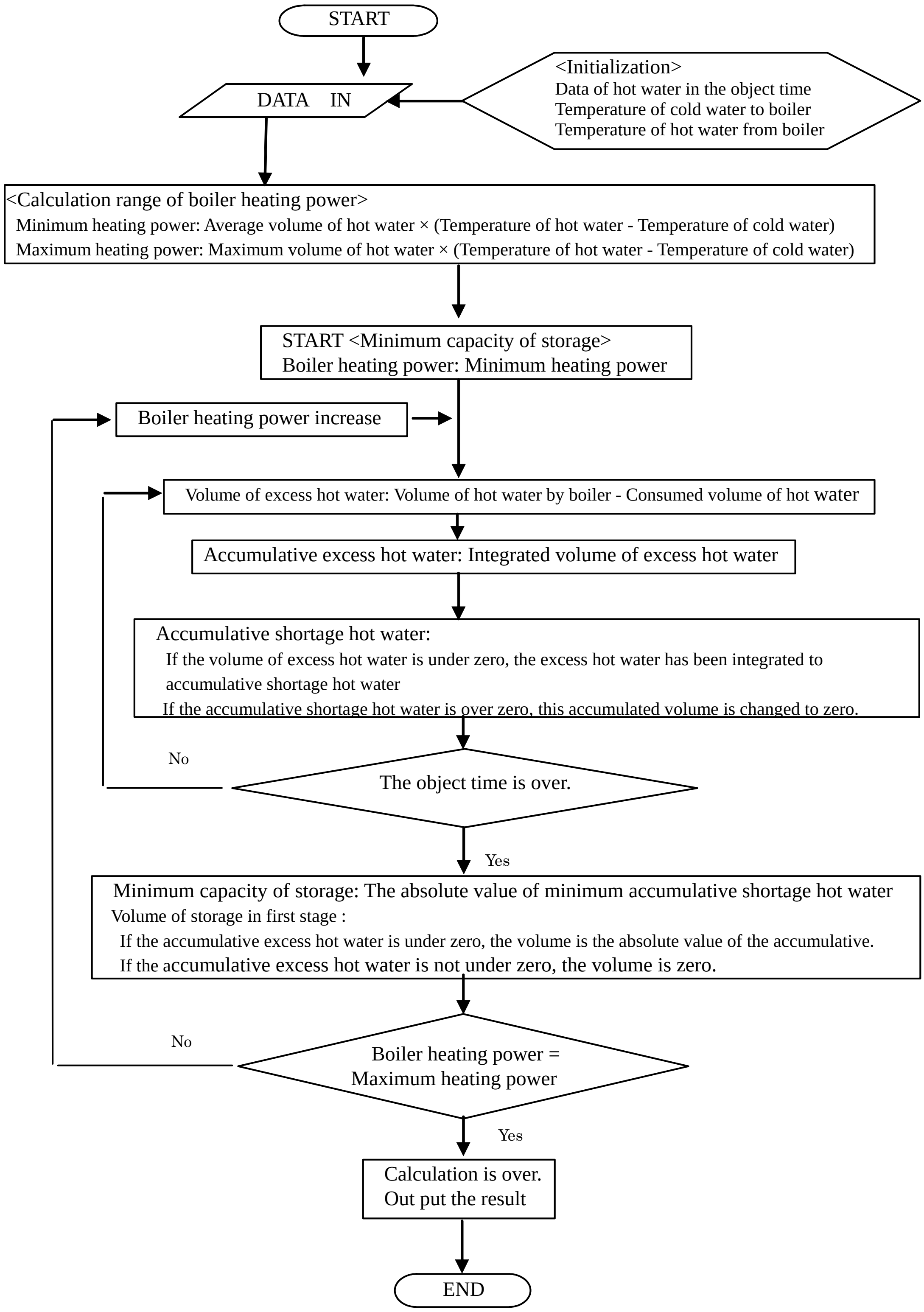

Figure 4 – Calculation process for equipment capacity

In this study, we apply the hot water demands in the time series of one minute interval through a day, and we carry out 100 times for the simulation. Based on the estimated hot water demands, the basic process is as follows.

When the hot water demands exceed the heating power, the shortage volumes that are calculated from the difference values between the heating power and hot water demand are accumulated. Moreover, the maximum value of the cumulative shortage volumes that are calculated through a day is decided as the minimum capacity of storage tank.

3.2 Calculation results of hot water demands

Figure 5 shows the calculation results of hot water demands as the hourly average values of 100 trials which were simulated in each usage type of building. On the total hourly values of three types usage in buildings, the peak value that is affected by apartment houses and guest rooms in city hotel appears at the time zone of 22:00 – 23:00.

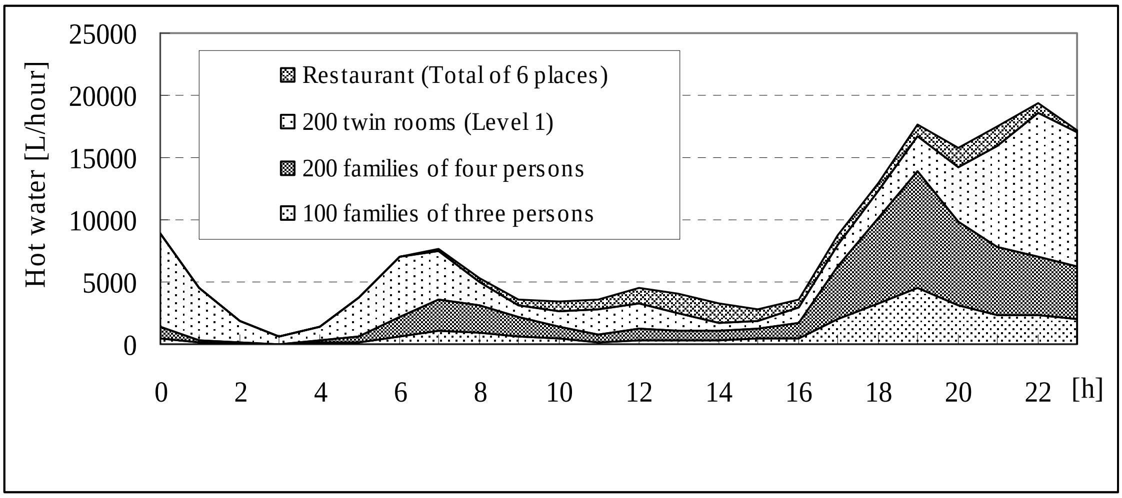

Figure 5 – Hourly average volumes of hot water demands

As an example of the simulation, Figure 6 shows the total instantaneous flow rates per minute that were calculated in each type of building. From these results, the total hot water demands at the peak time zones in the morning and night show the leveling values because the peak load in each type of building appears at different time zone.

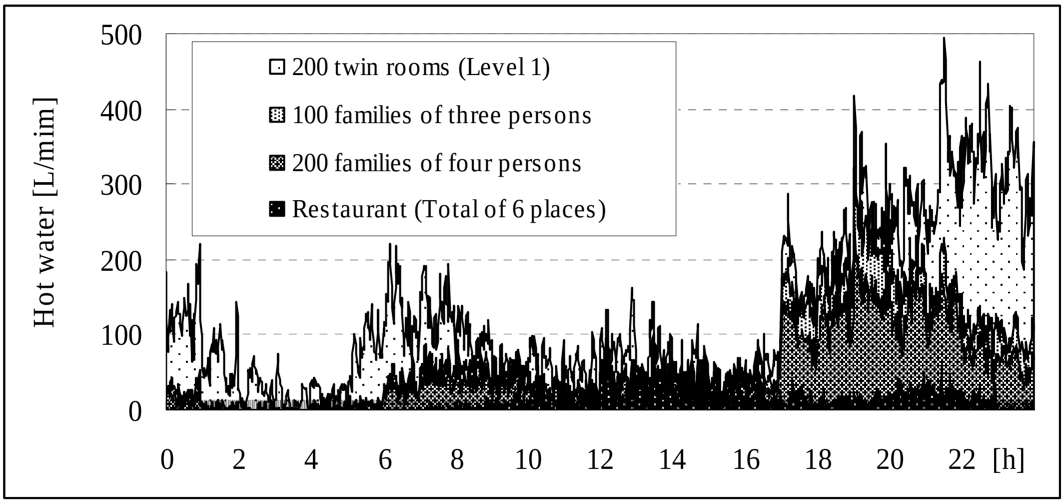

Figure 6 – Example of the instantaneous hot water flow rates per minute

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3.3 Calculation results of equipment capacity

Figure 7 shows the calculation results of equipment capacity for the complex building as the relationships between the heating power and the minimum capacity of storage tank. The marked value in the Figure 7 shows the existing design value that is calculated for dwelling houses or hotels by the Handbook of SHASE. The existing design method shows excessive calculation result when we compare with the simulation results proposed in this study.

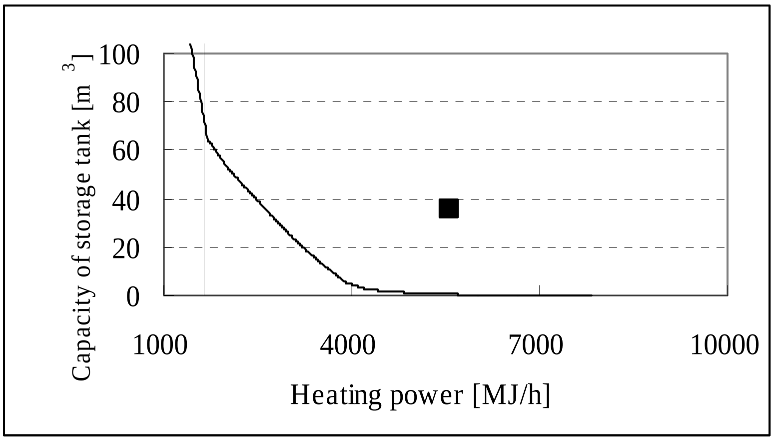

Figure 7 – Relationships between the heating power and the minimum capacity of storage tank

Also, Figure 8 shows the relationships between the heating power and the minimum capacity of storage tank as the percentage to the average values of daily hot water consumption in each type and complex building. The difference between the simulation

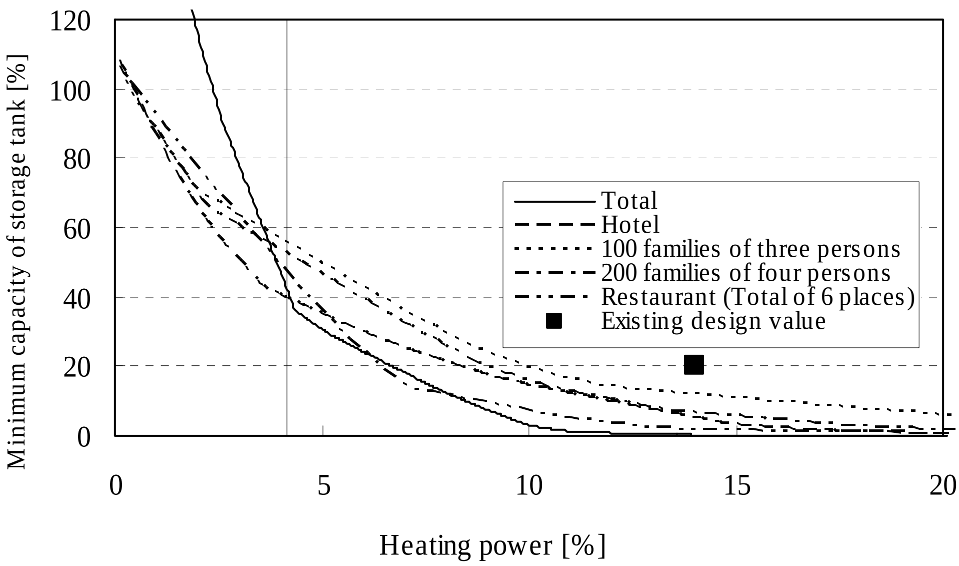

Figure 8 - Relationships between the heating power and the minimum capacity of storage tank as the percentage to the average values of daily hot water consumption

results in complex building and the existing calculation results is lager than that difference in each usage type. Therefore, it is supposed to reduce the equipment capacity when the three types of the central hot water supply system merge into one central system.

3.4 Effect to reduce the equipment capacity by leveling of loads

Figure 9 shows the capacity of heating power when the capacity of storage tank is set with 20% in the daily average hot water consumption. The combined value as a complex building is compared with the total value in each type of building.

In this case study, the heating power of central system as a complex building is reduced about the value of 774.4 [MJ/h] in comparison with that calculated in each type of building. It is about 22.1 [%] as the reduced ratio to the total value calculated in each type of building. The reduced effect ratios are shown in Figure 10, when the percentage of storage tank capacity to the daily average hot water consumption is changed. In case of the value of 20 [%] storage tank capacity, the reduced effect ratio shows the most small value.

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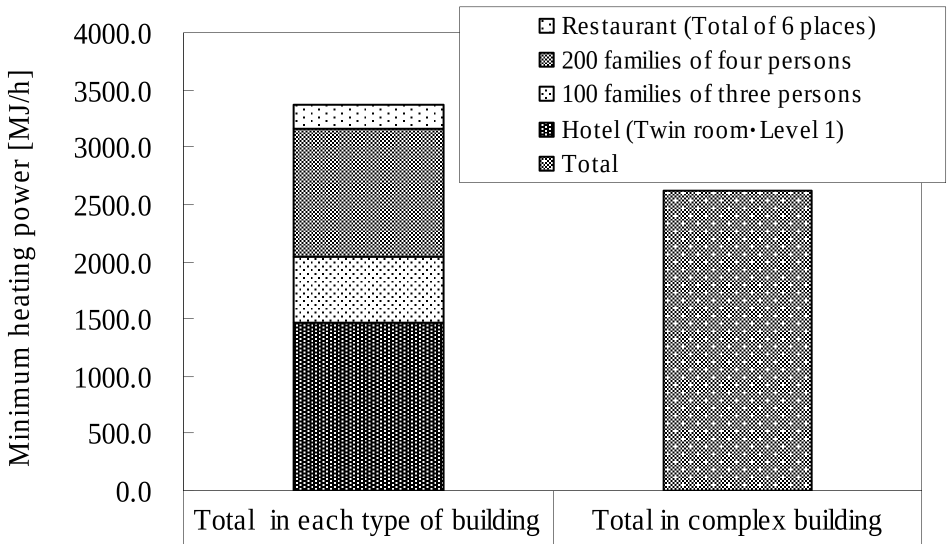

	Total in each type of building	Total in complex building
Restaurant (Total of 6 places)	209.0	
200 families of four persons	1123.2	
100 families of three persons	574.7	
Hotel (Twin room･Level 1)	1462.8	
Total	3369.6	2625.2

Figure 9 – Comparison of heating power in the complex building and the total value in each type of building (Example: Capacity of storage tank=20% in the daily average hot water consumption)

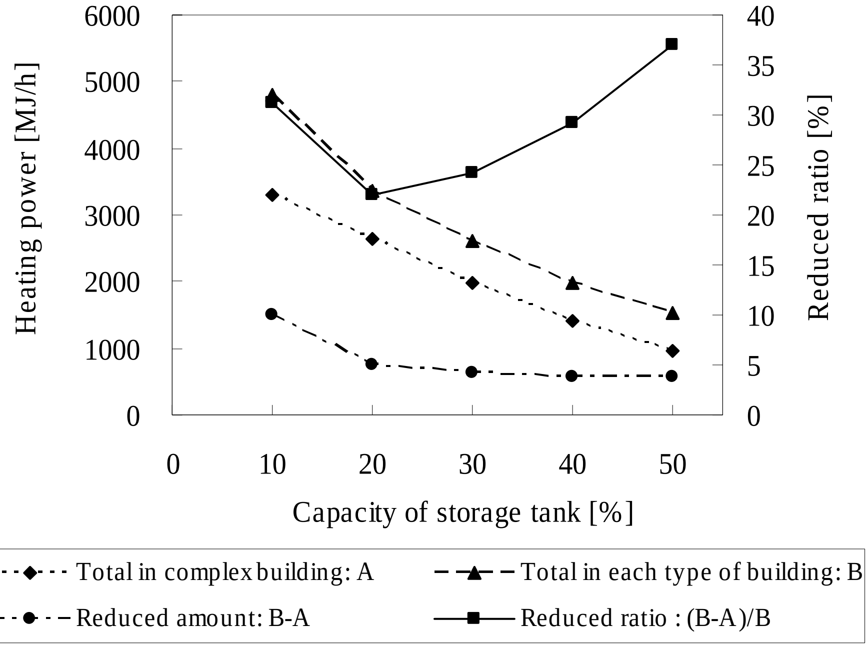

Figure 10 – Reduced heating power in changing of the capacity of storage tank

4. Conclusion

In this paper, we proposed the calculation models for hot water supply demands in each type of building; apartment houses, guest rooms in city hotel and restaurants. We carried out the Monte Carlo Simulation technique to estimate the hot water consumption in the time series through a day.

On the basis of the calculation loads for hot water consumption in each type of building, we analyzed the relationships between the heating power and the capacity of storage tank, in comparison with the total value calculated in each type of building and the value calculated in a complex building. We clarified the effect to reduce the capacity of storage tank and heating power by the leveling of hot water supply demands as the central supply system in a complex building.

As shown in this paper, it is very important to estimate accurately the hot water supply demands in the time series through a day. We propose to apply the simulation technique as for the suitable design method to decide the scale of building equipments.

Acknowledgement

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6. Main author presentation

Saburo Murakawa is the Emeritus Professor at Hiroshima University. His special fields are building and city environment engineering, plumbing engineering and environmental psychology. He is now studying to develop the new calculation technique for cold and hot water demands in various buildings to establish the standard method.

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B5) A study on the energy efficiencies of condensing type gas water heater and CO_2 heat pump water heater for household use in winter season of a cold climate area

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Abstract

The author compared the efficiency of the condensing type gas combustion water heater with that of the CO_2 heat pump water heater, and analyzed the primary energy consumption and the CO_2 emission in a cold area of Japan. The performance of each water heaters was investigated in the same house with changing them in turn. The mean of energy efficiency was 0.85 in the case of condensing type gas combustion water heater, and it was 0.61 in the case of CO_2 heat pump water heater. The primary energy consumption of the gas combustion water heater was less than the CO_2 heat pump water heater, and energy efficiency was higher.

Keywords

CO_2 emission; hot water supply; gas combustion water heater; electric power water heater with heat pump

1. Introduction

Energy saving water heater in a house could reduce the amount of CO_2 emission. Natural gas and electric power are mainly used for it. The authors investigated the two different water heaters and analyzed the performance for most appropriate.

2. Outline of measurement

The detached house in Obuse town, where is located at the northern cold area in the

Nagano Prefecture, has been constructed in dependence upon insulation standard of the saving energy laws of Japan. The total floor area is 142.56m² and the number of occupants is five as a family, which are man, his wife and three children. They have used the hot water at bathroom (shower and bath), the dressing room (hand wash), and kitchen (cooking and washing-up). Two type water heating systems were installed to the same house and used in changing over, and the performance of each system was analyzed.

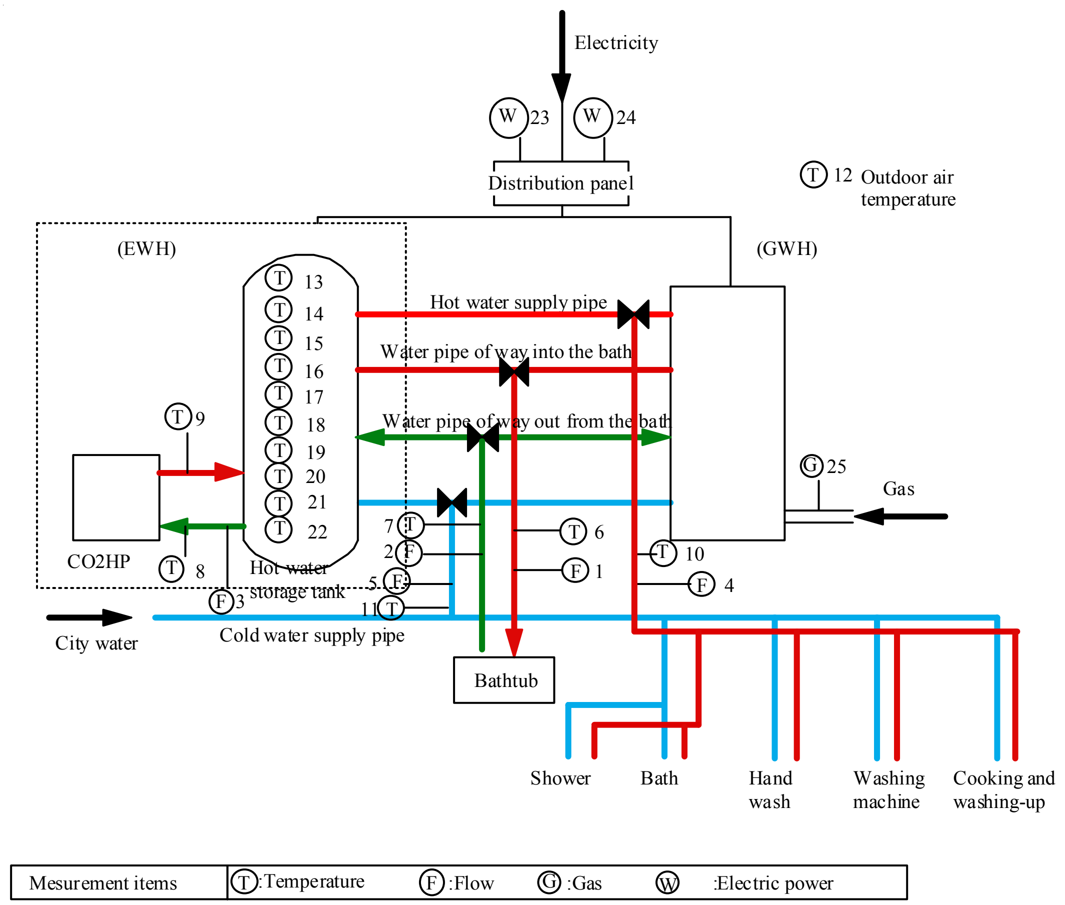

Figure 1 – Hot water system for investigation.

2.1 Measurement system

The measurement system is shown in Figure-1 and the measurement items are shown in Table-1. The measurement interval was one minute. The electronic power consumption was measured in the distribution panel, and the natural gas mass flow measured in the diverging pipe line to the water heater. The gas combustion water heater (GWH) used the latent heat of the burnt gas after combustion in addition to energy on combustion, which increased the city water temperature. This system is shown in Table-2. The electric water heater (EWH) used the heat pump (HP) in which heat carrier was CO_2, and operating period was mainly in night. This system has the storage tank, in which hot water is keeping at 80 °C in heating, is shown in Table-3.

2.2 Measurement period

The measurement period was from October 2nd 2007 to February 4th 2008.The operating schedule of each water heating system is shown in Figure-2. The investigated period was two weeks for each system. However, EWH included the learning function which adjusted the amount of the hot water demand, for which 7 days were necessary in automatically. The period for one time operation of EWH was three weeks.

Table 1 – Measurement items

Items	Measurement items	Measure	Number (figure-1)
Flow	Water flow of way in to the bath	L/min	1
	Water flow of way out from the bath	L/min	2
	Water flow of way in to the HP	L/min	3
	Hot water supply flow	L/min	4
	Cold water supply flow	L/min	5
Temperature	Water temperature of way in to the bath	° C	6
	Water temperature of way out from the bath	° C	7
	Water temperature of way in to the HP	° C	8
	Water temperature of way out from the HP	° C	9
	Hot water supply temperature	° C	10
	City water temperature	° C	11
	Outdoor air temperature	° C	12
	Storage tank surface temperature	° C	13 - 22
Electric power	EWH	Wh	23
	GWH	Wh	24
Gas	GWH	m^3	25

3. Investigation of EWH

The water temperature of way in/out of HP, outdoor air temperature, the city water temperature and power consumption during 24hours from 12:00 January 23th, 2008 are shown in Figure-3 as an example of the operation status of HP from 16:30 to 3:20. The water temperature of way out from HP was kept up to about 80°C, and it of way in to HP increased gradually and stopped at about 55°C. Sometimes HP did not generate the thermal calorie because the defrost operation was done in the cold air temperature.

4. Performance evaluation

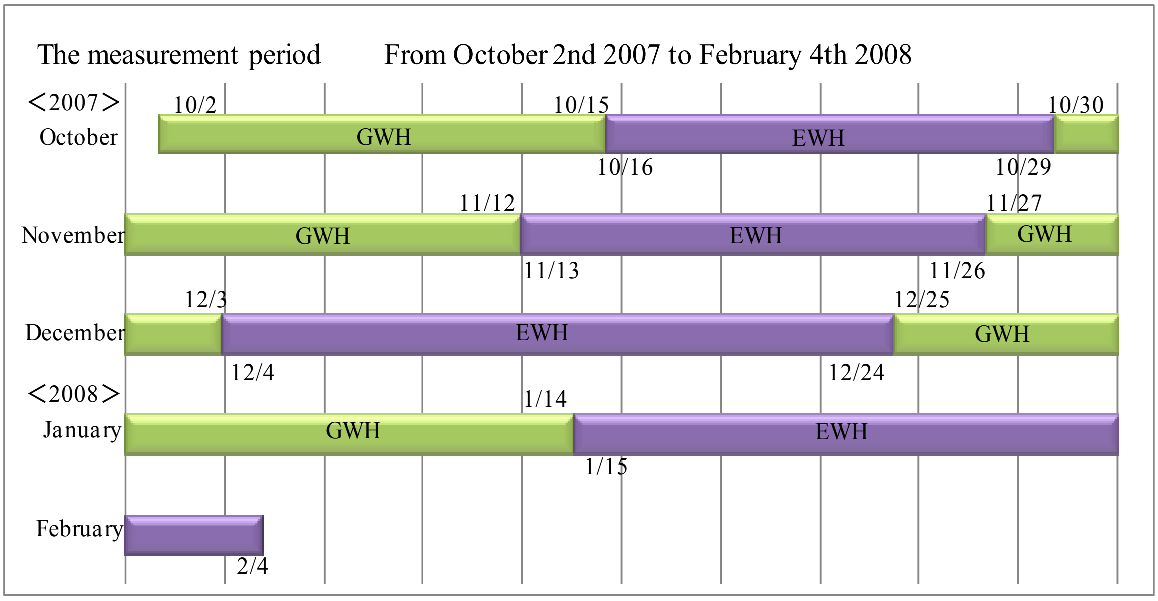

Figure 2 – The operating schedule

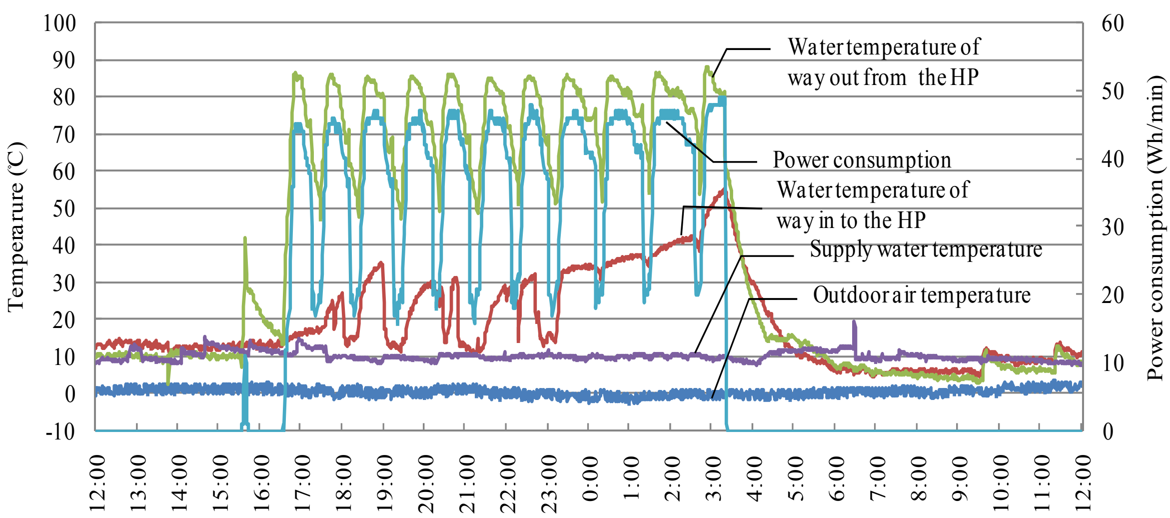

Figure 3 – Temperature and power consumption of EWH

Table 2 – The specification of GWH

	Specification
Thermal capability	4.88 - 48.8 kW
Rated efficiency	95%
Power consumption	0.19 kW
Defrost heater	0.288 kW

Table 3 – The specification of EWH

		Specification
Storage tank volume		460 L
Thermal capability		6.0 kW
Standby electricity		0.011 kW
COP (specification)		4.6
Power consumption	Rating	1.30 kW
	Winter	1.79 kW

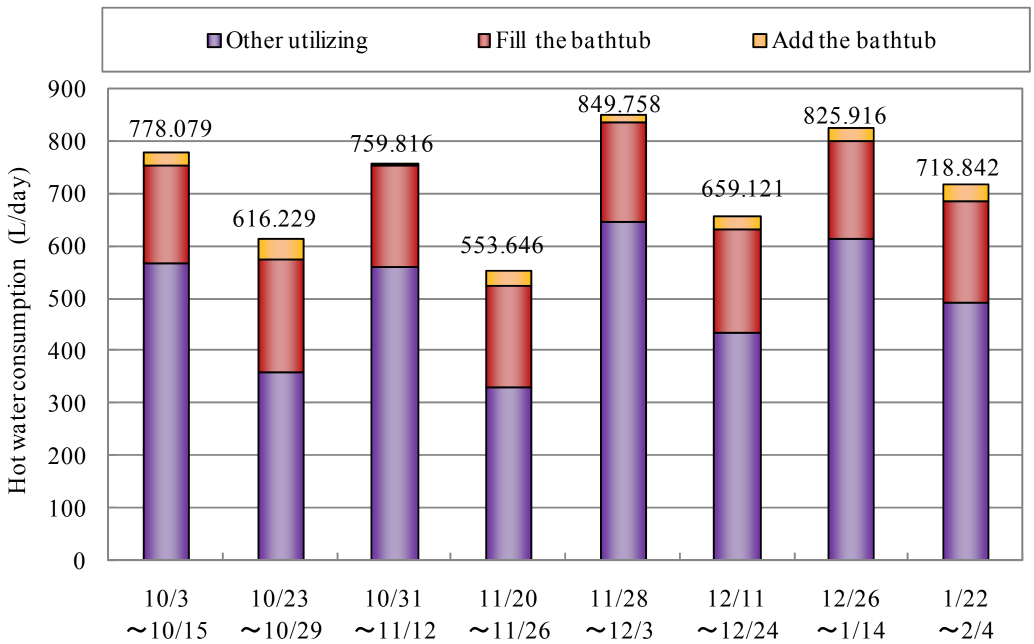

Figure 4 – Hot water consumption

4.1 Load of hot water

The purpose of use was classified (1) fill the bathtub, (2) add the bathtub, (3) reheat the water in the bathtub, (4) further utilizing, and (5) total use, in accordance with the intended use. The amount of used hot water at every period was daily averaged in each purpose of use, and they are shown in Figure-4. The variation of hot water thermal loads and outdoor air temperature are shown in Figure-5. GWH was operated for 45 days. The correlation coefficient of the daily integrated calorie of hot water in service and the daily mean outdoor air temperature were calculated, and they are shown in Table-4.

EWH was operated for 36days without the learning period. The correlation coefficient of the daily integrated calorie of hot water in service and the daily mean outdoor air temperature were calculated, and they are shown in Table-5.

The variation coefficient of "fill the bathtub" was small, but those of "add the bathtub", "reheat the bathtub" were remarkable. The correlation efficient of "add the bathtub" was small. There were difference between GWH and EWH about "fill the bathtub", "add the bathtub" and "reheat the bathtub", but there were not necessarily difference between GWH and EWH about "further utilization" and "total use", when the difference of the population mean value was tested by the significant level 5% in each purpose of each water heater.

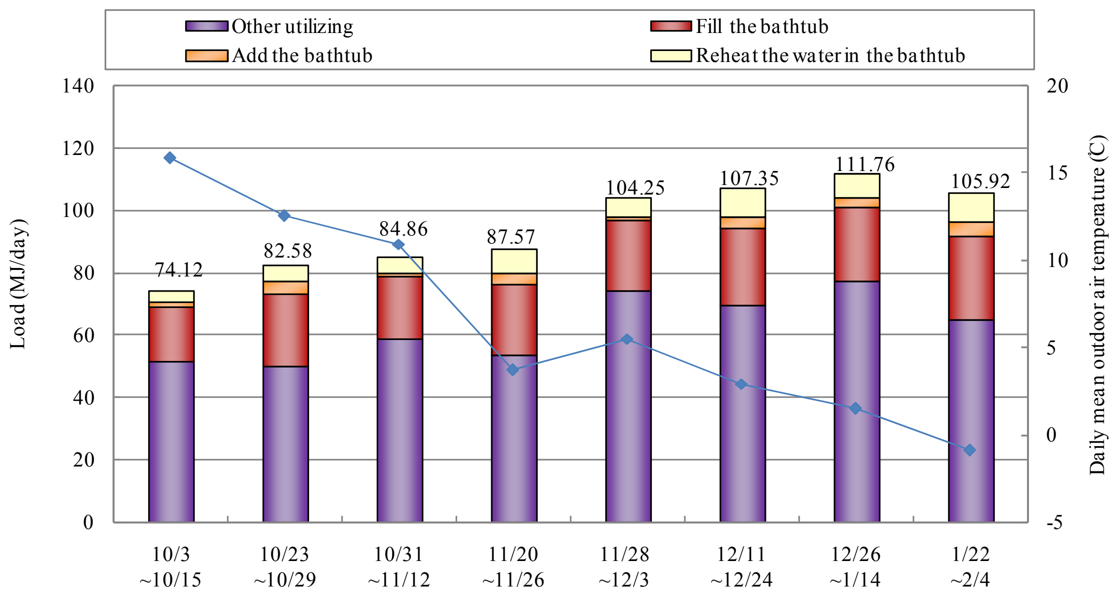

Figure 5 – Variation of temperature and hot water loads

Table 4 – The energy consumption of GWH

Purpose of use	Energy consumption (MJ/day)				Coefficient of variance (%)	Coefficient of correlation
	Mean	Standard deviation	Max.	Min.		
Fill the bathtub	21.04	2.56	24.40	17.07	12	-0.94
Add the bathtub	1.93	1.97	7.95	0.00	102	-0.25
Reheat the water in the bathtub	5.51	2.34	12.04	1.55	42	-0.73
Other utilizing	65.00	18.78	102.76	26.07	29	-0.55
Total use	93.48	22.51	136.01	49.75	24	-0.67

4.2 The secondary energy consumption, the primary energy consumption, and amount of CO_2 emission

In the case of GWH the electric consumption on December 26th, 2007 - January 14th, 2008 increased more than other periods, since the electric heater fitted with GWH was operated for the frozen prevention. In the case of EWH there were not necessarily difference of the daily mean power consumption between learning period and ordinary operating period, when the difference of the population mean value was tested by the significant level 5%. The calorific value of natural gas is 43.14MJ/Nm3, and the primary energy of electric power is 9.76MJ/kWh in Japan.

Table 5 – The energy consumption of EWH

Purpose of use	Energy consumption (MJ/day)				Coefficient of variation (%)	Coefficient of correlation
	Mean	Standard deviation	Max.	Min.		
Fill the bathtub	24.78	1.58	27.02	22.47	6	-0.78
Add the bathtub	3.90	2.59	14.26	0.00	67	-0.14
Reheat the water in the bathtub	8.54	2.84	15.00	2.85	33	-0.50
Other utilizing	62.24	13.84	89.23	36.91	22	-0.31
Total use	99.45	17.13	131.83	69.78	17	-0.43

Table 6 – The statistical values of energy consumption

		Mean	Standard deviation	Max.	Min.
Secondary energy consumption (MJ/day)	GWH	106.39	25.84	153.05	58.24
	EWH	62.98	15.12	91.61	31.69
Primary energy consumption (MJ/day)	GWH	111.24	29.43	166.32	58.78
	EWH	191.98	40.99	248.37	85.92
CO_2 emission ($kg\text{-}CO_2$/day)	GWH	5.62	1.48	8.38	2.97
	EWH	8.41	2.02	12.24	4.23

The statistic values of the secondary energy, the primary energy and CO_2 emission are shown in Table-6. The specific CO_2 emission value is 0.0506kg- CO_2/MJ in the natural gas and it is 0.481kg- CO_2/kWh in the electric power. The daily mean secondary energy consumption of GWH was larger than EWH, but the daily mean primary energy consumption of EWH was larger than GWH.

4.3 Efficiency of hot water supply and energy efficiency

The efficiency of hot water supply based on the energy consumption in the house is named "the hot water efficiency", and the efficiency of hot water supply based on the primary energy consumption is named "the energy efficiency". The variation of energy efficiency in each period is shown in Figure-7. The daily mean hot water supply efficiency of GWH was 0.88, and standard deviation was 0.03. On the other hand, they of EWH were 1.64 and 0.37. The energy efficiency through the investigated period of GWH was 0.85 and it of EWH was 0.61.

4.4 Relation among the secondary energy consumption, efficiency of hot water supply and daily mean outdoor air temperature

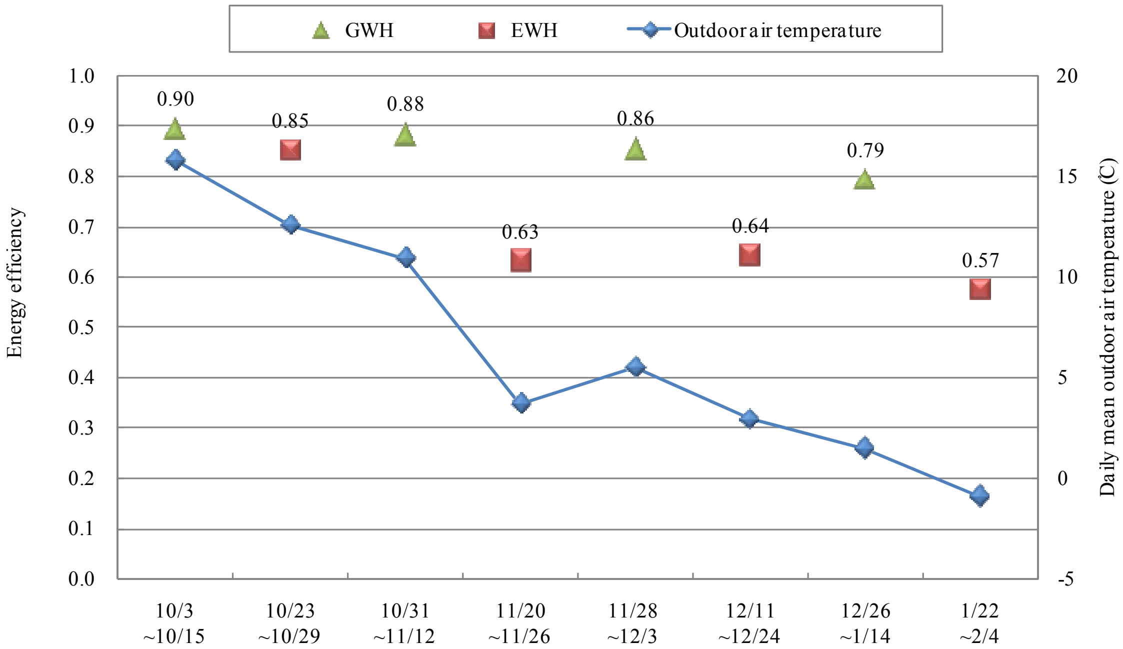

Figure 6 – Energy efficiency of GWH and EWH

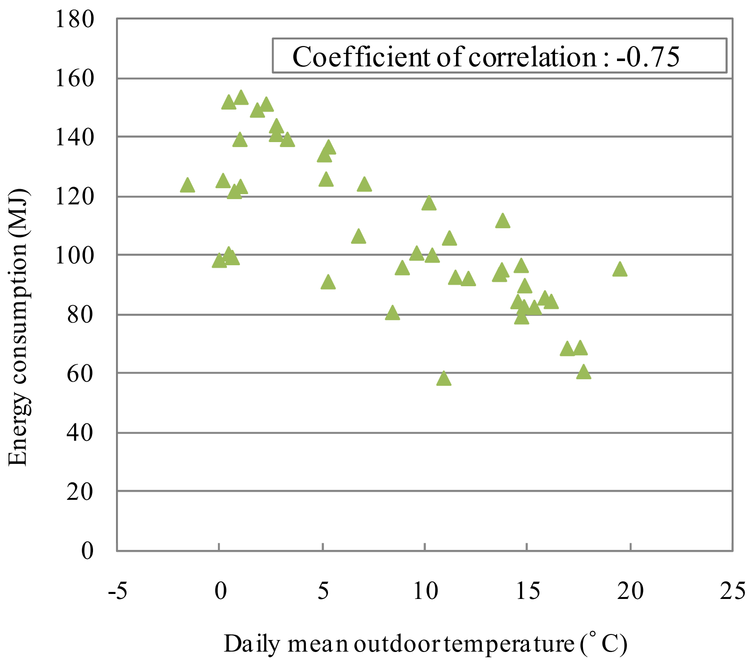

Figure 7 – Secondary energy consumption of GWH

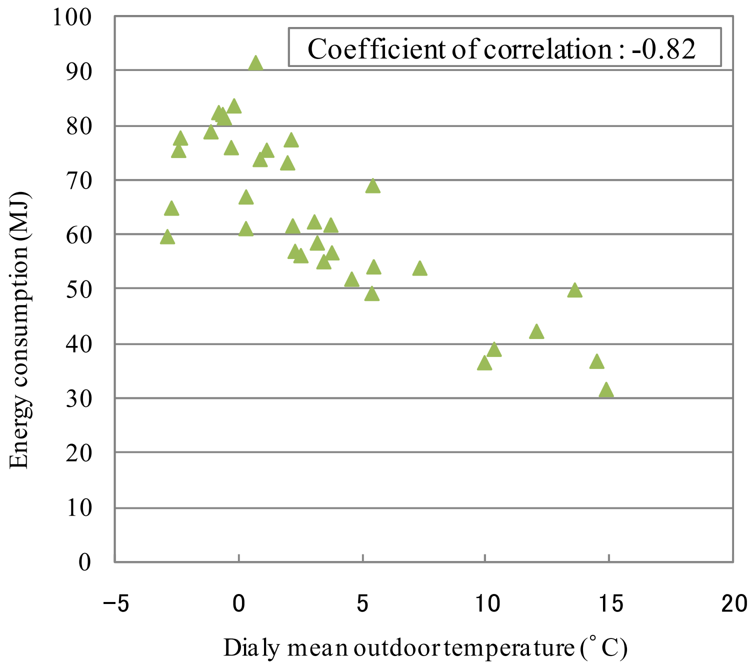

Figure 8 – Secondary energy consumption of EWH

The correlation between the daily secondary energy consumption of GWH and the daily mean outdoor air temperature is shown in Figure-6, and it of EWH is shown in Figure-7. The coefficient of correlation was -0.75 in the case of GWH, and it was -0.82 in the case of EWH. The secondary energy consumption had strongly associated with the outside air temperature. The correlation between the daily efficiency of hot water supply of GWH and the daily mean outdoor air temperature was 0.85. They of EWH and HPCOP were 0.61 and 2.22. The value of HPCOP is the coefficient of performance of the heat pump fitted with EWH. The coefficient of correlation between HPCOP and the outdoor air temperature was 0.71. The value of HPCOP had strongly associated with the outdoor air temperature.

4.5 Performance comparison of GWH and EWH

The mean outdoor air temperature was various among the sectionalized periods. The periods, which were presumed to be equivalent, were extracted shown as Table-7. The statistical values of the primary energy consumption, the energy efficiency and the CO_2 emission were compared between GWH and EWH. The primary energy consumption and CO_2 emission of GWH were less than EWH. The energy efficiency of GWH was more than EWH.

4.6 Performance comparisons in operating below the freezing point

The statistic values of the secondary energy consumption, the primary energy consumption, CO_2 emission, the efficiency of hot water and the energy efficiency, are shown in Table-8, when the daily mean outdoor air temperature was below the freezing point. There were 9 applicable days in operating GWH and ten days in operating EWH. The energy efficiency was 0.72 in the case of GWH, and it was 0.55 in the case of EWH.

Table7 – The statics value of primary energy consumption

		Mean	Standard deviation	Max.	Min.
Primary energy consumption (MJ/day)	GWH	122.75	26.62	166.32	58.78
	EWH	156.17	40.66	248.37	85.92
Energy efficiency	GWH	0.83	0.07	0.94	0.67
	EWH	0.64	0.14	1.01	0.41
CO_2 emission (kg-CO_2/day)	GWH	6.20	1.34	8.38	2.97
	EWH	7.70	2.00	12.24	4.23

Table 8 – The statics value of secondary and primary energy consumption below the freezing point

		Mean	Standard deviation	Max.	Min.
Secondary energy consumption (MJ/day)	GWH	132.56	23.70	162.72	98.02
	EWH	76.27	7.94	83.70	59.71
Primary energy consumption (MJ/day)	GWH	151.93	25.79	183.02	113.66
	EWH	192.12	20.00	210.83	150.41
CO_2 emission (kg- CO_2/day)	GWH	7.77	1.31	9.35	5.81
	EWH	10.19	1.06	11.18	7.98
Efficiency of hot water supply	GWH	0.83	0.02	0.86	0.79
	EWH	1.38	0.20	1.60	1.02
Energy efficiency	GWH	0.72	0.03	0.76	0.68
	EWH	0.55	0.08	0.63	0.41

4.7 The defrost operation and the hot water load efficiency of EWH

The electric power consumption could increased on the defrost operation in winter season of the cold region. The ratio of the mean electric consumption only depending on the defrost operation and daily electric consumption in the sectionalized period was from 1.3% to 6.5%. The thermal loads of hot water divided by generated heat quantity is named the load efficiency of EWH. It was 0.76 in order to operation in winter season.

5. Conclusion

The CO_2 emission of GWH utilized the latent heat of the burnt gas after combustion in addition to energy on combustion for increasing the city water temperature, was less than EWH utilized the HP in which heat carrier is CO_2, in winter season of the cold region. The deciding factor of annual efficiency of hot water supply of GWH and EWH would be analyzed further in the future.

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7. Presentation of Author

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

B6) A preliminary study for localized waste heat recovery system at hot water shower drains in high-rise residential buildings of Hong Kong

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Abstract

This paper investigates the potential of thermal energy recovered from hot water shower drains in bathrooms equipped with instantaneous type water heaters in high-rise residential buildings of Hong Kong. In particular, a simple single-pass counter-flow heat exchanger installed at a horizontal shower drainage pipe was used as a preliminary heat recovery measure by heating up the cold water supply to a water heater. The thermal energy exchange at the heat exchanger was evaluated with the effectiveness number-of-transfer-units (ε-NTU) approach. User shower patterns including shower operating time and water flow rate were sampled from an interview survey with the Monte-Carlo sampling technique. Yearly water temperatures at the shower heads, shower drains and cold water supply taps were recorded in sample operations of hot water showers in bathrooms and used for sample inputs in this study. The results showed that 4-15% thermal energy would be recovered from a shower drain with a 1.5 m long single-pass counter-flow heat exchanger for a drain pipe of 50 mm diameter.

Keywords

Hot water shower; waste heat recovery; residential buildings.

1. Introduction

There has been a great concern about energy consumption in Hong Kong. Based on the record of Hong Kong energy statistics, the energy consumption of residential buildings represents 17% of total energy budget (HKEMSD, 2007). The breakdown of energy consumption in residences showed that 20% of them were used for hot water production, and a large portion of the hot water was used for personal hygiene such as hot water bathing/showering. A recent survey of domestic water appliance (Wong and Mui, 2007) showed that individual instantaneous type water heaters were commonly found in residential washrooms of Hong Kong for heating up cold water for bathing/showering purposes. Compared with the centralized installation system, it was popular because of the ease of metering the energy cost, the simplicity of installation, appliance ownership and operation. It was also reported that an instantaneous water heater was compact in size compared with a storage-type water heater. It is, therefore, suitable for those high-dense living environment like Hong Kong. With the shower operating time and water flow rate sampled from an interview survey using the Monte-Carlo sampling technique, the energy saving potential from the waste heat recovered from the residential hot water shower drains was investigated.

2. Waste heat recovery

A localized waste heat recovery system would have some benefits in terms of the amount of heat recovered from the shower drain pipe works (Peereboom and Visser, 1998). It would serve as the first stage of further heat recovery at a centralized plant for the waste heat from shower drains of residential buildings. In order to illustrate the potential waste heat recovered from a hot water shower drain, a simple localized heat exchanger as the primary heat recovery measure is proposed to preheat the cold water supply to an instantaneous type water heater as shown in Figure 1.

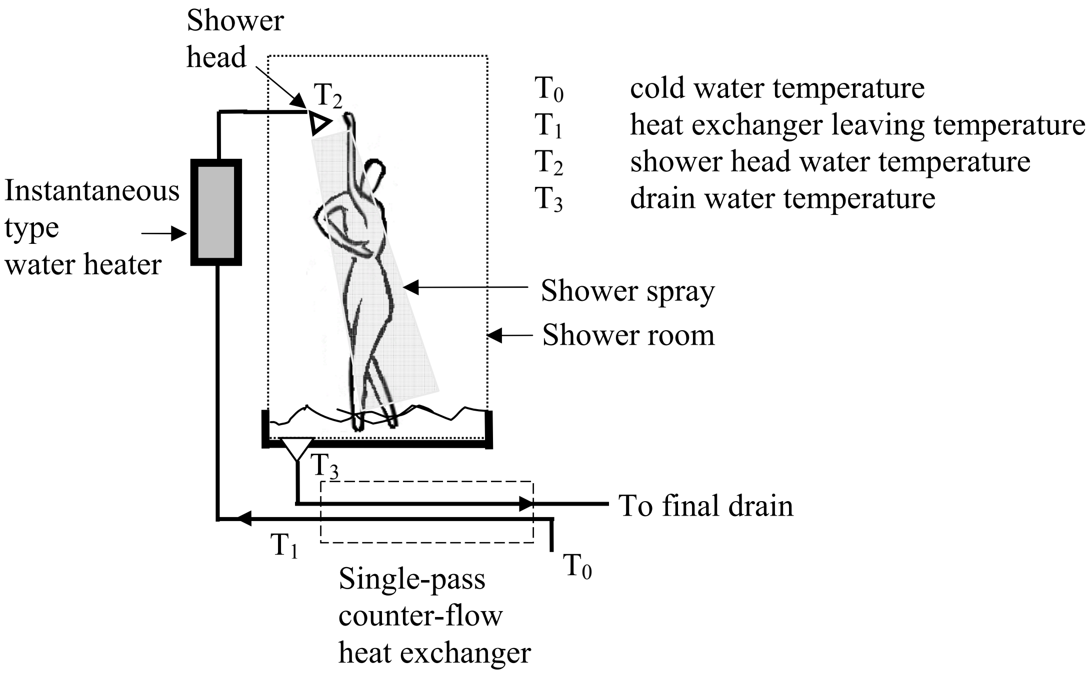

Figure 1 – A typical shower installation for residential buildings with a proposed single-pass counter-flow heat exchanger

For simplicity, no heat loss of the cold water supply pipe outside the system shown in Figure 1 was assumed. The energy consumptions of the water heater for heating up the cold water supply to the shower head supply water temperature T_2 (ºC), with Q_1 (kW) and without Q_0 (kW) the heat exchanger, are determined by, where T_0 (ºC) and T_1 (ºC) are the cold water supply temperatures to the water heater, c_p (kJ kg^{-1} ºC^{-1}) and m_c (kg) is the mass flow rate of cold water supply to the heat exchanger.

$$\begin{cases} \dot{Q}_0 = m_c c_p (T_2 - T_0) \\ \dot{Q}_1 = m_c c_p (T_2 - T_1) \end{cases} \qquad \dots (1)$$

The energy saving of a shower operation due to the heat recovery measure is determined by, where τ (s) is the shower operating time, where subscripts 0, 1 are denoted for the case without and with the heat exchanger installed.

$$\Delta E = E_0 - E_1 = (\dot{Q}_0 - \dot{Q}_1)\tau \qquad \dots (2)$$

A simple single-pass counter-flow heat exchanger was used for analysis. The heat exchanger was attributed by the overall heat transfer coefficient U_o (kW m^{-2} ºC^{-1}) and the heat transfer area A_o (m^2). It was also operated at the entering cold water supply temperature T_0 (ºC) and entering drain water temperature T_3 (ºC) as shown in Figure 1. Assume the pipe length between the shower drain and the heat exchanger was short and the heat loss from the pipe was insignificant, then the leaving heat exchanger cold water supply temperature T_1 (ºC) could be evaluated by the effectiveness number-of-transfer-units (ε-NTU) approach (Kreider and Rabl, 1994),

$$T_1 = T_0 + \frac{\dot{Q}}{\dot{C}_{min}} \quad ; \quad \dot{Q} = \varepsilon \dot{C}_{min}(T_3 - T_0) \quad ; \quad \varepsilon = \frac{1 - \exp[-NTU(1 - C_r)]}{1 - C_r \exp[-NTU(1 - C_r)]} \quad ;$$
$$NTU = \frac{U_o A_o}{\dot{C}_{min}} \qquad \dots (3)$$

where, $\dot{Q}$ (kW) is the actual heat transfer rate, ε is the heat exchanger effectiveness, NTU is the heat exchanger number-of-transfer-units, C_r is the capacitance ratio, $\dot{C}_c$ and $\dot{C}_h$ are the heat capacitance rate, $\dot{C}_{min}$ and $\dot{C}_{max}$ are the minimum and the maximum heat capacitance rates determined by,

$$C_r = \frac{\dot{C}_{min}}{\dot{C}_{max}} \; ; \; \begin{cases} \dot{C}_{min} = \min(\dot{C}_c, \dot{C}_h) \\ \dot{C}_{max} = \max(\dot{C}_c, \dot{C}_h) \end{cases} ; \; \begin{cases} \dot{C}_c = m_c c_p \\ \dot{C}_h = m_h c_p \end{cases} \qquad \dots (4)$$

where, m_h (kg) is the mass flow rate of hot water supply to the heat exchanger.

3. Shower usage patterns

The usage patterns of domestic hot water showers were determined from some survey studies reported earlier (Wong and Mui, 2004, 2007). The survey was conducted with a total of 1300 randomly picked households in 14 typical high-rise residential buildings in

5 housing estates of Hong Kong. The 5 estates provide 26,500 apartments for a population of 113,000. The selected buildings were based on various geometrical locations, building ages and architectural designs to study the usage patterns of domestic washroom appliances. Invitation letters were sent to introduce the study objectives, the survey period and details through the estate management offices. Each of the representatives of the 597 selected households participated in a face-to-face interview survey in their respective apartments. Most of the interviewees were those occupants who stay at home for the longest time. During the interviews, they were asked to provide information of the shower 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 also surveyed. For each installed appliance, its type, physical size, brand name, and usage frequency were recorded. Average flow rate of shower taps installed was measured with simple operations by the occupants as well.

The survey reported that an occupant would take a shower everyday. Figure 2 shows that some occupants would take more than one shower a day. It was reported that, on average, an occupant would take 1.6 (SD=0.6) shower in a summer period, 1.1 (SD=0.3) shower in a winter period, giving an overall average of 1.4 (SD=0.6) shower per day. It was also reported that 98% showers were operated with hot water supply. Figure 3 shows the geometric average discharge time of a shower operation of 12 minutes with a geometric standard deviation of 1.6 minute.

4. Temperature measurements

Long-term measurements with sample shower operations were conducted in this study in order to obtain the water temperatures of the system. Measurements of water temperatures at water supply mains, shower heads, shower drains of sample shower operation with 3 invited volunteers were made in 2 typical domestic washrooms. The measurements were repeated for shower operations in a week, when the outdoor air temperatures ranged from 13ºC to 22ºC. It was found that the cold water supply temperature was much higher than the outdoor air temperature ($p<0.01$). It could be explained by the water was preheated as supply water pipes embedded in building structure, and no evaporation heat loss was encountered for water in an enclosed water pipe. A relative constant water temperature at the shower head T_2 (ºC) was measured with an average of 40.7ºC (SD=1.2ºC) from the observations. Once the hot water left the shower head, the water temperature dropped from T_2 (ºC) down to T_3 (ºC) at the shower drain. To simplify, the cold water supply temperature T_0 (ºC) and the entering heat exchanger water temperature T_3 would correlate with the outdoor air temperature T_a (ºC) from the measured data. The correlations are given by ($p\leq 0.05$, t-test),

$$\begin{cases} T_0 = 10.4T_a^{0.29} \\ T_3 = T_2 - 821T_a^{-1.88} \end{cases} \qquad \ldots (5)$$

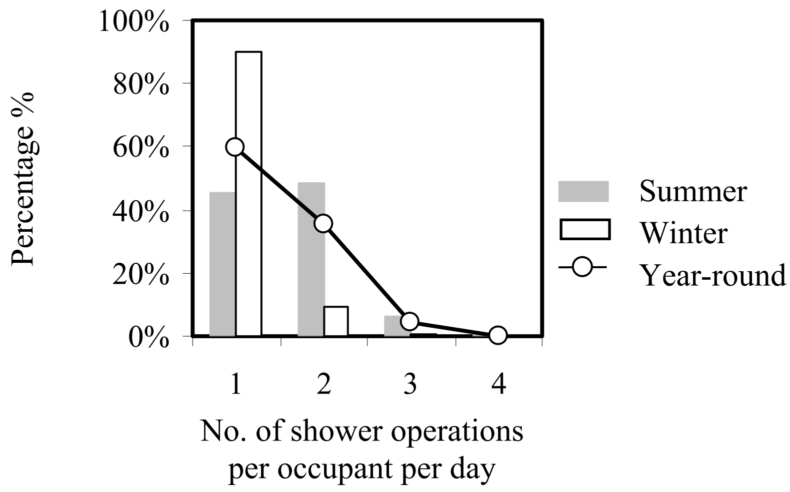

Figure 2 – Daily shower operations per occupant in residential buildings of Hong Kong

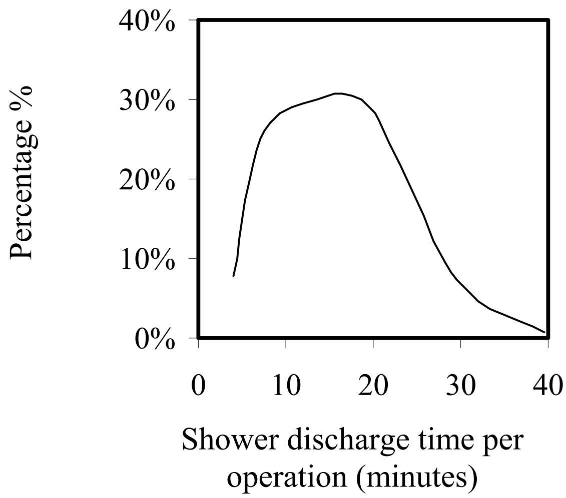

Figure 3 – Shower discharge time of each operation

With the reported outdoor air temperature variations for Hong Kong and showers taken in time periods of 18:00 to 01:00 and 06:00 to 09:00, The outdoor air temperature at typical shower time, the yearly input temperature profiles of cold water supply to the water heater and the temperature drop of the hot water from a shower head to the shower drain are shown in Figure 4. These profiles were adopted for subsequent evaluation in this paper.

5. Numerical experiments for energy saving potential

Input parameters ζ_i for simulations, including the water temperatures, number of showers per person per day, duration of showers etc., were sampled with the Monte-

Carlo sampling technique from distribution functions $\tilde{\zeta}_i$ of typical domestic washrooms of Hong Kong, where ζ_i is a dummy variable for the input parameters.

$$\zeta_i \in \tilde{\zeta}_i \qquad \ldots (6)$$

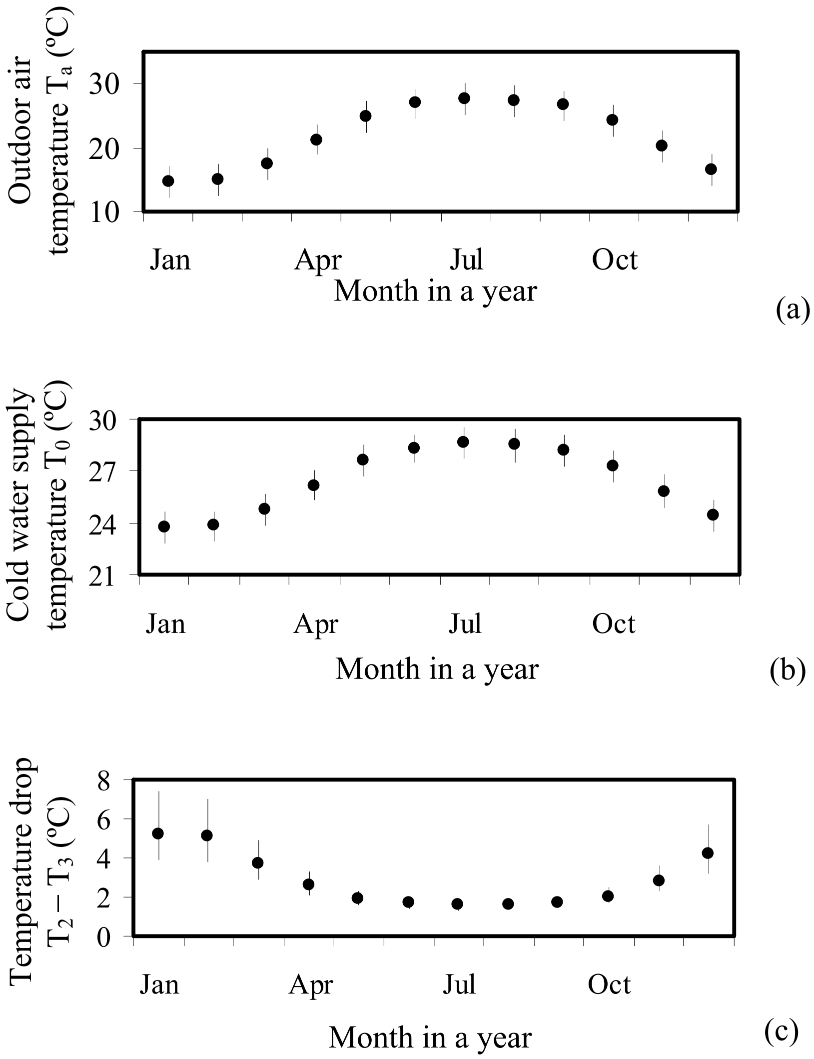

Figure 4 – Yearly profiles of (a) outdoor temperature; (b) cold water supply temperature (c) temperature drop of hot water from a shower head to the shower drain, at a shower head temperature of 40.7ºC±1.2ºC

For a shower facility with a typical slope drain pipe of diameter 0.04 m to 0.05 m, length of 0.6 m to 1.5 m, the annual energy saving S (%) of each case was determined by the annual energy consumptions E_1 (kWh yr^{-1}), E_0 (kWh yr^{-1}) for j showers by an occupant, with and without the heat exchanger installed,

$$S = \sum_{j=1}^{n} \frac{E_{0,j} - E_{1,j}}{E_{0,j}} \quad \ldots (7)$$

Figure 5 shows the expected annual energy saving <S> (%) due to a single-pass heat exchanger installed at the slope drain pipe with the standard error <<S>> approximated by ($R=0.9984$, $p < 0.0001$, t-test),

$$<< S >> = 0.052 < S >^{0.89} \quad \ldots (8)$$

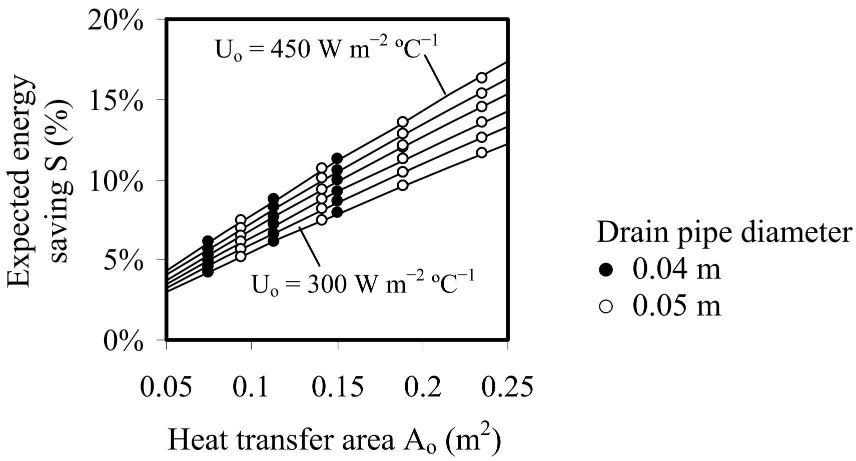

Figure 5 – Expected energy saving for hot water shower from heat recovery at shower drains

6. Energy saving potential prediction

The result was used to quantify the potential energy saving of localized heat recovery systems at shower drains for a high-rise residential building. The building had 20 apartments per floor and 40 floors in height (Wong and Mui, 2007). The design population of each building was 3500, with a total floor area of 41500 m^2 and a total number of 800 showers installed. The occupant-area ratio was 0.084 person m^{-2} with a standard deviation of 0.032 person m^{-2}. The expected occupant load of this building was 3486 persons. The duration of shower operations was surveyed and the corresponding outdoor temperature range was reported similar with the input parameter range selected in this study. For illustration, two specifications heat exchangers were considered in terms of the overall heat transfer coefficient U_o, shower drain pipe diameter D (m) and length L (m), i.e. (U_o, D, L) = [(300, 0.04, 0.6), (450, 0.05, 1.5)], which considered as the worst and the best scenarios for practical installations. The simulations showed that the expected annual thermal energy consumption for hot water showers was 60.7 kWh m^{-2} yr^{-1} (SD=13.3 kWh m^{-2} yr^{-1}). With the performance data of the heat exchanger shown in Figure 5, the total expected annual thermal energy savings of this sample building were from 104 (SD=21) MWh yr^{-1} to 406 MWh yr^{-1} (SD=84).

7. Conclusion

The potential of thermal energy recovered from a hot water shower drain in bathroom equipped with an instantaneous type water heater for high-rise residential buildings of Hong Kong was investigated. A significant energy saving potential was demonstrated with a localized, simple single-pass counter-flow heat exchanger installed at the horizontal shower drainage pipe to heat up the incoming cold water supply to the water heater. For illustration, user showering patterns including shower operating time and water flow rate obtained from interview survey and water temperatures at the shower heads, shower drains and cold water supply taps measured from typical operations of hot water showers in bathrooms were used to justify the energy saving potential. With the sample installation of a 1.5 m long single-pass counter-flow heat exchanger for a drain pipe of 50 mm diameter at the hot water shower drain, the potential year-round thermal energy saving for hot water showering was 4-15%.

Acknowledgement

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9. Presentation of Authors

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C1) Physical treatment of water in buildings

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Abstract

Amongst different methods used for treating potable water or sanitary hot water in buildings, the use of magnetic or electromagnetic fields or any other method based on the use of physical action is increasing. The advantage of such devices is to introduce no chemical in water and to have simple and cheap maintenance. It is therefore in line with the concept of sustainable development. The action of magnetic field is now known as having an obvious effect on water behaviour, mainly on scaling phenomena. Other actions such as corrosion inhibition and even bacterial growth reduction are claimed, without clear understanding of the involved mechanisms.

This paper presents different on site experiments made with such devices. Some examples are related to anti-scaling properties, and some others are first results related to the evaluation of action against corrosion or bacterial growth. On site experiments are preferred to laboratory experiments because the obtained results are widely depending on local conditions such as water use scheme and water local composition.

Keywords

Water treatment, scaling, calcium carbonate, bacterial growth, corrosion, magnetic field

1. Introduction

Scaling is one of the major pathologies that affect water distribution systems. Mostly constituted of calcium carbonate precipitated on boilers, pipe walls, shower heads and tap filters, it can lead to blockage, energy loss and bacterial growth. A radical solution consists in water softening where calcium removal eliminates calcium carbonate. However, many devices based on the action of water physical treatment (magnetic field, electromagnetic waves, turbulent action) are now on the market and claim an action on scale building, but also on corrosion and bacterial growth in water distribution systems. These physical actions on water are now well known regarding to calcium carbonate formation. They usually favour the precipitation inside liquid phase of water of the non adherent crystalline aragonite form and prevent the heterogeneous precipitation of calcite form, adherent on solid surfaces.

Figure 1 – Calcium carbonate in aragonite form

Figure 2 – Calcium carbonate in calcite form

More difficult to understand are actions of physical devices on corrosion of metallic pipes and on bacterial growth in water distribution systems. Until now, no scientific paper has been published on the subject, neither on theory nor on laboratory tests. It is why we have started tests in laboratory and in existing buildings. The first results show a tendency, but it is too early to take definitive conclusions.

2. Existing techniques

Generally, the device is installed on direct flow, and water to be treated passes through it. They are also, most of the time, preceded by particle filters (sand or metallic particles) in order to facilitate their functioning, as well as a by a trap for eliminating iron and its oxides.

2.1 Magnetic devices

They are based on the use of a permanent magnetic field. This field is externally applied on the water pipe. An example is given on figure 3.

Figure 3 - Magnetic water treatment device

2.2 Electromagnetic devices

These devices generate a sinusoidal electromagnetic field or electromagnetic impulses. The installation is usually realised by an induction coil around the water pipe as shown on figure 4.

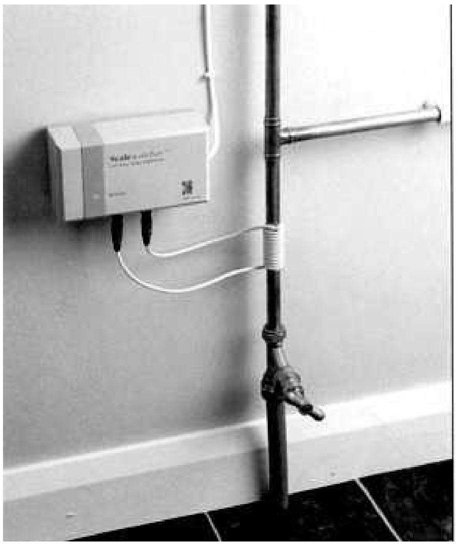

Figure 4 - Electromagnetic water treatment device

2.3 Catalytic processes

These systems are based on the action of a catalyst that increases the germination of calcium carbonate crystals inside the water phase. The catalyst is progressively consumed during the use of the device. An example is given on figure 5.

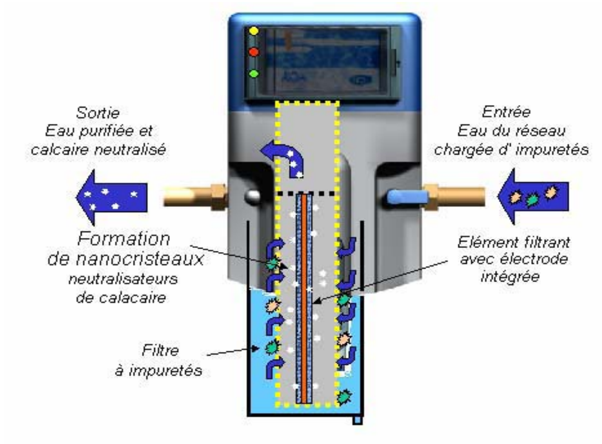

Figure 5 - Catalytic water treatment device

2.4 Turbulent processes

Such processes generate turbulent flow that increases the germination of calcium carbonate crystals in water phase. An example is given on figure 6.

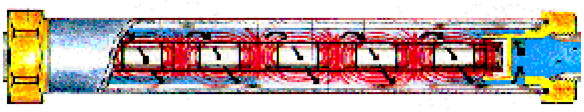

Figure 6 - Water treatment device generating turbulent flow

3. The state of the art in process assessment

3.1 Introduction

Different laboratory techniques are available in order to determine the effects of any physical action on water. Amongst them the following ones have been developed at CSTB laboratory :

- chronoamperometry,
- chronoelectrogravimery based on the use of a quartz crystal microbalance,
- degassing by controlled stirring, eventually completed by filtration,
- particle size measurement.

In addition to these laboratory tests, test rigs have been developed for more realistic experiments and the possibility of using different water qualities.

3.2 Laboratory

Chronoamperometry is a method based on acceleration of scaling process by application of an electrical current to an electrode. The variation of potential towards negative direction precipitates calcium carbonate and the interpretation of current as a function of time gives the scaling capacity of the water. The disadvantage of such a method is that it can only be applied on metallic surfaces and that the potential reached on the electrode surface is not corresponding to the situation existing in real installations.

Chronoelectrogravimetry gives the possibility of understanding the deposition process on a surface. It is the most complex, but also the most complete technique. It involves a quartz crystal microbalance, which is a quartz slice covered with gold and integrated in an oscillating circuit. The quartz frequency is a function of the quantity of calcium carbonate that precipitates on its surface. This precipitation is favoured by application of a potential between the gold surface and a reference electrode. The system is realised in a way that it constitutes an electrochemical cell where current measurements give additional information. Attention is drawn on some experiments carried out with this technique. A magnetic water treatment device was installed at a tap in a water public distribution plant, at a place where water had a high scaling capacity. Two important effects where thus revealed.

The first one is the transient nature of the magnetic field effect on calcium carbonate in water. Figure 7 is the reference where non treated water shows no difference in scaling properties when tested just after being drawn and 42 minutes later. Figure 8 shows scaling capacity of treated water, widely lowered compared to non treated water, but progressively coming back to the original value during time. This effect is of great importance, because water has long stagnation periods in water distribution systems, especially in one-family houses.

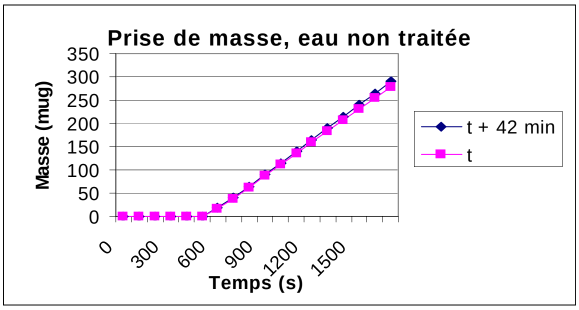

Figure 7 – Reference water – mass of precipitated calcium carbonate

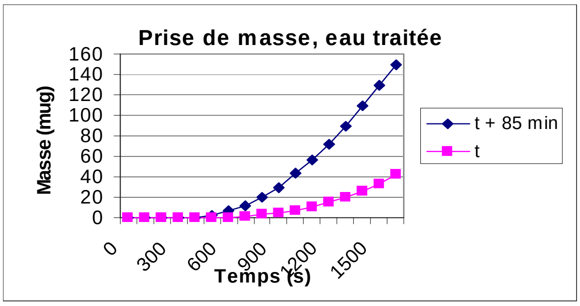

Figure 8 – Treated water – mass of precipitated calcium carbonate

The second effect can be described as the existence of a certain concentration of active elements in water, these active elements being created by the magnetic field. Scaling property of the tested water has been drawn on figure 9, where different solutions of treated water in non treated water were realised.

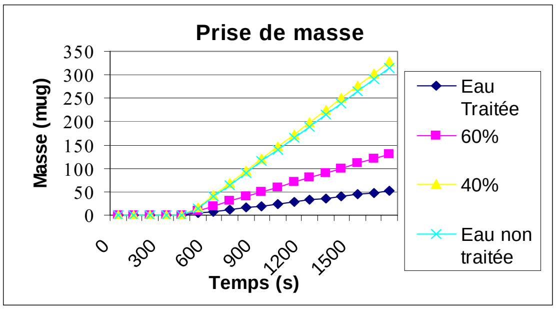

Figure 9 – Treated water scaling properties as a function of its concentration in non treated water

Degassing by controlled stirring : here the precipitation is obtained by stirring water. This action eliminates a certain quantity of carbonic gas from water, raises the pH value and precipitates calcium carbonate. After precipitation, water can be filtered on 0,2 µm filters which gives the quantity of calcium carbonate precipitated in the water itself and not on the vessel's walls.

Particle size measurement : this method allows the assessment of particles formed inside the water (number as a function of size) under the action of a physical action. These particle sizes are situated between 1 µm and 32 µm. An example is given on figure 10. The method shows a variation of these particles sizes in water before any effect is detected by other methods. The influence of magnetic field appears as leading to particle size growth (aggregation in water before precipitation in a sludge form).

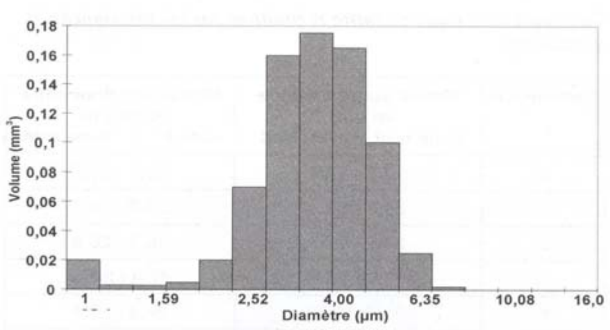

Figure 10 – Calcium carbonate particles in water

3.3 Test rigs

Laboratory experiments are giving a lot of information on effects resulting from physical water treatment devices. However, this information is not sufficient to interpret all parameters influencing the real efficiency of such devices. A major problem is that in a laboratory, either tests are carried out with tap water, only possible if that this tap water is calcifying, or tests are carried out with bottled water, assuming that water composition is steady from one bottle to the other. In addition, dissolved gas in bottles may vary, mostly as a function of time. Furthermore, water in laboratory vessels behaves differently than water in a water distribution system. Therefore, test rigs have been realised. They reproduce realistic water systems. One of them is movable, allowing tests in different locations. They are based on two identical water heaters, and in both cases, water is drained off through shower heads which are equipments where scale formation is quick and easy to detect.

The first test rig is equipped with an electromagnetic device, and mass measurement on boiler electrical resistances and shower heads show significant differences between treated and non treated waters, as shown on table 1.

Table 1 – Calcium carbonate mass measured on electrical resistances and shower heads –test rig 1

Experiment	Mass on resistance in g/m^3 without treat. / with treat.	Mass on shower head in mg/m^3 without treat. / with treat.
1	19,2 / 17,9	52,2 / 25,7
2	21,9 / 20,1	35,7 / 19,7
3	23,8 / 15,1	40,4 / 26,9
4	16,5 / 20,5	42,4 / 20, 5
5	43 /28	54,4 / 18,4
6	135 / 88	33,7 / 21,8

The second test rig, a movable one, which principle is shown on figure 11 is equipped with a magnetic device, and mass measurement on boiler electrical resistances and shower heads also show significant differences between treated and non treated waters.

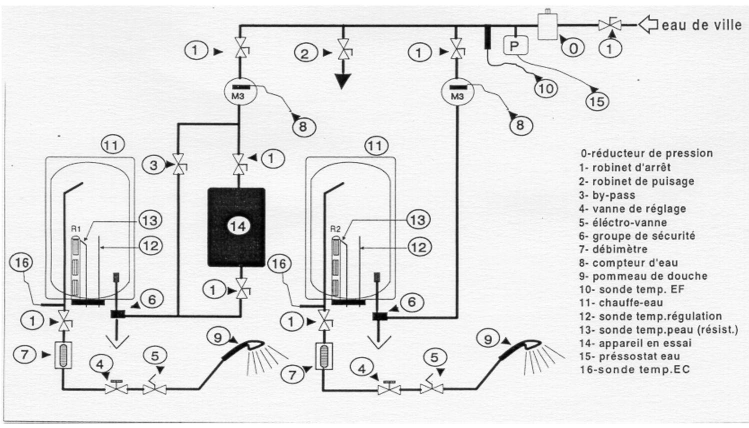

Figure 11 – Scheme of movable test rig

A first experiment was carried out with water having a hardness 40 °f and total alkalinity 24 °f. The quantity of calcium carbonate (identified as being calcite) is lower in the boiler supplied with treated water. Surface temperature on both electrical resistances was also measured and progressively increased on the surface where non treated water was used (see figure 12).

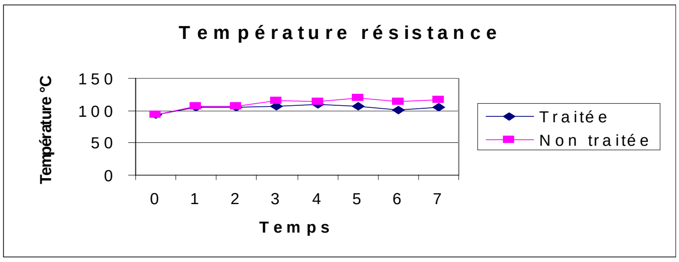

Figure 12 – Surface temperatures on resistances

A second experiment was carried out with water having a hardness of 46 °f and total alkalinity 38 °f. As shown on table 2, there is no significant mass difference on electrical resistance surface, but only on shower heads.

Table 2 – Calcium carbonate mass measured on electrical resistances and shower heads – test rig 2

	Boiler	Mass variation on shower head (mg/m^3)	Scale mass obtained on electrical resistance and in the bottom of water container (g/m^3)
Experiment without treatment	1	47,16	8,09
	2	47,24	9,24
Experiment with treatment on water heater number 1	1	33,33	9,26
	2	37,50	9,21

Conclusion of these two first test rig experiments is that they are good systems to test the efficiency, and that shower heads can be used as scaling sensors, easy to dismount, and preventing from heavy evaluations like weighing boiler resistances.

The third test rig was designed for the evaluation of anti-corrosion effect. It consists in two identical circuits, made of iron pipes. In one of them, a magnetic device (figure 13) was installed. Laboratory tap water was used for the experiment, flushed during two hours every day and stagnant the rest of the time. The evaluation consists of water analysis once a week, with a special attention to dissolved iron parameter.

Figure 13 – Magnetic device for corrosion experiment

The device manufacturer request is to transform FeOOH into Fe_3O_4, adherent and protective. Iron concentration in water is shown in table 3:

Table 3 – Iron concentration in water

Time	Iron content part 1 of rig	Iron content part 2 of rig (with magnetic device)
Start	4,15	4,71
1 week	3,73	2,62
2 weeks	6,49	6,24
3 weeks	8,7	11,1

Analysing the results shows no effect on iron dissolution, although the manufacturer claims an evident effect after one week.

4. Field measurements

4.1 Introduction

The best way to evaluate the efficiency of a physical device, even if its effects have been observed in a laboratory, is to install it on a real water distribution system in a building. This installation shall be preceded by an audit of the water system, with a specific attention to corrosion and scaling situation. The observation of some sensitive equipments like heat exchangers, filters, valves, or control pipes are the basis of the device assessment. Proceeding as such incorporates parameters identified as being important during laboratory or test rig experiments, like stagnation time, piping system materials or water composition. Many experiments have been now carried out for the assessment of anti-scaling effect, very few for looking at the influence of such physical devices in water distribution systems.

4.2 Anti scaling effect

Below are shown some observations made in a hospital where a magnetic device was installed. The sanitary hot water distribution system was suffering from evident scaling effect. Figure 14 shows the position of two of these devices.

Figure 14 – Position of two magnetic devices

Table 4 gives different water analysis results. It appears that there is no significant iron concentration increase in the system. Zinc concentration (between 0,3 and 0,4 mg/L) is higher in the loop than in tap water. An explanation is that the magnetic system prevents the formation of calcium carbonate on piping system surfaces, facilitating the contact of galvanised steel with water inducing zinc dissolution.

Water analyses show that physico-chemical parameters of water are not modified by the water treatment device. The concentration consistency in calcium and magnesium reveals that no precipitation of calcium carbonate occurs in the system.

The three different water analyses show that these waters are all encrusting. Control pipes have also been installed and show no calcium carbonate precipitation. No corrosion is detected on these pipes although water analyses reveal a corrosive character of these waters against galvanised steel.

Table 4 – Physico-chemical analyses of waters

	Tap water	Sanitary hot water (entry)	Sanitary hot water (loop end)
Temperature (°C)	18,1	57,2	49,8
pH	7,3	7,5	7,8
Alkalinity (°f)	nd	0,8	1,0
Total alkalinity (°f)	24	22	25
Calcium (mg/L)	98	95	94
Magnesium (mg/L)	3,4	3,3	3,6
Hardness(°f)	26	25	25
Total iron (mg/L)	0,2	0,1	0,2
Zinc (mg/L)	<0,1	0,4	0,3

Observation of a valve installed in the sanitary hot water loop (figure 15) shows a rapid evolution of deposits in it. This proves that physical processes can also remove calcium carbonate deposits encrusted during years on piping internal surfaces.

Start of experiment

One month later

Figure 15 – Evolution of calcium carbonate deposit in a valve

4.3 Anti corrosion effect

The above mentioned test rig experiment leads to the conclusion that the tested device in the local water has no effect on corrosion protection of iron pipes. The scaling study in the sanitary hot water installation presented above leads to the secondary conclusion that no corrosion appears in the hot dip galvanised pipes at least during one year after the installation of the magnetic device. A new field experiment is starting on a corroded sanitary hot water system in a building housing offices in Paris suburbs. It is today too early for giving a first tendency of corrosion evolution.

4.4 Antibacterial effect

Many physical device manufacturers claim for an action on bacteria present in water and in biofilm inside piping systems. The requested action could be based on the formation of free radicals oxidising organic matters. This could lead to the destruction of algae, fungi and ferro bacteria as well as the habitat of legionella (biofilm).

Therefore, the field test in the hospital was completed by a study of the biofilm deposited in control pipes (see figure 16). The two control pipes show the same surface aspect (non sticky when touching). Water analyses give less than 250 UFC legionella pneumophila. The biofilm has been sampled by using a scraper and absorbent cotton, and solubilised afterwards in distilled water.

Figure 16 – Biofilm inside control pipe

Results are given in table 5. The analyses reveal the presence of a certain biological activity (significant colony count) but the absence of legionella, researched by two different methods (AFNOR and PCR). ATP dosing results are relatively low, but not negligible. A follow up during time would be interesting in order to interpret correctly the result.

Table 5 – biofilm analysis

pH	8,1
Temperature (°C)	43,8
ATP dosing	16
Legionella pneumophila, method PCR XP T 90-471 (UG/L)	<10 000
Extraction ADN method XP T 90-471	Yes
Legionella, method NF T 90-431 (CFU/L)	<500
L. pneumophila, method NF T 90-431	Non detected
L. pneumophila serogroup 1, method NF T 90-431	Non detected
Colony count at 22°C 72h, method NF EN ISO 6222 (/mL)	2,4E5
Colony count at 36°C 44h, method NF EN ISO 6222 (/mL)	7,4E4

In addition to this experiment the information concerning a multi-storey commercial building was collected. After three month following the installation of an electrolytic device, a strong legionella infection appeared in the sanitary hot water system, leading to giving up such a treatment and installing urgent chlorination disinfection.

5. Conclusions

The effect of physical devices on waters has been demonstrated at laboratory in relation to scaling properties. Having taken into account stagnation periods, this effect shows certain efficiency in existing water systems in buildings. Anti-corrosion and anti-bacterial effects are claimed by manufacturers of such products, but the first experiments carried out on rig test and real installation lead to be careful on conclusions. No effect was clearly proved and opposite results noted in corrosion observation interpretations.

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7. Presentation of Author

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C2) Effect of clean hot water on the Legionella-contamination in hot water draw-off branches : a laboratory study

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Abstract

At three branches, with lengths of 3, 5 and 15 m, a daily volume of 120 to 127.7 l of water (at 40°C) was drawn off for 121 days, simulating the domestic consumption in a single family house, at flow rates from 3.5 to 6 l/min. The water having a *Legionella pneumophilla* (*L. pn*) contamination of about 10^4 CFU/l. The aim was to develop a stable biofilm with *Legionella* –bacteria in the 3 pipes.

Afterwards the draw-off branches were fed by clean hot water (simulating a daily domestic consumption of 120 l at each branch) at 40°C in a first period (6 weeks), 50°C in a second (3 weeks), and for the 5 and 15 branches at 55°C in a third (2 weeks) and at 60°C in a final period (1 week). The concentration of *L.pn* in the water at the 3 taps was monitored.

The study showed that there is no real difference in the contamination level between the 3 pipe lengths. This indicates that a limitation of the branch length to 5 m, in order to limit the *L.pn* concentration in the water, as required in some codes, is not justified.
The study showed also that a feeding temperature of 50°C or more is effective in suppressing the *Legionella*-contamination to a level that is considered as low risk.

Keywords

Hot water supply, Legionella, effect of temperature, pipe length, biofilm

1. Introduction

The *Legionella pneumophilla* (L.pn) germ, widespread in all kinds of aquatic environments, causes the Legionnaires’ disease (1), a severe form of pneumonia with a mortality up to 20% (2). Susceptible individuals are infected by inhalation of water droplets with a size between 3 and 5 micrometre (i.e. aerosols), containing the bacterium. The occurrence of the disease in 2003 is indicated in table 1 for some European countries.

Table 1 – Occurrence of Legionnaires' disease in some European countries

Country	Number of Legionnaires' diseases per million of inhabitants in 2003
Austria	6
France	18
Italy	10
Netherlands	14
Spain	29

Actually the sanitary hot water system is considered as the primary reservoir for the Legionnaires' disease (3). This building water system provides suitable conditions for growth – especially adequate temperatures (between 25 and 45°C, with an optimum around 37°C), but also nutrients in the form of corrosion products (iron) and habitats like sediments and slime layers (biofilm)-, leading to *Legionella pneumophilla* concentrations well above the limit of 1000 CFU/l (colony forming units per litre) considered in many countries as the concentration above which there is, in hospitals, an increased risk for normal patients to get Legionnaires' disease.

The sensitivity of the bacterium to the temperature – the major growth influencing factor- provides a means for controlling it: maintaining the temperature either below 25°C or above 50°C in each point of the water system, avoids its growth. This is why many regulations request to keep the cold water distribution in the building below 25°C, while the hot water has to be produced at minimum 60°C and distributed by a system keeping the temperature continuously between 55 and 60°C.

As this last requirement cannot be fulfilled by the hot water draw-off branches (ie. the pipe between the tap and the hot water circulation loop), where the water cools down after each tapping so that the temperature remains –for a while- within the zone 25-50°C, Legionella might grow. Some regulations limit therefore their length to 5 m. The reasoning behind this requirement is that the longer the length of a contaminated pipe, the greater the volume of water in stagnation between two draw-offs (a 5m copper pipe with a nominal diameter of 18 mm has only a volume of about 1 l, which would be washed out before one stands under the shower) and also the greater the number of bacteria that might come into the fresh not contaminated water, flowing through the pipe during the tapping.

This 5m-rule, which effectiveness seems not to have been verified, has however some evident consequences for the conception of bathrooms as it limits severely their lay-out possibilities if one wants to avoid the costly sub-looping of the hot water circulation loop up to about each tap. This motivated the division of building services of BBRI to try to verify the validity of this limitation. This paper describes first the test rig which was set up hereto and presents and discuss afterwards the results.

2. Test rig and testing protocol

The test rig comprises 3 draw-off branches in polypropylene (PP) pipe, nominal diameter 20 (internal diameter 13.2 mm), with different lengths: 3, 5 and 15 m. These non insulated branches were set up in a boiler-room with room temperatures between 20 and 25°C during the day and between 15 to 20°C during night. Each pipe was equipped with a computer steered valve in brass at its end, a water meter with electronic outlet signal and a valve allowing the regulation of the flow rate. An insulated thermo-couple on the external wall of the brass valve measured the temperature at the outlet of each branch. A view on the branches is given in figure 1.

In a first phase the branches were fed by water contaminated with L.pn. (~1.2x10^4 – CFU/l) from a hot water system comprising a hot water storage tank of 300 l heated (up to 42.33°C in average -min 33.85°C, max 44.92°C-) with a heat exchanger connected to a boiler and a water circulation loop in copper of unknown length. During the first 51 days 127.7 l was drawn-off daily at each tap, in 48 different draw-offs, with a flow rate of 3.5 l/min. Afterwards this draw-off profile - chosen because a Dutch study (4) showed that

Figure 1 – View of the draw-off branches

it lead to a stable Legionella contamination- was modified to 120 l per day in 6 draw-offs at 6 l/min as indicated in table 2.

Table 2 - Tapping profile for a total consumption of 120 l/day

Hour of the day	Tapping volume (l)	Hour of the day	Tapping volume (l)
7h00	30	21h00	30
7h10	30	22h30	6
7h20	6	22h45	6
7h30	6	23h00	6

This profile was maintained for 70 days. The maximum temperatures during the draw-offs, at the end of the branches, are indicated in table 3.

In the second phase the branches were fed by clean hot water from an electrically heated water tank with a volume of 300 l. The 120 l daily draw-off profile was maintained, however at different temperature levels: first at 40°C, next at 50°C and then, for the 5 and 15 m branches, at 55°C and 60°C. The successive temperature levels of the hot water, the time during which they were maintained and the maximum temperature which was measured at the end of the branches during draw-off, are also indicated in table 3.

In the hot water tank the water was heated up to 60°C for the draw-off levels 40 and 50°C and up to 65°C for the levels 55 and 60°C, this in order to avoid any *Legionella*-development in this tank.

3. Measurements and results

Besides the measurement of the water consumption and the temperature at the end of the branches and at the level of the hot water production, water samples were taken about 3 times a week: one sample of 0.25 l, directly after opening the computer steered tapvalves at the 21h00 tap and one of 1 l, 1 minute later. These samples were analysed for *Legionella pn*. The results of the *Legionella*-counts, in the period when the branches were fed with clean hot water, are indicated in figure 2 for the samples taken directly after opening of the tap and in figure 3 for the samples taken after 1 minute. To be noted with respect to these figures is that the vertical axis gives the log-value of the counts, eg : $3.80 = \log_{10}(6400 \text{ CFU/l})$.

Table 3 – Temperature levels of the hot water in the branches

Phase	Temperature level	Duration (days)	Maximum temperature during the draw-offs at the end of the branches (°C)		
			3m branch	5m branch	15m branch
Contamination	40°C	121	40.40	40.25	39.81
Clean water	40°C	41	40.86	40.46	40.09
	50°C	21	49.19	48.90	48.75
	55°C	19	48.99	53.32	53.87
	60°C	4	50.65	61.83	57.48

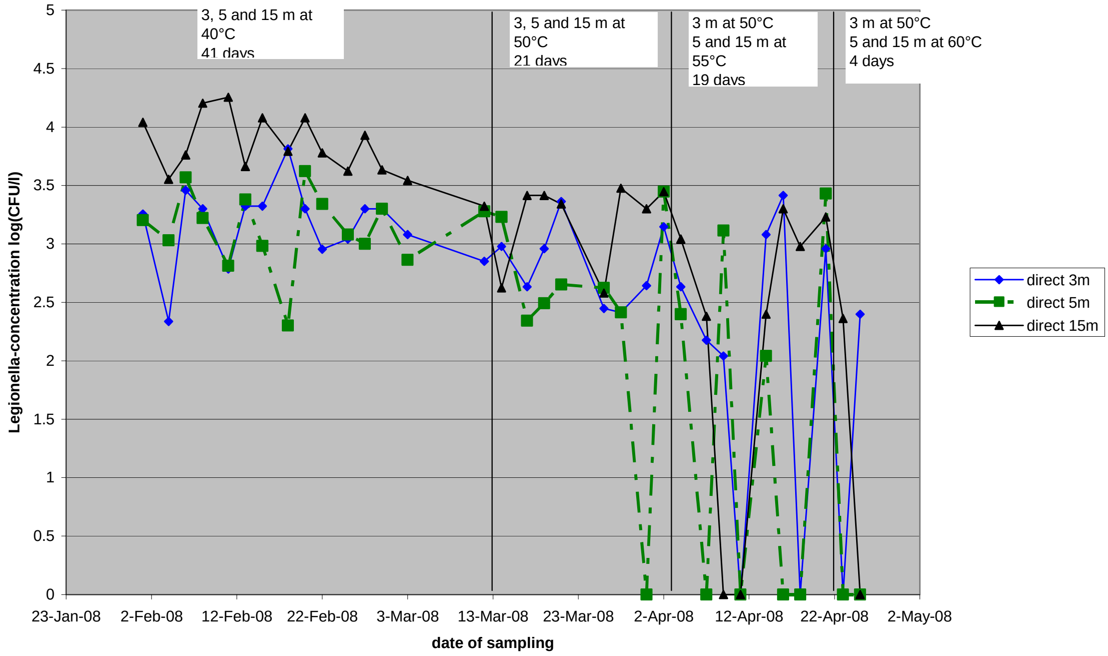

Figure 2 – Results of the *Legionella*-counts for the samples taken immediately after opening the tap

In the last 2 months of the contamination phase the mean *Legionella*-concentration in the water at the taps was 13100 CFU/ l at the 3m branch, 12660 CFU/L at 5m and 16100 CFU/l at 15 m.

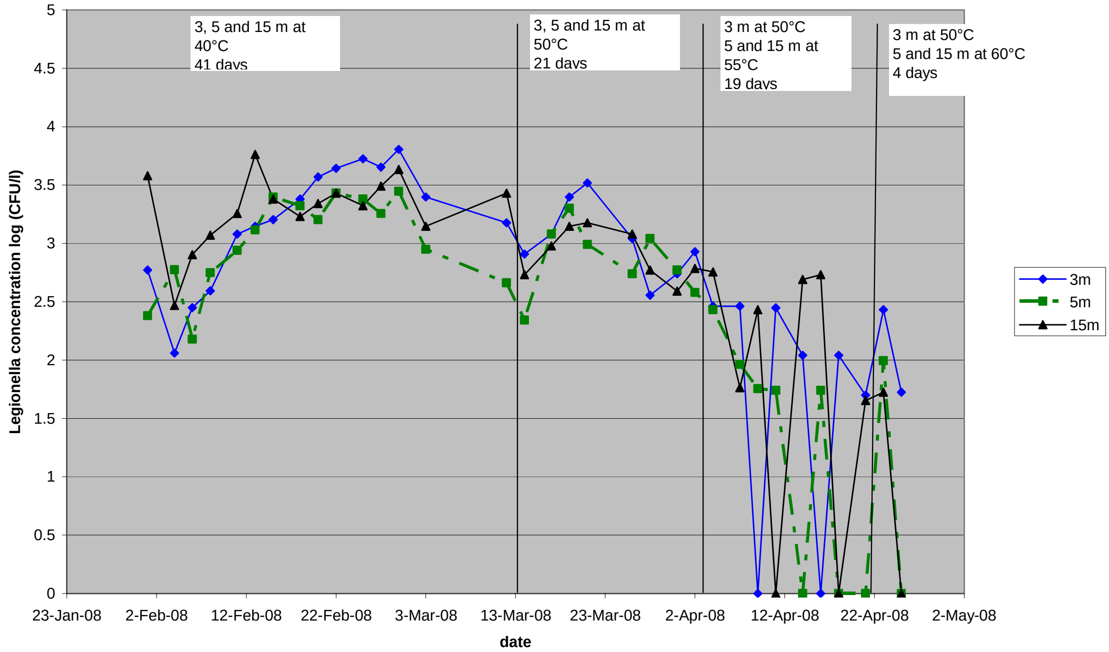

Figure 3 – Results of the *Legionella*-counts for the samples taken after 1 minute

Remark:

> Important is to keep in mind that the samples of 0.25 l, taken directly after opening of the valve, represent water that was in stagnation for about 13h30, while those taken after one minute concern fresh water, i.e. after having flushed about 6 l (the water content of the pipes is respectively 0.41, 0.68 and 2.05 l for the 3, 5 and 15m branches).

4. Discussion

4.1. Temperature level of 40°C

Legionella is detected in the hot water samples. This proves that a biofilm with Legionella-germs developed effectively in the pipes during the 121 days of contamination.

The results show that the bacterium is present as well in the water having been in stagnation, as in the water that directly flows through the branches. Contamination of the initially clean hot water does thus not only occur when the water stagnates in the pipe for a certain time.

It seems furthermore that the level of contamination is quite similar in both cases, irrespective of the pipe length: the water from the 3m branch, after stagnation, is as much contaminated as the water coming out of the 15 m pipe after 1 minute of flushing. This result is a first indication that the 5m-rule is not justified, as no difference in contamination level is noticed as function of pipe length.

After an initial decline in *Legionella*-counts during the first week, an increase for about 1 month can be observed. Then the counts tend to decline again. To which final level this decline would have lead is impossible to say as the change to 50°C was seemly made too early. This evolution in time of germ counts corresponds to a common grow/decline profile of microorganisms submitted to an environmental change. In this case the feeding with clean water, containing probably less nutrients for the germs, will have affected the weakest, leading to their killing and thus explaining the initial decline. The remaining germs will have adapted themselves allowing multiplication (i.e. the grow during ~1 month), which probably lead to an overgrowth, that was being corrected in the last 2 weeks of the observation period at 40°C.

4.2. Temperature level above 40°C

The change of the temperature level from 40°C to 50°C leads initially to same evolution in *Legionella*-counts as observed in the first period at 40°C. However as temperatures above 45°C lead to the killing of the *Legionella*-germ, the regular heating of the biofilm up to these temperatures, leads finally to the suppression of the bacteria, without however completely eradicating them as can be seen from the ups and downs in the counts from April 2nd on.

No real differences in suppression level or rapidity can be noticed between the 3 temperature levels (i.e. 50, 55 and 60°C), nor between the pipe lengths.

Important is however to notice is finally that the suppression leads to counts below the limit of 1000 CFU/l.

5. Conclusions

The pipe length of branches with a biofilm contaminated by *Legionella*, fed by clean hot water, does not influence the *Legionella*-concentration in the water at the taps: the BBRI study indicates that pipes from 3, 5 and 15 m do lead to similar germ counts. It seems thus that there is no evidence for limiting the length of branches to maximum 5 m in the *Legionella*-context.

Even the stagnation time of the water in the pipes seems not to influence the Legionella-concentration: a stagnation for more than 13 hours leads to similar contamination levels as those found when the water flows through the contaminated pipe without stagnation.

Feeding a contaminated branch with clean water at a temperature of 50°C or above, leads to the suppression of the *Legionella*-germ, so that their concentration in the water remains below the limit considered in many countries as being at risk ie 1000 CFU/l.

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7. Presentation of Author

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C3) A new hygiene system for cold drinking water installations

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Abstract

It is well known that the circulation of hot water at a relatively high temperature keeps the hot water installations hygienic. According to the European and German directives on the quality of water intended for human consumption the operators of the drinking water system have to observe the requirements for cold drinking water as well. The drinking water should be wholesome and clean if it is free from any micro-organisms and parasites and from any substances which, in numbers or concentrations, constitute a potential danger to human health. The stagnation of water in the domestic installations results in an unhygienic and unhealthy system. Therefore a circulation distribution unit has been developed for a forced flow in the unused pipes of the installations. This unit is based on the principle of the Venturi nozzle technology. After successful tests in the lab measurements on field test installations are shown in this paper.

Keywords

Hygienic installations, cold drinking water, quality of water, water hygiene, stagnation, circulation, Venturi nozzle.

1. Introduction

Within the scope of the present work a new hygiene system for cold drinking water installations was developed and tested. Flow measurements were carried out after the first installation of the new hygiene system in a building including shops, doctor’s surgeries and apartments for people needing special care. With the help of a newly developed circulation distribution fitting based on the Venturi principle a forced flow circulation was realized in sub plumbing systems when not being used as intended.

It is well known that temperatures within 30-45 °C lead to germination and to a biofilm in the installations pipes. Therefore directives and guidelines recommend a minimum temperature of 60 °C in a hot water storage sytem, 55 °C in hot water circulation pipes (1,2) and a maximum of 25 °C in cold water pipes. Regarding the cold water pipes the aim is to have a temperature below 20 °C (3).

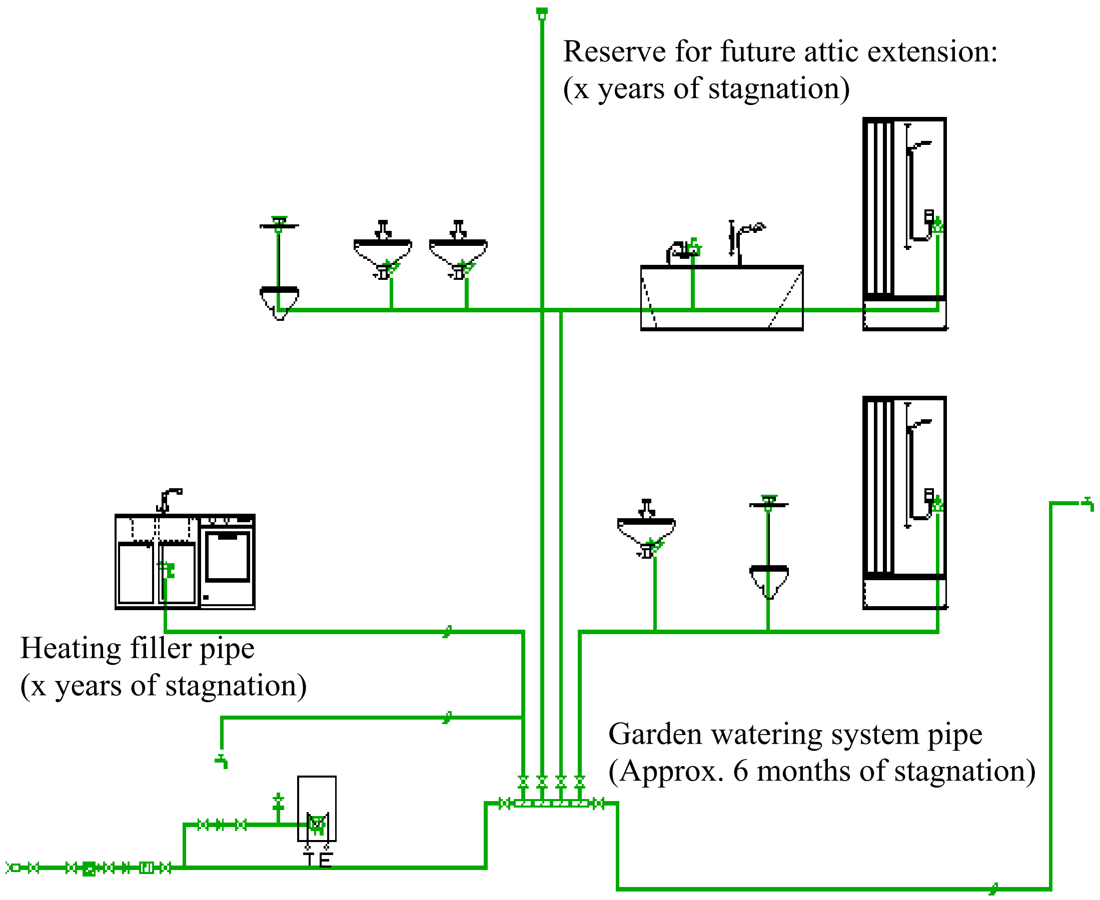


Figure 1 – Usual installations with stagnation in rarely used pipes

Until now in houses and the public sector buildings like hotels, hospitals and doctor surgeries etc. stagnated water in the pipes can be treated only by a manual or time controled flushing. House owners or users do not have any idea about the risks of their water system. The usual installations of a detached house (Figure 1) with the familiar flaws which lead to stagnation in the rarely used pipes with all the risks particularly for babies and elderly people.

A generally used method to optimize the installations is to loop through the rarely used pipes. This method also has still flaws. Depending on the length of the pipe larger diameters must be used when planning loops in case of different flow rates for e. g. caused by pressure flushing units (Figure 2).

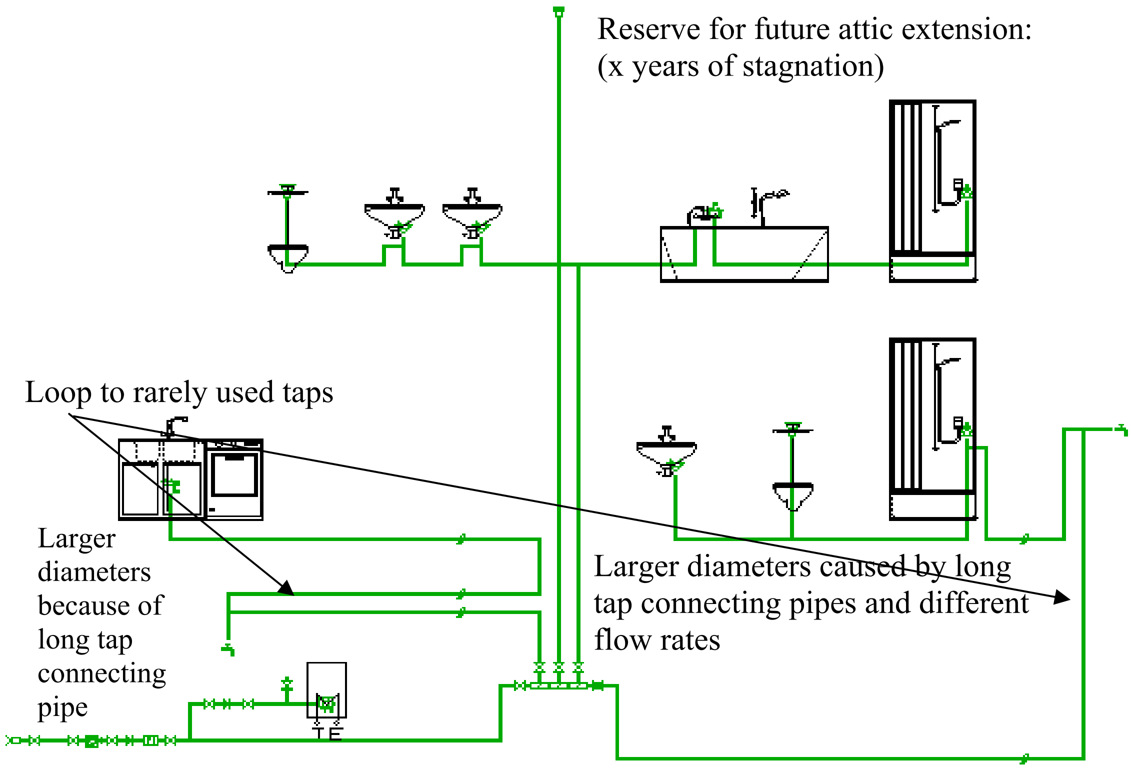


Figure 2 – Improved installations with without any stagnation in rarely used pipes

With the help of the innovative circulation distribution fitting hygienically safe installations can be realized (Figure 3). Here every consumption in upper flats causes a circulation of cold water in the rarely used pipes even if there is no consumption. The lightly warmed and stagnated water is replaced with cold and fresh water.

2. Experimental issues

Several components have been developed and combined to create a hygienic installations system for cold drinking water distribution. The most innovative component of the system is the circulation distribution unit. This unit in combination with other components were tested in the lab as well as in the first realized installations.

2.1 Venturi circulation distribution unit

This unit has been designed and dimensioned so that approximately 10% of a main flow branches off to a circulation loop pipe (Figure 4). The action principle of the unit is based on the Venturi nozzle technology. The minimal pressure difference between the main flow and the return pipe of the branched loop causes a forced flow to all taps, for instance, in bathrooms. This forced flow refreshes the water in the connection pipe and keeps the water temperature low so that provision and maintance of drinking water quality in the drinking water system up to the tapping point is certainly provided.

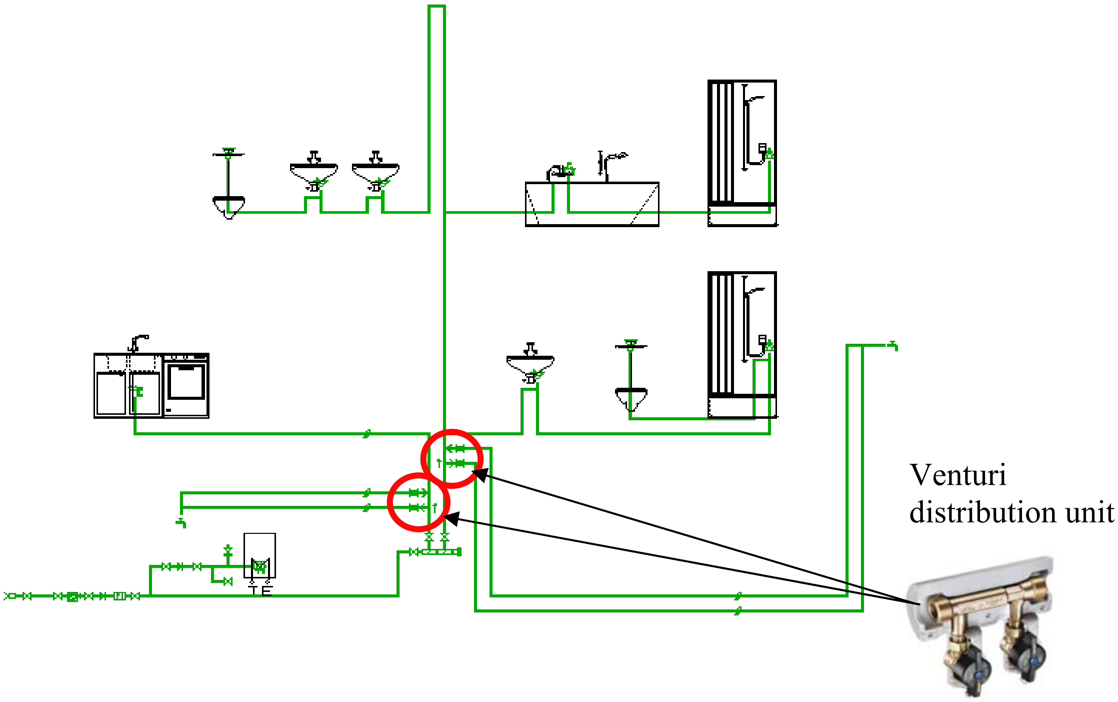


Figure 3 – Installations optimized by the Venturi circulation distribution unit

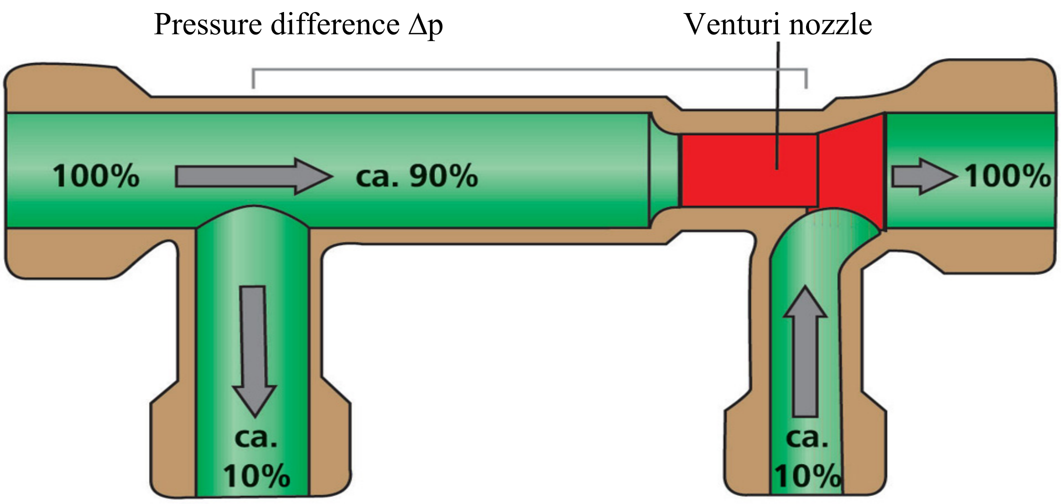


Figure 4 – Circulation distribution unit

2.2 Other components of the hygienic installation system

The system includes the following components:

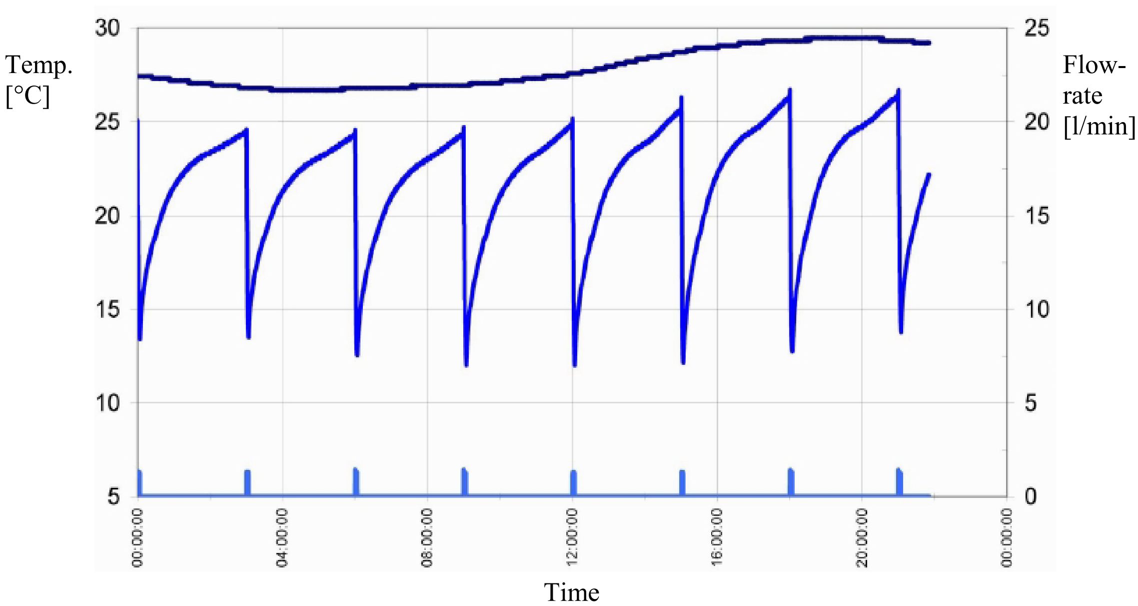
- The circulation distribution unit combined with stop valves
- Hygienic flushing unit with control valves
- Ball valve with spring-reset servo drive
- Timer unit
- Tee temperature sensor valve Pt 1000

- Vortex flow sensor
- Drain with overflow monitor
- Logic Control System incl. software and control modules for the sensors

By combining the sensors and the flow control units and valves intelligent installations can be realized controlled by temperature, volume or time. For example, if the temperature rises in pipes detected by the temperature sensor the control system activates a hygienic flushing unit or a valve for a forced flow. Though it is simpler to control the flow by the timer.

2.3 Measurements under lab conditions

Experiments done by Rickmann have shown that a pipe insulated according to the regulations warm up in less than 3 hours depending on the environment temperature (4). As shown in figure 5 the cold water temperature rises from approx. 13 °C up to 25 °C in approx. 3 hours which makes a flushing to refresh the water in the pipe every 3 hours necessary.



Upper curve : Lab environment air temperature
Middle curve: Cold water temperature in the pipe
Lower curve: Initiated flush water flow rate

Figure 5 – Time controlled flushing of a pipe (4)

2.4 Measurements at the first installations

For the first time this hygiene system was installed in a newly constructed building called "Martinus Höfe" in Olpe, Germany. It is an extension of the St. Martinus Hospital in the middle of the city. On the ground floor there are only retail trade shops. Doctors cooperating with the hospital have their surgeries on the first floor. On the second floor there are 21 apartments with nursing service. Elderly people who do not need special care can hire apartments on the third floor. It was very important for this building to have a hygiene system because the most of the users are elderly people and/or have immunodeficiency. On the other hand the doctors' surgeries and shops are closed at weekends, thus the sanitary facilities are not used for 1-2 days. That would inevitably lead to stagnation in the pipes. Another dangerous situation would be caused by the apartments and shops which are not hired for weeks and months (Figure 6).

Figure 6 – Martinus-Höfe-Building

Flow measurements were done on the second floor in the bathroom of apartment No. 7.38 after the valve No. 4 by a Fluxus ultrasonic flowmeter. The flowmeter was connected to the circulation pipe as shown in figure 7 and 8.

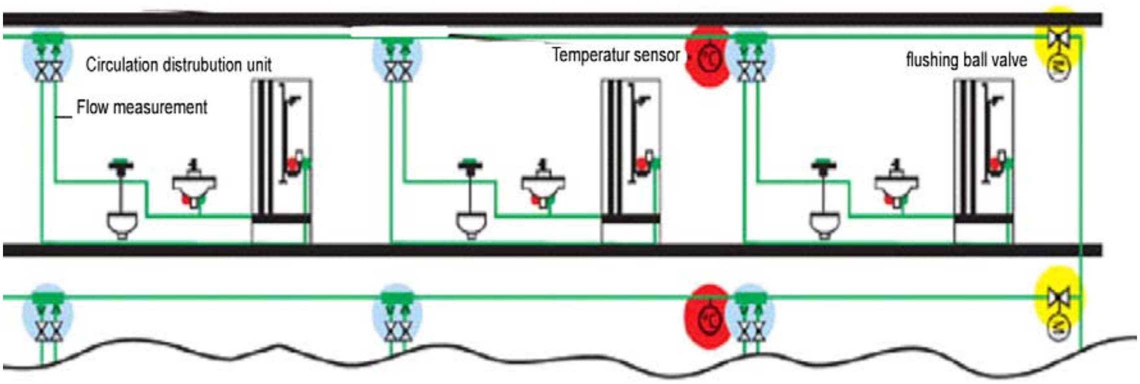


Figure 7 – Principle of installations as in Martinus-Höfe-Building

Figure 8 – Ultrasonic flow measurement

The PEX circulation pipe size was 16 x 2,2 mm and it was aprox. 7 m long. Therefore the water volume in the pipe was aprox. 0,75 liter. As shown in figure 9 every forced flow by a pipe flushing causes a flow with a volume of 2,9 liter in the observed circulation pipe. That means the water in the circulation pipe has nearly been refreshed 4 times. The water consumption in other apartments also causes forced flows. The forced circulating water volume (*without circulation water volume caused by the pipe flushing at 6.37*) between the two pipe flushes at 5.08 am and 8.37 am was 0,6 liters (Figure 9).

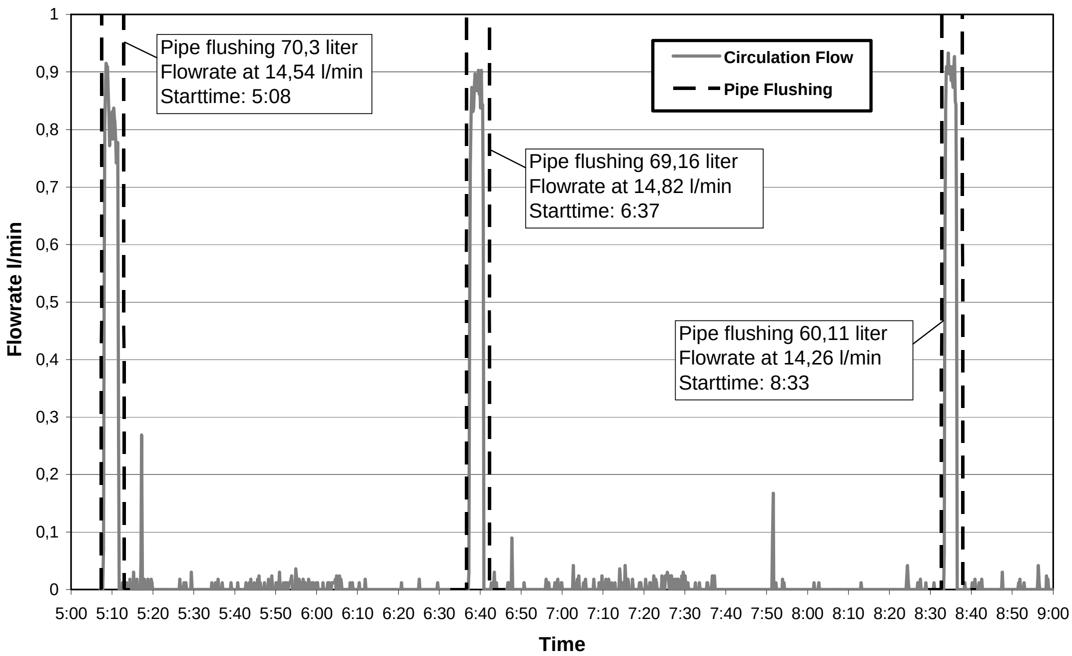


Figure 9 – Pipe flushing and circulation flowrates 07.06.2008

3. Conclusions

A circulation distribution unit as well a hygiene system has been developed for the purpose of a forced flow in the unused pipes of cold water installations. The system was successfully tested under real conditions.

The new system allows a simple provision and maintaining of the drinking water quality in the drinking water installations up to the tapping point. Further benefits of the system are

- Prevention of stagnation
- Use of installantions as directed
- Reduced water consumption
- Lower operating costs because of more efficient flushing
- Lower maintenance cost
- Less microbiologically induced corrosion in copper pipes

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C4) Study on evaluation of faucets in water supply space using AHP and utility function

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Abstract

This research discusses the decision making by users and experts, etc. when they select faucets in the water supply space. This research also discusses a way to approach development of faucets in the future.

To accomplish the research, we prepared two tools. The first tool is the Analytic Hierarchy Process: AHP. This analysis method was devised by Dr Thomas L. Satie in 1977. The second tool is a method using the single attribute effect function (probability lottery method). The first tool will clarify the decision making involved when faucets are selected by users and experts, etc. The latter tool is a method to distinguish an attractive quality from a necessary quality, regarding quality elements. That is, it is a tool to clarify elements in developing attractive faucets in the future. Moreover, product design with high CS: Customer Satisfaction can be made possible by combining the results drawn from both.

We obtained the following interesting finding from this research. Overall, operation and functionality are highly valued. In places where water is used for a comparatively long time, such as kitchens and bathrooms user's tendency, the tendency to value appearance was seen only for the mixing faucet for washing basins, where the importance of water-conservation is high, compared with other places. It was clear that especially users were paying attention to the design aspect. In regard to the above-mentioned , the expert was attaching importance to ease of operation, and so the difference by the

standpoint was clarified. From working with the utility function not often applied when concerning users, the user's deep demand regarding faucets was made clear.

Keywords

faucets, Analytic Hierarchy Process (AHP), utility function, 50-50 chance lottery

1. Introduction

In December 1997, the Third Conference of the Parties to the UN Framework Convention on Climate Change (COP 3) took place in Kyoto, Japan and adopted the "Kyoto Protocol" that imposed a target reduction in greenhouse gas emissions on each of the developed countries and ones in transition to market-based economies. Since the COP 3, environmentally friendly activities have been gradually and concretely implemented to reduce CO_2.

In March 2003, the Third World Water Forum was held in Japan. It pointed out that two thirds of the world population would suffer lack of water in 2025 and highlighted the importance of actively developing water saving technologies. In March 2006, the fourth forum took place in Mexico and stated that the overall management of water was necessary at local and global levels.

To keep water resources, individual countries have already made efforts to reduce water consumption. Japan has had many talks about water and conducted many studies of water to save water and reduce CO_2, and showed the fruits. For example, the Japan Environment Association introduced an "Eco Mark Certification System" for 21 water-saving equipment (water closets, urinals, various faucets, etc.) in 1990. The Center for Better Living certified an ultra low flow water closet as BL-bs (Better Living for better society) in 2004. N. Ichikawa, the author of this paper, made a presentation at the CIB-W062 2007 International Symposium held in Czech to describe the history of the "Eco Mark" certification system, the only ISO-compliant environmental label of water-saving equipment in Japan, certification criteria, and products to be certified[1)].

Activities for reducing loads on the global environment and for keeping water resources triggered off various standards developed by governmental agencies and had an impact on many fields. As a result, plumbing fixture manufacturers, for example, put a variety of products featuring water saving, beautiful design, or high functionality on the market. These plumbing fixtures perhaps satisfy many consumer demands (including users, architects, designers, and facility engineers who select them). However, decision making for selecting an actual product varies depending on the selector's sense of values. Therefore, we think that manufacturers are forced to produce and sell similar products in most cases because it is impossible to satisfy all requirements and priority is given to sales strategies. The purposes of this study are to clarify how users or experts, architects, designers, and facility engineers, make a decision to select a special faucet and to work on what future faucet development should be for water supply spaces.

2. Research method

2.1 Working on how to analyze decision making

A method of analyzing how users, or experts make a decision to select a special faucet should meet the following three requirements:
(1) Value judgment can correspond to human sense.
(2) Vagueness of human sense can be quantified.
(3) Method is reliable, versatile, and easy to use.
Accordingly, we made a decision to employ the AHP (Analytic Hierarchy Process) because it satisfied all the requirements above. Since the AHP was developed by T. L. Satie in 1977, it has been used in a variety of fields thanks to its versatility.

2.2 Applying the AHP to faucets

The AHP is a method of classifying purposes as hierarchical structure, making a one-to-one comparison on a level basis, and finding weights for each level and the whole hierarchy. Figure 1 is a hierarchical diagram for applying the AHP to mixing faucets for washstands. The hierarchy consists of problems, evaluation standards, and alternatives.

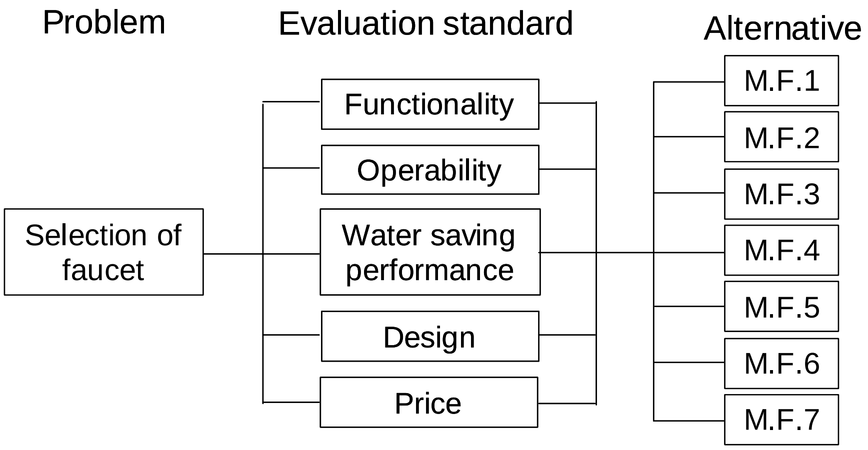

Figure 1 – Hierarchical diagram for evaluation (ex. mixing faucet for washstands)

Figure 2 – Alternative (ex. mixing faucet for washstands)

Table 1 – Evaluation standard

Functionality	Additional function
Operability	Ease of use
Water saving performance	Water saving rate based on inquiry of manufacturer and experiment in the past
Design	Form, color, material etc.
Price	Price described in catalog

We evaluated the four elements of single faucets: the price, design, water saving performance, and operability.

The evaluation standards are versatile depending on the problems to be addressed. As shown in Table 1, this study includes functionality, operability, water saving performance, design, and price in the evaluation standards.
In this study, the objects are single and mixing faucets for washstands, mixing faucets for kitchens, and showerheads for bathrooms, and we saw the catalogues to select and determine alternatives. Figure 2 shows a mixing faucet for washstands as an example of the alternative.

2.3 Working on how to develop faucets

To study the direction of future faucet development, we reached a decision to use the "50-50 Chance Lottery" that can classify quality elements—determine whether quality is attractive or must-be. This utility function has been used as an evaluation standard for risks. It can classify quality into one of three types: 1) risk averse type (must-be quality), 2) risk prone type (attractive quality), and 3) risk neutral type (one-dimensional quality) to clearly define what element is attractive[2)]. Conventionally, a commodity was developed according to its importance (weight), but the combination of results from the AHP and utility function makes it possible to design a product having high CS while taking its quality characteristics into consideration.

2.4 Applying the utility function to faucets

The utility function defines a utility value as a dependent variable when an arbitrary value between the best (maximum) and worst (minimum) values of a certain attribute is given to an independent variable. The 50-50 chance lottery used this time is a utility function found with respect to a single attribute. We evaluate the resulting 50-50 chance lottery in the range of each attribute to define a shape. Procedures for applying the 50-50 chance lottery are shown below.

(1) Specifying the best (maximum) and worst (minimum) values

First of all, to determine the range of target quality, we specify the best and worst values of each evaluation standard (quality attribute) or the maximum and minimum values. This is preparation work for deriving a 50-50 chance lottery.

Table 2 – Quality attribute

	Questionnaire item	Min.	Max.
Faucet for washstand	Operability	10	90
	Water charges performance	¥8,000	¥20,000
	Design	0	100
	Price	¥2,000	¥70,000
Mixing faucet for washstand	Functionality	0	100
	Operability	10	90
	Water charges performance	¥12,000	¥20,000
	Design	0	100
	Price	¥10,000	¥100,000
Mixing faucet for kitchen	Functionality	0	100
	Operability	10	90
	Water charges performance	¥10,000	¥20,000
	Design	0	100
	Price	¥10,000	¥150,000
Showerhead for bathroom	Functionality	0	100
	Operability	10	90
	Water charges performance	¥14,000	¥20,000
	Design	0	100
	Price	¥3,000	¥30,000

In many cases, the quality attribute is either the best (maximum) or worst (minimum) values or both are unknown. For example, we can easily find the maximum and minimum values of the price and water saving rate of a product by seeing the corresponding figures appearing on the catalogue or contacting the manufacturer, and by checking the existing experiments and investigations. However, it is very difficult to determine the best and worst values of the functionality, operability, and design.
In this study, we specified the following five conditions to determine the best and worst values. Table 2 lists the resulting quality attributes.

1) About functionality

We defined "Functionality = Additional function" to evaluate one adding a value or improving workability.

We gave zero to the minimum value (only opening/closing function) and 90 points to the maximum value (most versatile functions). Note that we reserved 10 points for future development as in the case of increased operability.

2) About operability

We defined "Operability = Ease of use" to evaluate two points: how easily the faucet is opened/closed and how easily the flow rate is adjusted.

We set zero to no faucet but this condition is not realistic when a faucet is chosen. Therefore, we gave 10 points to the worst value and 90 points to the best value (10 points reserved for future development).

3) About the water saving rate

The catalogues showed that the maximum water saving rate of the showerheads was 30 percent. Therefore, this range (0-30%) was too narrow and easy-to-evaluate representation was necessary to the respondents, so we changed the water saving rate to the water charge.

Namely, we set the water charge at 20,000 yen when the water saving rate is zero and at 14,000 yen when 30 percent.

4) About the design

We gave zero and 100 points to the worst and best values of the design respectively. These values vary depending on people. Accordingly, we made the respondents imagine them.

5) About the price

We found the highest and lowest prices from single and mixing faucets for washstands, mixing faucets for kitchens, and showerheads for bathrooms that appeared in the catalogues and gave to them the maximum and minimum values respectively.

(2) Checking whether the utility function increases or decreases monotonously

If the function does not show a monotone change and has a peak or valley, we investigate the point. We represent the worst level of the satisfactory x of a quality element as x^0, the best level as x^*, and the corresponding utility value as $u(x^0) = 0$ or

$u(x^*) = 1$.

(3) Finding the certainly equivalent

We find the certainty equivalent $x^{0.5}$ through the 50-50 chance lottery.

(4) Shape of the function

We find the worst value ($u(x^0) = 0$) and best value ($u(x^*) = 1$) of the attribute, and the confirmation value (certainty equivalent $x^{0.5}$) that is traded off for a lot between the best and worst values, each having half probability, derived from the 50-50 chance lottery to determine another point, resulting in the shape of the function.

As shown in Figure 3, the function shapes are classified into three: the risk averse type (must-be quality), the risk neutral type (one-dimensional quality), and the risk prone type (attractive quality).

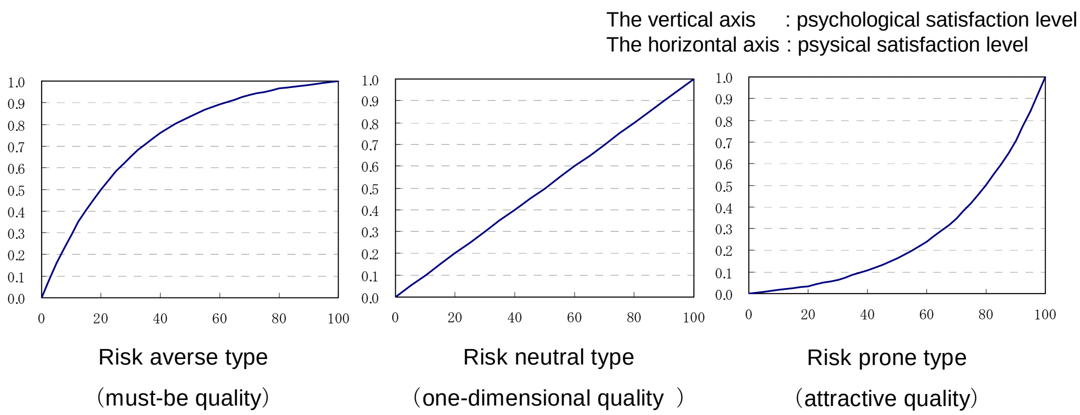

Figure 3 – Utility function type

2.5 Evaluation method

Prior to evaluation and consideration, we specified three patterns as shown in Table 3 according to the combination of the importance of an evaluation standard and its quality characteristic.

Pattern I is the most ideal combination, which means that development focusing on the resulting quality is regarded as significant. Pattern II shows that getting enough satisfactory is difficult even if the quality is improved. If the characteristic of the second evaluation standard is attractive or one-dimensional quality, priority is given to it. Pattern III indicates that making the product having high satisfactory is difficult even though the quality is improved significantly. When many meet Patter III, it is important to devise new evaluation standards or to make another examination, for example, asking people what quality they satisfy.

Table 3 – Evaluation pattern

Pattern I	When a certain evaluation standard is regarded as the most important and its characteristic is attractive or one-dimensional quality
Pattern II	When a certain evaluation standard is regarded as the most important and its characteristic is must-be quality
Pattern III	Evaluation standards other than Patterns I and II and the combination of their characteristics

2.6 Questionnaire

We made four kinds of questionnaires separately for single and mixing faucets for washstands, mixing faucets for kitchens, and showerheads for bathrooms, and gave each to up to 20 persons including users and experts, that is, the total number of respondents was about 100.

3. Results and consideration

We have gotten a vast amount of data as a result and it is impossible to show it all in this paper. Therefore, we present part of the results from the evaluation of mixing faucets for washstands and our brief consideration.

Concerning the mixing faucets for washstands, seven of 26 respondents (the closest to the second) think that design is the most important (Table 4). All the seven respondents meet Pattern I (the design is regarded as the most important and its quality characteristic is attractive quality). Table 5 shows that only one respondent meets Pattern II (the water saving performance is regarded as the most important but most of the respondents think that the design is highly valued and its quality characteristic is attractive quality), that is, about 30 percent of the respondents feel that the design is attractive or one-dimensional quality.

Table 4 – Result (1) the number of person by evaluation method

Evaluation standard	AHP	50-50 chance lottery		
		must-be	attractive	One-dimensional
Functionality	5	1	0	4
Operability	6	2	1	3
Water saving performance	6	2	0	4
Design	7	0	6	1
Price	2	1	1	0

Table 5 – Result (2) overall evaluation

Evaluation standard	type Ⅰ	type Ⅱ	type Ⅲ	Overall evaluation
Functionality	4/5	0/5	1/5	4
Operability	4/6	1/6 *1	1/6	4
Water saving performance	4/6	1/6 *2	1/6	5
Design	7/7	0/7	0/7	8
Price	1/2	0/2	1/2	1

*1:Element whose importance took second place and whose characteristic was attractive or one-dimensional quality.
*2:Sum of respondents who met Pattern I for an evaluation standard and respondents who met Pattern II for the other evaluation standards.

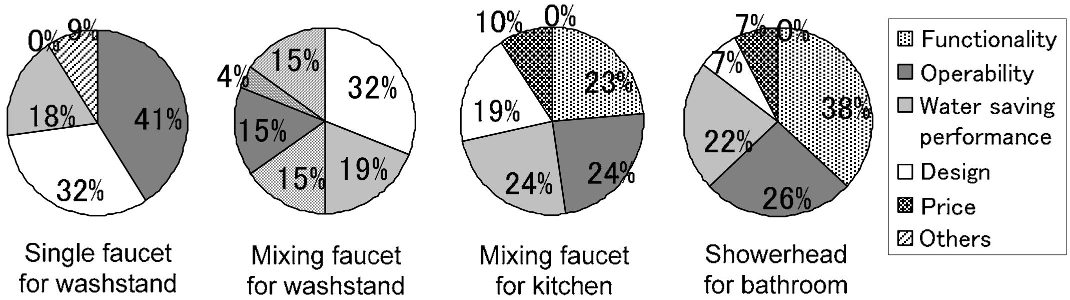

Figure 4 – Overall evaluation

These results indicate that developing a mixing faucet for washstands while priority is given to its design raises the possibility of offering an attractive new product. The overall evaluation results shown in Table 5 expect that the functionality, operability and water saving performance also have an effect of improving the quality. We think that the price has a certain effect after the other evaluation standards are taken into consideration. Figure 4, to be described later, shows the overall evaluation results, which suggest that there are other evaluation standards because the ratio of other answers is large. Note that we have evaluated the other faucets according to the same procedures.

Figure 4 shows the overall evaluation results. The users highly value the operability and design of single faucets for washstands, the functionality, operability, and water saving performance of mixing faucets for kitchens, and the functionality, operability, and water saving performance of showerheads for bathrooms. Therefore, it is very important to pursue these elements actively.

Different persons have different concepts of faucets in water supply spaces. To clarify this, we compared users and experts on a faucet basis. Table 6 shows an example of weights that each expert gave to the evaluation standards of mixing faucets for washstands. The experts tend to think that the operability is important, while the users tend to give priority to the design. Therefore, the former needs to further understand the requirements for design held by individual users. Concerning single faucets for washstands, both tend to put importance on the operability, resulting in negligible differences in concepts. Moreover, the users and experts have the almost same concept with respect to the evaluation standards of mixing faucets for kitchens except for the price. Concerning showerheads for bathrooms, the experts have a common thought—the operability is important, while the users tend to think that the functionality is important. Moreover, many users give priority to the water saving performance, while the experts attach less importance to it. Accordingly, the experts must be aware that users want easy-to-use showers featuring water saving because of long-time use.

4. Conclusion

We obtained the following interesting finding from this research.

1) Overall, operation and functionality are highly valued.
2) In places where water is used for a comparatively long time, such as kitchens and bathrooms user's tendency, The tendency to value appearance was seen only for the mixing faucet for washing basins, where the importance of water-conservation is high, compared with other places.
3) It was clear that especially users were paying attention to the design aspect.
4) In regard to the above-mentioned 3), The experts was attaching importance to ease of operation, and so the difference by the standpoint was clarified.
5) From working with the utility function not often applied when concerning users, t he user's deep demand regarding faucets was made clear.

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6. Presentation of author

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C5) An investigation of microbiological potable water quality in high-rise residential buildings of Hong Kong

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Abstract

In Hong Kong, the potable water in residential buildings is generally supplied through water pipes and available at water taps in washrooms and kitchens. It is known that microbial growths in water supply systems are highly associated with enteric diseases. However, the information and guideline on the microbiological potable water qualities in Hong Kong is limited. This study aimed to investigate the microbiological potable water qualities in high-rise residential buildings. Tap water samples (100 mL) were collected at the water supply systems from residential buildings during summer of Hong Kong. The age of buildings of the sampling sites ranged from 5 to 48 years and located at both rural and urban areas. The results showed that the heterotrophic plate counts (HPC) bacteria ranged from 0 CFU mL^{-1} to 1.60 CFU mL^{-1}. The identified bacterial genera in water were *Acinetobacter, Aeromonas*, *Bacillus*, *Escherichia coli*, *Micrococcus*, *Pseudomonas*, *Staphylococcus* and *Streptococcus*. And the fungal count ranged from 0 CFU mL^{-1} to 0.20 CFU mL^{-1}. The identified fungal genera were *Aspergillus*, *Penicillium* and non-sporulating fungi. Future investigations regarding the possible association between the environmental factors and microorganisms in the potable water of high-rise residential buildings in sub-tropical climate as well as their health effects were recommended.

Keywords

Bacteria; fungi; high-rise residential buildings; water quality; water supply.

1. Introduction

In Hong Kong, water is supplied form rainfall collected from natural catchments and the East River (Dongjiang) of China. Water is disinfected in the treatment plants to an acceptable level and then supplied to the buildings by gravity via extensive networks of water mains. The pressure in the system is generally sufficient to provide a direct supply to six or seven storeys above street level and the upper floors of tall buildings are supplied from their own roof tanks, filled by their own pumping systems (WSD, 2008). Storage tanks would be constructed by reinforced concrete with access cover and periodic cleaning every three months is recommended (WSD, 2008).

During 2006 and 2007, domestic freshwater consumption contributed to 53.3% of total water consumption and the per capita domestic fresh water consumption was 127.6 L day^{-1} (WSD, 2008). As a major concern in drinking water safety, microbiological water quality has been identified as one of the key issues in reducing the risk of transmissions of waterborne diseases. It is well known that microorganisms in water systems would degrade the water quality by depletion of dissolved oxygen (O_2), reduction of hydrogen sulfate to hydrogen sulfide, corrosion of pipes, and occurrence of bad taste and color (van der Wende and Characklis, 1990). There, microbiological water quality is an indicator of the performance of building's drinking water distribution system.

The most common method to assess the microbiological water quality is to measure the amount of heterotrophic plate count (HPC) bacteria (Edberg and Allen, 2004). Under the Safe Drinking Water Act, the United States Environmental Protection Agency (USEPA), has set a standard for drinking and recreational water at 500 colony forming units per milliliter (CFU mL^{-1}) for HPC bacteria (USEPA, 2003). Most of commonly recorded HPC bacteria are not human pathogens, but some of them are considered to be opportunistic pathogens, included *Acinetobacteri, Aeromonas, Flavobacterium, Klebsiella, Legionella, Moraxella, Mycobacterium, Serratia, Pseudomonas* and *Xanthomonas* (WHO, 2004; Edberg and Allen, 2004). It is also reported that the waterborne fungi may caused infections to the immunocompromised patients (Anaissie and Costa, 2001). However, to our knowledge, there is no report on the exposure level of fungi in drinking water of domestic buildings in Hong Kong. This study aimed to investigate the microbiological potable water qualities in high-rise residential buildings.

2. Methodology

Water samples were collected from the water tap of a washbasin of restroom of in-use, high-rise residential buildings (N=63) of Hong Kong during June 2007 to November 2007. All samples were taken on daytime of weekdays. Upon each measurement, a water sample of 100 mL was collected by using a 250 mL sterilized bottle which containing sodium thiosulfate (1 mL 10% w/v solution). The water samples were diluted and 0.1 ml of samples were spreaded on triplicate plates of R2A (Oxoid) and Malt Extract Agar (MEA) (Oxiod) for isolation of heterotrophic plate count (HPC) bacteria and fungi respectively. The plates were incubated at 35°C for 48 hours and 25 °C for 1 week. After incubation, the number of colonies (colony forming unit, CFU) was counted, and the bacteria and fungi were isolated and identified.

3. Results and Discussions

3.1 Bacterial and fungal levels

The microbiological quality monitoring results of drinking water of high-rise residential buildings of Hong Kong are shown in Table 1. A total of 63 water samples were collected from different locations of Hong Kong. None of the sampling location installed with the household water disinfection or filtration machine. The temperature of water samples varied from 18.6°C to 28.3°C.

It is found that the HPC bacteria levels are below the USEPA HPC limit (USEPA, 2003). The present study supported previous findings in Hong Kong that the chlorination process for drinking water in Hong Kong wee reported satisfactory (Chan *et al*., 2007; Ho *et al*., 2003). The HPC bacteria were detected in 68% of water samples with levels varied from 0 CFU mL^{-1} to 1.60 CFU mL^{-1}. The average level was 0.52±0.53 CFU mL^{-1} which was higher than the previous findings in the office building reported in Hong Kong, which was 0.26±0.23 CFU mL^{-1}. However, levels were comparatively low when compared with some problematic cases of HPC ranged from <0.10 CFU mL^{-1} to 20,000 CFU mL^{-1} (Reasoner, 1990; Edberg *et al*., 1996; Cloete *et al*., 2003; Allen *et al*., 2004).

The results also showed that fungi were detected in 35% of water samples. The fungi levels varied from 0 CFU mL^{-1} to 0.20 CFU mL^{-1} and average level was 0.05±0.08 CFU mL^{-1}. The fungi levels were comparatively low when compared with studies ranged from 0 CFU mL^{-1} to 30 CFU mL^{-1} (Augustionos *et al*., 1995; Gottlich *et al*. 2002; Goncalves *et al*., 2006; Kanzler *et al*., 2008). However, there is no fungi detected in the water samples collected in office buildings previously (Chan *et al*., 2007).

The relatively higher microbial levels in drinking water of residential buildings when compared with the office buildings of Hong Kong may probably due to different cleaning practices, occupancy load, degree of water consumption and the environmental conditions (Chan, et al., 2007; Wong and Mui, 2008).

Table 1 – The HPC bacterial and fungal levels of drinking water in high-rise residential buildings of Hong Kong (N=63)

	Range (CFU mL^{-1})	Average ± Standard derivation (CFU mL^{-1})
HPC bacterial level	0-1.60	0.52±0.53
Fungal level	0-0.20	0.05±0.08

3.2 Bacterial and fungal composition

A total of 8 bacterial genera and 2 fungal genera were detected in the water samples and the compositions are presented in Table 2. It is reported that 57.3% are belonged to gram positive bacteria and 42.7% of isolates are belonged gram negative bacteria. None of the water samples contained pathogenic bacteria except that *Escherichia coli* was detected in 11.1% of samples. The *E. coli* levels varied from 0 CFU mL^{-1} to 0.8 CFU mL^{-1} with average level of 0.03±0.11 CFU mL^{-1}. This exceeds the WHO guideline for drinking water quality of "zero" *E. coli* per 100 ml water (WHO, 2004). The presence of *E. coli* indicated that the water was contaminated by human or animal wastes and would cause problems of probable infections. It may also due to improper cleaning practices of water taps. And some species were considered to be opportunistic pathogen from oral ingestion for immunocompromised patients, such as *Pseudomonas* (Rusin *et al*., 1997).

In general, *Micrococcus* was the most dominant genera, presented in 28.6% of samples, with relative abundance of 29.2%. The other isolated gram positive bacteria genera were *Bacillus* (with relative abundance of 6.5%), *Staphylococcus* (2.8%), *Streptococcus* (0.6%) and others (18.2%). The isolated gram negative bacterial genera were *Acinetobacter* (2.5%), *Aeromonas* (3.1%), *Escherichia coli* (5.2%), *Pseudomonas* (10.5%) and other (21.5%). These HPC genera were reported common bacteria in drinking water in Hong Kong and other countries (Allen *et al*., 2004; Chan *et al*. 2007).

Table 2 – The composition of HPC bacteria and fungi of drinking water in high-rise residential buildings of Hong Kong (N=63)

	Composition (%)	
	Occurrence frequency	Relative abundance
HPC bacterial genera		
Acinetobacter	9.5	2.5
Aeromonas	9.5	3.1
Bacillus	12.7	6.5
Escherichia coli	11.1	5.2
Micrococcus	28.6	29.2
Pseudomonas	19.0	10.5
Staphylococcus	6.3	2.8
Streptococcus	1.6	0.6
Other gram +ve HPC bacteria	30.2	18.2
Other gram –ve HPC bacteria	38.1	21.5
Fungal genera		
Aspergillus	15.9	53.1
Penicillium	14.3	31.3
Non-sporulating fungi	6.3	15.6

The fungal genera were detected in the water samples were *Aspergillus*, *Penicillium* and non-sporulating fungi, which were recorded in 15.9%, 14.3% and 6.3% of water samples respectively. The relative abundance of *Aspergillus*, *Penicillium* and non-sporulating fungi were 53.1%, 31.3% and 15.6% respectively. *Penicillium* and non-sporulating fungi are also found to be common in drinking water reported by other studies (Gottlich *et al*., 2002; Kanzler *et al*., 2008). *Penicillium* spp. are recorded in 40.6% to 48.7% of the samples (Goncalves *et al*., 2006; Kanzler *et al*., 2008).

Although these isolates are not considered as pathogenic fungi, *Aspergillus* spp. are considered to be predominantly opportunistic fungi (Anaissie and Costa, 2001). It is reported that *Aspergillus* spp. are not isolated frequently from water but in our study, it contributed to 15.9% of samples (Goncalves *et al*., 2006; Kanzler *et al*., 2008). Fungi in drinking water may lead to a health risk for infections, however, the critical concentration for people is not known so far, more investigation on the health impacts of these fungal isolates are needed.

4. Conclusions

Monitoring of microbiological water quality of drinking water collected from the water supply system of in-use, high-rise residential buildings of Hong Kong showed that the HPC bacteria and fungi were detected in 68% and 35% of samples. The bacterial genera in the samples were identified; 57.3% were gram-positive bacteria genera composed of *Bacillus* (6.5%), *Micrococcus* (29.2%), *Staphylococcus* (2.8%), *Streptococcus* (0.6%) and other isolates (18.2%), and 42.7% were gram-negative bacteria genera including *Acinetobacter* (2.5%), *Aeromonas* (3.1%), *Escherichia coli* (5.2%), *Pseudomonas* (10.5%), and other isolates (27%). Faecal indicating bacteria, *E. coli*, was detected in 11.1% of samples. The presence of *E. coli* was probably due to an inappropriate cleaning practice. The fungal genera in the samples were identified and belonged to *Aspergillus* (53.1%), *Penicillium* (31.3%) and non-sporulating fungi (15.6%). Although no pathogenic microorganism was detected in the samples, but some genera isolated are considered to be opportunistic pathogen for immunocompromised patients. Investigation regarding the probable transmission through a water supply system in buildings was recommended.

Acknowledgement

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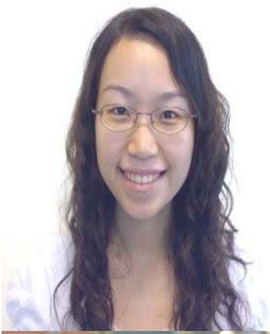

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D1) The pre-implantation of a water use program in Anel Viário of Campus do Vale of Federal University of Rio Grande do Sul

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Abstract

The water scarcity is one of the major problems facing man in the 21st Century. The current challenge is to meet the increasing water demand and at the same time preserve this resource that tends to become scarce. The most viable alternative is to work towards the management of the demand. Several institutions around the world have been implementing Program of Rational Water Use (PURA) on buildings, seeking a reduction in losses and making use of engineering actions to save water. There are several reasons for them to be doing, they are as it follows: reduction of the amount paid to the water concessionaire; reduction of the demand in order to expand their campus; the ecological necessity of saving water; and a concern with the issue of water scarcity. This study initially intended to perform an implementation of a program of rational water use at a building of Federal University of Rio Grande do Sul (UFRGS). However, due to many reasons, it has become necessary to shift the focus of the work to the planning of a pre-implementation of PURA in at the Anel Viário do Campus do Vale da UFRGS. The research started with a survey about water use conditions in Campus do Vale. It was followed by a documental research and interviews with the technicians that are responsible for the local maintenance. The implantation of a Program of Rational Water Use demands to have the practical understanding of the particularities of water utilization. The conclusion of the research was that the Campus do Vale does not have means the elements to implement a PURA immediately. The most important initial activity is to join all the fundamental information scattered throughout the University structure in a database. It is shown that to accomplish the implementation of a PURA in the Institution it is of the uttermost importance the existing conditions until this decision. This work contributes presenting the preliminary actions that turn the implantation of a PURA in this part of the University something possible.

Keywords

Water scarcity, programs of rational use, university campus

1. Introduction

Historically the access to water in abundance has been crucial to the evolution of civilizations, both in terms of quality of life and economic and social development. However, the rivers that supply the towns are no longer what they used to be. To be consumed, water must pass through treatment processes that make it proper for human consumption. Nowadays the volumes of water consumed are enormous. For example, in the United States the average is 600 liters per day per person, in England is 400 liters per day per person. However, the United Nations (UN) recommend about 200 liters per day per person.

According to AMORIM et al.[1], the UNESCO states that two thirds of humanity is doomed to the lack of water before 2025. Today, Brazil holds about 15% of world reserves of fresh water. However, they are dispersed through the country and only 12% of them are located in areas of high concentration of population, where its use is intensive.

Fresh water will be in the near future, the most disputed natural resource. In PEDROSO; ILHA [2] it is shown a scenery for 2025 where are identified the broad areas of lack of water, if the adopted ways for using water in different regions of the world do not change. Today, it is established a contradiction about the environment, because one part of people believes that nature is entirely to the human beings disposal, and the other part realizes that the sustainable development is important. This meant that the natural resources must be preserved for future generations. This dualistic relation presents itself the search for global access to fresh water and the search for rational water use.

Actually the great challenge is to supply the growing demand for water while preserving the resource that tends to become scarce. Nowadays, there is a consensus about the necessity of conservation of this resource and its rational use. It means to reduce the demand for water, or to reduce the per capita consumption.

Achieving the water conservation is not so simple. Often, in public buildings, for example, users are not concerned about the conservation of water because they are not directly responsible for the costs of its high consumption. In spaces located on university campuses, for example, the water system is often found with lack of maintenance, water losses on the network, for significant periods, without any action being developed to fix it, as underlined by PEDROSO; ILHA [2].

2. Research outline

One of the ways to deal with the lack of water is to develop a program to manage the water use. The universities, as centers of knowledge propagation, have an essential role in finding alternative solutions to the problem of water scarcity.

The initial proposal of this work, developed on a master´s dissertation, was to set up a Program of Rational Water Use (PURA) in a building in the Federal University of Rio Grande do Sul (UFRGS) as a pilot study. The search for a building started in Campus Central, the oldest one[1]. It would be used the methodology presented on the thesis of OLIVEIRA [3] entitled "*Methodology for Implementation of a Rational Water Use Programs in Buildings*".

The requirements set in the starting of the work were:

a) a meter connected to the water supply system of only one building – to avoid the necessity of installing meters to do the study;
b) measurement of water consumption in the building during three years – to be possible to compare before/after implementation of the program;
c) occupation unchanged in the last year and keeping these conditions in the following year - to make it possible to estimate the reduction of water consumption.

2.1 Research direction

The research started with a survey in UFRGS to identify a building in which it was possible, without major changes in the hydraulic system - such as installation of meters, substantial changes in the water distribution system in buildings nearby, among others – the development of the study.

It started by the identification of meters installed in the Central Campus. The collected information gave the false impression that each meter serves a single building. However, when it was deepen the knowledge about the water supply system of Campus Central and after starting the documentation of the hydraulic system of many buildings, it was realized that there is no meter that measures the individual supply of these buildings. The established condition of a meter for a single building was found only off this campus as is the Faculdade de Administração (Administration Faculty). Then the decision was to choose this building as the object of study. During the hydraulic system survey, it was realized that it had very different conditions when compared to the others University´s buildings. (Figures 1, 2, 3). Recently, the system was almost completely renewed, so there were not found leakages and there were installed water saving fixtures – such as low flow toilets and taps.

Finding such different situations among the University´s campuses got to the conclusion that only global actions would have the chance of being succeed. Thus, the aim of the

[1] UFRGS has three campuses in Porto Alegre, the Campus Central, the Campus Olímpico, build on the 60's for sports related faculties and the Campus do Vale, which has its occupation consolidated on the 70's.

inicial work changed to the planning of part of implantation activities, where it is included the definition of priorities, identification of sites with the greatest potential of water use reduction and structuring the UFRGS´PURA. Besides these actions, it was done the identification and justification of the first site where PURA could be implemented, the Anel Viário in Campus do Vale.

2.2 Research stages

The development of this study addressed the following stages:

a) documental survey of hydraulic systems of Anel Viário in Campus do Vale;
b) survey of the maintenance routine of the hydraulic system in Anel Viário;
c) proposal of PURA previous actions to PURA implementation.

Figure 1 – Students' restroom in Faculdade de Administração

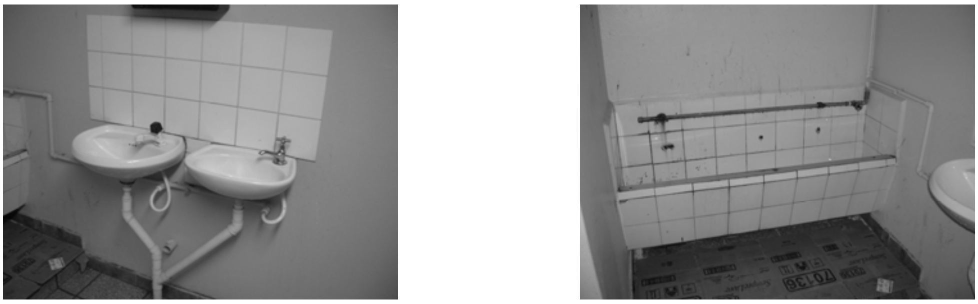

Figure 2 – Employees' restroom in Campus do Vale

Figure 3 – Students' restroom in Campus do Vale

2.2.1 Documental survey

The documental survey was considered an essential way of characterization of Anel Viário´s water system. It was requested to the department of Projects and Works (DPO) the Campus do Vale´s water system blueprints. This request had not to be attended in one year. During the documental survey it became very clear that without the commitment of the University administration it would be very hard to implement a PURA. All the information gathered about Campus do Vale and Anel Viário water distribution system was obtained with the maintenance staff that was involved with its construction and maintenance in the last 20 years.

2.2.2 Survey of the maintenance routines

During the survey to find out the maintenance routines, it were also identified the water supply system conditions. It was found that the administration of University´s buildings was decentralized and there were large differences among the water supply system conditions of all buildings studied. During this part of the study, it was also verified that the maintenance staff detains an important not written knowledge about the Campus do Vale´s hydraulic system. This knowledge will be lost when these professionals get retired, which should start in large number in the next two years. Apparently, there is no documentation about the University´s water system in any part, since it was not possible to obtain even the as built project.

The maintenance routines were investigated with the maintenance staff of Campus do Vale. The maintenance systematic is basically the same for all campus sectors. The requests for maintenance are usually done by fax. The problems are solved following the order of arrival. After concluded the repairation activity it is not done any report about the work performed. So, there is no indication of what are the most usual demands.

2.2.3 Actions of previous implementation of PURA in Anel Viário

The proposed actions are based on experiences of water conservation programs implementation in universities presented on the literature and on the survey made in Anel Viário´s water system. The PURA implemented in the University of São Paulo (USP) presented by Silva [6] is one of the most important examples. The proposed actions were also based on the methodologies developed by Oliveira [3] and Gonçalves at al. [7].

3. Results and final considerations

The information collected in the exploratory study have shown that in UFRGS there are problems on collecting information about the operation of water system. It is not possible to know how and where the water is used, since the data about water consumption is collected from the meters but is not analyzed by anyone.

Due to difficulties on finding a building that fits on the established characteristics for the development of the study, the study object turned to be the Anel Viário in Campus do Vale (Figure 4).

3.1 Campus do Vale characterization and developed activities

There are about 6,600 students, 1,300 technicians and 900 teachers that study and work on the Campus do Vale these days. Its occupation started in the beginning of the last century with the Faculty of Agronomy and later with the Institute of Hydraulic Research. The occupation was consolidated in the 70´s when it were constructed many buildings inside the area called Anel Viário. As TURKIENICZ et al. [8] elucidate, the occupation of Campus do Vale is restricted to a small portion of land, only about 10% of the total area available, corresponding to Anel Viário and the area nearby the Bento Gonçalves Avenue.

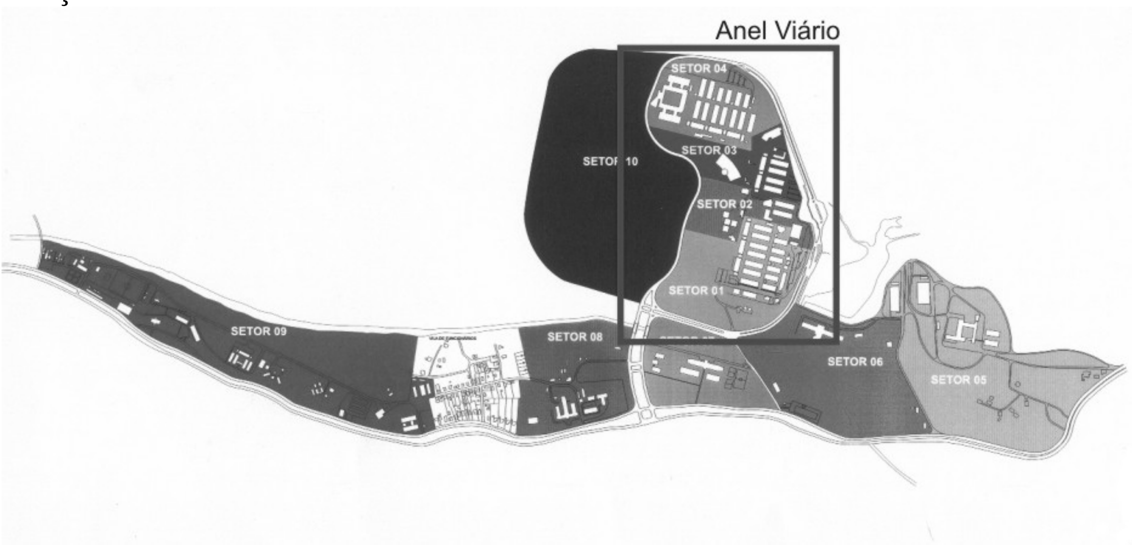

Figure 4 – Campus do Vale, detached the Anel Viário

About 51% of water consumption in the University happens in Campus do Vale, that has an average daily consumption of 185 m³. The meter that register the water consumption is located outside the campus, along to the Avenida Bento Gonçalves. As it can be seen on Figure 5 the water meter is exposed without any protection against the actions of vandals. The average monthly consumption from January 2003 to June 2005 was 5550 m³ and due to it around 60% of University expenses with water (Figure 6).

3.2 Actions of previous implementation recommended to PURA in Campus do Vale

The recommendations to the previous implementation of the Rational Water Use Program in Campus do Vale, are based on the structure presented by SILVA et al. [9]. The authors indicate that one of the main structuring actions of such a program is the formation of committees, one in the University administration to structure the politics and another to allocate practical responsibilities. Another important action is to search for external partnerships to exchange technologies and knowledge.

In UFRGS, the pre-implantation of a PURA must begin by actions that seek the commitment of the University´s managers with the program. That means that the headmasters should be aware and must promote the participation of all involved in the process. The search for partnerships with water utility companies and components manufacturers is very important to the success of the program. The rational water use policies must be permanent and should not change when the managers are changed. Also is important that all involved with the University are aware about the water conservation importance and its benefits.

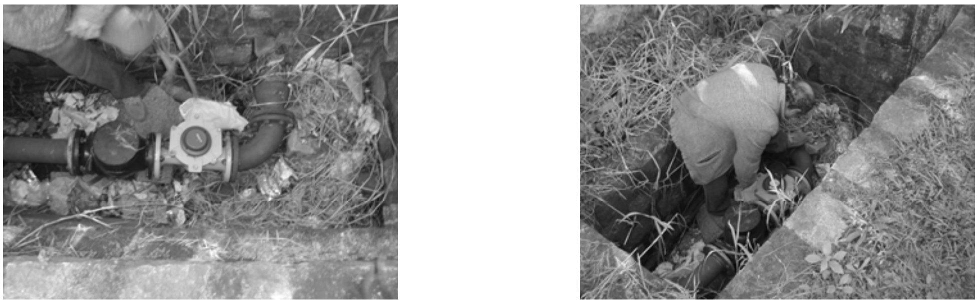

Figure 5 – Anel Viário water meter

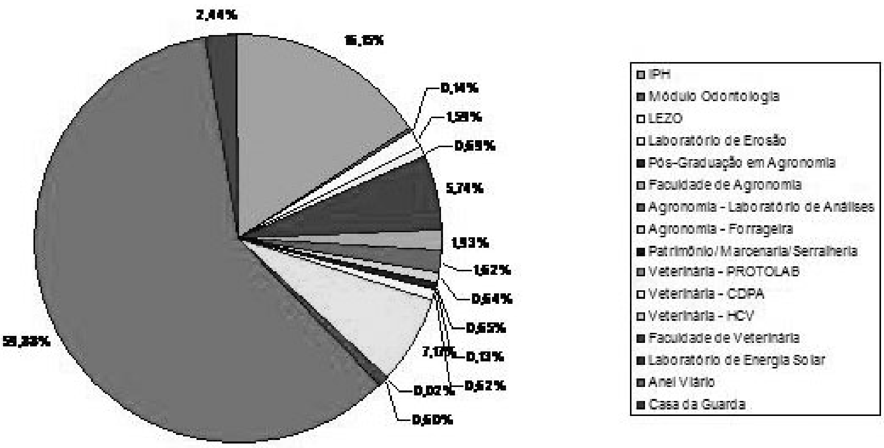

Figure 6 – water consumption on Campus do Vale meters

The assembly of a database to assist in the development of an intervention strategy is another important step on a PURA implementation. It must contain information about the water consumption, the distribution pipeline, the water use and its final destination. The database must support the decision making. It would also organize the historical information, which would be used to determine the program efficiency.

4. Conclusions

Nowadays, when episodes of water scarcity are more and more frequent, it is important to optimize the use of this resource, so that it would be available for future generations. The institutions of Higher Education are important reference centers in Brazil and in other countries when the subject is to save water: are major consumers and can act as a way of propagation of this idea.

The original intent of this work that was to implement a pilot study in a building of Federal University of Rio Grande do Sul as a way to encourage the establishment of a Program of Rational Water Use was unsuccessful. It follows that, currently, there are no conditions within UFRGS for the development of such action, without the prior existence of interventions in the installed infrastructure. The scenery assembled during the development of this work showed the lack of control, planning and maintenance systems. It is not done any preventive maintenance, and sometimes the reactive maintenance often takes too much time to be accomplished.

For the implementation of a Program of Rational Water Use in UFRGS it is recommended the development of further studies as to identify the situation of the hydraulic systems in the University. The corresponding information will help to define with greater precision steps and goals for the program. Finally, even not being possible to achieve the initial goals of this work, it was possible to identify the real conditions of the studied institution today and the endeavors that must be faced in the future implementation of a program of water conservation. Despite the good intentions and willing cooperation of some sectors of the University´s administration, more precisely, the Administration of Campus do Vale, it was not possible to pass through the stage of recognition of the problem.

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D2) Present State of the Operations Management and Construction of the Online Map Database on the Amenity Water Facilities

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Abstract

This paper reports the result of cooperative research with optional group "Study Meeting for Water Environment" that has been composed of designers and consultants of the amenity water facilities in Osaka, Japan.

In housing estates and city blocks, etc., amenity water facilities such as fountains and streams have mainly been founded as result of contributing to amenity improvement of the dwelling environment, playground of the child.

It is necessary to sufficiently consider cost time and money for the installation and maintenance in order to operate amenity water facilities that is artificially made water related facilities in the good condition. However, amenity water facilities are mainly seen in the shutdown from shortage of the recognition and deterioration on facilities, etc. Also, these factors it seemed to be a cause to not sufficiently share information about amenity water facilities, and it was considered that construction of map database which planner, designer, user can share was necessary.

Then, in this study, the hearing investigation was carried out in current situation survey for user and manager, while the specification is grasped by obtaining design data, and actual situation was grasped by the reconnaissance for eight amenity water facilities built in Osaka Prefecture and Hyogo Prefecture in Japan. In addition, the database that added the photograph in the field study by the construction of the blog system that can plot amenity water facilities installed at present on the map as an example was made on 324 facilities in Osaka City, and present state of the amenity water facilities was analyzed. Finally, the possibility of the utilization of the database was mentioned, while the consideration as the amenity water facilities maintained the work well was shown on the basis of these results.

Keywords

amenity water facilities, fieldwork investigation, Osaka City, web 2.0, information joint ownership

1. Introduction

In Japan, the amenity water facilities has been founded in great numbers in housing estates and city blocks, etc. as a result of improving the amenity of dwelling environment such as improving the landscape, a playground of the child, the creation of the natural environment and the relaxation of the thermal environment. It is necessary to sufficiently consider cost and labour which depend on installation and operation and maintenance in order to operate amenity water facilities that is artificially made water related facilities in the good condition. However, these become a shutdown and removed for these recognition shortage and deterioration of facilities, etc. And, the actual condition does not become sufficiently clear.

It seems to be one of the causes to not sufficiently share amenity water facilities mutual information on these factors. Then, it was considered that construction of the database that planner and designer and user can share was necessary with a grasp of the actual condition.

Then, it is made that the consideration of the operations management on future amenity water facilities is proposed to be a purpose of this study by extracting the problem on safety and sanitation of the amenity water facilities from the hearing to user and manager. And, work situation and the possibility of the online database map on the amenity water facilities are discussed which advances the construction at present.

Still, this paper carried out translation and correction on the basis of literature of 1), 2), 3).

2. Short history of amenity water facilities in Japan

"The Furukawa water park" (Photo-1) made in the Tokyo Edogawa ward in 1973's is called a beginning for the first amenity water facilities in Japan when the concept of "amenity of water" would be cried after 1970. However, the facilities that had the form of amenity water facilities such as Japanese garden and park in the Western style existed from it before (for example, Photo-2). And, "river improvement" which prevents flood damage and "water use" using the water were taken seriously, and especially the concept of "amenity of water" was not attempted in the interest in the situation of the relation with water such as water transportation and washing, fishing ground had originally been deeply related to the daily life. However, especially in the city, revetment improvement and under drains and water quality degradation, etc. for the end of the evolution of river improvement and water use caused the result of cutting off the relation with the water.

From such background, it became that it emphasized the human essence of being friendly with the water, and it seemed to connect it for the artificial limpid stream revival. There was a purpose that the place that is originally a river was made to restore the limpid stream on the Furukawa water park. However, because it is used the purified water that took water from Edogawa river and it was solidified in stone and concrete, it has not come to it in the restoration of original natural environment.

Afterwards, the amenity water facilities of the form that responded to the purpose have been founded by change and social conditions of the environment that surrounds the facilities. Considering disaster prevention and consideration to the environment, there is the extent of installation purpose and significance of the amenity water facilities (for example from Photo-3 to Photo-6).

Photo-1 Furukawa Water Park (First water park in Tokyo, Japan)

Photo-2 Suizenji Jojuen (Traditional Japanese garden in Kumamoto)

Photo-3 Kurumazuka Park (Disaster prevention park in Hirakata City)

Photo-4 Senkawa water park (Biotope in housing estates)

Photo-5 Oasis 21 (Large roof pond in Nagoya City)

Photo-6 Roppongi Hills (Mist spraying to reduce temperatures)

3. Trend in Japan and goal of study on the amenity water facilities

Since the research on the amenity water facilities is undertaken in 1995, the author has carried out the research for the purpose of the development of basic data and design technique which can mainly utilize from the action of the user to plan and design of facilities. At CIB W062, the paper on the amenity water facilities is being presented in the symposium (1997) [4] in Yokohama which I participated first. After doctoral dissertation (1998) [5] made on the basis of this announcement, the research has been advanced for the purpose of offering useful basic data by mainly grasping situation of utilization from the field study, for plan, design, urban planning of facilities [6), 7)]. In the study by the except for author, there are many results of carrying out the research from psychological viewpoint of the user and city-planning viewpoint. In the research in recent years, Shimizu and Matsumoto (2002) [8] have clarified the necessary item from utilization action and evaluation of the protector in the facilities improvement, and the material which is useful for plan and design is offered. And, Minoda and Kuroyanagi (2005) [9] have clarified the transition of the water park improvement in Tokyo 23 wards from questionnaire and interview of the administration to the park staffs, and it describes future problem from the viewpoint of whether it makes existing park to be how loved thing.

On the operations management of the amenity water facilities, there is questionnaire survey for 30 facilities by Suzuki and Tanaka (1986) [10]. And, in the report of foundation building management education center (2001 - 2002) [11), 12)], survey on actual situation and Legionella species investigation in the amenity water facilities are carried out degree of the each year on facilities over 90, and "Legionnaire's disease prevention measure manuals in the amenity water facilities" is arranged on the basis of this knowledge. Like this, knowledge on the operations management of the amenity water facilities is little. Especially, it is considered that the knowledge that is necessary for future operations management of evaluations and mutual relation from the viewpoint of user and manager, etc. of the amenity water facilities must be continually obtained.

Then, in this study, in obtaining the evaluation for the amenity water facilities of user and manager by the interview, while installation situation and operation condition of the amenity water facilities are grasped, the role of the amenity water facilities in the region should be clarified as a beginning of the continual research in future.

4. Method of the field research and result

The investigation for 8 amenity water facilities in Osaka and Hyogo Prefecture of which installation site and form and scale differ was carried out in order to clarify situation of utilization, operation and management conditions of the amenity water facilities. Concretely, the specification for each facility was grasped by the procurement of design data, and the hearing investigation for user and manager was carried out in the field, and the situation was grasped by the reconnaissance. Taking the investigation outline as a Table-1, taking the facilities outline as a Table-2, the photograph of each facility is shown in the Photo-7.

Still, facilities A became the operation stop, since the facility has broken down.

5. Problem of the amenity water facilities in the object facilities

From the result of interview investigation and field survey in the research object facilities, the problem was arranged in Table-3 by separating in facilities or thing on the operation and safety or sanitation. The survey result is examined in detail in the following.

5.1 Problem on operation or facilities

There are many problems to be considered on facilities in plan and design For example, facilities A becomes a shutdown by the shortage in the repair budget, the running cost of facilities B is high and the operating program is a rut and that the machine room is conspicuous in facilities E etc. From the plan stage, it sufficiently considers repair and operational cost; it seems to have to decide the scale of facilities.

On the operation, the facilities that are stopping the operation as a whole at the night are mainly seen. And, the crack by the Han-Shin Awaji Earthquake disaster effect has remained in B (Photo-8). This may become a cause of the water leakage. And, the succession of the manager is not well carried out in F. In H, the periodic maintenance of the equipment has not been made. The improvement of the manual is required.

5.2 Problem on safety or sanitation

On the safety, children are greatly related. There are many cases in which metallic gratings and nozzles, etc do slip and injury. And, the nearby damage to the human has

Table 1 – Outline of investigation

Investigation period	11 Sep. - 17 Oct.2006
Investigation number of persons	4 groups are formed at the number of persons of about each group of 5 persons, and 2 facilities are respectively investigated.
Specification investigation	Procurement of drawing and specification (plan, facility system diagram, specification, etc.)
	* Survey item otherwise tables -2 (designer, facilities manager, use electric power, lighting, classified area, etc.)
Field investigation	Interviewing to user and manager
	* For the user, it is interviewed in respect of utilization purposes, effects, problems of the amenity water facilities, etc.
	* For the manager, it is interviewed in respect of management consignment, relation with the inhabitant, maintenance frequencies, frequencies of the water quality survey and items, situations of the water, situations of each facility, availability of the inhabitant, etc.

Table 2 – Outline of investigation facilities

Facility	A	B	C	D	E	F	G	H
Installed city	Minoo, Osaka	Kobe, Hyogo	Amagasaki, Hyogo	Hirakata, Osaka	Hirakata, Osaka	Suita, Osaka	Itami, Hyogo	Neyagawa, Osaka
Installation year	1997	1990-1993	2004	2005	2006	2000	2006	2005
Installation site	Compound welfare facilities	Pedestrian mall	Hospital site	Station square	Disaster prevention park	Block park	Neighborhood park	River greenland
Installation intention	Relaxation and peace of mind are given to the citizen	Symbol of the developing region	Peace of mind is given to strolling human	Indistinctness	Complement of main landscape symbol and disaster prevention function of the park	Familiar and natural touch	Field of the relaxation of the inhabitant and disaster prevention park	Regeneration of the river
Utilization purpose.	Amenity of water and Landscape	Amenity of water and Landscape	Landscape	Amenity of water	Amenity of water and Landscape	Outlook on nature	Amenity of water	Amenity of water
Form or water	Fountain, Wall fountain and Stream	Fountain, Wall fountain and Stream	Wall fountain and Basin	Fountain	Fountain and Wall fountain	Fountain and Pond (Biotope)	Wall fountain, Stream and Pond	Stream
Holding water quantity	$80m^3$	$3,800m^3$	$8m^3$	Nothing	$40m^3$	$180m^3$	$36m^3$	$4m^3$ (Pump pit)
Water source	Tap water	Tap water	Tap water	Tap water	Tap water and Rainwater	Tap water	Tap water	River water
Filtration or purifying method	Upward style filtration	Sand filtration	Automatic compression rapid filtration	Nothing	Levitation filtration	Charcoal clean up	Sand filtration	Upward style filtration
Disinfection method	Chlorine	Chlorine	Chlorine	Nothing	Copper ion and Chlorine	Nothing	Copper ion	Nothing
Operating time	Stopping	11:00-	7:00-19:00	10:00-17:00	9 hours at amenity water equipment, 24 hours at filter assembly	24 hours	8:00-17:00 at amenity water equipment, 7:00-18:00 at filter assembly	7:00-22:00

Photo-7 Photo of investigation facilities

also been generated by fact to the nozzle in which they play, etc. The generation of such accidents, etc. seems to have been generated, since the prediction of measures of the hazard control and action is insufficient. The generation of these accidents seems to have been generated, since hazard control measures and action prediction are insufficient. And, the note has done stretching rope for preventing the entrance to the dangerous space (Photo-9). Though it is desirable that such safely facing countermeasure is also examined from the design stage, the necessity of examining by the operational phase anytime seems to occur.

On the sanitation, the problems of refuse and fallen leaf have mainly been raised (Photo-10). And, there is the feces injury of the bird in D. It is necessary that these warn in the amenity water facilities for playing in water especially, because it is related to the water quality degradation.

For the water examination, carrying out facilities is only two's within 8 facilities. Users opinion was mainly asked, since that the user knows information on water qualities such as the existence of type and inspection of raw water is not possible.

Table 3 – Problem in the investigation facilities

Facility	Problem on operation or facilities	Problem on safety or sanitation
A	* After the trouble of the facility which disinfects the Legionella species, operation has been stopped. * Water in the pond is being removed.	Nothing for the work stop
B	* Height of the running cost. * There are ground subsidence, crack.	* There are many refuse and fallen leaves. * There are dangerous places such as an intake. * Height of the bridge is dangerous, when the child plays.
C	* There are small publicity of facilities.	* Withered leaf of tree and grass is the floating. * Algae adhere to the flagstone.
D	* It is difficult to carry out controlling time and cost, correspondence of the accident (It was transferred after the completion). * It runs only in tap water. * For direct connection to water supply , there is a problem on the water supply law.	* Since it did the injury, as the child slipped in the grating in the pond, the use of the pond is being stopped. * Passage person may get wet by the mischief to the nozzle. * There is the feces injury of the bird.
E	* Operating program can not be chosen. * Machine room is conspicuous.	* White lye which comes out of stone applying of the wall fountain is conspicuous. * Child may slip, when nozzle metallic material of the bottom face has got wet in the water. * There is the entrance of the child to the wall fountain upper.
F	* For the biotope pond, the grass grows thick and is hard to approach. * On the management practice of sewage disposal facilities in the pond, the succession to staffs is not well carried out.	* Though the iron railing has been installed the circumference in the shallow pond, the entrance of the child is easy. * By choking the charcoal up, it is not possible to carry out clean up.
G	* Though the management by the volunteer is carried out, the maintenance of pumps and filter assembly in the water storage tank, etc. is not possible.	* Though there are 3 places for facilities guide plate, there is no it in the amenity water facilities.
H	* There is a human for scribbling and mischief in wooden stairs, etc.. * Periodic maintenance of the equipment has not been made. * It is difficult to walk, since the vegetation grows around the stream.	* There is a human who discards the refuse. * There are no utilization on the stream and guide plate on the use water, note. * mud adheres to the filter assembly, and the plugging has been caused.

Photo-8 Crack of the ground in facility B

Photo-9 Fence and signboard that prevent the entrance to the wall fountain robust in facility E

Photo-10 Refuse of the water surface in facility B.

6. Consideration on the operations management of the amenity water facilities

It was put together that it was got from the investigation to the research object facilities. The consideration as the amenity water facilities maintained the operation well was arranged in Table-4 and Figure-1. Especially, it is desirable that information is shown by carrying out the display on amenity water facilities like Figure-2, for the user. On the display content, the uniform standard must be examined. And, it is important to raise the attachment to facilities in search of the positive participation of the citizen to operation and management from plan and design stage of the amenity water facilities. It is desirable that owner and manager and citizen continue the operations management of facilities in the equal standpoint by constructing a framework like Figure-3.

Table 4 – Consideration on the operations management of the amenity water facilities

Plan and Design	
*	The necessary cost from plan and design stage of facilities to the operations management is considered.
*	By adopting the request of the citizen from the plan stage of facilities, facilities with the attachment are built.
Operation and Management	
*	The cheap water source is chosen considering the cost which depends on water purification.
*	The manual on the management of the amenity water facilities is improved.
*	The periodic and appropriate maintenance is carried out after the completion of facilities on the equipment of amenity water facilities such as pump and filter in the water storage tank.
*	The operations management is carried out in not owner initiative but the standpoint in which owner, user, neutral third person (NPO, etc.) are equal.
*	The management is carried out within the citizen being possible mowing, cleaning, arrangements of the bicycle parking lot, guidance of the usage which is right facilities, monitoring of the doubtful person, etc..
Safety and Sanitary	
*	It is thrown of cross cut prohibition and refuse to the place dangerous, and the note on the prohibition is displayed.
*	The material which does not slip in the grating in the amenity water facilities is used.
*	Water quality examination is carried out periodically.
*	Specification of facilities and information such as the water quality are opened to public in order to it put in the water, and in order to the user feel easy.

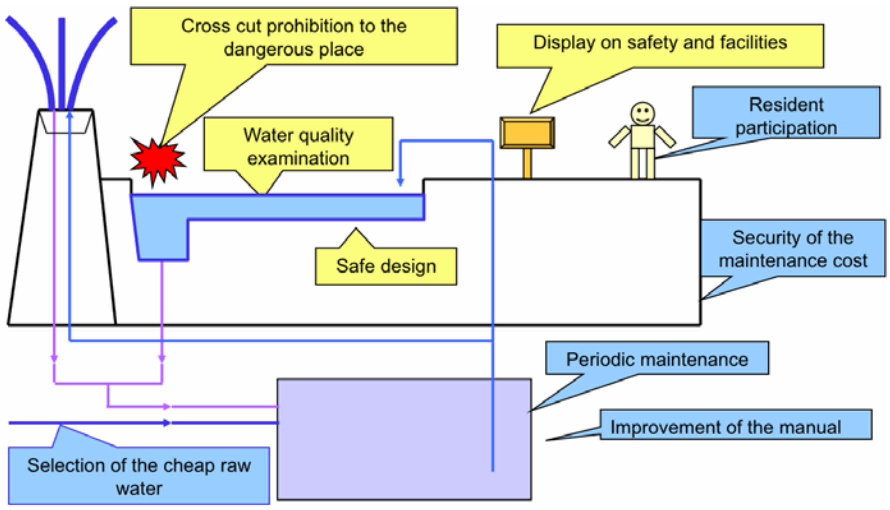

Figure 1 – Summary of consideration on the operations management of the amenity water facilities

About this amenity water facilities

Name	****** park
Installation year	2002
Form or water	Fountain, Wall fountain and Stream
Water source	Tap water and Rainwater
Holding water quantity	3,800m^3
Water quality examination item	Escherichia coli, BOD, pH and turbidity

* Water quality examination carries out 4 times (January, April, July, October) in the year.
* The cleaning carries out 1 time for 2 weeks.

Attention in the utilization
* Don't discard the refuse in the water.
* Don't approach nozzle, intake, because it is dangerous.
* Don't let in the pet in the water.

Place to contact

Park management section of the ****** City
--* *** Street, ****** City
Tel.***-***-****

Figure 2 – Display example on the amenity water facilities

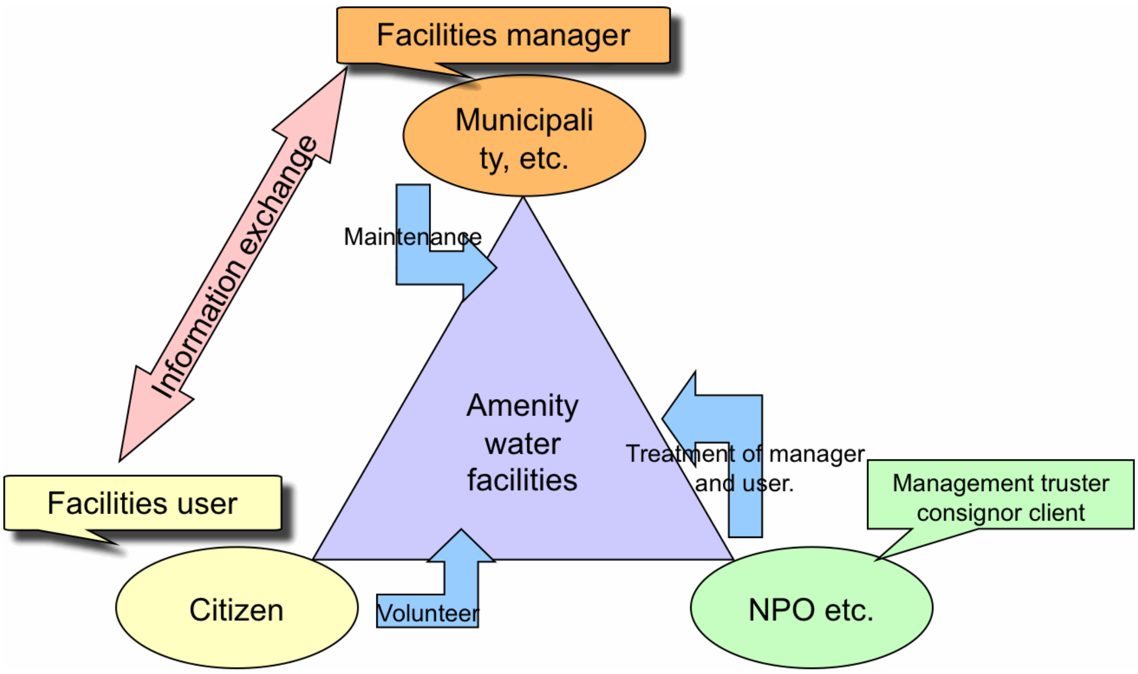

Figure 3 –Operations management system of the amenity water facilities by the co-operation

7. Construction of the online map database

Though amenity water facilities utilized in various places has also produced many problems above mentioned, the actual condition is not sufficiently clear. To begin with, the material that can grasp in what kind of situation the amenity water facilities has been founded, does not exist in Japan. It becomes possible by the basis which shares such information utilizing online service such as the Google map, and the map database has been constructed in great numbers even in Japan by users such as the "Post map" 11).

And, the safety of internal and external building facilities of carrier facility of elevator and escalators, and play facilities of amusement park, etc. becomes often a problem in Japan. As one of the reasons why these occur, it is raised that information on the safety is not shared.

Considering this fact, by constructing "Amenity Water Map" in which citizens, designers, managers, administration, etc. can share information on the amenity water facilities, the activation method is examined.

In this paper, examination content in fiscal 2007 is reported.

8. Construction of the online amenity water map

8.1 Outline of the system

The database of the amenity water map (Figure-5) is used Google maps API developed and offered by Google, Inc. and Movable Type developed by Six Apart, Ltd. It is what is called "Blog" type. The construction of the system was carried out on the basis of the Web site of 12).

Since to observe this database by the Web browser is possible, there is no necessity of special software and system. And, by the standard function of blog, it is possible that the database is satisfactory by many people participating, because comment and truck back are possible, and it would be able to cope with the problem for the renewal of the data.

By the cooperation of "Water Environment Study Meeting" which investigates maintenance of the amenity water facilities, etc. in making Osaka to be the activity base, amenity water facilities data of 324 in Osaka City was collected by January 2008. This data was input into the amenity water map, and the database was constructed. The explanation of situation and field photograph has been written each facility additionally with the position information on the map (Figure-6). At present, though comment, track back and search system are not used, it is examined that these are used in the study in fiscal 2008.

8.2 Composition of the map

The amenity water map made two types. One offers the matter which displayed six of "Park", "Public facility", "Public and so on", "Commercial facility", "Private and so on", "Stopping facilities" by doing color code in the marker as " Management division map".

http://team-6.eng.toyo.ac.jp/suikeimap/

And, in making to be "Facilities form map" in another, color code of nine of "Fountain", "Waterfall", "Flow", "Pond", "Fog" "Composite facilities", "And so on" (the amenity water facilities of special forms such as well pump) "Indistinctness", "Stopping" is done in the marker, it is displayed.

http://team-6.eng.toyo.ac.jp/suikeimap/shape.html

Still, the use language is only Japanese.

9. Future problem on the construction of the amenity water map

It became clear that facilities with not correct position and facilities might not already exist in the field study in May 2008. The amenity water map has been established by the information service of many people. However, it is a problem that the thing in design and construction is abounding for this information. In the small number of member, large labour depends on the renewal of information. Therefore, it is important to incorporate the mechanism that user and manager who can grasp present state can participate for the maintenance of the database.

10. Conclusions

In this paper, the outline of scientific research on the amenity water facilities in this about 10 years was described. And, the extraction result of the problem based on the field study in fiscal 2006 was described. In addition, future problem was described, while the construction of the online database on the amenity water facilities was explained. The value as a society assets is improved, if information of the amenity water facilities can be sufficiently shared. It is considered, if a series of research can contribute in this.

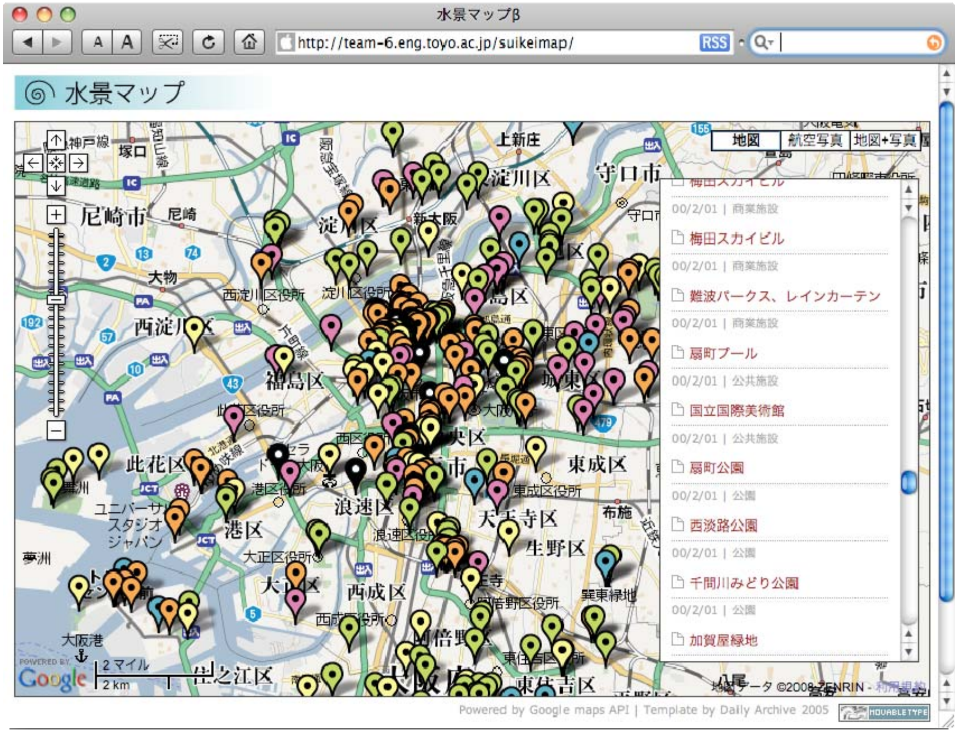

Figure 5 – The Amenity Water Map (Management division map)

Figure 6 – Data example of the amenity water map

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This study is cooperative research with water environment study meeting (Representative: Mr. Kenji NAKANISHI) that has done the activity in Osaka.

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12. Presentation of Author

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, water environment and environment enhancement. At present, it wrestles in the co-operation between citizen and administration in respect of the preparation of the amenity map of Kawagoe, Tatebayashi and Yamakoshi in proportion to region the actual circumstances.

D3) Planning for Water Supply Main Burst in Hong Kong

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Abstract

In Hong Kong, six million people live mainly in urban area with heavy traffic and congested road conditions. The water supply main was laid in earlier 50's under the traffic route below roads. The condition of water supply main was extremely poor till year Y2K. Frequent main burst problem was brought to the attention of public. Deterioration was the main cause. With the approval and funding support from the government, the replacement of main buried under main traffic is progressing for a period well over twelve years. It is afraid after a total replacement; the second cycle of replacement shall also begin. Can we make use of the special road network system in Hong Kong? With the assistance of common duct, it is proposed a new intelligent scheme of design allowing for a better and efficient re-distribution of water supply main services to support the future maintenance and replacement. Hong Kong suffered from main burst damage to substantial financial loss and affecting the daily living. Main burst causes landslide and related environmental problems and damages. A new proposal and planning should be focused to alleviate the problem to a permanent condition. Water supply system reliability is very essential. Besides, protection and prevention from further environmental problems staying in our daily life should be sought for. With due consideration for the public concern, it can justify that the new scheme should be considered for the benefit of public.

Keywords

Main burst problem, road network system, common trench, second cycle of replacement, intelligent scheme, re-distribution of main, water supplies system reliability, environmental problems

1. Introduction

In Hong Kong, the water main buried under the road has a total lengthen of approximately 7700 kilometres, which the earliest portion was laid in earlier 50's. Due to the deterioration, material fatigue, and heavy traffic imposing life load attack, the main burst becomes so frequent daily, about two cases happened all over the places in Hong Kong. Over fifty percents of the main possessed over thirty years old.

The pipe burst and the associated water leakage accumulates about 2000 million cubicle meters of water, which is equivalent to one quarter of the total water consumption annually in Hong Kong. In the account of costing, it is approximately equal to 6180 million dollars loss. If we account for the cost of water treatment and purification cost, we lost about 9000 million. That means each of the 600 million people will loss $15 annually as reported in 2004.

The most harmful effect is the associated problems in affecting the daily life and operation of the society, the financial loss, latent problem in affect the safety of people (Photo 1) and environmental problems.

Photo 1 - Road cracks (with courtesy from Apple Daily News dated 10th June 2008)

In Hong Kong, the water mains laid mainly under the main traffic routes. The road conditions having heavy daily traffic from 8:00AM till 11:00PM renders the road repair work extremely difficult. The maintenance and replacement of broken main were un-permissible. Furthermore, the government imposed a rule of no re-open of main traffic road within one year after the most recent repair work. This also limited the possibility of periodic maintenance of water main.

2. Problem, Consequence, Seek for new solution

To begin, let start up with two cases study to examine the conditions and the review the underlying problems in understanding why the situations become the upmost importance. In these two cases, the first one involves significant financial loss and the second one involved a fatal case. There are also many incidents and minor disasters happened, which could not be elaborated all in view of time and similarity in nature.

On 20th July 2004 1:30 AM, Admiralty in Hong Kong Island, a district including finance centres and shopping centres existed landslip and road cracks due to a 400mm diameter main burst. The heavy flooding created a huge financial loss in stopping the daily business operation. One government office building, courts and high court stop their operation, three hotels cannot maintain their service without catering services due to no water supply. The guests were transported to other hotels for washing. The British council and shopping mall stop over the day without administration og immigration matters and no business. The repair work took over fourteen hours of emergency work.

About 10 hours later to the urgent repair work and resuming the normal water supply services, on 22nd July, a branch main of the repaired main broken again. The whole processes and associated problems reappeared. Of course, losses and interference were unavoidable. Consequence of huge financial loss, nuisance to road user, and halt for business are un-acceptable within such a short duration. The repair work could be in hurry and the insufficient preparation due to the permissible conditions.

The second case is a fatal accident due to the main burst. It is a bad consequence after series of main burst in resulting significant momentary losses. On 21st January 2008 morning in Hong Kong Island, Heng Fa Sun Chuen, two workers assisted the repair of a burst main. The 51 years old male worker’s head was hit by a 20 kg loosen gate valve stem which was jetted up at a speed of 20 miles per hour from a broken main while closing down a control valve. The accompanying female worker was also wounded. The male worked passed away in the next day.

The working condition of water supply main was extremely poor till year 2000, frequent main burst problems were brought to the attention of public. Deterioration was the main cause. With the approval in 2003 with approximate HK$2100 million dollars funding from the government, the replacement of the buried main under traffic is progressing for a period well over twenty years. There comes with two main problems. The mains will still be buried under the road without considering the future repair and periodic maintenance. Secondly, the repair programme will last for twenty years or more. The end day will mean for the end of the materials life cycle of the main and the second cycle of relaying new mains should also begin. Actually, there is no allowance for periodic repair, maintenance or replacement due to emergency cases.

By that time, the Highways Department raised the issue to develop the common trench. The author will consider a common duct similar to the Mass Railway Transport system (Photo 2 and 3) in Taiwan, Shanghai of China, and in United Kingdom underground railway system.

Photo 2 - Taipei Xinyi Metro line was the first common duct project

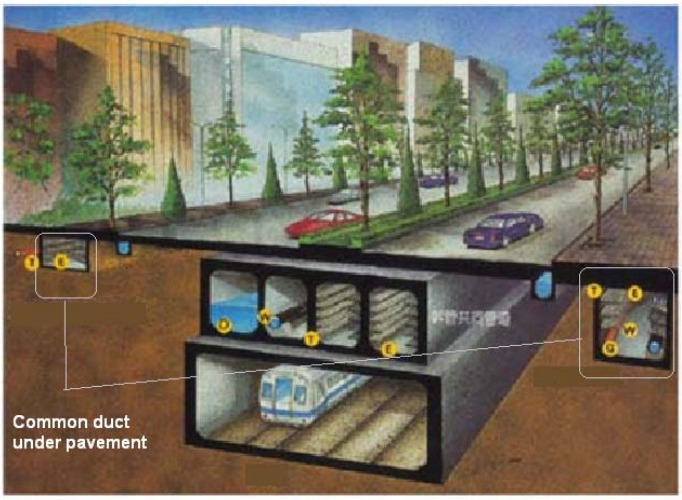

Photo 3 - Common duct under pavement

Photo 2 and 3 - With courtesy from MAA consulting Engineer Web pages

More hazardous, there could be health risk. When a main burst, high water pressure jetted up earth worms, sands and debris into other end of the water supply main. It had been reported that a 5 cm long worm existed inside a cold water supply system. A house woman collected it when she opened a tap on 31st May 1998 during her cooking. It can be revealed foreign material ingress to a piping system after a main burst is not un-common. Furthermore, some underground matters will cause corrosion effect when they were accidently migrated. The road crack as shown in Photo 1, road settlement undergoing (main seepage occurred) without notification in creating serious damage and roots of trees were deteriorated are fairly common. It is categorized as environment impact. All aspects sustainability and environmental impact have to be considered simultaneously.

Replacement cost, business loss, and interference to the normal routine daily operation are in no doubt placed in the top priority. Indeed, the environment impact could bring out disaster in subsequence days due to ignorance and negligence.

3. Facts

The records of broken main were investigated by the author starting in 1990. The sources can also be found out from the annual reports from the Water Supplies Department. To substantial the problem, the following broken main records are abstracted from the annual reports of the Water Supplies Department:

Table 1 – Summary of broken main records in Hong Kong starting 2001

Year	Fresh water (case)	Flushing water (case)	Total incidents
01/02	916	966	1884
02/03	943	942	1885
03/04	1024	1040	2064
04/05	941	871	1812
05/06	758	827	1585
06/07	811	822	1633

It is found out the daily water main burst cases round up to about 5 cases over a period of six years starting from 2001 to 2007. The author comments that it is extremely serious. The financial loss from Public and to the individual citizens as mentioned earlier in the amount of HK$15 per person annual. Government finally approved $223 million on 30th August 2006 to the Water Supplies Department to repair and replace the corroded main since 2000. But it is anticipated that all the works for replacing and rehabilitating water mains can only be completed by 2015. Legislative council members of Hong Kong raised their concerns and asked for a shortened period in expediting for earlier completion in April 2008. Actually, the phase 2 progress will be ended in early July 2008. It has recorded about 460 Km of water mains was completed and 890 Km of them is in progress. After a total of fifteen years of the rehabilitating work, there may turn out the second cycle of replacement due to the materials fatigue re-begins. The real problem is timing required and no significant improvement to the protection and extension of plant life.

4. The problem still exist after replacement

The main replacement period lasts for fifteen years. It is unexpected undue long and may reach the end of pipe materials life cycle in normal. Irregularly road excavation, more heavy traffic imposed life load acting on buried pipes, un-permissible periodic maintenance (due to under main vehicular traffic) and new water supply teed-off from main for new building or development conclude after completion in fifteen years later, the recycle of second replacement is expected to re-begin. The reoccurrence of digging the road and replacement again, the same problems re-appear. It cannot totally resolve the problem. The water supply main installed in the soil, a suspicious space without workable space for repair, undetectable condition with or without leakage, the problem or more serious problem will arise unless new concept to improve it.

Nowadays, facilitates management demands for good trace of services condition, the water supply main although is a public utility, still demands for monitoring and proper maintenance till its end of life. Then, a suitable replacement takes place.

5. Common duct system

From Wikipedia[2], the free encyclopedia for the explanation of - advantages of common utility ducts. It explained fully: "*the advantages of such facilities are the reduction of maintenance manholes, one-time relocation, and less excavation and repair, compared to separate cable ducts for each service. One of the greatest advantages is public safety. Underground power lines, be the ducts common or separate, prevent downed utilities from blocking roads, thus speeding emergency access after natural disasters such as earthquakes, hurricanes, and tsunamis. When they are well mapped they also allow rapid access to all utilities without having to dig access trenches or resort to confused and often inaccurate utility maps.* "

You might be aware in UK, Taiwan and Shanghai of China, common duct or common utilities duct are getting more popular and becoming a must provision. Further reference to Wikipedia[3], examples are:

1) Xinyi and Sonshan MRT rapid transit lines in Taipei, Taiwan
2) Azabu-Hibiya Common Utility Duct in Tokyo, Japan
3) Minatomirai District lines in Yokohama, Japan
4) Poundbury Village in Duchy of Cornwall, Prince Charles' master planned community in England incorporates common utility ducts
5) "Utilidors" in Disney theme parks
6) German cities such as Bremen.

Inside these cities, you can observe a nearly perfect surface on its footways, cycle ways and streets.

However, this basic theme is a key component in the proposed concept scheme in Hong Kong. It has tried successfully in those railway subway systems, together with a common trench and duct work to facilitate utilities distribution. In Hong Kong, it will be suggested as a short cut for replacement of main. The open up the trench and duct work connection can be simplified. To establish a common duct system in HK is extremely difficult or impossible due to geographically constraint. Underground utilities, building foundations of densely built premises over congested development areas, rejected the possibility. But, if it is not for a continuous and linkage throughout Hong Kong, the chances will be higher.

The feasible short linkage and intermittent common duct linked up to external bridges and flyover systems are definitely worthwhile to be examined for their application in Hong Kong.

6. Special road network system in Hong Kong

From the information of new planning sourced from the Highways Department policy and planning development report in 2002.[1] The following diagram is a overall plan indicating the main trunk of highways and express highways in the format of flyover system in Hong Kong.

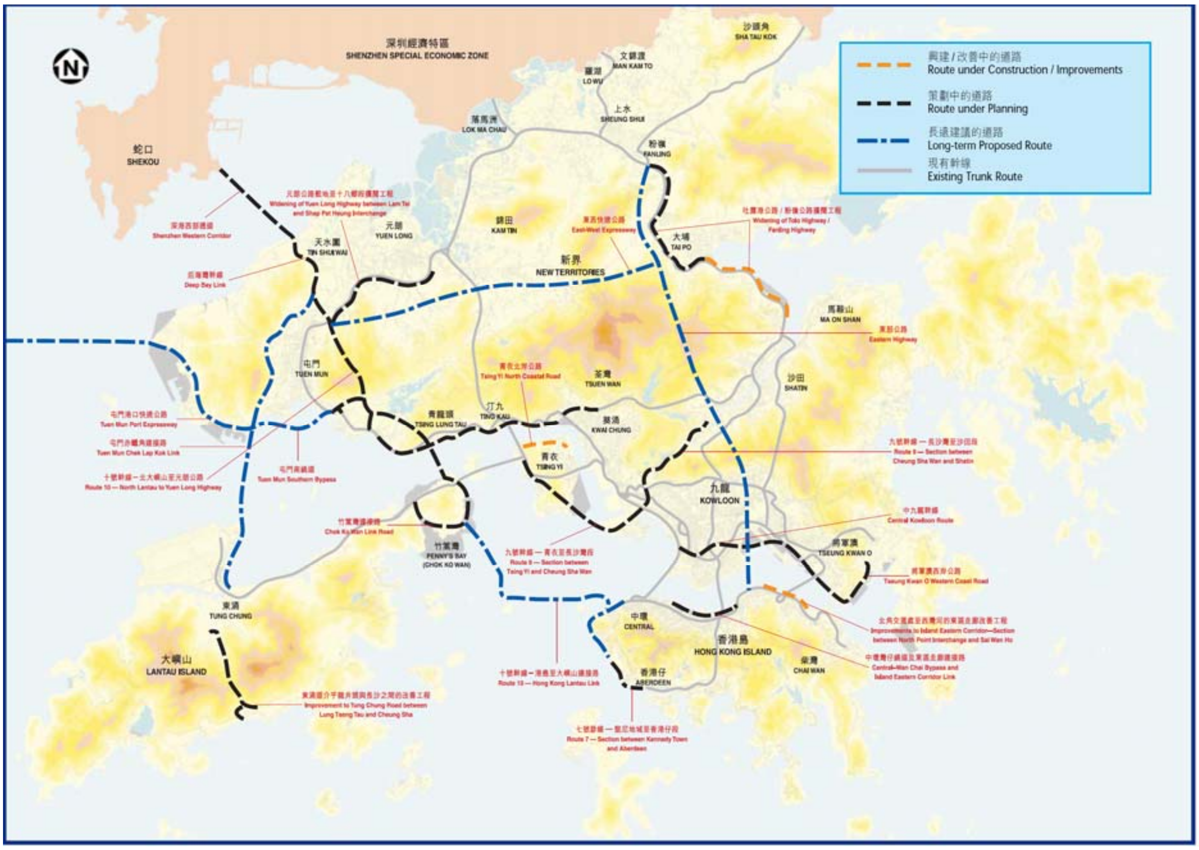

Figure 1 – Future highway network in Hong Kong – From Manual of Highways Department "Building for future" [1]

Flyover, highways, express highways in Hong Kong are linked up and further extended to Main Land China. Can we think deeply regarding it?

Equipped with mains in the flyover (i) in an surface mount manner, or (ii) a module attached on its sides. Some similar methods were introduced in the latest "Tsing Ma Bridge" as shown in Photo 5 which shown the services were housed inside the flyover or can be considered as a module.

Photo 4 - A perspective view of a typical flyover

Photo 5 - Services housed inside "Tsing Ma Bridge"

7. Concept and design

The main burst problem was revealed inherent with many problems and also having a fatal case. The latent problem in future maintenance and repair were also noted. The existing system cannot cater for the need and the practical requirements. However, we cannot stud up at this stage. The problem could not be totally resolved. An attempt was suggested to make use of the existing road network system in Hong Kong to alleviate to an optimum solution.

The future system will be the trunk main leading from the service reservoir to be laid a short section in the common duct system (Fig. 2). Of course the common duct will permit the future maintenance and accessibility to maintain the system pipe work, future repair and replacement. Then the main trunk will be attached to the highway, and express highway flyover system for the distribution. The branch will be standard teed off to supply individual premises and to the development demanding the water supply.

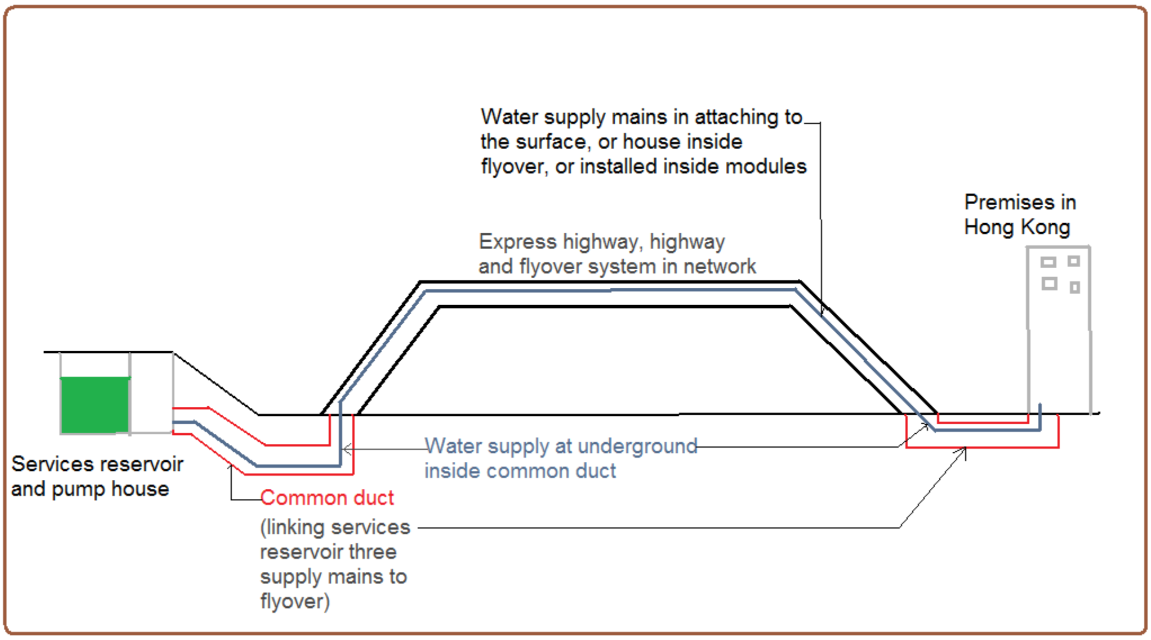

Figure 2 – Proposed common duct to flyover to common duct system concept diagram

The linkage from a flyover to the development and premises can also make use of the common duct system. Lastly, the overall system is from a common duct to flyover to a common duct system as an integral. The system avoids the buried portion by locating the services mains: cold water, flushing water and fire main in a common duct. Additionally, the module system is an alternative to the surface mounted pipework system in attaching to the underside or sides of a flyover (Fig. 3).

A short run in the form of common duct link up water supply mains through footpath and pedestrian walkway to buildings, which is the main in hanging and following the main network could be an ideal situation to permit the maintenance and repair requirement without hindrance to the repair work.

Figure 3 – Proposed module system

8. Benefits

The common duct to flyover to common duct system is an integral system. The portion in the flyover system can be either a surface mounted system or a module system as shown in Fig. 3 above. This precast system is taking the advantages of prefabrication, shortening the site installation, save materials cost, save the labor cost in the practical issues. Connections can be provided in advance during the prefabrication.

Practically speaking, the permissibility of maintenance, repair, replacement, practical work space, safe environment, and stopping future environmental pollution are the main benefits in parallel to cost saving. It would be practically solved the aforesaid latent problems.

In elaborating the above, the proposal facilitates the greatest benefit for periodic maintenance without constraining by the road traffic and no road re-open-up constraint in the next year as required in the regulations.
Second main benefit, visualize leakage problem from the earlier stage with just minor nuisance are easily observable.

To explain the significant cost saving in cut down the repair cost are less in excavation and minimum administration of road work associated planning and special approval for re-open up of the road.

In the sustainability aspect, the prevention of environmental problem brings out and also trims down the health risk.

9. Conclusion

The proposed common duct linked up to the flyover (Fig. 2) and from where tee to premises nearby makes fully utilization of the special road network system in Hong Kong. In Hong Kong, the express highway and highway linked up the major roads and small roads and even to Mainland China is already the development trend. The water source is also supplied from China. These factors in consideration together for planning the proposed water supply main system by main trunks attached to the highway network would be beneficial. The water supply main from reservoir and service reservoirs is supplied to the user by short sessions in the common duct system in parallel to the main trunk attached to the highways road network in the format of flyover. This is the main concept of the common duct to flyover to common duct system.

The traditional water supply system by buried underground has to be change. The benefits of the proposed system are early detectable from leakage to burst, less but possible maintenance with the least time and nuisances to road user and practical road works hindrance, comparative lower cost with least labor and road excavation, the repair time for burst and maintenance part is speedy and more controllable.

In comparing to the world wide system of utilities distribution system, the proposed system may only be applicable in Hong Kong due to the water supply main can rely its distribution by the flyover system with the help of a common duct system. Other country may only consider the common duct system due to their boundary conditions implication. If the module system can be further developed, the speed replacement within half a day or a few hours will be possible. Then further cost and time saving will be recognized. The existing problem in Hong Kong may be the same problem in foreign countries when water supply main loading is increasing to cater for population and business growth.

Towards the 21st century and a modern trend demanding speedy, spare available, less disturbance, cost saving, sustainability, standardization of module design (when module system is applied) and reliability of the observable system. Unlike Roman Empire, they made use of the open nullahs and duct work system in water supply system, which permits system maintenance easily. Nowadays, the cleanliness demands water supply to be covered or piped. The subsequent maintenance problem would then arise.

Acknowledgement

Photo 1 was reproduced from Apple Daily News 10th June 2008
Photo number 4 and 5 were provided by Mr. Raymond Wong of City University of Hong Kong

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11. Introduction of Author

Ir Lonnie Cheung Siu Hung possessed over 28 years experience in consultancy, teaching, and advisor role to many professional institutions and also serving as an independent consultancy for the Hong Kong Housing Authority for many consultancy projects and trainings well over five years period.

D4) Water efficiency of products and buildings: the implementation of certification and labelling measures in Portugal

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Abstract

This paper outlines some of the actions being pursued in Portugal with a view to improving water efficiency in buildings and products. First, a demonstration project that is under development is described. This is the AveiroDOMUS House of the Future, and it will be used to study various efficiency solutions for resources' use in buildings, and to assess their economic and environmental value. Afterwards we examine an initiative by the universities and firms in the sector, which has led to the forming of an association (ANQIP – National Association for Quality in Building Installations) to decide on the implementation of a voluntary water-efficiency certification and labelling system for products.

Keywords

Water-efficiency; water-efficiency labelling; products and buildings.

1. Introduction

As water is a limited resource which has to be safeguarded and conserved, its efficient use is an environmental imperative in every country in the world.

It may be recalled that, according to forecasts by the World Water Council, 23 countries will be facing absolute water shortage in 2025, and between 46 and 52 countries (encompassing 3000 million people) could be suffering "hydric stress" by then.

Climate change in Mediterranean countries like Portugal could significantly affect the short- / medium-term availability of this resource, and so measures must be developed in all sectors, as a matter of urgency, to improve water-use efficiency.

Countries like France, Italy, Spain and Portugal will, indeed, be at risk of 40% or more hydric stress in at least some of their territory (Figure 1).

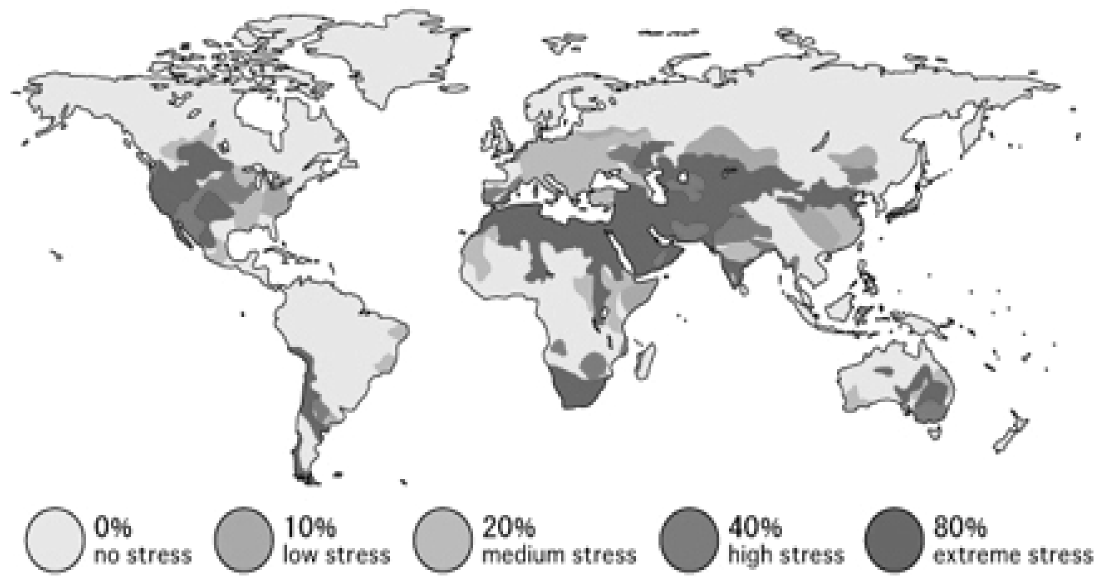

Figure 1 – Hydric stress. Scenario in 2025 according to the World Water council

In terms of sustainability, the priority measure to is obviously to increase efficiency in the use of water.

It is reckoned that total inefficiency in water use in Portugal, in all sectors, amounts to 3100 x 10^6 m^3/year, which represents nearly 0.64% of national GDP. About half this figure can be ascribed to inefficiencies in urban supply (public and building systems).
In the building sector, special heed should be paid to the use of efficient products and the overall efficiency of buildings. So not only should efficient fixtures and fittings be used, but water must be re-used or recycled and alternative sources tapped (like rainwater and groundwater).

In light of this context, the Portuguese government has recently chosen to implement a National Plan for Efficient Water Use, which provides for the water-efficiency labelling of products and specifies incentives designed to increase water efficiency in buildings.

The plan establishes that labelling should be entrusted to non-governmental organisations, working with official government bodies in the sector, and it will be voluntary, as a rule.

2. Water efficiency in buildings: a case-study

2.1. Aveiro's House of the Future Project

The Portuguese city of Aveiro is 250 km from Lisbon, the capital, and 10 km from the Atlantic coast. It is surrounded by a saltwater lagoon system that occupies 110 km^2 of the River Vouga estuary (Figure 2 and Figure3).

Figure 2 – Location of Aveiro

The region of Aveiro is on the northern part of Portugal's coast and is regarded as a highly vibrant economic zone. A considerable number of industrial sectors are based there, involving all kinds of business activity, especially in the construction sector.

Figure 3 – Aveiro Ria – Lagoon Area

The University of Aveiro, in association with a group of interested companies, has created an association called AveiroDOMUS, the main purpose of which is to design and build a "House of the Future". This house is developed under sustainable construction principles making use of state-of-the-art and environmentally friendly technologies (Figure 4).

The design of House of the Future was concluded in 2007, and it is hoped that work will start on its construction in the near future.

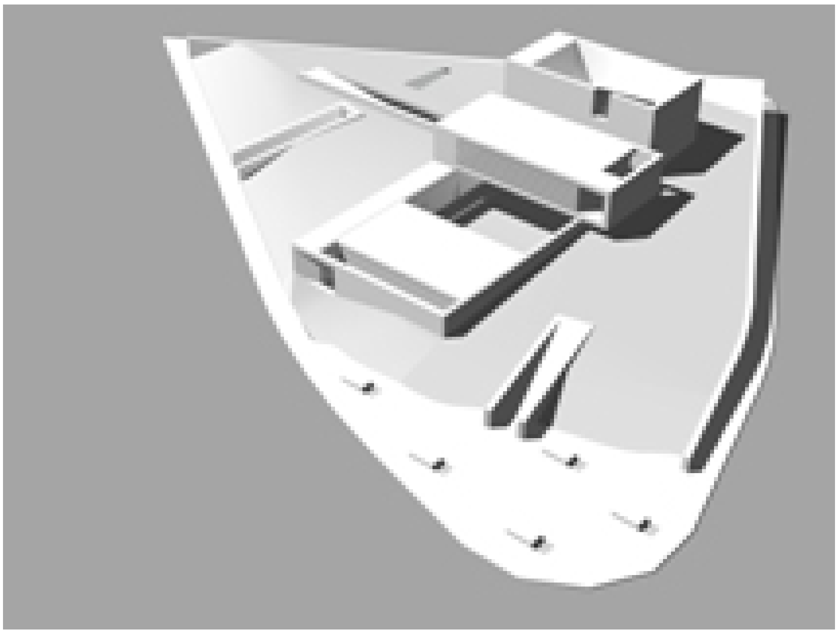

Figure 4 – AveiroDOMUS House of the Future

The house must obviously be of an advanced design, but the main objective is to build it in accordance with sustainable building standards, ensuring proper interaction with local ecosystems and a good interior environment (air quality, absence of noise, comfortable temperature and humidity, light, etc.). Another pertinent aim is to reduce consumption of essential resources through the appropriate choice of materials and use of renewable energies and by optimizing the water cycle.

In fact, one of the major goals of the project is the optimization of the hydrologic cycle in the House, under sustainability principles such as water recycling and reutilization, the incorporation of low-flow fixtures and the use of rainwater, groundwater and salt water, which is abundant in the area where the house is to be built – the Aveiro Salt Lagoon.

The AveiroDOMUS House of the Future will be a permanent research and development laboratory, open to both industry and the public. In fact, one part of the house will be open to visitors, another part will be inhabited and a third part will be under study and evolving. These areas will be rotated from time to time.

This project will also support the study and development of a possible model for the certification of water efficiency of buildings in Portugal, under the proposals of the National Plan for Efficient Water Use.

This model, like the European model used for the Energy Certification of Buildings, will use an alphabetic hierarchy (A, B, C...) to rate the efficiency of a building. But in this case it will be a voluntary model, at least to start with.

2.2. The water cycle in the "House of the Future"

As stated before, the efficient use of water is an environmental priority today, and this is the main goal in terms of optimizing the water cycle in the House of the Future.
It is general knowledge that water use in the home has different quality requirements, and this creates the chance to make use of different sources of supply, depending on the quality needed for the specific use.

A rainwater collection system can save 50% of treated water (from the public mains system), with no loss of comfort or hygiene, within the consumption profile.

Rainwater can be used for flushing toilets, in washing machines, for cleaning the floor, washing cars, watering the garden, although pre-treatment may needed for some uses. First flush elimination is generally a minimum requirement here.

A system that includes the partial recycling of domestic wastewater has been planned for the House of the Future, with the aim of cutting the use of mains water to a minimum. At the same time, low-consumption devices will be used, linked to the use of alternative sources. In addition to rainwater, the House of the Future has also contemplated the use of saltwater and groundwater. Since the land occupied by the House is very close to the area of influence of the Aveiro Ria's town canals, the groundwater is quite likely to have some salinity (Figure 5).

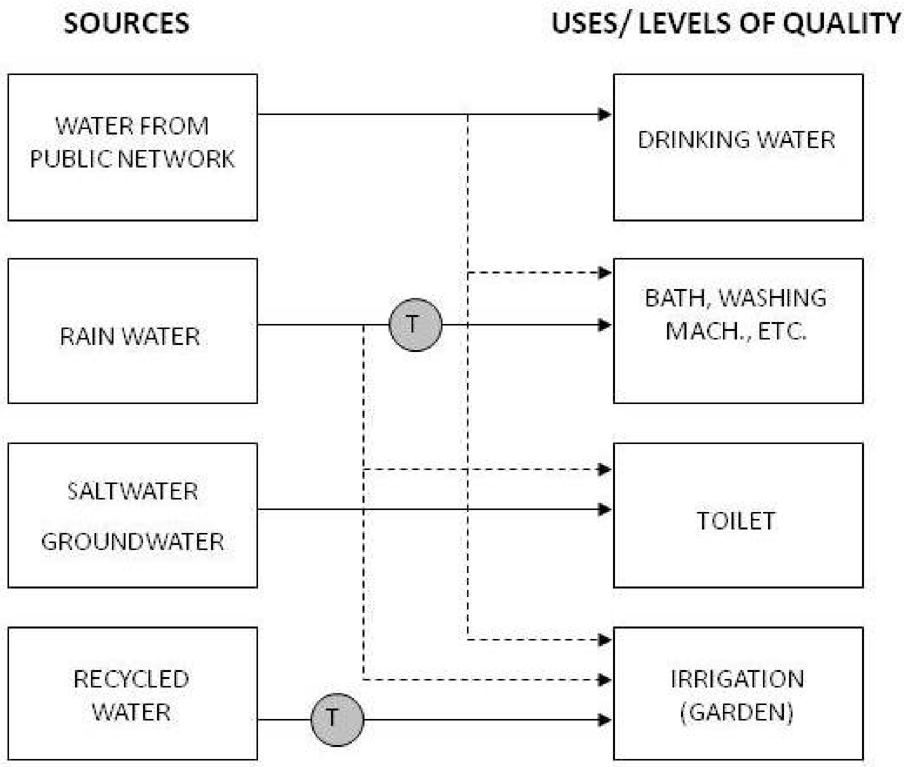

Figure 5 - Water use scheme

The establishment of a non-desalinated saltwater supply line is one solution that could be a useful alternative when drinking water is in short supply, in coastal regions (like Aveiro), for purposes that do not need high quality water (toilet cisterns, for instance). But there may be some problems in terms of treating these wastewaters, and the University of Aveiro is currently looking at solutions for their appropriate treatment.
In particular, some toilets in the House of the Future will use liquid/solid separation systems so that the waste can be treated separately for possible re-use.

In terms of water-efficient products, the following were among solutions considered for the House of the Future: use of small volume cisterns; low-flow fixtures; timers and other automatic control devices; air emulsifiers; waterless/chemical urinals, and low-consumption washing machines. Within this consumption-cutting goal, special attention will be given to cisterns, which can waste a considerable amount of water (over 30% of total consumption in the residential sector, in Portugal). In the case of urinals, the use of chemical ones (with a liquid sealant) that do not consume any water is envisaged.

In terms of wastewater, several treatment systems will be looked at in this project, bearing in mind the proposed water cycle. The ultimate aim for non-reused water will be to achieve a quality that will allow the effluent resulting from the treatment process to be used on the garden or to ensure a level of quality so that it can be discharged into the receiving environment.

3. Water efficiency of products: certification and labelling

3.1. The National Association for Quality in Building Installations (ANQIP) Brief description

ANQIP (www.anqip.pt) is a Portuguese non-profit association, established in 2007. Its members include several universities, firms from the sector, management organisations and self-employed technicians, whose basic aims are to promote and ensure water quality and efficiency in the water supply and drainage fittings and fixtures of buildings. ANQIP hopes to do this by: developing or supporting technical and/or scientific studies; promoting training courses for technical workers, installers and other interested parties; publishing articles; organizing seminars, meetings and other technical and/or scientific events; disseminating studies, standards and regulations; creating voluntary water quality and efficiency certification systems for the use of its members and other interested parties; conducting audits of existing installations and those under construction, on request, and issuing opinions on projects and designs, also on request.
Under its powers and in accordance with the proposals of the National Plan for Efficient Water Use, ANQIP decided to introduce a product certification system, along with a water efficiency labelling scheme, in Portugal.

The model used (described below) will be implemented progressively and it is anticipated that product certification will start with cistern toilets, since these account for most consumption in building systems.

3.2. The water efficiency labelling model proposed for Portugal

The water efficiency labelling of products has generally been implemented voluntarily in various countries.

In some countries efficiency is not graded, but an efficiency label is awarded when consumption is less than a specific amount. This is the labelling system in use in the US and Nordic nations, for example.

In Australia and Ireland (Dublin), however, the label indicates a classification that varies with the product's efficiency.

In Portugal, ANQIP has opted for a voluntary model of the latter kind. Figure 6 shows the labels used. The base colours are green and blue.

"A" signifies the greatest efficiency, and there is a graphic indication by means of drops, for a better understanding of the symbol, and a small informative bar at the side. The A+ and A++ ratings are meant for special applications, as explained in the next point, and it matches the present energy certification system in compulsory use in Europe.

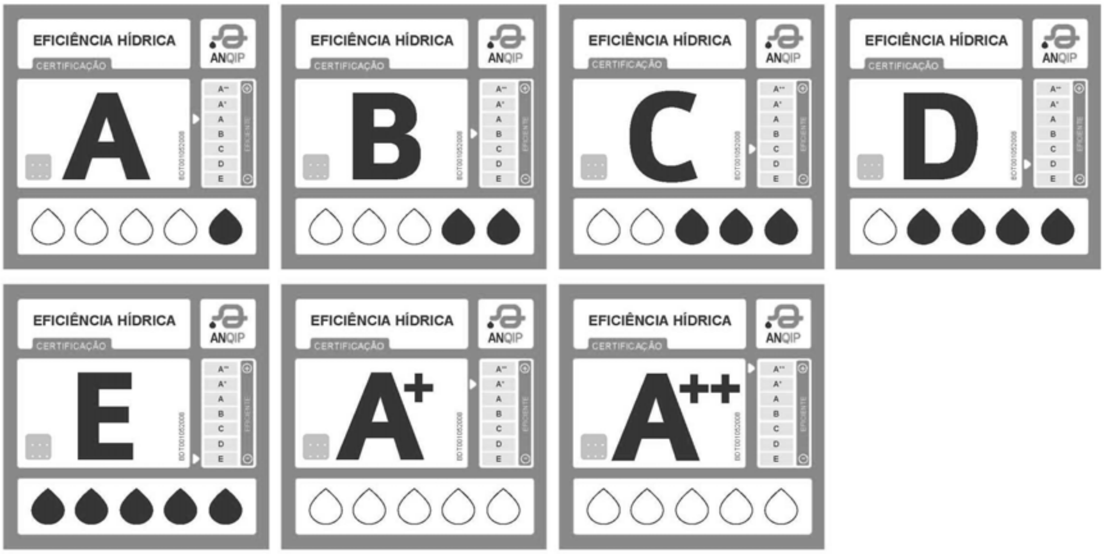

Figure 6 – Portuguese Water Efficiency labels

ANQIP is drawing up Technical Specifications (CTA) for different products so as to create and establish the necessary benchmark values to be assigned to each letter. These Technical Specifications also establish the certification testing conditions.

Firms signing up to the system will sign a protocol with ANQIP which will define the conditions under which they can issue and use the labels.

In principle, the initial tests, which will be the basis for the conformity statement and permission to use the labels, are carried out by the manufacturer/importer. A conformity evaluation system analogous to that used in CE labelling (employed in Europe for building materials) will be used. ANQIP conducts an initial certification of the internal control of production and carries out random tests at intervals of labelled products on the market.

The labels have a code with alphanumerical references for the firm and the product, and showing the date of the last conformity evaluation.

The schedule for introducing the water efficiency labelling of products in Portugal is given in Table 1. This schedule takes into account the significance of each product in overall consumption in buildings, giving priority to products that consume most.

Table 1 – Schedule for the introduction of water efficiency labelling of products in Portugal, by product

Product	Date of labelling introduction
Flushing cisterns	End of 3rd quarter of 2008
Showers	End of 4th quarter of 2008
Taps and flow meters	End of 1st quarter of 2009
Washing machines	End of 2nd quarter of 2009
Other	After July 2009

3.3. Labelling system for flushing cisterns

As mentioned earlier, cisterns were regarded as a priority, since toilet flushing systems are one of the biggest consumers of water in building in Portugal.

As there is a project for a European Standard for WC and urinal flushing cisterns (prEN 14055:2007) it was decided that the labels of water efficiency to be used in Portugal would comply with this Standard, where applicable.

So, not only can the label only be awarded to flushing cisterns that comply wholly with the European Standard, but the nominal and actual discharge volumes considered for the various label classes also comply with Table 3 of prEN 14055.

The following mechanisms are also regarded as water-saving devices, under this Standard:
1. Double-action mechanisms (interruptible)
   - one action initiates flushing and
   - a second action stops the flush
2. Double-control mechanisms (dual control)
   - one control releases the flush volume and
   - another control releases a reduce flush volume

The reduced volume cannot be greater than two-thirds of the maximum flush.

Table 2 shows the range of flush volumes considered in prEN 14055, and the tolerances for testing purposes.

Table 3 gives the water efficiency class proposed by ANQIP, which was still under review at the time this paper was being prepared.

The award of A+ and A++ is reserved for the combined use of toilets suitable for low-volume flush, since not all toilets on sale in Portugal work properly with low-volume flush cisterns. The water efficiency label to be used in these circumstances must mention this factor.

Table 2 – Flush volumes in compliance with prEN 14055:2007

Nominal flush volumes (l)	Flush volumes (l)			
	For complete flushing		For water saving (dual) flushing	
	Minimum	Maximum	Minimum	Maximum
9.0	8.5	9.0	3.0	4.5
7.0	7.0	7.5	3.0	4.0
6.0	6.0	6.5	3.0	4.0
5.0	4.5	5.5	3.0	4.0
4.0	4.0	4.5	2.0	3.0

The use of these letters will also depend on whether there is a drainage system (building and public) designed for such reduced volumes. It may be recalled, for example, that European Standard EN 12056-2 (Gravity drainage systems inside buildings – Part 2: Sanitary pipework – Layout and calculation) does not allow the use of 4 litre flushing cisterns in drainage systems designed under System I of the Standard. Here, too, the label must mention this factor.

Table 3 – Proposed Rating for water efficiency labelling of flushing cisterns in Portugal

Nominal flush volumes	Flushing	Water efficiency rating
9.0	water-saving flush	C
7.0	water-saving flush	B
6.0	water-saving flush	A
5.0	water-saving flush	A+
4.0	water-saving flush	A++
9.0	complete	D
7.0	complete	C
6.0	complete	B
5.0	complete	A
4.0	complete	A+

4. Conclusions

The efficient use of water is an environmental must for every country in the world. Some countries, like Mediterranean countries, must develop measures to ensure this as a matter of urgency, since water availability could be significantly affected in the short-medium-run.

Reducing hot water use will also reduce energy consumption. Washing machines, dishwashers and shower heads can all affect energy use by reducing water consumption. Reducing water use will also yield savings and improvements in the area of wastewater disposal. Indeed, savings in water use may reduce the costs of running and providing waste water collection and treatment systems.

In the building sector, special heed should be paid to the use of efficient products and the overall efficiency of buildings. So not only should efficient fixtures and fittings be used, but water must be re-used or recycled and alternative sources tapped (like rainwater and groundwater).

By using water-efficient products and practices, homeowners can help save natural resources and cut their water consumption and costs. In order to achieve these savings, consumers need to be able to identify products and services that use less water, without sacrificing performance.

In Portugal, ANQIP, a non-profit NGO, has decided to launch a voluntary water efficiency labelling system for products, similar to those developed in other countries.
But the best outcome would be for water efficiency labelling to follow a common European standard (or even worldwide), so as to facilitate the free trade in efficient products and stimulate habits leading to the sustainable use of water throughout the planet.

The CIB W062 forum could be very important indeed, in this context.

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6. Presentation of Authors

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Carla A. Pimentel Rodrigues graduated from the University of Aveiro (Portugal) in Civil Engineering. She is currently studying for her Masters in the area of water efficiency, again in the University of Aveiro. She is a member of the technical secretariat of ANQIP – National Association for Quality in Building Installations.

D5) An Investigation on Dew Condensation on Water Supply Pipe in a Detached House

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Abstract

The purpose of this study is to grasp a change of temperature and humidity in piping space by higher insulation and air tightness of a detached house, and to examine a risk of surface condensation of a water supply pipe. A prediction of dew condensation is judged by the pipe surface temperature and by temperature and humidity in piping space. In high air tightness house, it is not easy to be higher humidity and lower temperature in the night, so a risk of dew condensation is low.

Keywords

Water supply pipe, Dew condensation, Piping space

1. Introduction

To save energy for cooling and heating, it is promoted that the highly insulation and air tightness of residences. At residence with the highly insulation and air tightness, it is expected that the thermal environment of a piping space as well as a habitable room is changed. Usually, surface temperatures of water supply pipes are lower than a temperature of surrounding space. Therefore it is easy to build up the surface condensation in the season which becomes high temperature and humidity, and the pipe is generally covered with an insulating material to prevent surface condensation. In this case, the calculating method for thickness of the material which covers the pipe is shown in Japanese Industrial Standard A9501 (JIS A9501). In practically, it is generally used a design data, which is the thickness of the required insulating material for each water supply pipe diameter, calculated with a certain water temperature and a surrounding temperature and humidity. Consequently, it is thought there is some possibility that the thickness of the insulating material is more than requires.

The purpose of this study is to grasp an influence on the water supply pipe condensation by the highly insulation and highly air tightness of the detached house, and to estimate the temperature and humidity of piping space by changing the insulate property and air tightness, and to estimate the amount of the water supply pipe condensation under the condition. The temperature and humidity of the piping space was estimated by dynamic thermal calculation of the multiple rooms, and the amount of the surface condensation of the water supply pipe was estimated by steady state heat transfer.

It was confirmed that low air tightness house was easy to be high humidity and low temperature in the night, so a probability of dew condensation was high. Moreover, it is confirmed that there is some possibility that the condensation amount of the horizontal pipe is more than that of the vertical pipe.

2. Simulation Methods and Conditions

2.1 Simulation Methods

Figure 1 shows a flowchart of an estimation of the dew condensation. First of all, the temperature and relative humidity of the piping space is calculated by the dynamic thermal calculation of the multiple rooms. Outer surface temperature of the feed pipe is calculated by the steady state heat transfer using estimated temperature and relative humidity. The generation of the dew condensation is judged and amount of this is estimated with the surface temperature.

Table 1 shows the formula for the outer surface temperature. The surface temperature is calculated by heat transfer from the fluid in the pipe to its outer surface (equation (1)) and from the surface to the atmosphere (equation (2)). Dew condensation is determined by comparing the absolute humidity of plumbing space with saturated absolute humidity of the water supply pipe surface which is calculated by using its surface temperature. If dew condensation is built up, amount of the condensation is estimated by equation (3) in Table 2 that is based on analogy between heat transfer and mass transfer.

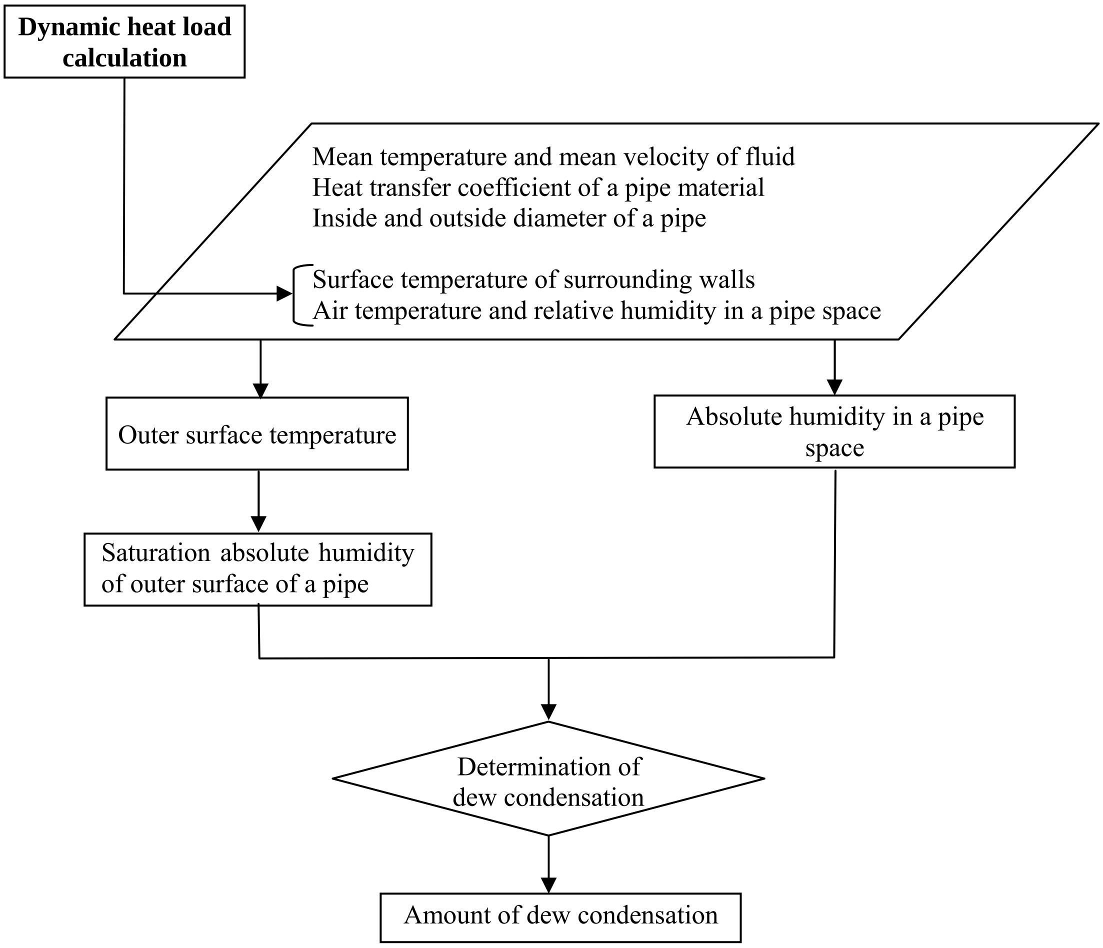


Figure 1 – Estimation flowchart for dew condensation

Table 1 – The formula for the Outer surface temperature

Heat transfer from fluid in a pipe to outer surface ; $Q_1 = \frac{1}{R_T}(\theta_o - \theta_w)$ [W] (1) $R_T = \frac{1}{\pi \cdot h_i \cdot d_0 \cdot L} + \sum \frac{\ln(d_k / d_{k-1})}{2\pi \cdot \lambda_k \cdot L}$, $h_i = \frac{(1663 + 24 * \theta_w) v_m^{0.8}}{d_i^{0.2}}$ where R_T ; thermal resistance of a pipe [m・K/W] , θ_o ; outer surface temperature [℃] θ_w ; mean temperature of fluid [℃], L ; length of a pipe [m] h_i ; internal convective heat transfer coefficient [W/(㎡・K)] 1) λ_k ; thermal conductivity of *k* layer from inside [W/(m・K)] d_k ; diameter of *k* layer from inside [m], v_m ; mean velocity of fluid [m/s]
Heat transfer form outer surface of a pipe to piping space ; $Q_2 = \pi d_o L \{ h_o(\theta_a - \theta_o) + \varepsilon_o \sigma (T_{am}^4 - T_o^4) \}$ (2) Where d_o ; external diameter of a pipe[m] h_o ; external convective heat transfer coefficient [W/(㎡・K)], $h_o = Nu \cdot \lambda_{air} / d_o$ ε_o ; emittance of external surface , σ ;Stefan-Boltzman constant[W/(㎡・K)] T_o ; absolute temperature of external surface [K] T_{am} ; absolute temperature of piping space's wall [K] λ_{air} ;thermal conductivity of air [W/(m・K)] Calculation of Nusselt number 2) Horizontal ; $\frac{2}{Nu} = \ln\left(1 + \frac{2.475}{C * PrGr^n}\right)$ $C = \frac{3}{4}\left(\frac{Pr}{2.4 + 4.9\sqrt{Pr} + 5Pr}\right)^{0.25}$, $n = \frac{1}{4} + \frac{1}{10 + 5PrGr^{0.175}}$ Vartical ; $Nu = 0.515(GrPrd_0 / L)^{1/4} + 0.683(GrPrd_0 / L)^{1/24}$ Where Gr ; Grashof number, Pr ; Prandtl number

Table 2 – Formula for calculation of amount of the dew condensation

Amount of dew condensation ; $M = k_x(X_a - X_s)$ (3) $k_x = h_o / C_{pm}$, $C_{pm} = C_{pa} + C_{pv} \cdot X$ where M ; mass flow rate of water [kg/(㎡・s)], k_x ; mass transfer coefficient [kg(DA)/(㎡・s)] X_a ; absolute humidity of ambient air[kg/kg(DA)] X_s ; saturated ambient humidity of a pipe surface [kg/kg(DA)] C_{pm} ; humid specific heat [J/(kg・K)] C_{pa} ; constant pressure specific heat of dry air(＝1004.6) [J/(kg・K)] C_{pv} ; constant pressure specific heat of dry air of water vapor (＝1846.0)[J/(kg・K)]

2.2 A building model for simulation of the thermal condition of the piping space

Figure 2 shows a building model using for the estimation of the temperature and relative humidity of the piping space. However, the building is smaller in scale than the Japanese ordinary house, it is not a large influence on the estimation of the condition of the piping space.

The temperature and the humidity are estimated over four cases that are made a change in the insulate property and air tightness of the building (Table 3). Table 4 shows the regulation of the insulation. The air change rate is established as 0.5 times per hour under the condition of the high air tightness with high insulation, and 3times per hour under the condition of the low air tightness with high-insulation and 6 times per hour of low air tightness with low insulation. The Set temperature and humidity, and heating and cooling schedule in room 1 and room 2 are shown in Table 5. Simulated area is Tokyo. The exuding large amount of vapor in rooms is unconsidered.

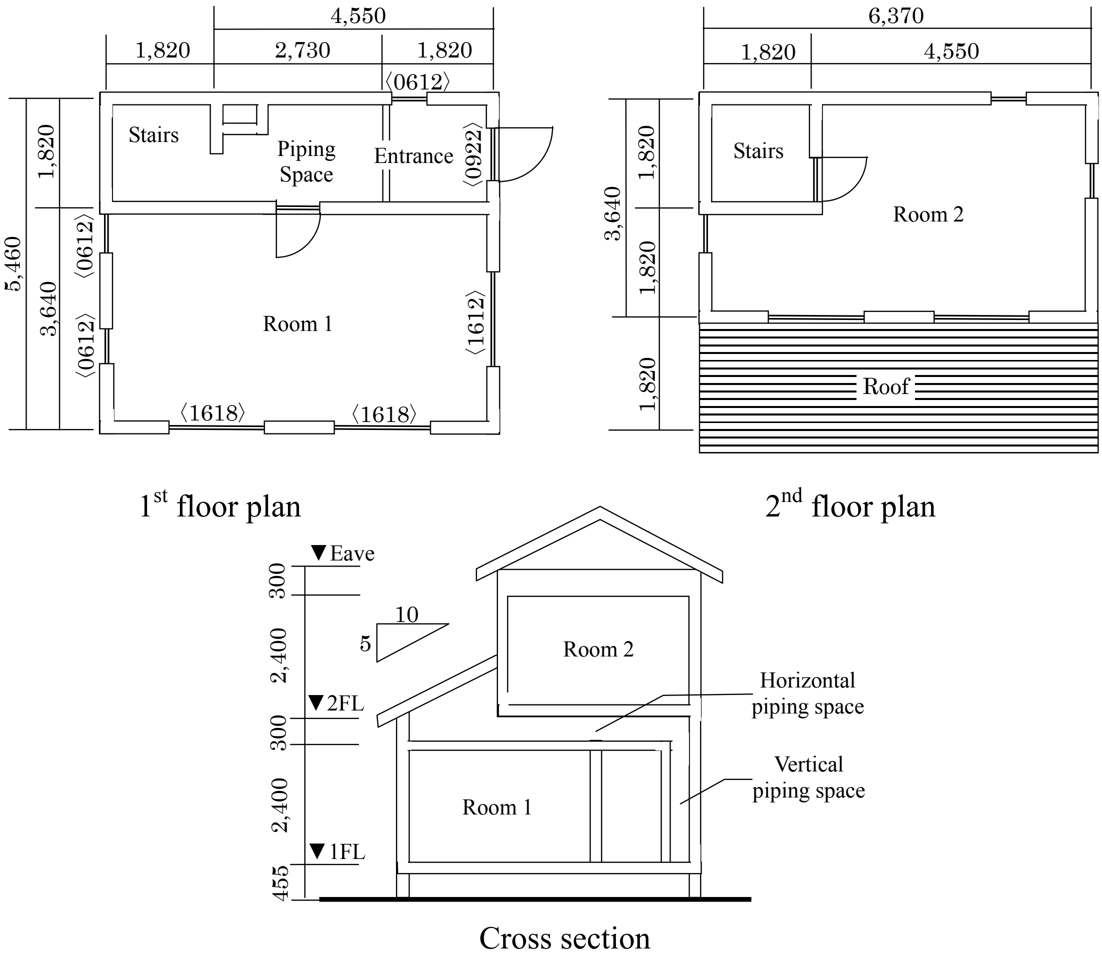


Figure 2 – Building model for the estimation of thermal condition of piping space

Table 3 – Simulation case

	Insulating property	Air tightness (Air change rate[times/hour])
Case1	High insulation	High air tightness (0.5)
Case2		Low air tightness (3.0)
Case3	Low insulation	High air tightness (0.5)
Case4		Low air tightness (6.0)

Table 4 – The regulation of the insulation

Building element	High Insulation		Low Insulation	
Roof	Polystyrene form	50mm	—	—
Ceiling	Rock wool (25K)	200mm	Glass-wool insulation (10K)	50mm
Wall	Glass-wool insulation (16K)	100mm	Glass-wool insulation (10K)	50mm
Floor	Glass-wool insulation (16K)	100mm	Glass-wool insulation (10K)	50mm
Groundwork	Polystyrene form	50mm	—	—

Table 5 – Heating and cooling condition

Setting temperature and relative humidity	Heating；20℃,　Cooling；26℃,60%
Heating operating time	Room 1;　7:00 - 9:00, 17:00 - 20:00 Room 2;　21:00 – 22:00 Other rooms are heatless
Cooling operating time	Room 1;　14:00 – 20:00 Room 2;　21:00 – 22:00 Other rooms are not cooling

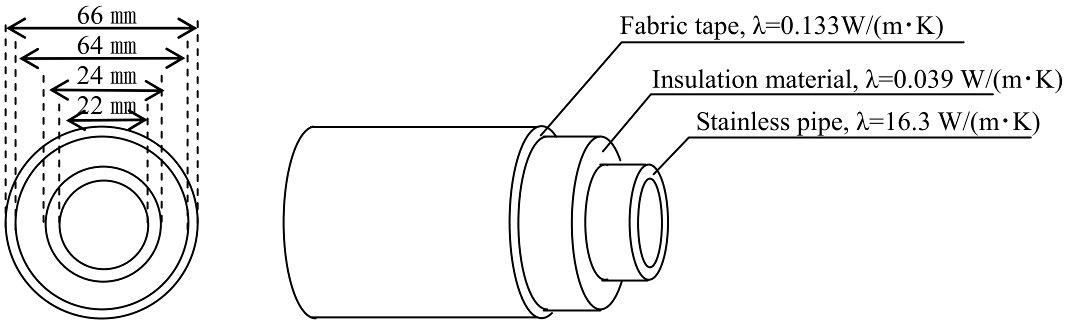


Figure 3 – Thermophysical properties of the pipe

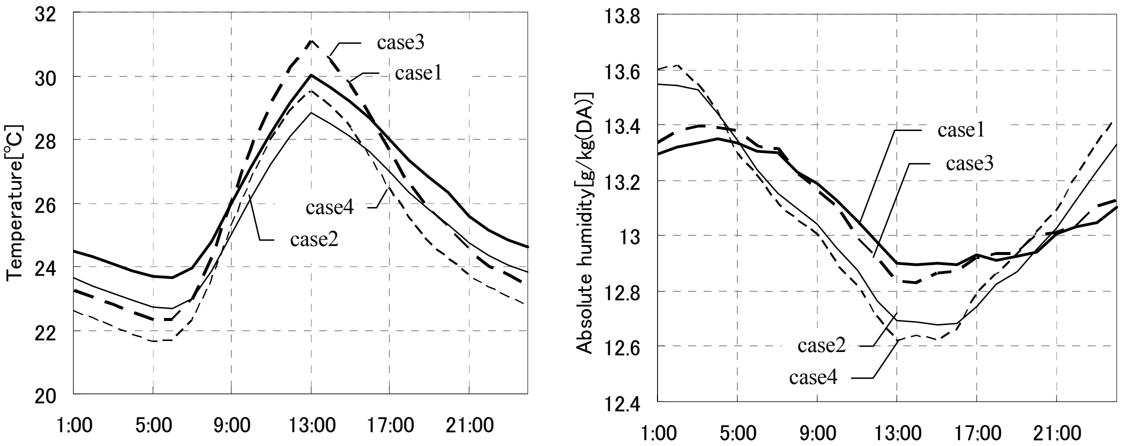
2.3 An estimate condition of the pipe surface temperature and dew condensation

A stainless steel pipe which bore diameter is 20mm, with insulating material of 20mm thickness is set up for estimating the pipe surface temperature and the dew condensation amount. This thickness is calculated as the condition of 30℃ ambient temperature, 85% relative humidity and 15℃ water temperature in a pipe, which is commonly-used value[3)] in Japan. Figure 3 shows thermophysical properties of the pipe for estimating condensation. The pipe surface was assumed to be moisture impermeability. Water temperature in the pipe sets 20℃, and water in the pipe remains rest. The water supply pipe is installed horizontally and vertically.

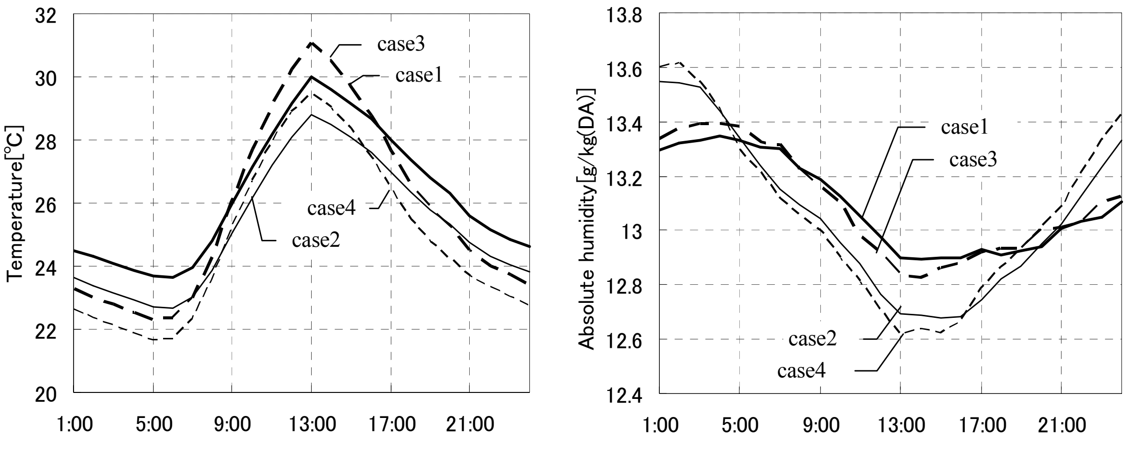
3. Results

3.1 Temperature and humidity of the piping space

Figure 4 shows the temperature and absolute humidity of the piping space which are the average by hour in September when , as described later, the dew condensation was built up. Temperature change was small in the high air tightness case (case1 and 3), and was large in the low air tightness case (case2 and 4) at the horizontal piping space and vertical piping space. The same tendency was seen in absolute humidity. Absolute humidity of high air tightness case rose in the daytime, and the value of low air tightness case rose in the night time. This is supposed to be because that low air tightness cases are easy to be affected by outdoor air compared with the high air tightness cases.



Horizontal piping space



Vertical piping space

Figure 4 – The temperature and absolute humidity of the piping space

3.2 Estimated dew condensation of the water supply pipe

Table 6 shows annual total amount of condensation and hourly amount of it when condensation was built up. Dew condensation was seen only once through the night and into the early morning in September in the low air tightness case. Although hourly amount of condensation was little, the risk of water drop expected to be high because of the large amount of the total dew condensation if it is generated continuously. Moreover, these were identified that the amount of the dew condensation is increase in the case of high insulation, and is increase in the case of installing vertical than that of installing horizontal. It is supposed that vertical piping has higher convective heat transfer coefficient at the outside surface of the pipe than horizontal piping.

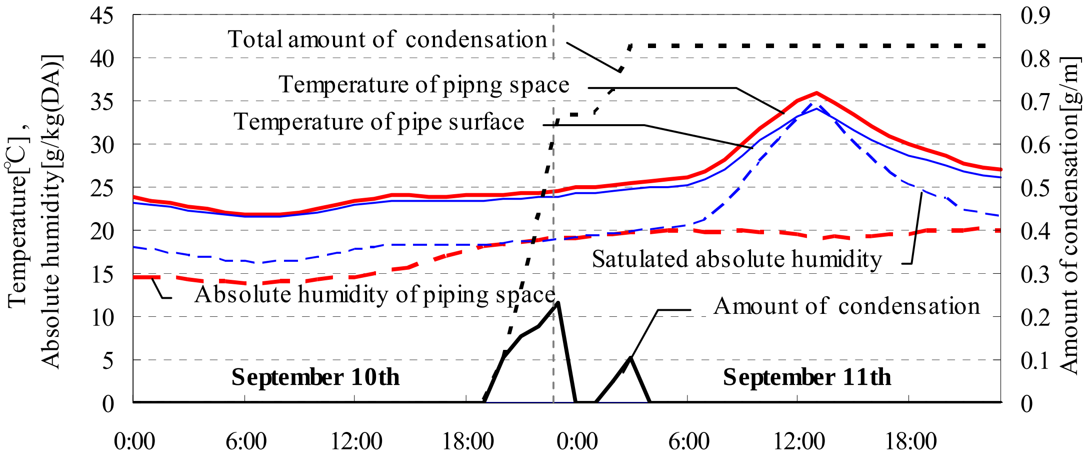
Figure 5 and 6 shows the temperature and absolute humidity of the piping space, the temperature of the outside surface of the pipe, and the amount of dew condensation of the day when dew condensation was generated in case2 and case4. The temperature change from day time to the night is little on September 10^{th}, and it is expected that it was rainy weather on that day. Besides, in case2, dew condensation was built up earlier time than in case4. It is because that in case2(low air tightness) a chain of phenomena, temperature of the piping space gets down and it makes temperature of the pipe surface gets down and this makes saturation absolute humidity around the pipe lower than absolute humidity of the pipe, causes earlier than in case4.

3.3 Observations

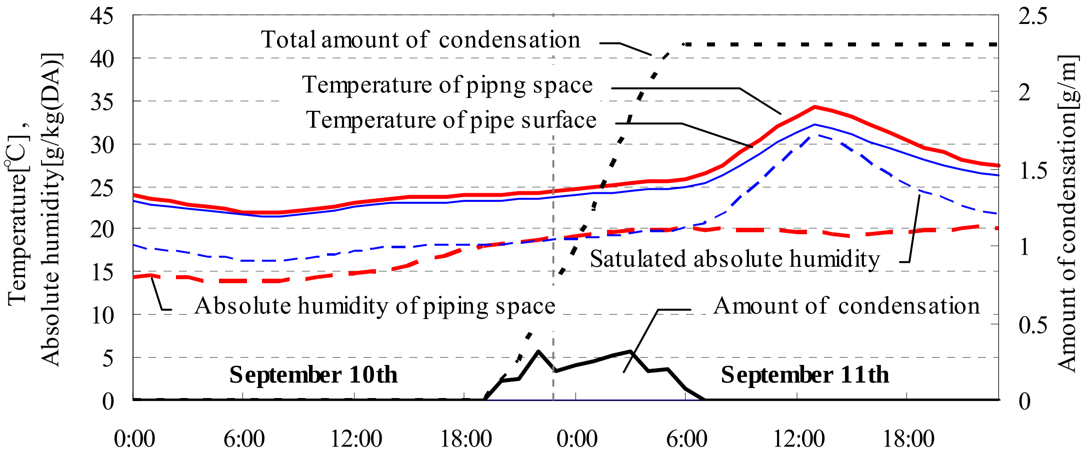
This study under the condition of taking no account of exude large amount of water vapor from indoor, dew condensation is hard to form with a high air tightness case because of less affection from the outdoor air. Besides, in case of low air tightness, high insulation contributes to decrease the amount of dew condensation. Since the risk of condensation of water supply pipe can be decreased by making a house high insulation and high air tightness for energy saving, insulation thickness of the water supply pipe can be decreased. However, it is necessary to be sure water vapor doesn't break into the piping space if a lot of water vapor is generated in the rooms.

Table 6 – Amount of dew condensation

	Horizontal piping			Vertical piping		
	Condensed hours [h]	Annual Total amount of condensation [g]	Average amount of condensation [g/h]	Condensed hours [h]	Annual Total amount of condensation [g]	Average amount of condensation [g/h]
case1	0	0	0	0	0	0
case2	7	0.83	0.12	11	2.31	0.21
case3	0	0	0	0	0	0
case4	8	4.19	0.52	12	4.18	0.35

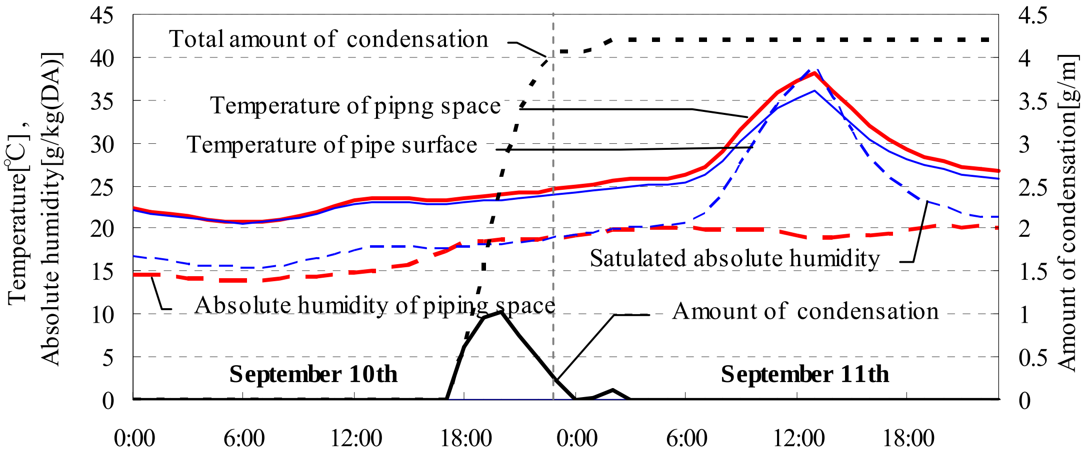


Horizontal piping space

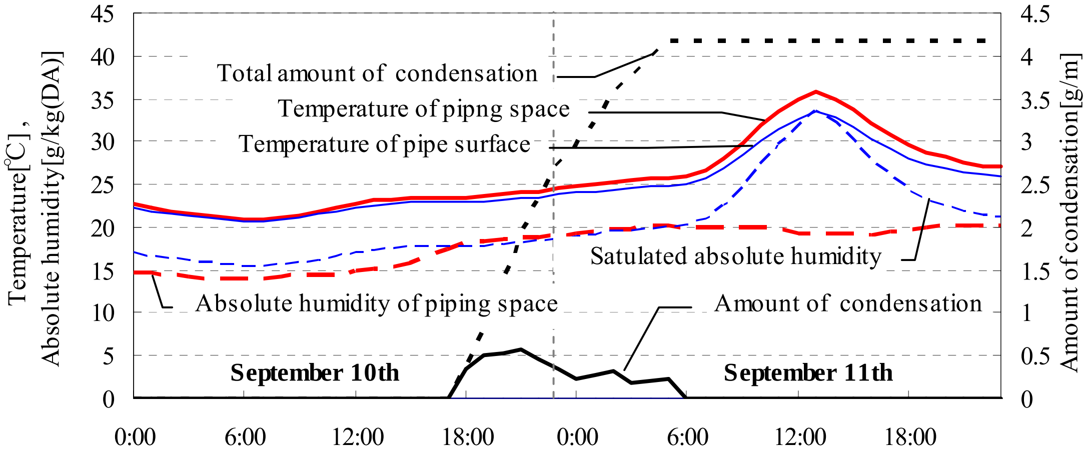


Vertical piping space

Figure 5 – Thermal condition and amount of dew condensation (case2)



Horizontal piping space



Vertical piping space

Figure 6 – Thermal condition and amount of dew condensation (case4)

4. Conclusion

In this study, affection on the piping space of a detached house with high insulation and high air tightness was made clear and examine the possibility of generating the dew condensation on the water supply pipe. Results were as following.

1. High air tightness can prevent the piping space from generating dew condensation if a lot of water vapor isn't exuding.
2. In case of low air tightness, the amount of dew condensation is little and the damage of water drop is little under the condition of high insulation.
3. It is expected that insulating material using for the water supply pipe can be reduced by making high insulation and high air tightness under the condition of preventing water vapor exuding in the room from invading the piping space.

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6. Presentation of Authors

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E1) A Study on the Test Method of Trap Performance Using Simple Test Apparatus

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Abstract

This paper is concerned with establishing a test method of evaluating seal strength of trap. Over the past years, a considerable number of studies have been conducted on the subject using real-scale experimental drainage tower and accurate test apparatus. We have developed a smaller and less expensive simple test apparatus, and evaluated its validity.

In this study we examined test methods of trap performance by analyzing response characteristics of seal vibration of various traps using a simple test apparatus, and comparing the results with those obtained from experiments with a real-scale experimental drainage tower.

Keywords

Drainage system, trap, induced siphonage, test method, three-sine-waves

1. Introduction

Anti-pressure performance (referred to as “Seal strength” below) of trap must be known before one can set out to design a proper drainage system. However, no adequate methods have ever been established to evaluate seal strength of each trap.

Given the situation, we focused our attention on induced siphonage, and concerned ourselves with conducting various studies with a view to establishing a test method of seal strength of trap. Although accurate test apparatus has been developed for this purpose, it has disadvantages of being both cumbersome and costly. Smaller and less expensive simple test apparatus has been developed to compensate these drawbacks. In previous studies with simple test apparatus, pressure load experiments with the three-sine-waves was considered as a valid way of testing trap performance. But the validity of the method has not been properly verified to date[1].

We conducted experiments with a view to confirming the validity of the three-sine-wave test using a simple test apparatus. In order to clarify the fundamental performances of test traps, we began by examining response characteristics of seal vibration when sine wave pneumatic pressure (referred to as "single sine wave" below) with uniform frequencies was applied. Next we conducted discharge experiments with test traps in the real-scale experimental drainage tower, and measured pneumatic pressure fluctuations in drains and seal losses at constant discharge flow rate. We analyzed the data, and compared the seal losses of various traps obtained from the tower with those from a simple test apparatus.

2. Test trap

Four types of test traps: P trap, S trap, Bell trap and Contrary bell trap, made of transparent acrylic resin were designed after standard traps used in the conventional home (Figure 1).

Table 1 shows natural frequencies of the traps obtained by the free vibration test[2] and the calculate equation of natural frequency[3]. The natural frequencies of fixture traps when seal water is full or half-full have been found to fall within 1 ~ 3 Hz.

3. Experiments on response magnifications of trap

3.1 Experimental apparatus

Figure 2 shows the diagrammatic representation of the simple test apparatus used in the experiments. It consists of pistons, a frequency variable device, various chambers, drainage pipes, and an analyzer. It has a triple-piston structure with cranks adjustable at 8 steps between15 ~ 50 mm in increments of 5 mm. Frequencies are variable in increments of .033 Hz within the range of .166 ~ 4,500 Hz. It is also equipped with a small blower as a bias pressure device, which reproduces the steady pressure component. Amplitudes were adjusted by changing the water contents of vertical cylindrical chambers and pressure adjustment chambers, which in turn changed air volume in the chambers. Only one of the pistons on the apparatus was operated in these experiments.

3.2 Method

Each test trap was connected to the simple test apparatus in half-full conditions, and seal fluctuations were measured when single sine waves of amplitude not large enough to cause seal loss were applied. Various frequencies of single sine wave (25 types in total) were applied, and ratios of static seal level to response seal level (referred to as “response magnifications” below) were calculated for each frequency. Then response characteristics of seal vibration were examined by response magnification curve which showed the relation between the response magnifications and the frequencies.

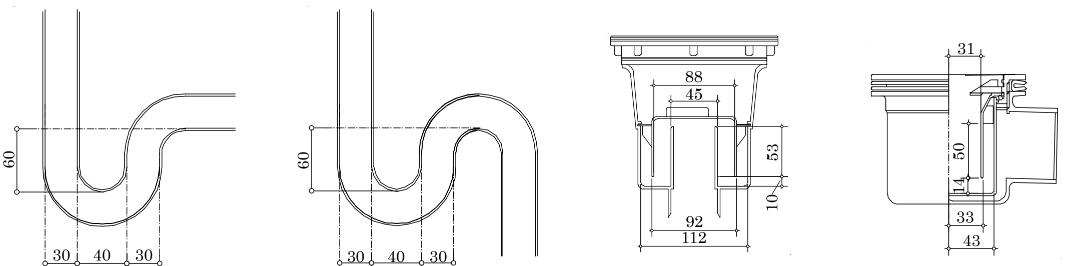
3.3 Results and discussion

The response magnification curve of each type of trap is shown in Figure 3. In S trap, the response magnification showed an abrupt increase near a natural frequency. In Bell trap and Contrary bell trap, the frequencies of single sine waves seem to have exerted only minimal effects on the response magnifications. The reason for this seems to be that the complex shapes of Bell and Contrary bell traps caused large resistance between the seal and inner surface of trap, which in turn inhibited resonance phenomenon. However, regardless of the type of trap, the frequency at which response magnification became largest corresponded with the natural frequency of trap.

4. Discharge experiments in real-scale experimental drainage tower

4.1 Test drainage system

Two types of drainage systems, one, the drainage system with stack vent and special drainage fittings and, the other, the conventional drainage system with JIS drainage fittings, were used as the test drainage system (Figure 4). The system with special drainage fittings was tested on the 15-story equivalent. It was the maximum scale on the real-scale experimental drainage tower used in these experiments. And the system with JIS fittings was test on the 8-story equivalent which was maximum story of adapting this system. In addition to these two, the drainage system with stack vent and special drainage fittings was tested on the 8-story equivalent as a control for comparison with the system with JIS fittings.



P trap — F: 1.00 — Use: Wash basin

S trap — F: 1.00 — Use: Wash basin

Bell trap — F: 1.41 — Use: Kitchen sink

Contrary bell trap — F: 1.26 — Use: Floor drain in bath room

F : (ratio of leg’s sectional area) = (mean sectional area of inlet leg) / (mean sectional area of outlet leg)

Figure 1 - Test traps

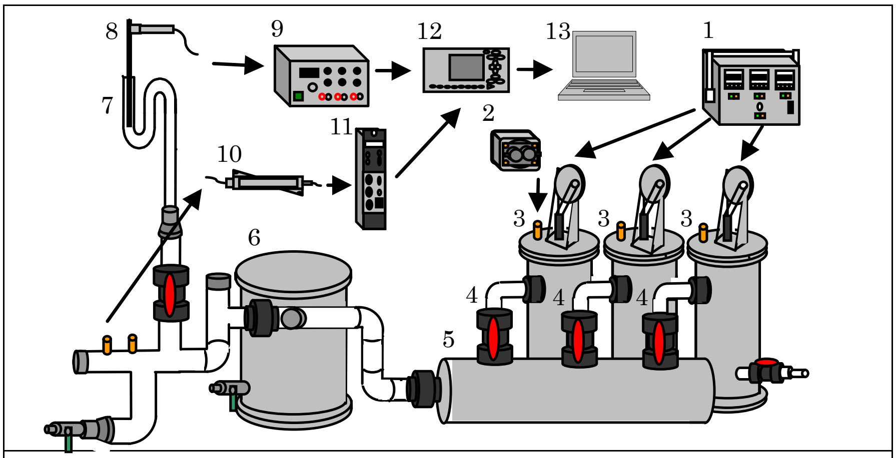
Table 1 - Natural frequencies of test traps and calculate equation of natural frequency

Test traps	Experiment [Hz]	Calculation [Hz]	
	1/2 Full Level	1/2 Full Level	Full Level
P trap	1.95	1.93	1.60
S trap	1.93	1.93	1.60
Bell trap	2.43	2.38	1.87
Contrary bell trap	2.57	2.43	1.92

Calculate equation of natural frequency

$$f = \frac{1}{2\pi}\sqrt{\frac{\left(1+\frac{A_1}{A_2}\right)g}{\left(1+\frac{A_1}{A_2}\right)H+\frac{A_1}{A_0}L}}$$

f : Natural frequency [Hz]
A_0 : Sectional area of bottom part [cm^2]
A_1 : Sectional area of inlet leg [cm^2]
A_2 : Sectional area of outlet leg [cm^2]
g : Gravity [cm/s^2]
H : Stationary balance level [cm]
L : Sickness of partition or distance between inlet leg and outlet leg [cm]



1; Changing device of frequency 2; Blower for bias pressure device
3; Chamber with piston 4; Pressure control valve 5; Mixing chamber
6; Pressure control chamber 7; Test trap 8; Water level sensor
9; Amplifier 10; Pressure sensor 11; Amplifier 12;Data roger 13; PC

Figure 2 - Simple test apparatus

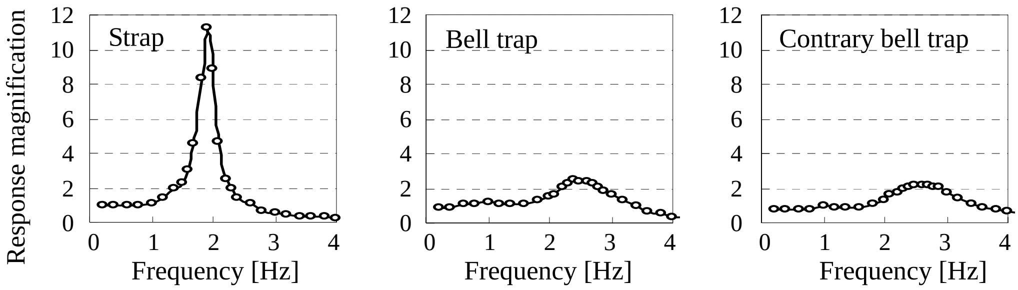
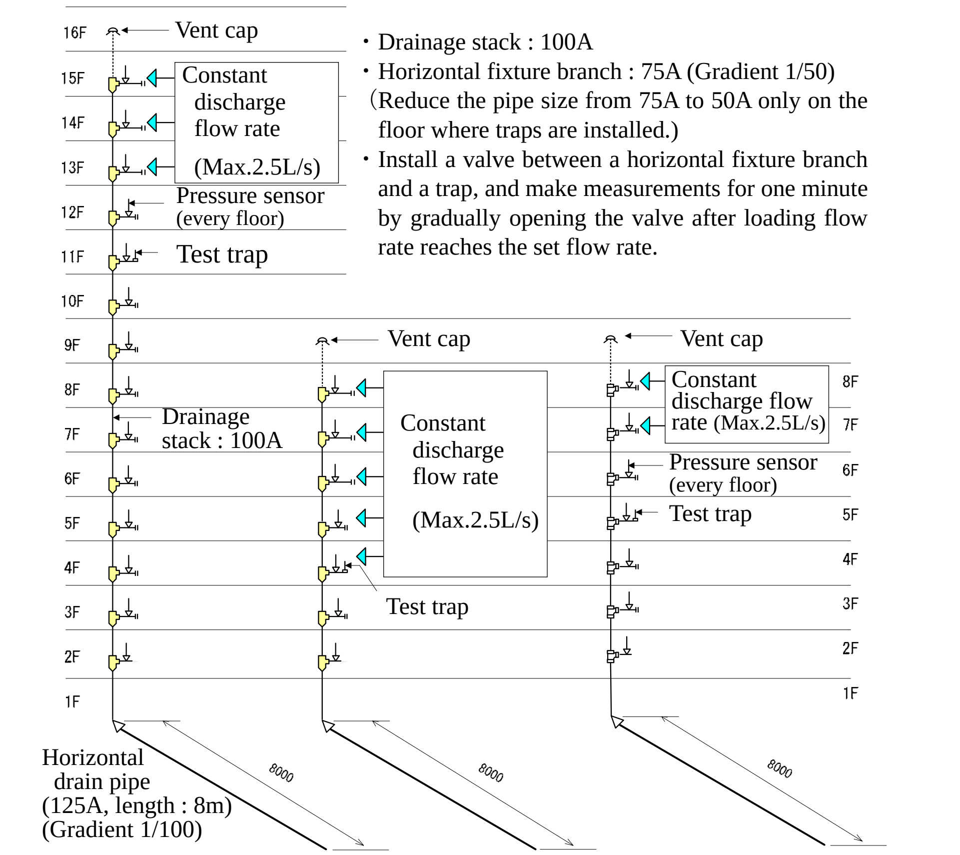


Figure 3 - Response magnification curve



a 15-story equivalent Drainage system with Stack vent system and Special drainage fittings

a 8-story equivalent Drainage system with Stack vent system and Special drainage fittings

a 8-story equivalent Conventional drainage system and JIS drainage fittings

Figure 4 - Test drainage systems

Table 2 - The flow rate of discharge load relative to the target minimum pressure (P_{smin})

Target minimum pressure (P_{smin}) [Pa]			-300	-400	-500
Flow rate of discharge load [L/s]	Drainage system with stack vent system	a 15-story equivalent	5.0	7.0	7.5
		a 8-story equivalent	7.5	10.0	12.0
	Conventional drainage system	a 8-story equivalent	2.3	2.9	3.4

4.2 Methods

Full test trap was installed in horizontal fixture branch of the floor where the minimum pressure is expected to occur, and pressure fluctuations in the horizontal fixture branches and seal loss were measured when discharge load was applied from the top floor. The target minimum pressures (referred to as "P_{smin}" below) were approximately set at -300Pa, -400Pa, and -500Pa. These were adjusted by changing the flow rate of discharge load. The flow rates of discharge load relative to P_{smin} are shown in Table 2. Sample measurements were made at intervals of 20ms, and no low-pass filter (referred to as "LPF" below) was used. Measurements were made one minute after discharge flow rate became stable. To avoid the influence of seal fluctuations when more than one trap was connected at the same time, each test trap was installed individually.

4.3 Results and discussion

A strong correlation has been found between seal loss (referred to as "H_{loss}" in graph) and the minimum pressure in the actual pressure (referred to as "P_{min}" below) in some previous studies[4]. Here P_{min} refers to the pressure value after LPF treatment at 3 Hz, and the cut-off frequency of 3Hz was determined taking into consideration the fact that recordings are made with a pen recorder. We have examined the coefficient of determination of a regression line (referred to as "R^2" in graph) between P_{min} after LPF treatment at various cut-off frequencies and seal loss (Figure 5).
The coefficients of determination for all the data exceeded 0.7 indicating a strong correlation between P_{min} and seal losses as found in the previous studies (Figure 6). In P trap and S trap, the coefficients of determination for each of the three systems were higher with LPF treatment than without it, but no significant difference was found among various cut-off frequencies. In Bell trap and Contrary bell traps, no difference in the coefficients of determination was found with or without LPF treatment.

5. Pressure load experiments using simple test apparatus

5.1 Experimental apparatus

We used the simple test apparatus, and operated three pistons in these experiments.

5.2 Methods

5.2.1 Formulation of three-sine-waves

Two types of three-sine-waves: three-sine-waves which didn't consider response magnifications (referred to as "three-sine-waves A" below) and three-sine-waves which did (referred to as "three-sine-waves B" below), were created using the formula (1) based on the actual pressure data obtained in Section 4 above[5,6].

$$P = P_{ave} + \sum_{i=1}^{3} A_i \sin 2\pi f_i t, \quad A_i = k_i \left(P_{ave} - P_{\min}\right) \cdots\cdots\cdots\cdots (1)$$

P_{min} **:** Minimum actual positive pressure [Pa]
P_{ave} **:** Average actual pressure [Pa]
A_i **:** Amplify of single sine wave [Pa]
f_i **:** Predominant frequency [Hz], t **:** Time [s]

k_i **:** Raito of root of power spectrum to predominant frequency

$(\sqrt{PS_1} : \sqrt{PS_2} : \sqrt{PS_3} = k_1 : k_2 : k_3, \quad k_1 + k_2 + k_3 = 1)$

(*i*=first, second, third predominant frequency)

(1) Three-sine-waves A

The parameters necessary for making three-sine-waves A were selected based on the following methods.

a) We adopted actual pressure with LPF treatment at 3 Hz and its P_{min}. That took into account the fact that SHASE-S218 bases its arguments on the P_{min} with LPF treatment at 3Hz and that there is no significant difference among various cut-off frequencies in Section 4 above.

b) The three largest predominant frequencies in the power spectrum of pressure fluctuation (f_1, f_2, f_3) were chosen from those that fall within the 1 ~ 3 Hz range as the frequencies in this range are thought to affect seal fluctuation of trap.

An example of actual pressure wave patterns and density distribution of the power spectrum are shown in Figure 7.

(2) Three-sine-waves B

We paid attention to the response magnification curve obtained in Section 3 above, and included the following considerations in addition to 5.2.1(1)-a) and b) above.

c) The three frequencies were selected from actual pressures with response magnification of 1 or higher.

d) Frequencies with extremely large response magnification were excluded (in this study, frequencies with response magnification of 5 or higher were excluded).

e) If addition of c) and d) makes it impossible to select three frequencies, the same frequencies were adopted twice.

5.2.2 Pressure load experiment

Full test traps were installed in the test apparatus, and seal loss was measured after applying three-sine-waves for one minute.

5.3 Results and discussion

5.3.1 Three-sine-waves A

Examples of seal losses caused by three-sine-waves A and by actual pressure are shown in Figure 8, and frequencies of the three-sine-waves A are shown in Table 3.

In P trap, seal losses caused by three-sine-waves were much smaller than seal losses caused by actual pressure. The reason for this seems to be that frequencies close to 3 Hz that are not likely to affect seal loss were adopted as f_1. On the other hand, in S trap, seal losses by three-sine-waves A were much larger than seal losses by actual pressure. This is probably due to the fact that frequencies near the natural frequency (1.9Hz) were adopted as f_1 and they were affected by resonance phenomenon.

5.3.2 Three-sine-waves B

The list of frequencies of three sine waves B is found in Table 4, and seal losses caused by three-sine-waves B and by actual pressure are shown in Figure 9.

In the 15-story equivalent drainage system with special fittings, coefficients of determination were above 0.80 for all traps. Coefficient of regression showed the difference in seal losses between actual pressures and three-sine-waves B to be 16%, which can be thought to have high reproducibility of seal loss.

In the 8-story equivalent drainage system with special fittings, if evaluated based on coefficient of regression, the difference in seal losses was 17% at maximum. S trap showed the coefficient of determination of 0.73, which was slightly lower than other types of trap. This is because seal loss by three-sine-waves B for which the same frequencies were adopted twice deviated considerably from the value of seal loss by actual pressure.

In the 8-story equivalent drainage system with JIS fittings, coefficients of determination were 0.68 for S trap and 0.66 for Bell trap, slightly lower than other two systems as the data tended to converge on the graph. However, an evaluation based on coefficient of regression showed the difference in seal losses to be 16%, just about the same as the other two systems.

From the above results, it can be concluded that experiments using three-sine-waves B on the whole were able to reproduce seal losses caused by actual pressure.

6. Conclusion

We first applied single sine waves to various types of trap, and obtained response magnifications of seal fluctuation at different frequencies. As a result it was found that the frequency at which response magnification reached maximum roughly corresponded with the natural frequencies of traps. Next we examined the relationship between pressure fluctuation and seal loss in discharge experiments, and found a strong correlation between P_{min} after LPF treatment at 3 Hz and seal loss as has been pointed out in the previous studies. We then conducted experiments using a simple test apparatus to see if seal loss normally caused by actual pressure could be reproduced by three-sine-waves. The results of the experiments confirmed the validity of three-sine-waves as used in a simple test apparatus, and the conditions for formulating three-sine-waves have been clarified.

We intend to focus our efforts not only on finding test pressure waves that are more appropriate to the test methods used with a simple test apparatus, but also on toilet basins and improving traps.

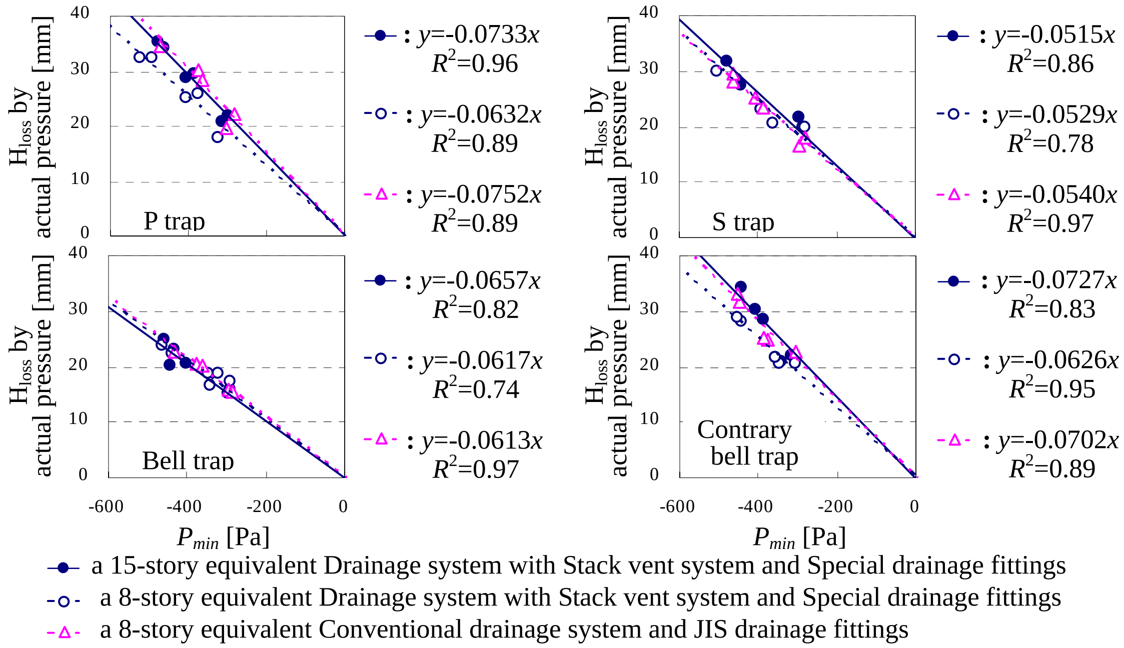


Figure 5 - Comparison of H_{loss} by actual pressure and P_{min}

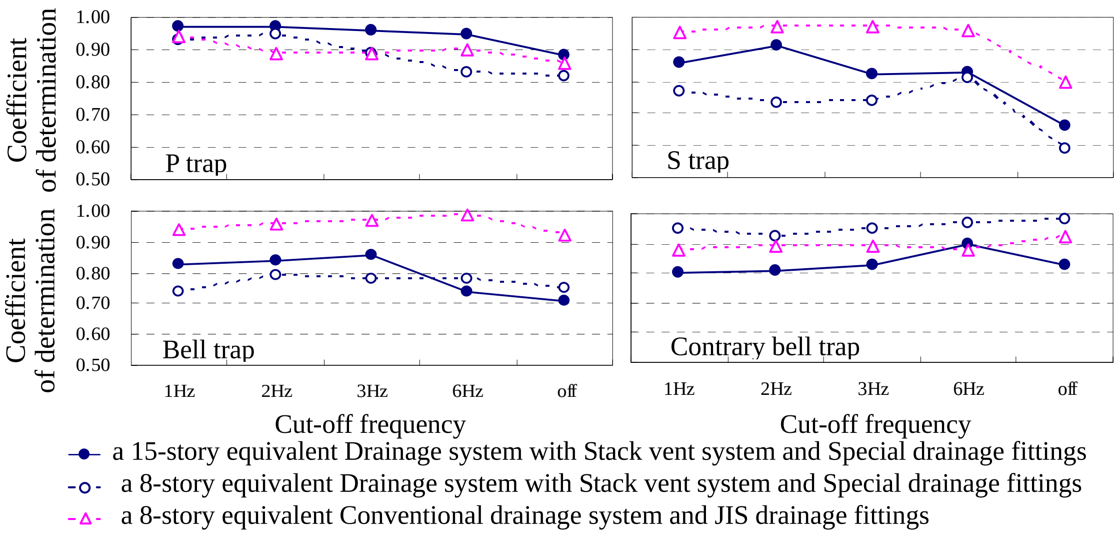


Figure 6 - Comparison of the coefficient of determination of a regression line and various cut-off frequencies

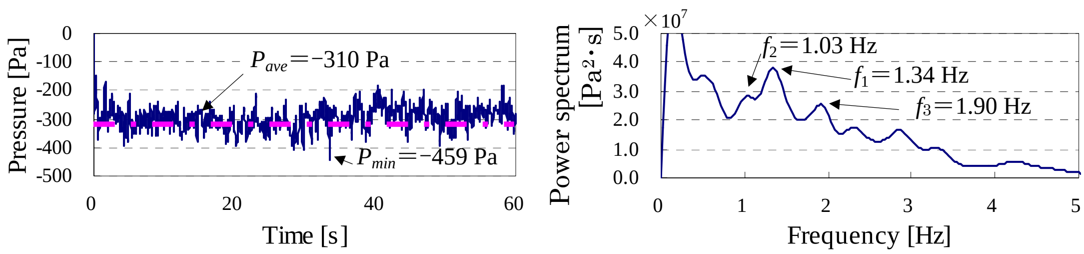


Figure 7 - Actual pressure fluctuation and power spectrum

Constant discharge flow rate: 7.5L/s,

Table 3 - Ave. and min. pressure and predominant frequencies for three-sine-waves A

Test traps	P_{ave} [Pa]	P_{min} [Pa]	Predominant frequency [Hz] f_1	f_2	f_3	Amplitude [Pa] A_1	A_2	A_3
P trap	-204	-304	2.66	1.22	*3.47*	37	35	27
	-206	-284	1.05	1.66	2.20	28	26	24
	-262	-364	2.59	1.44	**1.95**	39	32	31
	-269	-372	**1.93**	1.59	*3.34*	36	34	34
	-317	-416	1.15	2.71	2.44	34	33	32
	-327	-470	2.59	*3.47*	1.37	57	45	41
S trap	-210	-282	1.27	1.54	**1.81**	25	24	24
	-211	-297	2.22	1.59	2.71	32	28	26
	-276	-406	**1.86**	2.39	*3.00*	47	42	41
	-278	-388	*3.27*	**1.81**	2.69	38	37	36
	-322	-465	2.76	**1.98**	1.49	54	46	43
	-333	-464	1.32	**1.98**	2.47	46	44	42

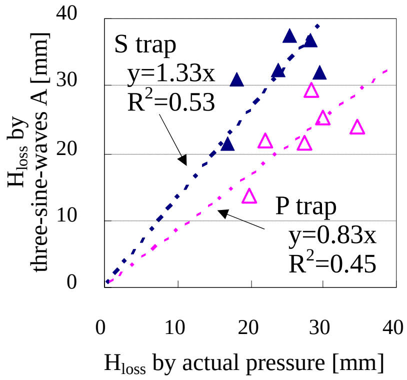


Figure 8 - Comparison of H_{loss} by three-sine-waves A and actual pressure

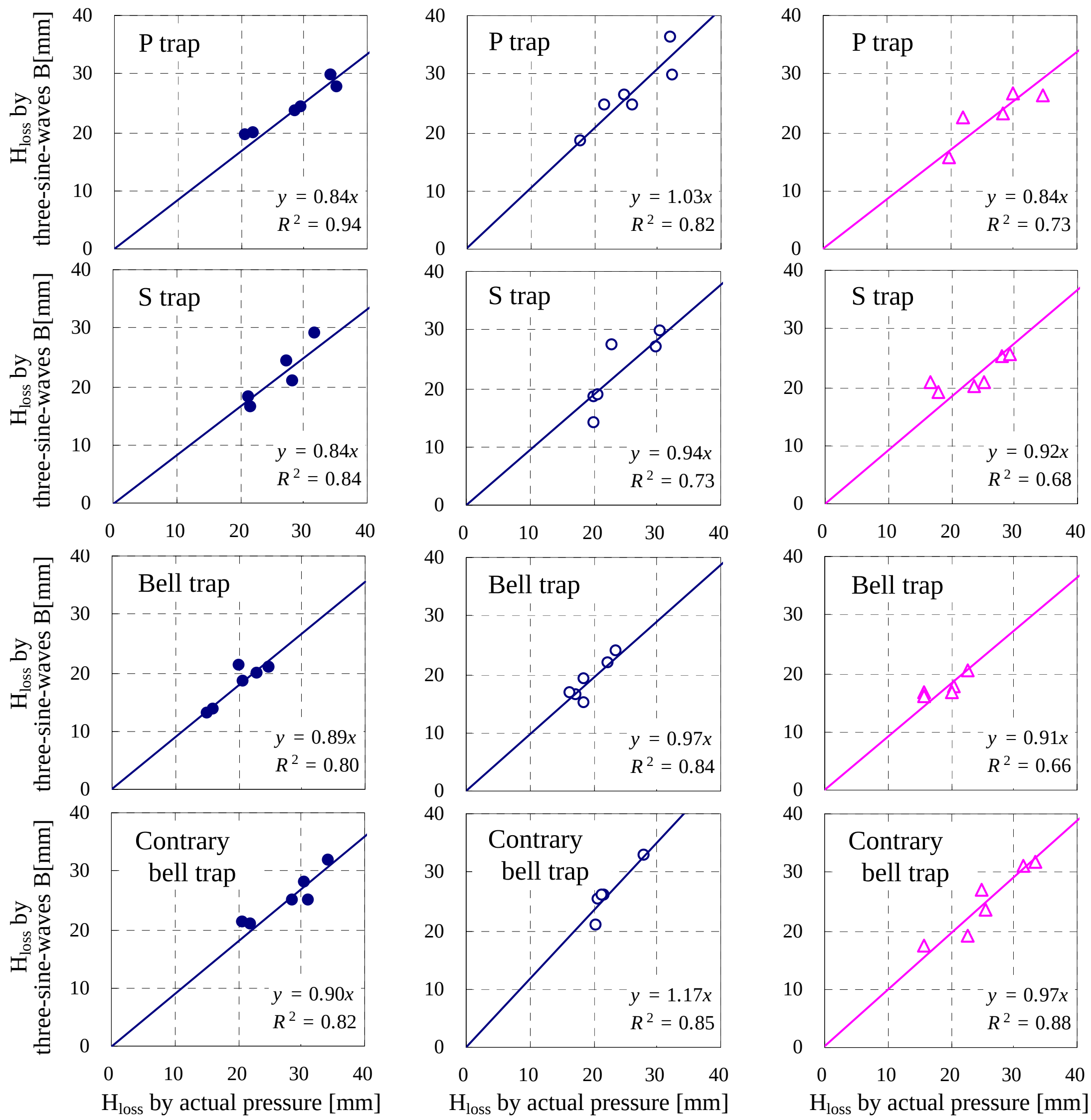


Figure 9 - Comparison of H_{loss} by three-sine-waves B and actual pressure

Table 4 - Ave. and min. pressure and three predominant frequencies for three-sine-waves B

a 15-story equivalent Drainage system with Stack vent system and Special drainage fittings

Test traps	P_{ave} [Pa]	P_{min} [Pa]	Predominant frequency [Hz]			Amplitude [Pa]			Test traps	P_{ave} [Pa]	P_{min} [Pa]	Predominant frequency [Hz]			Amplitude [Pa]		
			f_1	f_2	f_3	A_1	A_2	A_3				f_1	f_2	f_3	A_1	A_2	A_3
P trap	-179	-300	0.95	2.22	2.22	46	38	38	Bell trap	-181	-289	1.37	2.69	1.78	42	34	32
	-181	-311	0.81	2.25	1.71	50	43	37		-183	-294	1.54	1.05	3.03	42	40	29
	-257	-384	2.15	1.37	1.37	45	41	41		-273	-444	1.37	1.66	2.88	62	57	52
	-266	-405	2.25	1.37	1.37	52	43	43		-274	-403	2.08	1.29	1.07	45	43	41
	-305	-460	2.32	1.10	1.71	56	55	44		-295	-431	1.03	2.00	1.34	48	47	42
	-311	-475	0.81	2.44	1.32	57	56	52		-310	-459	1.34	1.03	1.90	56	48	46
S trap	-184	-293	1.46	2.15	2.15	44	32	32	Contrary bell trap	-189	-340	1.59	1.88	2.25	60	48	42
	-198	-296	2.54	1.27	1.27	34	33	33		-198	-316	1.44	2.20	2.73	44	38	36
	-264	-390	2.32	1.71	1.15	47	40	39		-271	-405	1.34	1.86	2.49	58	39	37
	-280	-441	1.00	1.34	2.29	59	53	50		-277	-384	1.29	2.12	1.61	38	36	33
	-297	-455	1.10	2.66	2.66	54	52	52		-289	-405	1.10	2.03	1.54	43	37	35
	-305	-479	1.03	2.17	1.51	63	61	51		-297	-442	1.22	1.93	2.44	53	47	45

a 8-story equivalent Drainage system with Stack vent system and Special drainage fittings

Test traps	P_{ave} [Pa]	P_{min} [Pa]	Predominant frequency [Hz]			Amplitude [Pa]			Test traps	P_{ave} [Pa]	P_{min} [Pa]	Predominant frequency [Hz]			Amplitude [Pa]		
			f_1	f_2	f_3	A_1	A_2	A_3				f_1	f_2	f_3	A_1	A_2	A_3
P trap	-155	-325	1.15	1.15	2.29	62	62	47	Bell trap	-167	-291	1.34	1.81	2.44	44	41	39
	-156	-355	1.20	1.61	2.61	73	69	56		-169	-319	3.34	1.39	1.98	52	50	48
	-187	-406	1.29	0.90	2.08	75	74	71		-200	-338	1.07	1.49	1.90	56	44	39
	-197	-373	1.20	1.54	2.25	66	59	50		-202	-347	1.25	1.95	2.73	58	49	36
	-276	-494	0.93	1.32	2.12	84	76	58		-270	-438	1.22	1.71	2.29	75	52	41
	-281	-521	2.44	1.64	1.64	89	75	75		-282	-460	1.42	2.56	2.88	65	57	57
S trap	-161	-283	1.44	2.27	2.27	41	41	41	Contrary bell trap	-171	-345	2.15	3.00	3.25	72	52	49
	-163	-279	0.90	0.90	2.08	44	44	27		-178	-307	1.34	3.59	2.10	50	40	39
	-199	-361	0.83	1.34	2.32	62	53	47		-193	-355	1.25	1.54	2.25	57	55	51
	-200	-389	1.39	1.39	2.12	68	68	53		-208	-354	1.32	1.71	2.64	59	44	43
	-275	-451	1.42	1.42	2.32	62	62	52		-275	-454	1.73	2.91	2.29	70	55	55
	-285	-502	2.51	1.27	1.27	73	72	72		-286	-443	1.10	1.90	2.66	70	50	36

a 8-story equivalent Conventional drainage system with JIS drainage fittings

Test traps	P_{ave} [Pa]	P_{min} [Pa]	Predominant frequency [Hz]			Amplitude [Pa]			Test traps	P_{ave} [Pa]	P_{min} [Pa]	Predominant frequency [Hz]			Amplitude [Pa]		
			f_1	f_2	f_3	A_1	A_2	A_3				f_1	f_2	f_3	A_1	A_2	A_3
P trap	-204	-304	2.66	1.22	2.12	38	36	26	Bell trap	-210	-285	1.03	1.73	2.10	31	25	20
	-206	-284	1.05	1.66	2.20	28	26	24		-212	-293	1.12	2.05	2.64	35	24	22
	-262	-364	2.59	2.59	1.44	36	36	29		-276	-364	1.51	1.20	3.25	32	30	26
	-269	-372	1.59	2.51	2.51	38	32	32		-279	-375	1.32	1.83	3.25	38	30	27
	-317	-416	1.15	2.44	1.78	37	34	28		-322	-434	1.32	1.76	3.39	39	37	37
	-327	-470	2.59	2.59	1.37	52	52	38		-327	-428	1.20	1.76	3.32	41	30	29
S trap	-210	-282	1.27	1.54	2.42	26	25	22	Contrary bell trap	-213	-304	1.03	1.90	1.44	31	30	29
	-211	-297	0.88	2.22	1.59	33	29	25		-214	-292	1.29	2.17	1.61	31	24	23
	-276	-406	2.39	1.17	1.17	47	42	42		-275	-377	1.32	1.81	2.81	37	36	29
	-278	-388	1.25	1.25	2.39	37	37	37		-275	-385	1.37	1.68	3.27	39	37	34
	-322	-465	0.81	0.81	1.49	49	49	46		-328	-447	1.61	1.37	2.86	41	39	38
	-333	-464	1.32	2.47	2.47	47	43	43		-338	-453	1.49	1.88	2.83	46	41	28

_: the data excluded from the consideration as the H_{loss} deviated greatly from the other

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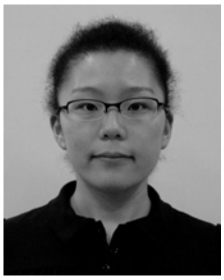
8. Presentation of Authors



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E2) Testing Method and verification of a portable measurement and Analysis for Air Pressure Distribution in the Stacks of Building Drainage Systems

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Abstract

The major function of the building drainage system is to ensure proper operation and to keep a health interior space for human's life. And trap seal water in a drainage system acts as an integral part of a hygiene system in existing residential buildings. If the trap seal failure in an exciting building that will cause many health problems. So, the purpose of this paper is the development of a non-destructive testing method of air pressure fluctuation in a stacked building drainage system using field observation and experimental study of stack fluid mechanisms. Therefore, a portable testing device developed to execute a field testing in existing drainage system for determine air pressure fluctuation is needed. With Fast Fourier Transform Process to analyze the power spectrum of air pressure fluctuation in a drainage stack and to verify the previous theoretical study in this paper. The results of this research would contribute to the domestic building technology and improve the design of a drainage system. And it would promote the building quality and better living.

Keywords
building drainage system、trap、a indestructible testing、air pressure transient

1. Introduction

In recent years, high-rise buildings have appeared in metropolitan areas all over the world. Nevertheless, the importance of building drainage, which is a humble but very substantial issue, might not be ignored. Generally speaking, the gravity drainage system without any energy supply is commonly used in building all over the world. However, inappropriate design of drainage system is facile to cause the sanitary problems in high-rise building and inconvenient utility. Particularly, people recognize the importance of healthy environment through the impact of SARS disease. The community infections of Hong Kong give us a great lesson that the problems of drainage system including the infectious disease caused from loss of seal water in trap, and we should not ignore the hidden troubles of building drainage. Therefore, the drainage system of exciting building is a critical issue. And it should be inspected by a specific method. Accordingly, the purpose of this research is developing a nondestructive testing method for air pressure fluctuations in the stack of a building drainage system using field observations and experimental study of stack fluid mechanisms. A portable testing device is developed to execute field investigations in existing drainage systems for air pressure fluctuation in stacks of buildings. And we must to improving the design and diagnosis of drainage systems within existing buildings.

2. Theoretical Reviews

Trap seal water in a drainage system acts as an integral part of a hygiene system in existing residential buildings, and provides an essential component in order to minimize the possible infection risk due to the transmission of contaminants and to safeguard occupied space from stench and vermin from the drainage network. The air pressure in the drainpipe will fluctuate with the flow of wastewater. According to previous research, flowing wastewater tends to generate negative pressures in the drainage system one or two stories below the discharge floor, which can pull the water seal out of the trap. However, at the main horizontal drainpipe or the system one or two stories above, its influence will cause positive pressure and may push the water seal out of trap. Both of those mechanisms can lead to depletion of the water seal. Since the drainage system of a building has a network-like arrangement, the risk of disease spreading through it will rise if the trap seals mentioned above fail.

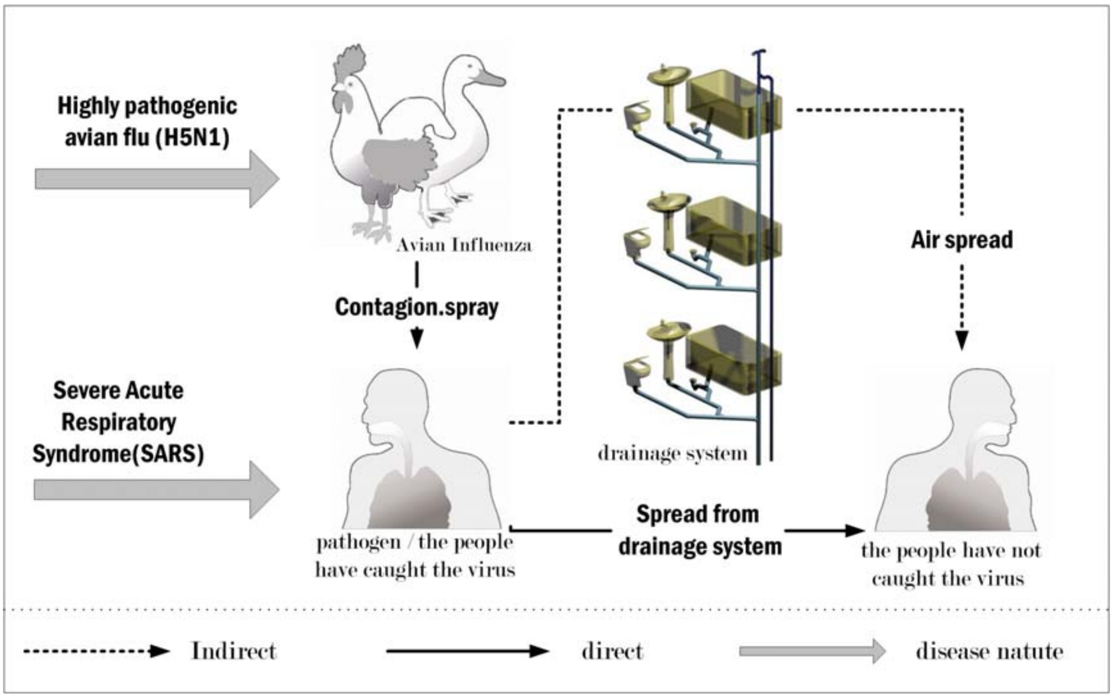


Figure 1 - Infectious Diseases spread Diagram.

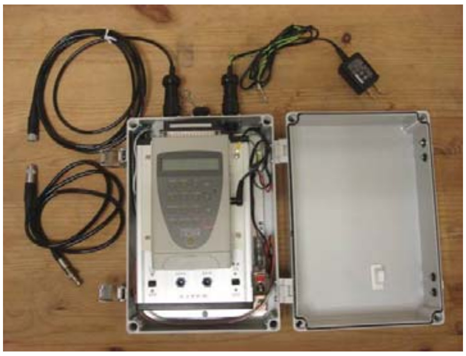
Research at Heriot-Watt University in the UK used a variable frequency generator to apple pressure wave with frequencies of 0.5 Hz to 30 Hz to assess the status of appliance trap seal within the building drainage. Frequencies lower than 2.0 Hz would generate large oscillations in the water surface of the trap, and it was seen that the worst oscillations were found at 0.5 Hz and 1.0 Hz. As the frequency was increased, the oscillations reduced until at 10.0 Hz. There was no influence upon the trap seal, providing a non-invasive test drainage system using a remote transient.

The Fast Fourier Transform Process is one kind of linear integral transformation. Its basic concept was proposed by the French scholar, Joseph Fourier, and it is now widely used in Physics, Combinatorial Mathematics, Signal Processing, Probability Theory, Statistics, Acoustics and Optics. When used in signal processing, a typical application of the Fast Fourier Transform Process is to process signals from time domain to frequency; hence, the Fast Fourier Transform Process is also one kind of harmonic analysis. It is done by using easier periodic functions to represent complex periodic structures; thus, any complex waves can be simplified to the sums of sinusoids. Therefore, the current study applies the Fast Fourier Transform Process method to the data collected from measurements and transforms them into waves under 100 Hz.

3. The consist of instrument

Usually, the practical test is physical model method, simulation and on-site measurement. But the practical test would waste huge resources and the dependence of simulation was low. In practical situations, the origin of the draining load in practical cases was due mostly to normal toilet use and lower volume toilets in the drainage system. Furthermore, it is recommending on-site measurement, and a non-destructive testing method and the portable device for air pressure fluctuation in the stack of the building drainage system which can operate in an existing building system.

Hence, in this study, all the equipment will be combined and the portable device will be established. The equipment consists of a pressure sensor, data receiver and amplifier, data logger, power supply equipment and pressure hose as shown in figure 2.



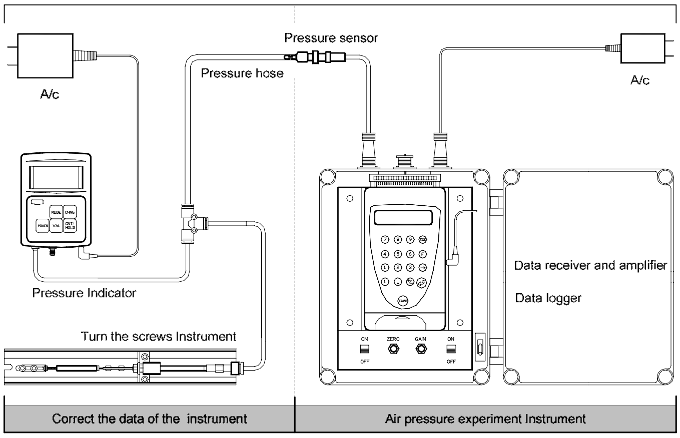


Figure 2 - experimental device

For the drainage test, there are four locations to be measured including pipe-system drain, floor drain and the traps of the faucet and water closet. Pipe-system drilling would lead to damage of buildings, and the testing of floor drain and faucet traps would lend to air release. Accordingly, in this study, water closets were chosen as the testing object. The process of field measurement was divided into two steps. First, one end of the pressure hose was fitted to the air pressure sensor and the other end was put into the W.C, making sure it passed through the water trap. Once installed the data logger was set to receive data as shown in figure 3.

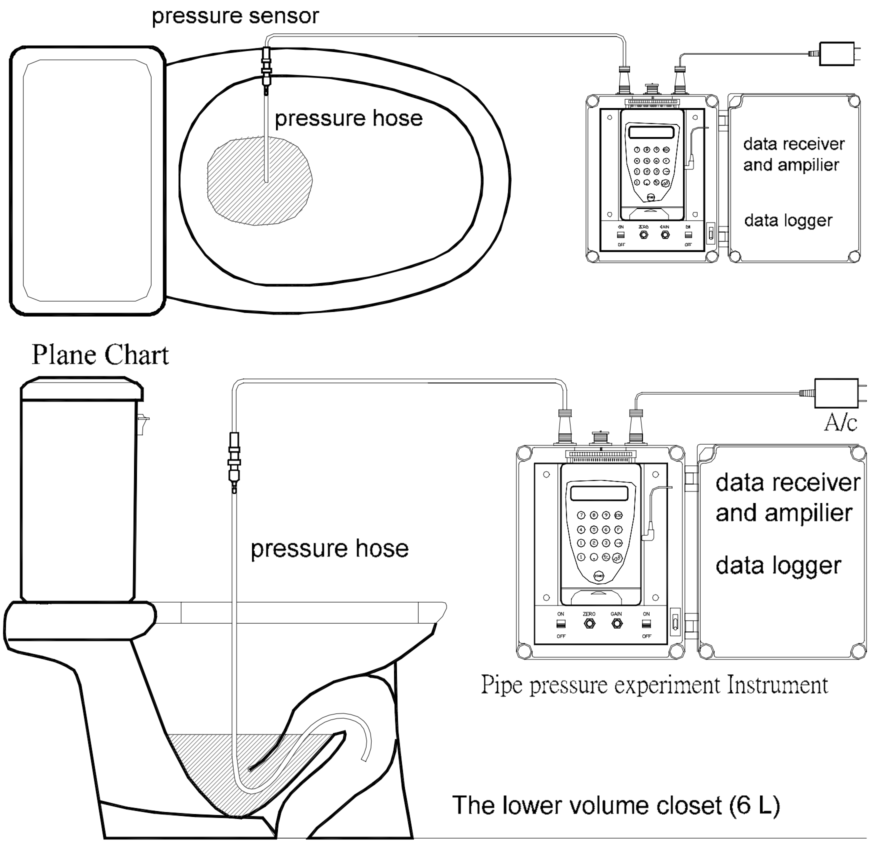


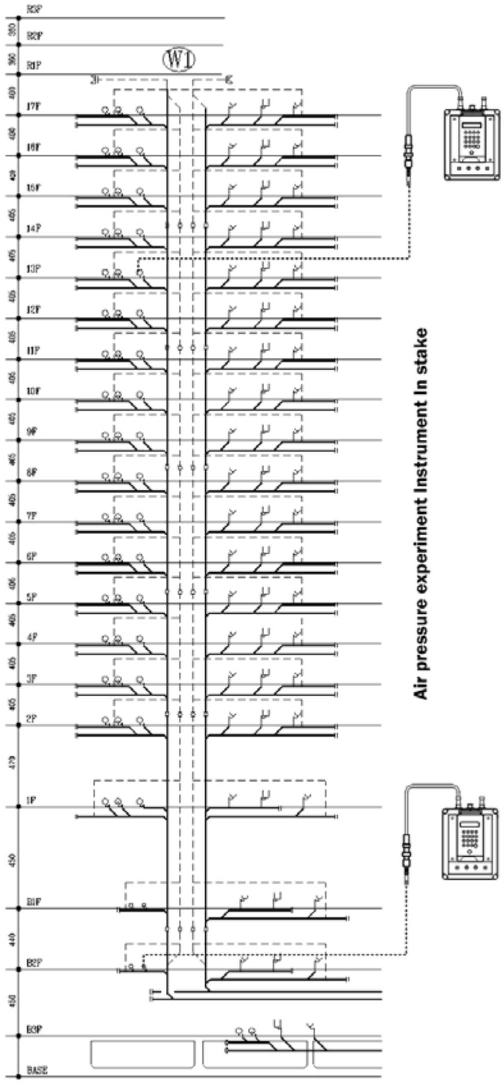
Figure 3 - site-measurement

4. Analysis and discussion

For a case of an office building with a height of seventeen floors height, the measure with a non-destructive testing method for air pressure fluctuation in the stack of the building drainage system. And the Fast Fourier Transform Process to explore the frequency composition of the maximum positive/negative air pressure in the drainpipe .According to the field investigation, the portable pressure-measuring device was installed in the toilets of the thirteen floors and Basement two, which were supposed to be the locations with maximum positive and negative pressure. The experimental data were obtained by long-term observation in order to obtain a precise record of the fluctuation and frequency composition of air pressure in the drainpipe.

（a）building facade

(b) measurement setting



(c)The location of portable pressure-measuring device

Figure 4 - Diagram of field measurement profile in the office building

This pressure-measuring device can gauge one hundred data per second, so it is able to analyze frequency composition under 100 Hz. The experimental data were processed in advance by the moving average method to confirm their rationality, thus, followed by an analysis diagram in which the point A with largest pressure fluctuation could be located. Using the 3,000 data collected within the thirty second time interval including point A, the frequency composition could be analyzed via the Fourier Transform Process as shown in figure 5. Subsequently, the risk of trap seal failure in the test subject could be identified by the analysis of data sequences.

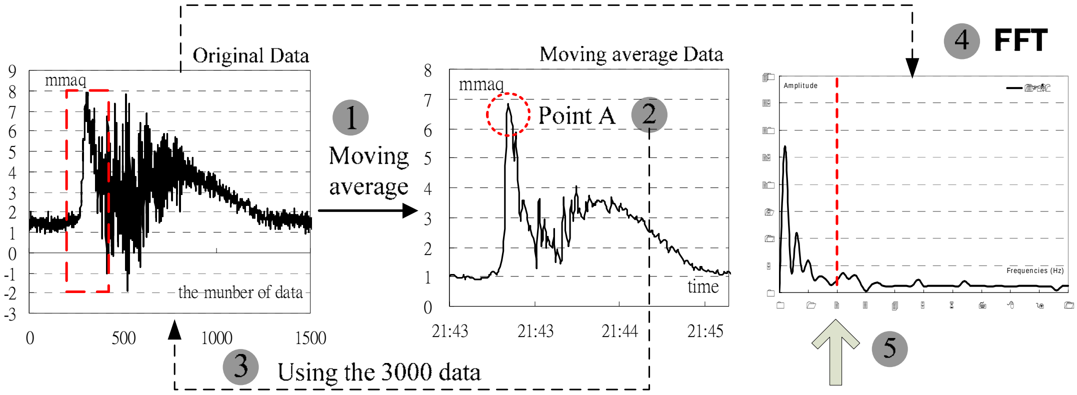


Figure 5 - Diagram of air pressure signal analysis process

4.1 Analysis results from the moving average method

For the peak hours of using sanitary apparatuses in the test subject, this research adopted long-term observation to determine the distribution and frequency composition of air pressure in the drainpipe. The peak hours were from8:00 to 9:00, 10:00 to 11:00, and 12:30 to 13:30. According to the test results, the drainpipe air pressure of the lower floors was mainly positive, while for the higher floors, it was mainly negative. During the peak hours, the lower the floor was, the bigger the discharge load would be. Consequently, the pressure fluctuation in the drainpipe would also be increased. Figure 6 shows the results of long-term observation and records.

According to exciting reference point out , the permit pressure value of the pip pressure fluctuation was verified to be fairly accurate especially with reference to the SHASE-S218 threshold of ±40mmaq(±400Pa) and below. And to the main horizontal drainpipe or the system one or two stories above, its influence will cause positive pressure and push the trap seal to depletion. However, in this case study, the peak hours of pressure value is 47mmaq. Accordingly, we can conjecture that the sanitation appliance in the Basement two was caused the trap seal failure.

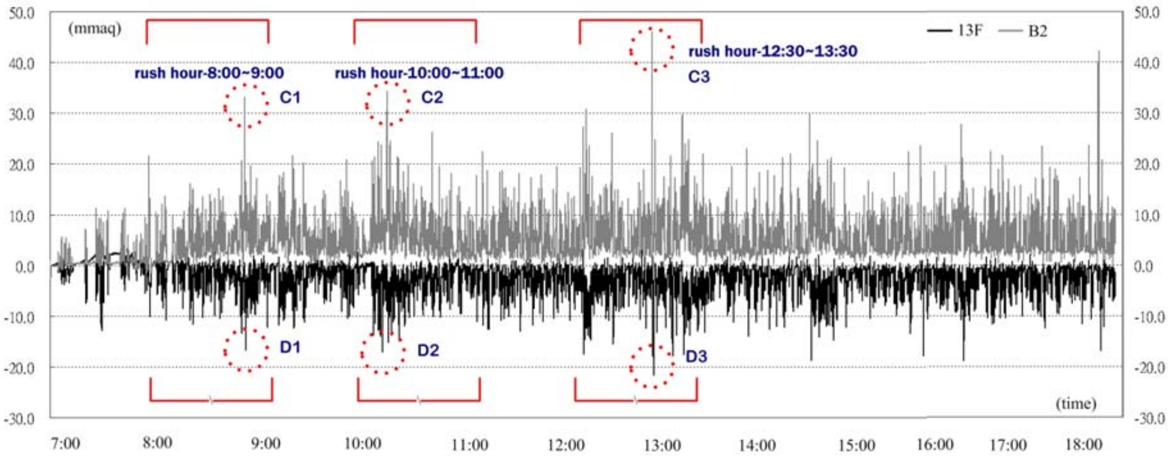


Figure 6 - The long-time observation and data sequence in the official building

4.2 Frequency analysis results from the Fast Fourier transform

After the moving average process, the time period with peak air pressure fluctuation could be singled out as the analysis object. Collecting the 3,000 data within the thirty seconds of time interval including the individual analysis point, the Fast Fourier Transform Process could then be performed and accordingly generate the results as shown in figure 7. The analysis results of the long-term observation data showed that the discharge load and power also concentrated in the 'low frequency' region under 10.0 Hz. The densest power concentrates in the region with frequency below 1.0 Hz. Accordingly, the air pressure and energy in the drainpipe would rise as the number of sanitary apparatuses and floors of the test subject increased. In the meanwhile, it will cause more influence on the trap when the position with the most positive and negative air pressure makes the frequency.

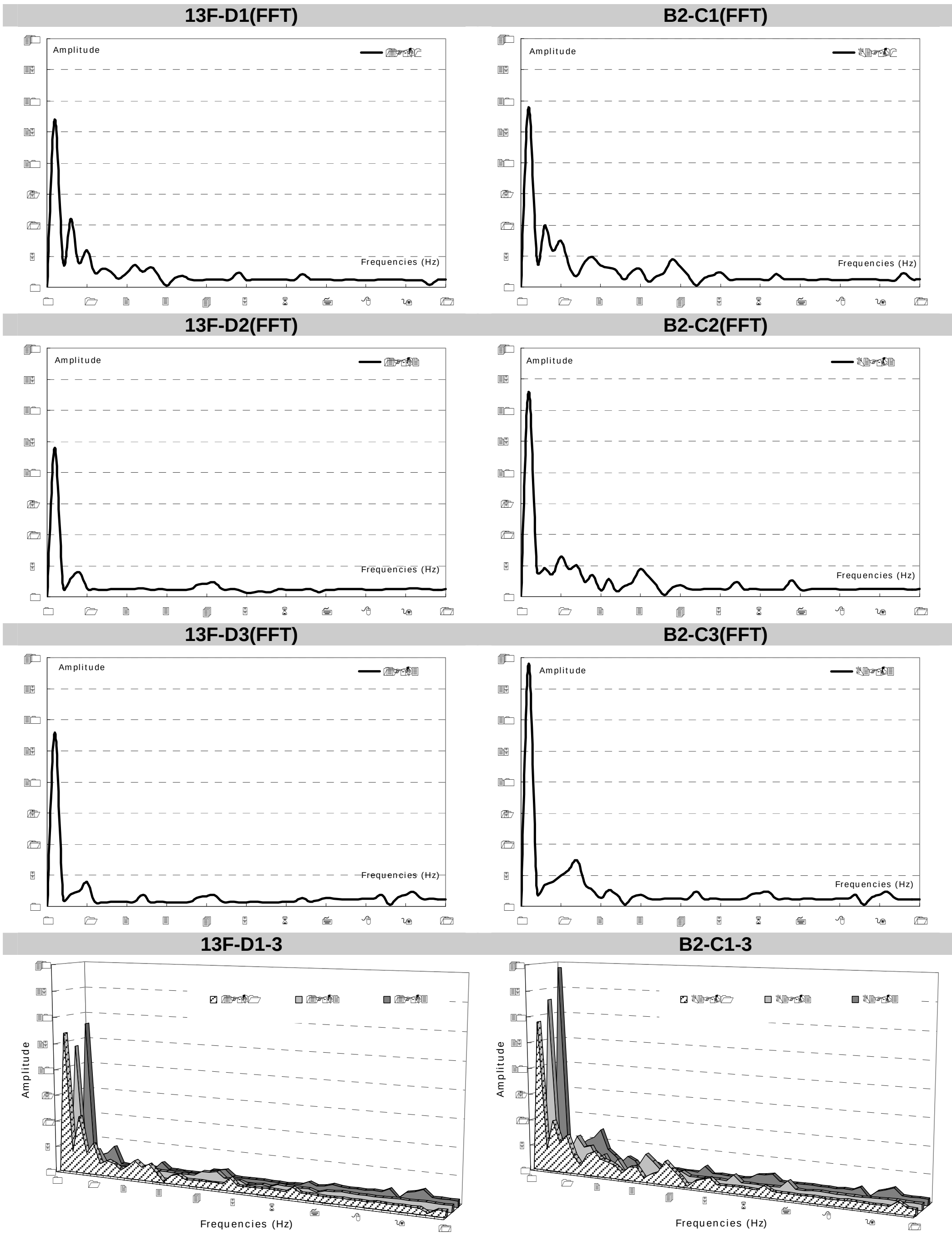


Figure7 - Frequency analysis results from the long-time observation in the office building

5. Conclusion

The portable pressure-measuring device used in this research is a non-destructive testing facility which will not influence the operation of the existing drainage system in the test subject. In cooperation with the moving average method and the Fast Fourier transform process, to understand the frequency composition and energy distribution, which can be used to evaluate the performance of drainage system in the test subject. After the Fast Fourier transform, the analysis results of the long-term observation data showed that the wastewater discharge load and energy also concentrated in the low frequency region. And in the peak hours, although the drainage system was adopted the double pipe system, the closets were tending to occurring trap failure easily and increasing the risk of infection and influence our life. The procedures in this research can be used in the drainage system with other types and scales in the future. With the measuring system developed in this research, the performances of more buildings are expected to be known better so as to generate more concern about this issue in our society.

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7. Main author presentation

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E3) Positive Pressure Profiles in Drainage Stacks – Full Scale Tests

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Abstract

After SARS plague in 2003, it is well known that communicable diseases spread fast via the drainage systems in buildings. In Hong Kong, with the flourishing of the economy, building heights are ever increasing. The Building Ordinance for design of drainage system is often interpreted without properly taking into account of the increasing building heights that the sizes of the drainage stacks and ventilation stacks are not adequate in pressure relief.

Trap seal lost due to siphonic suction is a well known phenomenon. In Hong Kong, a higher risk of trap seal lost is due to the air pressure profile built up with water discharge flow from heights. This paper illustrates the pressure profiles measured from full scale test rigs and real building. It is important in predicting operation problems and locating air pressure relief devices in drainage stack.

Keywords

SARS; ventilation stack; seal lost; pressure profiles; drainage test rigs.

1. Introduction

A highly developed city usually has an increasing and high-density population. As such, the building heights in Hong Kong have increased in order to accommodate more and more people. Similar situations can be found in developed cities in mainland China. High density population means that there are more frequent contacts among people, causing increased chances of infection, and sicknesses to spread easily. There have been a number of such experiences in the past few years: Outbreaks of the bird 'flu (H5N1) virus in poultry in Hong Kong from 2001 to now; of the H5 virus in poultry in Hong Kong in 2002; of the Severe Acute Respiratory Syndrome (SARS) in 2003.

Furthermore, related diseases occurred throughout the region, in Mainland China, Taiwan as well as Hong Kong SAR, all of them are densely populated places where people have more chances to interact with each other.

If the harmful virus invades our environment, our office, our apartment and related the public areas, transmission of infectious diseases will be facilitated. The SARS epidemic in 2003 taught us that drainage systems are an important environmental factor for public health. Empty U-traps and excess positive and negative air pressure inside drainage stacks are the main factors for risk management of building drainage systems (BDS). A healthy system requires effective design, careful installation and good maintenance to minimise these risks.

In the work described in this paper, two full-scale rigs and an actual building were used for assessment of air positive pressures in BDS. The rigs and the building are located in and run by The Hong Kong Polytechnic University (PolyU).

2. Drainage Research Rig in the Industrial Centre, PolyU

A 3-storey drainage test rig is located in the Industrial Centre (IC) of the University. The transparent pipe and vent connections are demountable and the air flow is adjustable. It offers Hong Kong students a unique opportunity to learn from a full-scale drainage facility. Moreover, it is a useful facility for drainage research, particularly for the study of positive pressure in drainage systems, one of the main topics in BDS research.

Figure 1(a) Drainage Research Rig

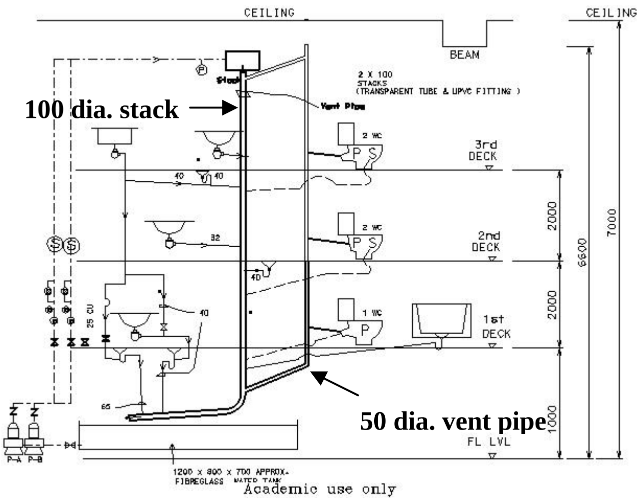

Figure 1(b) Drainage Research Rig Schematic Drawing

2.1 Formation of air positive pressure and hydraulic jump

When water is discharged through the 100 mm diameter transparent stack of the rig, it travels downwards, a vertical speed and reaches the toe of stack. Water will change its direction from vertical to a flat inclined angle (near horizontal). Velocity of water will reduce to flow in horizontal. Hydraulic jump will occur at this moment and perform change of kinetic to potential energy (Figure 2). Hydraulic jump works as a water curtain to stop air passing to downstream, because part of the air accumulated at the bend of stack to form positive pressure zone.

Normally, small variation of air pressure is accepted in BDS (less than 1 mbar, i.e. 10 mm water pressure). However, for a higher discharge flow in BDS, it induces a higher air pressure inside the drainage stack and may break and destroy water seal of traps suddenly.
Experiment formula demonstrates the comparison between vertical speed and horizontal speed of discharge flow. If vertical speed is larger than velocity flow in an inclined discharged pipe, hydraulic jump will occur.

$V_T = 10.7\ (q_w/d)^{2/3}$ is to calculate the speed of discharge stack.
$L_T = 0.1706\ V_T^2$

Where

V_T	Terminal velocity	m/s
L_T	Terminal Length to reach terminal velocity	m
q_w	Discharge flow	L/s
d	Diameter of stack	mm

Using Manning equation, $V_H = 1/n\ R^{2/3}\ S^{1/2}$ to calculate speed of discharge at inclined pipe with gradient S.

For calculation, if a flow of 2.5L/s discharge to 100 mm diameter of stack and then to the inclined pipe, slope is 0.01, using 0.015 as the coefficient n for waste water, and R is hydraulic radius (0.375 for half full bore). V_T and V_H are calculated as 2.3 m/s and 0.7 m/s respectively. Velocity difference causes hydraulic jump and forms positive pressure at the toe of stack.

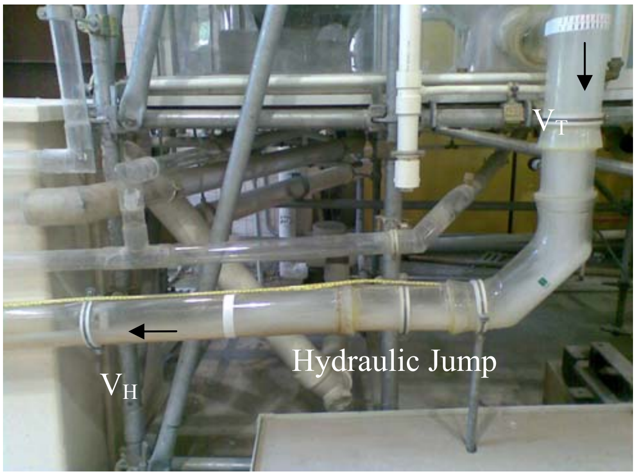

Figure 2 – Hydraulic jump occurs when vertical and horizontal speeds are different, trapping air at the bend

2.2 Air Pressure value of in stack of the rig

Positive pressure is an air pressure transient inside the drainage stack which is greater than the atmospheric pressure. Its value is related to the water discharge flow, the air flow and the pipe size. Its evaluation can be either by simulation or on-site measurement in DBS.

In an experiment in June 2008, pressure sensors (WIKA) were installed at various survey points as indicated in Figure 3, and the data were logged by a controller (ADAM) and computer. This experiment introduces an on-site method to assess pressure profile. One set of data is to use 2.5 litre/s discharge of water from a tank at the top of the stack. The tank is located at the ceiling and 5.2 m above the toe of the stack. Air flow was extracted from the centre of the stack (Figure 4).

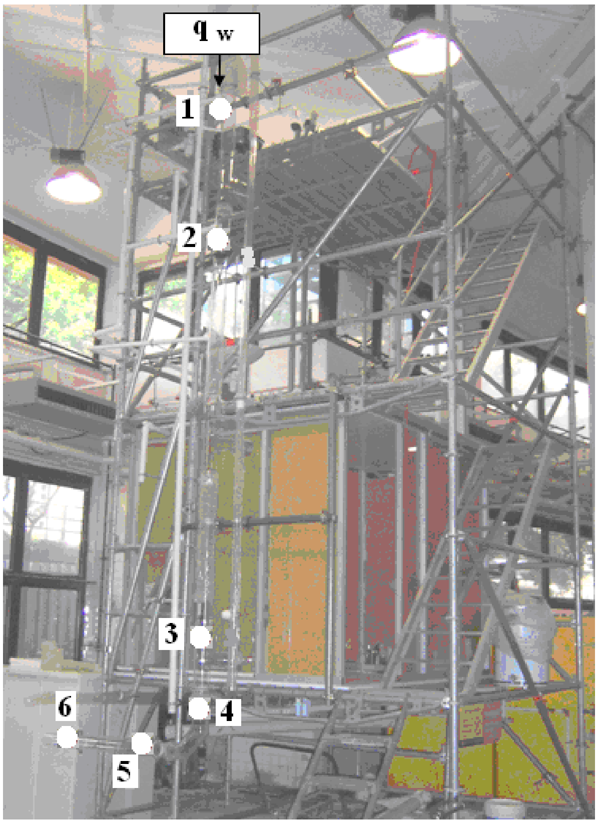

Figure 3 – PolyU drainage research rig

Table 1 Experiment data record in the PolyU Drainage Research

Point	Air pressure (mbar)	Height (m)
1	-0.5	4.7
2	0.5	3.6
3	2.0	0.9
4	3.9	0.3
5	0.8	0.05
6	1.4	0.04

Discharge flow q_w = 2.5 L/s

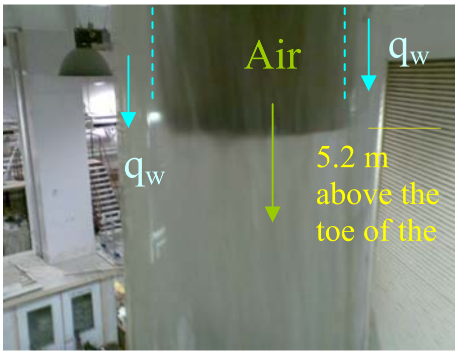

Figure 4 – Water discharge from a tank installed at the ceiling

Points 1 to 4 in Figure 3 are located along the 100-mm transparent pipe, points 5 and 6 are on the inclined pipe. Between points 1 and 4, a typical pressure profile obtains, negative at the discharge point and positive at the toe of the stack. Point 5 locates the crown of the hydraulic jump and air pressure is less than that at point 4. It shows that air is not fully passing through the hydraulic jump (point 5) and has the largest positive pressure near point 4. (Pressure at point 6 is determined by velocity of horizontal flow). The air pressure inside the BDS is governed by energy conservation and continuity. However, an approximation method may be used for determining the air pressure profile in the rig. The kinetic pressure $P = 1/2\ \rho V^2$, where ρ is the density of the fluid and V is its velocity. The velocity of the discharge flow causes air movements, so a pressure coefficient C_P is assigned to allow for the effect on air pressure of the velocity of discharge flow.

$$P_a = C_P\ 1/2\ \rho_w V_w^2$$

where P_a is the air pressure in Pa, V_w is the velocity of water flow in m/s and ρ_w is density of water (1000 kg/m^3). In the experiment, variable discharge flows were released from the top of stack only, and static pressure is ignored.

For a 2.5 litres/s discharge flow, and a terminal velocity of 2.3 m/s the terminal length $L_{T.}$
May be calculated as follows

$$L_T = 0.1706\, V_T^2 = 0.9 \text{ m (just below point 1) and } V_w = V_T$$

The pressure coefficient $C_P = 2P_a/\rho_w V_T^2$
Let a pressure factor $K = C_P\, \rho_w/2 = P_a / V_T^2$
Where P_a is in mBar and V_T is m/s (see calculation in Table 2)

Table 2 - Calculated values of the pressure factor K

Point	pressure factor K	Distance from discharge point (m)
1	-0.094	0.5
2	0.094	1.6
3	0.377	4.3
4	0.754	4.9

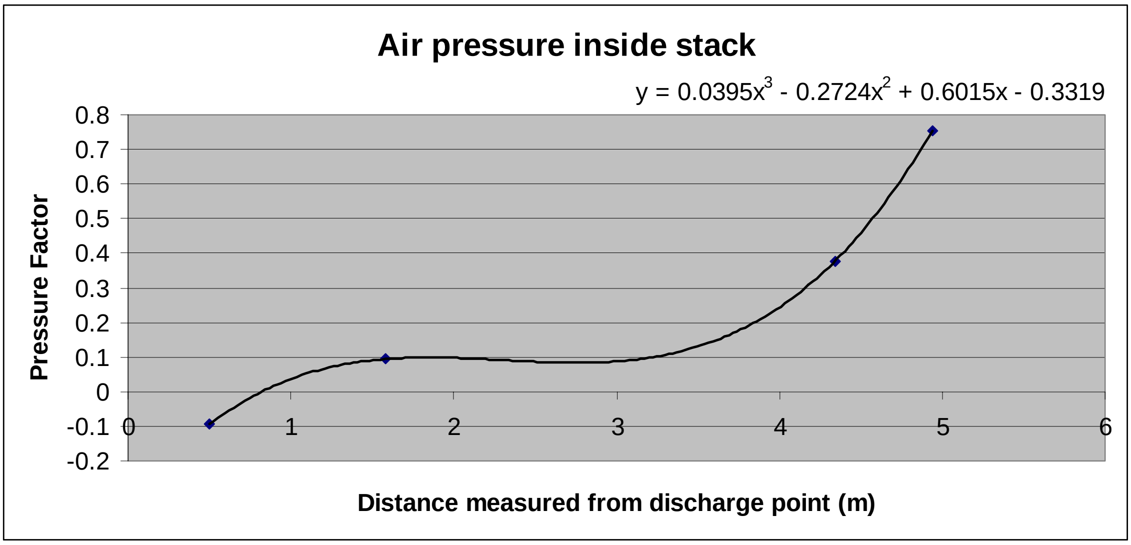

Figure 5 – Air pressure inside 100 dia. stack at IC drainage research rig with the pressure factor from discharge point

To estimate air pressure at the toe of stack (0.3 m under point 4), i.e. x = 5.2 m

Pressure factor K at the toe of stack $= 0.0385(5.2)^3 - 0.2724(5.2)^2 + 0.6015(5.2) - 0.3319$
$= 0.98$
Hence the air pressure at the toe of the stack $= K\, V_T^2 = 0.98\text{x } 2.3^2 = 5.2$ mbar
Similarly, the pressure profile of the whole stack may be obtained.

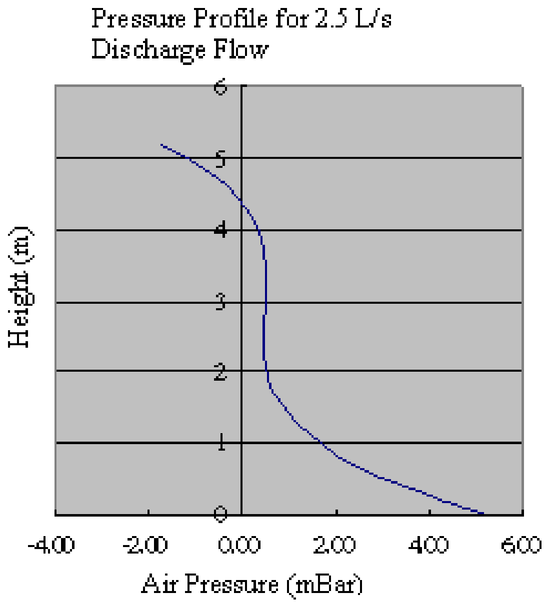

Figure 6 – Air pressure profile diagram

Table 3 - Prediction of air pressure profile inside the drainage stack

Air Pressure (mBar)	Height (m)
-1.76	5.2
-0.50	4.7
0.19	4.2
0.48	3.7
0.52	3.2
0.46	2.7
0.46	2.2
0.69	1.7
1.29	1.2
2.42	0.7
4.25	0.2
5.21	0

3. Positive Pressure at Li Ka Shing Building of PolyU

The Li Ka Shing building is the tallest building in The Hong Kong Polytechnic University and is located at the centre of the campus. The 14th floor is a restaurant, the 3rd is a student computer centre and the rest are offices. The 3rd and 14th floors are found to have a relatively high utilization of the sanitary appliances throughout the whole day.

3.1 Monitoring stations

An investigation was made in April 2008 whereby 3 air pressure survey points were installed on the main foul-water stack (150mm dia.) of the building, on the mezzanine (M) floor, the 6th floor and the 12th floor respectively. The objective was to determine the air pressure distribution of the main stack and how it varied.

Data were obtained from 8:00 to 19:00 hours on Monday, 28 April, and show its peak usage. The air pressures inside the stack were recorded using WIKA pressure sensors with a range of $\pm$200 mbar, and 0.25% accuracy and logged by PLCs and computers.

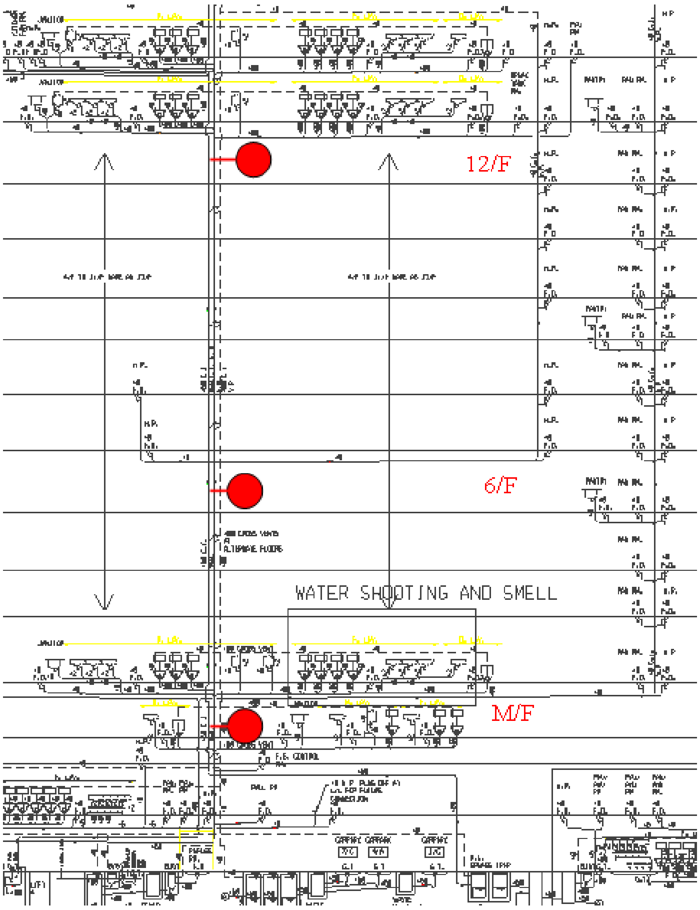

Figure 8a 12/F

Figure 8b 6/F

Figure 8c M/F

Figure 7 – Schematic drainage diagram for 150 dia. Main stack and air pressure survey points

Figure 8a to 8c Survey stations at 12/F, 6/F and M/F at Li Ka Shing Building of PolyU

3.2 Survey data of air pressure in 150 drainage stack

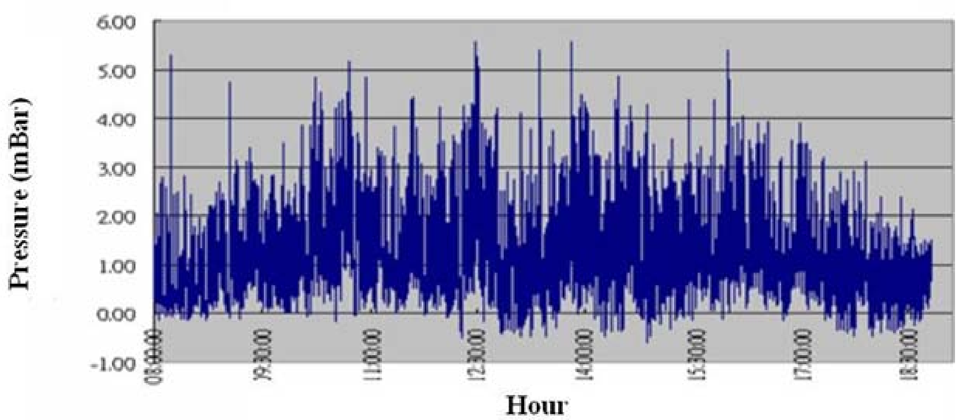

Figure 9 – Air pressure inside 150 stack at M/F, Li ka Shing Building

3.2.1 Data at M/F

From the recorded data, the average air pressure was 1.18 mbar (with a maximum at 5.57 mbar and a minimum of -0.59 mbar). The peak and densest periods of utilization appeared to be at about 11:45 and 14:15.

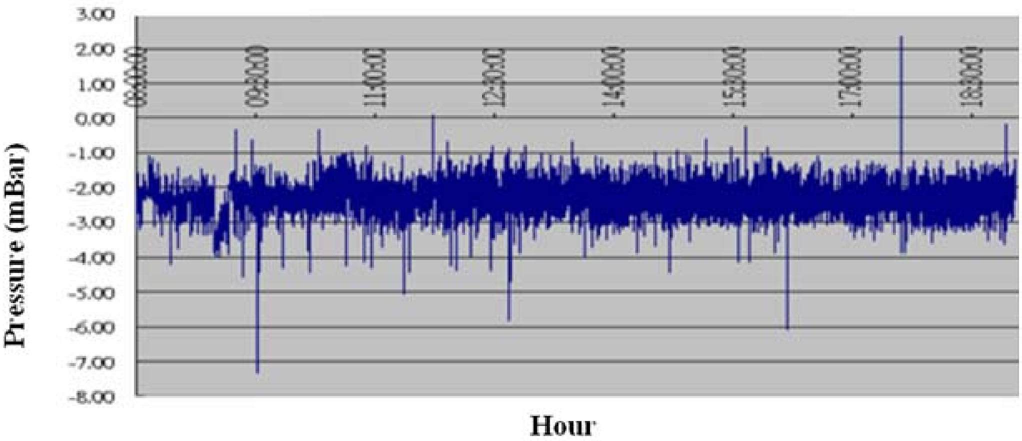

Figure 10, air pressure inside 150 stack at 6/F, Li Ka Shing Building

3.2.2 Data at 6/F

From the recorded data, the average of air pressure is -2.28 mbar (with a maximum at2.38 mbar and minimum of -7.32 mbar). There were no great variations or maxima at particular times. Air pressures in the stack at 6/F appeared more stable that at the M/F.

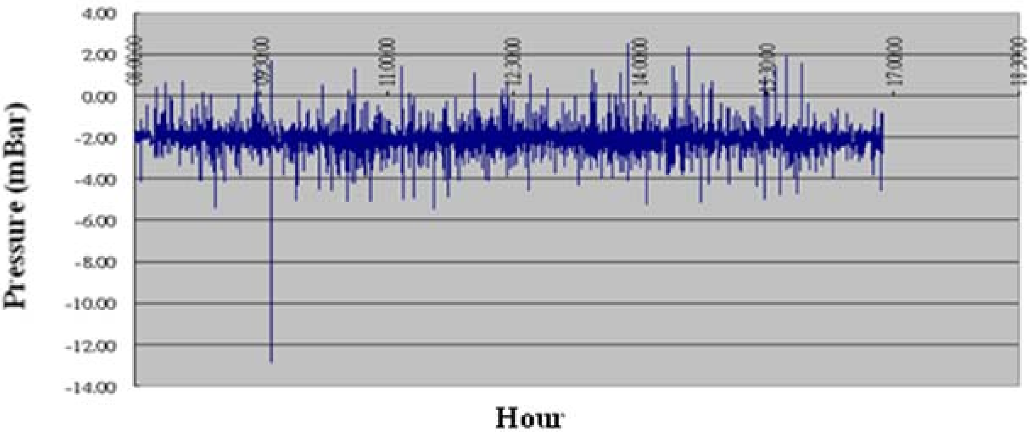

Figure 11 – Air pressure inside 150 stack at 12/F, Li Ka Shing Building

3.2.3 Data at 12/F

Like 6/F, the 12/F is in a negative pressure zone. The average of air pressure is -2.05 mbar (with a maximum of 2.52 mbar and minimum of -12.83 mbar). There were no great variations or maxima at particular times. Air pressures in the stack at 12/F, like the 6/F, appeared more stable that at the M/F.

Table 4 Air pressure analysis for Li Ka Shing Building

Air Pressure inside the stack of Li Ka Shing Building from 8:00 to 18:00 (weekday)

Monitoring Point	Max. mBar	Min. mBar	Average mBar	RMS mBar	Standard Deviation	Number of Record selected
M/F	5.57	-0.59	1.18	1.46	0.87	38206
6/F	2.38	-7.32	-2.28	-2.31	0.34	38055
12/F	2.52	-12.83	-2.05	-2.07	0.30	32357

There are over 20 times of high positive air pressure between 11:45 and 14:15. Their value is over 4.5 mBar including 5 times at 5.5 mbar. It means that many sanitary appliances are used simultaneously in this period and water seal of all traps including water closet are unstable. From Table 4, the standard deviations of the 6/F and 12/F data were similar, but much smaller than the value for the M/F, indicating that the pressure variation is much larger at the M/F.

The RMS values of air pressure (P_{RMS}) were 1.46 mbar for M/F, -2.31 mbar for 6/F and -2.07 mbar for 12/F and these floors can be used as reference points inside the stack to develop an air pressure profile for the building. The main discharge point can be above 12/F, say on the 14/F (where there is a restaurant so the toilets are highly utilized from 11:45 to 14:15) and main discharge flow for whole building can be determined using a simulation method. On the other hand, the maximum positive air pressure taken at M/F should be noted and closely monitoring at this peak usage period.

4. Test rig for water seal of traps

The maximum positive pressure reached 5.5 mbar at the M/F. Normally, minimum water seal for a trap is regulated at 50mm for ventilated BDS and 80mm water seals for single stack systems. From Figure 9, it is seen that positive pressures of 5 times the stated value are found at the M/F, which would break the trap's water seal. Fortunately, these occur for very short times, about 1 second. If the excessive air pressure lasts over 3 seconds almost all the water seals will be broken. It is thus necessary to know the breaking level for the water seals fo the various types of trap.

4.1 Positive pressure tests for water retention capability of floor trap

Another test rig in IC is used to test the breaking level of traps (Fig. 12). It has a reversible air pump providing adjustable positive and negative air pressures. Traps can be tested for pipe sizes from 32 to 100 mm and can also test the evaporation rates by means of an air chamber. Air pressure tests were held to determine the pressure required to break the water seals on different traps: the 'P' trap, the bottle trap and the anti-suction trap (Figures 13 to 15). Pressure sensors were installed at BDS and near water seal and the air pressure data were recorded by a controller (ADAM) and computer. The pressure was increased until the trap's water seal was broken.

Figure 12 – Test Rig for Traps

Figure 13 – 'P' trap under positive pressure

Figure 14 – Anti suction trap under positive pressure

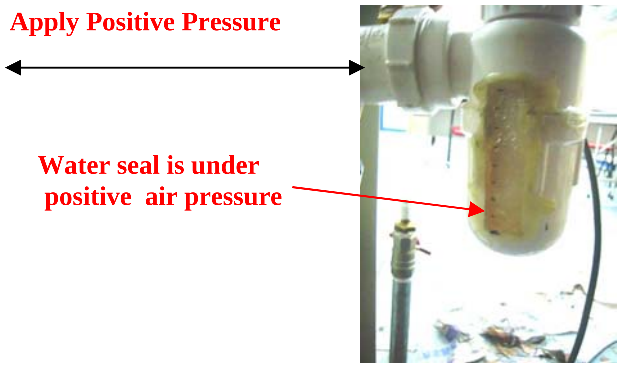

Figure 15 – Bottle trap under positive pressure

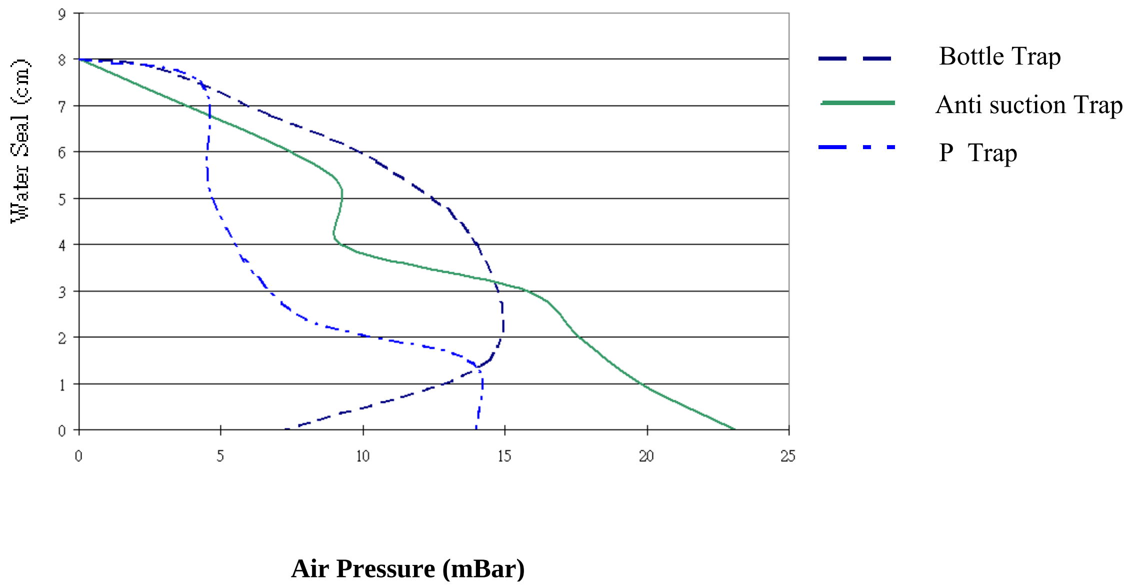

Figure 16 – Capability of Retaining Water Seal for Bottle, P and Anti-suction Traps

As seen in Figure 16, the traps initially have an 80 mm water seal. The results show that the 'P' trap quickly lost its water seal and that when the air pressure reached 14 mbar, the water seal of the bottle trap was totally destroyed.

5. Conclusion

The positive pressure test and real case study provide an easy on-site measurement and numerical assessment. It is simple, easy and directly relevant to the BDS. However, such testing methods on existing pipes may not be adopted by clients. Alternatives are installing sensors at specially-made detachable joints for stack, or the special design of a cleaning eye for the BDS.

It is highly recommended to include drainage survey points at the design stage of a building. It is recommended that:

- BDS monitoring systems are set up for monitoring and as a precaution. The concept is clear and straightforward. Better to have cure been done before problems begin, making a long-lived and healthy BDS. An automatic monitoring system would be better still but cannot be compulsory.

- Ventilation pipes of larger size than conventionally used are employed to prevent excess suction and reduce the influence of air pressure on BDS. The minimum size of ventilation pipe should be the same as the stack size.

- An air attenuator and admittance devices should be included to strengthen the ventilation capacity in BDS. The preferred locations can be found by numerical assessment of the pressure profile..

- A smart trap should be developed which would withstand excess air pressure.

Acknowledgments

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6. References

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E4) Air Leakage Test of the uPVC Combined Stack System

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Abstract

After the SARS outbreak in 2003, more attention has been paid to the potential problems caused by improper functioning of the uPVC effluent discharge piping system. It was found that the cause of rapid spread of SARS disease was due to the malfunctioning of traps in the soil discharge systems in a residential building. Hong Kong is a densely populated city. High-rise multi-storey buildings are built densely and close to each other. As such, dispersion of contaminated air leaking from the malfunctioning combined stack piping components was not easy, especially in the windless weather condition. The densely populated urban area faces a shortage of fresh air ventilation for dispersion of the contaminated air from the combined soil stack. In Hong Kong, uPVC piping system is used in most of the residential buildings for drainage. The ideal uPVC effluent discharge piping system should be water-sealed and air-leak proof. The perfection of the uPVC discharge piping system can hardly be achieved due to the following main reasons:

- The manufacturing imperfection in the piping fittings and piping design.
- Improper installation of the piping fittings and poor workmanship.

This article is to investigate

- The source of contaminated air leakage from a typical residential uPVC piping system. Laboratory test results and findings will also be demonstrated.
- Justify the methodology, practicability and the degree of acceptance by the industry for adopting the following sanitary piping testing methods

Keywords

Combined soil stack, uPVC pipe, water seal, air-leak proof, malfunctioning of traps

1. Introduction

1.1 Background

Hong Kong is a densely populated city. The densely populated urban area faces a shortage of good air ventilation for dispersion of the contaminated air from the combined soil stack. After the SARS outbreak in 2003, more attention has been paid to the potential problems caused by improper functioning of the uPVC effluent discharge piping system. It was found that the cause of rapid spread of SARS disease was due to the malfunctioning of traps in the soil discharge systems of a residential building. The ideal uPVC effluent discharge piping components should be water-leak proof and air-leak proof. The perfection of the uPVC discharge piping system can hardly be achieved due to the following main reasons:

1.1.1. The manufacturing imperfection in the piping fittings and sealing design.
1.1.2. Improper installation of the piping fittings and pipe works.
1.1.3. Poor workmanship.

This article is to investigate the source of contaminated air leaking from the uPVC piping system. Laboratory test results and findings will also be demonstrated.

1.2 Objective of the Tests

The objective of the tests is to justify the methodology, practicability and the degree of acceptance by the industry for adopting the following sanitary piping testing methods:

1.2.1. Low Pressure Air Test (generally in accordance with BS5572)
1.2.2. High Pressure Air Test (generally in accordance with USA practice)

A typical 1:1 scale model including branch pipes was set up for the tests. The air leak test was applied to uPVC pipes for the verification of air-tight pipe joints and U-traps. The possible difficulties when the proposed testing methods were being carried out and the proposed precautionary measures to prevent the corresponding difficulties were both discussed.

2. High Pressure Air Test

In order to be in line with the sequence of erecting the sanitary piping on site, the order of tests is recommended as follows:

High air pressure test went first (all sanitary appliances were uninstalled, the sanitary system was still dry and all the traps were sealed before applying high pressure air at 0.34 Bar to the system)

Finally, low air pressure test (all sanitary appliances and traps were installed and the sanitary system were charged with water)

High Pressure Air Test was used to test the air-tightness of uPVC pipe joints and uPVC fittings of all above ground sanitary pipework

The test was conducted on completion of all external and internal pipework while leaving all sanitary appliances un-installed.

A high internal air pressure (i.e. 34kPa or 3.4m w.g.) and a longer testing period (i.e. 15 min.) was applied to the drainage piping system. A higher standard in workmanship and a more reliable system for leakage free were established with the installation of the High Pressure Air Test in the drainage system.

The drawing (Fig 1) below showed the schematic of the uPVC drainage under high pressure test

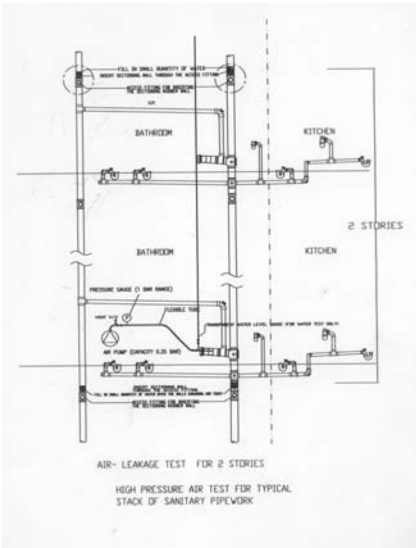


Fig 1 showed the schematic of the uPVC drainage system under high pressure test.

Fig 2 Insertion of rubber ball into the vent Stack for sectioning the tested floors

For detail please refer to appendix 1

2.1 Set up and Procedures:

i) All the open ends of the pipework were plugged off with pipe caps/plugs.

ii) Smooth surface rubber ball with diameter close to the uPVC pipe internal diameter were inserted into the pipework and vent stack through the access fitting. A stopper (see figure 5) was placed to prevent the ball from slipping away under high pressure. The ball was charged to a pressure of about 0.3 Bar so that its surface is strongly pressing against the internal surface of the PVC pipe. A small amount of water was filled to cover the ball sufficiently in order to provide perfect air seal.

Fig 3 Cover the inflated ball with water for perfect air seal

iii) The electric air pump discharge was connected to the inlet of the air control valve combination set (fig 4). The outlet of this set was connected to the air inlet valve at the W.C. drainage pipe. This air control valve combination set was to control the air pressure to the uPVC piping under test. The air pump discharge valve was opened slowly. If there was air leakage, the pressure dropped quickly when air pump was switched off.. The rate of pressure drop showed the seriousness of the air leakage. After repairing all the leakage points, the result was considered satisfactory if the pressure (i.e. 34 kPa / 0.34 bar) inside the uPVC pipework can sustained for 15 minutes after shutting off the air pump.

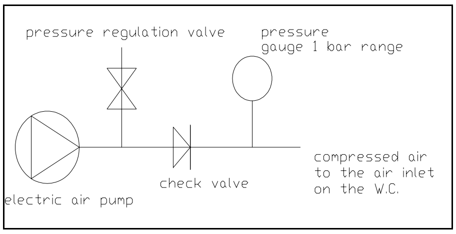


Fig 4 Air control combination set

Fig 5 PVC stopper is inverted to prevent sectioning ball slipping away under pressure

iv) Soap bubble solution was used to test the air leakage points

2.2 Test Result

Figure 6 The photo showed that with the air pump running, the air pressure indicator can only be maintained at a pressure of 0.1bar although the maximum air pump capacity can reach to 0.35 bar. If there was air leakage the pressure indicator returned to zero immediately when the running air pump was switched off.

Figure 7 After repairing all the air leak points, the highest reachable test pressure was only 0.3 bar (30kPa). Just after 0.3 bar, all the sectioning rubber balls were suddenly forced out of their position under the great air pressure (0.3 bar)

In this high air pressure test, the reachable air pressure inside the uPVC pipework was only 30 kPa for 15 minutes after all the suspected leakage defects had been repaired. There were a number of air leak points found including:

Figure 8 The leakage at the expansion joint was due to poor workmanship in applying PVC solvent cement.

Figure 9 The leakage at the bottle trap

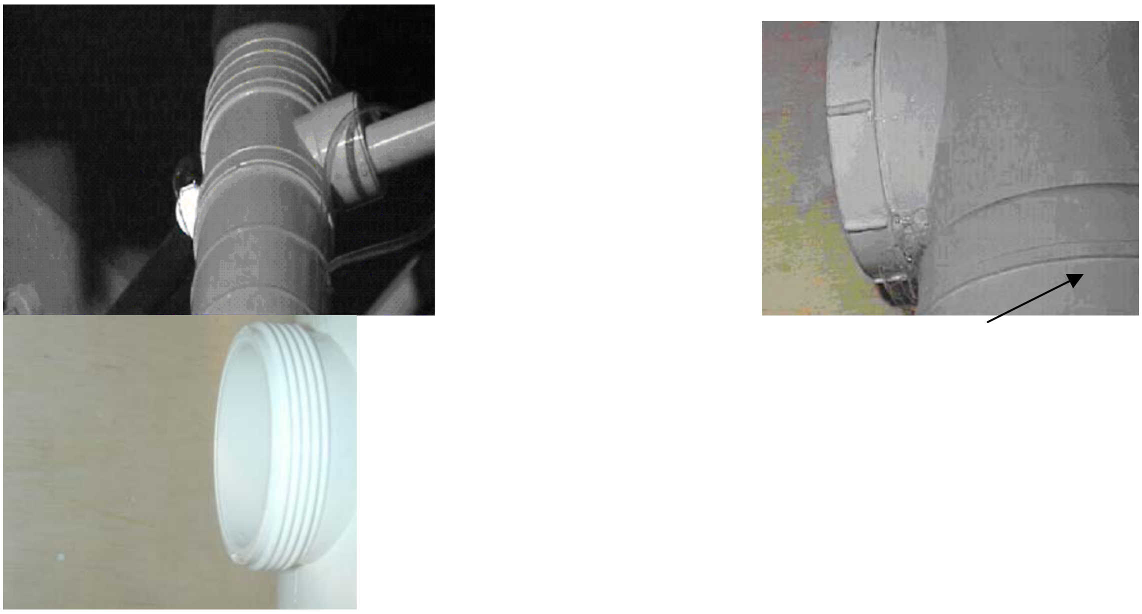


Figure 10 The air leakage at the cleaning eye cap due to moulding defect

2.3 Analysis of high pressure Test Results

The test results showed that there were a lot of defects coming from the following

sources. They can be divided into two kinds of sources:
The air leak points in the uPVC components including:
i) The sealing seat protrusions on the cleaning eyes and access fittings by moulding process. These defects cause air leakage through the sealing gasket ring.
ii) The structure of the bottle trap was not strong enough for tightening the sealing ring. Slipping on the tightening thread sometimes occurs.
iii) Installation defects from the workmanship of the plumber:

It was found that the uPVC piping system could only withstand a pressure of 0.3 bar. Just after 0.3 bar both the upper and lower sectioning rubber balls were forced out of its original position suddenly! It may be due to the fact that wet uPVC pipe internal surface was quite slippery. Under such a pressure of 0.3 bar the friction between the ball and the uPVC pipe cannot hold the ball and slipping of the balls suddenly occurred. It was strongly recommended to insert a uPVC pipe stopper through the access fittings (fig 5) so that once the ball slipping occurred under a high pressure the stopper can stop the ball movement as showed in fig 5. In this test the sudden ball slipping occured at a pressure of 0.3 bar.

At the beginning of the test, there were serious leakages, and the pressure gauge can only reach a pressure of 0.05 ba.Only After all the leakage points has been checked and repaired, the pressure can gradually increase from 0.1 bar to 0.3 bar.

3. Low Pressure Air Test

Low Pressure air test was used for the test of air-tightness of pipes and fittings of all above ground sanitary pipework and above the lowest appliance. The test is to be conducted on completion of the whole drainage installation including external and internal pipework with all sanitary appliances installed.Fig. 11 below showed the schematic of the uPVC drainage under low pressure test.

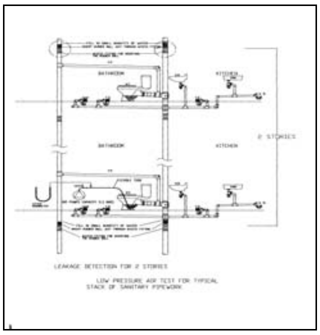


Figure 11 The schematic of PVC drainage under low pressure test Details are shown in Appendix 2

Figure 12 Insertion of rubber ball into the vent stack for sectioning the tested floors

3.1 Test Setup and Procedures for low pressure test

i) All seal traps of sanitary fittings (including water closet, wash basin, floor drain, shower tray and washing machine) were charged with sufficient water. The rubber balls were inserted into the pipework and vent stack through the access fittings to section the tested floors. The rubber balls were inflated to a pressure of about 0.3 Bar so that its surface was strongly pressing the internal surface of the pipework. A stopper was placed (showed in fig 5) in order to prevent the rubber balls from moving away.

ii) The air pump and manometer were connected to the system by flexible tubing. The air pump discharged air into the uPVC pipework through a specially designed spring tube. This spring tube was inserted into the pipework of the drain stack through the W.C. as shown:

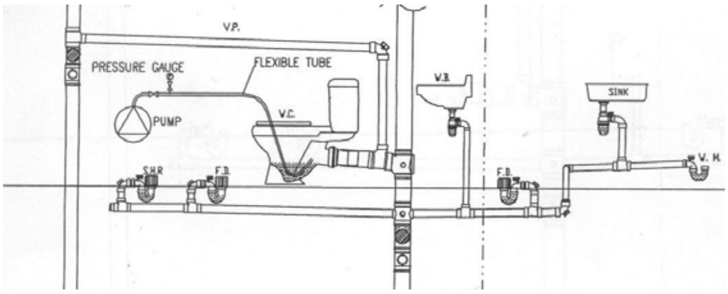


Figure 13 The spring tube was inserting into the combined stack through the W.C.

iii) Specially designed spring tube was used so that it can bend and pass through the u-shape pipeline without tube collapsing causing air blockage.

iv) The electric air pump discharge was connected to the inlet of the air control valve combination set (fig 4). The outlet of this set was connected the spring tubing and the manometer. Spring tubing was inserted into the drain stack through the lower level W.C.

v) After all preparation has been connected and checked, the manometer inlet valves should be closed temporarily for purging procedure to ensure that no residue water in the flexible spring tubing. After purging the manometer valve can be opened slowly and the air pump outlet valve should be adjusted carefully so that a 150-mm w.g. pressure should be obtained. If the applied air was too much, water in the traps will rise up and finally excessive air from the air pump will escape from the u-trap so that the water gauge pressure can hardly reach 160mm for 80-mm traps. The air pump outlet should then be turned off. If there was any air leakage defect, the manometer reading will drop gradually. If this happened, the air pump should be turned on again and the leakage defects should be located by jetting the bubble solution to the suspected leakage locations while the air pump was running. After repairing all the defects and there was no air leakage, the manometer reading should be able to sustain a constant reading of at least 38mm w.g. for 3 minutes. The drop in pressure was recorded.

The test was considered satisfactory when the pressure (at least 38mm w.g.) can sustained for three minutes with the air pump stopped running.

3.2 Low Pressure Test Results

The low-pressure air test was completed in this test. In this test, soap bubble was applied for easier detection of leakage. Besides, a higher air pressure of about 150mm w.g. had been supplied from the air pump in order to provide a more obvious bubbling detection. Although the applied air pressure was not as high as the high pressure air test, air leak defects can also be located by the air bubble method as shown below:

Figure 14 The big soap bubble was formed under a testing air pressure of 38mm w.g. on a loose cleaning eye cap. This showed that the low pressure air could also identify air leak defects

After all the defects on the pipework components were all solved, a pressure of 38mm w.g. in the uPVC pipework can sustain for a 3 minute period after stopping the air pump.

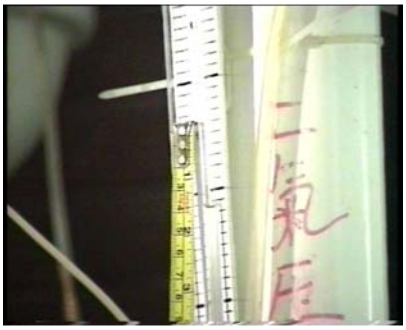


Figure 15 L A 38mm w.g. test pressure can be maintained for 3 minutes after the air pump was switched off.

Figure 16 R The above photo showed that once pressure in the pipe was broken by pushing the anti-siphon valve, the manometer reading dropped to zero immediately

After the 38 mm air pressure test was witnessed and verified, the above witness tried to depressurise the uPVC pipeline by pushing up the anti-siphon disc guide pin. The manometer reading returned immediately to zero after depressurization. This also proved that sealing function of the ant-siphon valve was good for its sealing function under a 38mm w.g. test air pressure. The above photo showed that once pressure in the pipe was broken, the manometer reading was back to zero immediately. If the manometer reading cannot return to zero after depressurization by opening one of the sealing, there may be some kind of tricky suspect.

3.3 Analysis of Test Results

The low-pressure air test can locate a major air leak defect using bubble solution. The air leak defects include the serious leakage defect on the expansion joint, and the workmanship defects leading to a more serious air leak. If the defect is minor, such as the cleaning eye defect by the moulding extrusion, the low-pressure air method can hardly locate these minor defects. These hidden defects are mainly due to the manufacturer' mould defects. Due to the mass-less property of the air, this testing can be theoretically applied to the whole installation but there will be more leakage detection difficulties for detecting the whole installation in one test.

4. The functions and installation of uPVC drainage traps with an anti-siphon valve

4.1 Function of the anti-siphon valve

The following picture shows the schematic structure of the anti-siphon valve.

The purpose of the anti-siphon valve is to break the partial vacuum created when there is a fast water flow down the main stack based on the Bernoulli's principle of flowing fluid. Moreover, when the soil stack momentarily exceeds the design flushing water flow rate, the flush water mass can fill up part of the soil pipe. This mass of water compresses the air in front of it and creates a partial vacuum behind it. So that the pressure at the drain trap outlet always fluctuate about the vented atmospheric pressure with transient positive and transient negative fluctuation. An excessive siphon action will have the danger of exhausting the water inside the water trap as shown . The water sealing between the drain inlet and the main stack cannot function properly if the U-trap is dried.

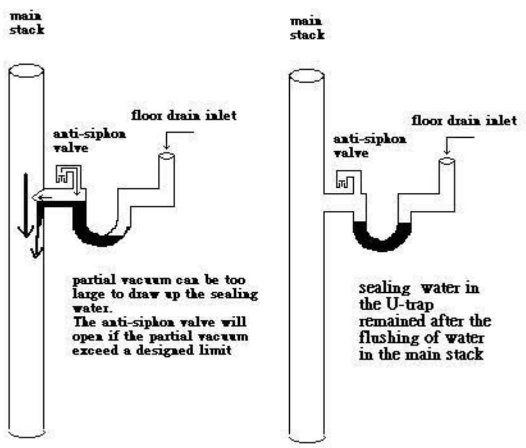


Figure 17 Proper installation of U-traps for sealing the floor drains from the main stack

It is verified that the air valve of anti-siphon U-trap is able to keep closing tightly under the positive air testing pressure. The copper sealing valve disc can provide rigidity against deformation under positive air pressure.
But it is found that the efficiency of the anti-siphon depends on both the design and the aging of the anti-siphon valve. As seen in the following short video film

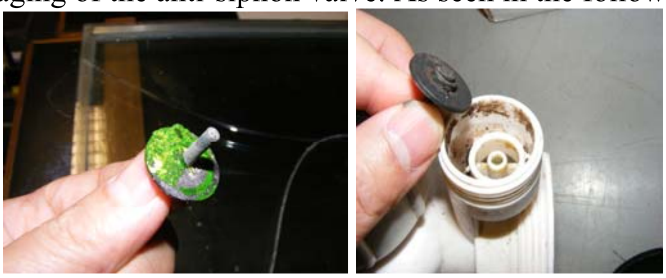


Figure 18 and 19 Anti-siphon rubber valve disc was found stained at valve seat side
Performance test of a bottle U-trap found in the debris of renovation dumping site

Figure 20 A functional anti-siphon copper valve disc with gasket lining
Performance test of a good bottle U-trap used in the uPVC pipe test

4.2 Calculation of optimum weight of copper disc

In the following calculation we would like to determination of the optimum weight of the anti-siphon valve disc that could sustain the 38 mm - 50 mm water gauge air pressure without affecting the operational performance of the U-trap under normal operational condition.
The suitable weight of the copper disc is to ensure the rapid return of the air-valve to its sealing position under the gravitational action. The mass of the anti-siphon valve, based on copper disc valve, was plotted against suction pressure as follow:

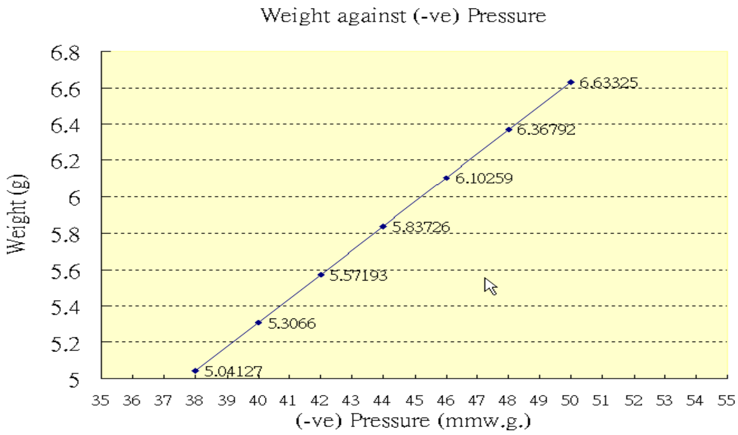


Figure 21 The mass (in grams) of the anti-siphon valve was plotted against suction pressure (mm w.g.)

5. Conclusion

5.1 High pressure test

In the high pressure test it was found that the air bubble method was very effective in detecting air leakage defects. High air pressure was strong enough to form soap bubble from the minor defective point. If there were air-leakage defects in the uPVC pipe system, the pressure inside the uPVC pipework dropped rapidly immediately after shutting off the air pump. Only after all the leakage points have been checked and repaired, the pressure can gradually increase from 0.1 bar to 0.3 bar (i.e. 34 kPa / 0.34 bar/3.4m w.g.) and maintained the pressure at 0.3 bar for 15 minutes with the air pump stopped running.

5.2 Low pressure test

The low-pressure air test is suitable for old buildings because all the sanitary appliances have been installed. Disassembling these appliances for have pressure test is troublesome and costly

It was found that the low-pressure air test is effective in locating the major leakage defects such as the workmanship defects by jetting bubble solution to the suspected defective points. But for minor defects such as the moulding defect it was difficult to locate the minor defects because the small 38mm w.g. air pressure is not strong enough to form soap bubble from the minor defective point.

5.3 Finding and Limitation

Anti-siphon valve with metal disc provides rigidity and weight for better air seal. In regards to air-test during the course of construction, there are several measures in terms of practicality. One of the measures which require special attention is that the section of pipes which has been undergone air pressure test should be properly protected from being damaged. It is always advised to test the whole system at the pre-handover period. However, considering the height of building which could be more than 300 meters, it is advisable to test the system by sections.

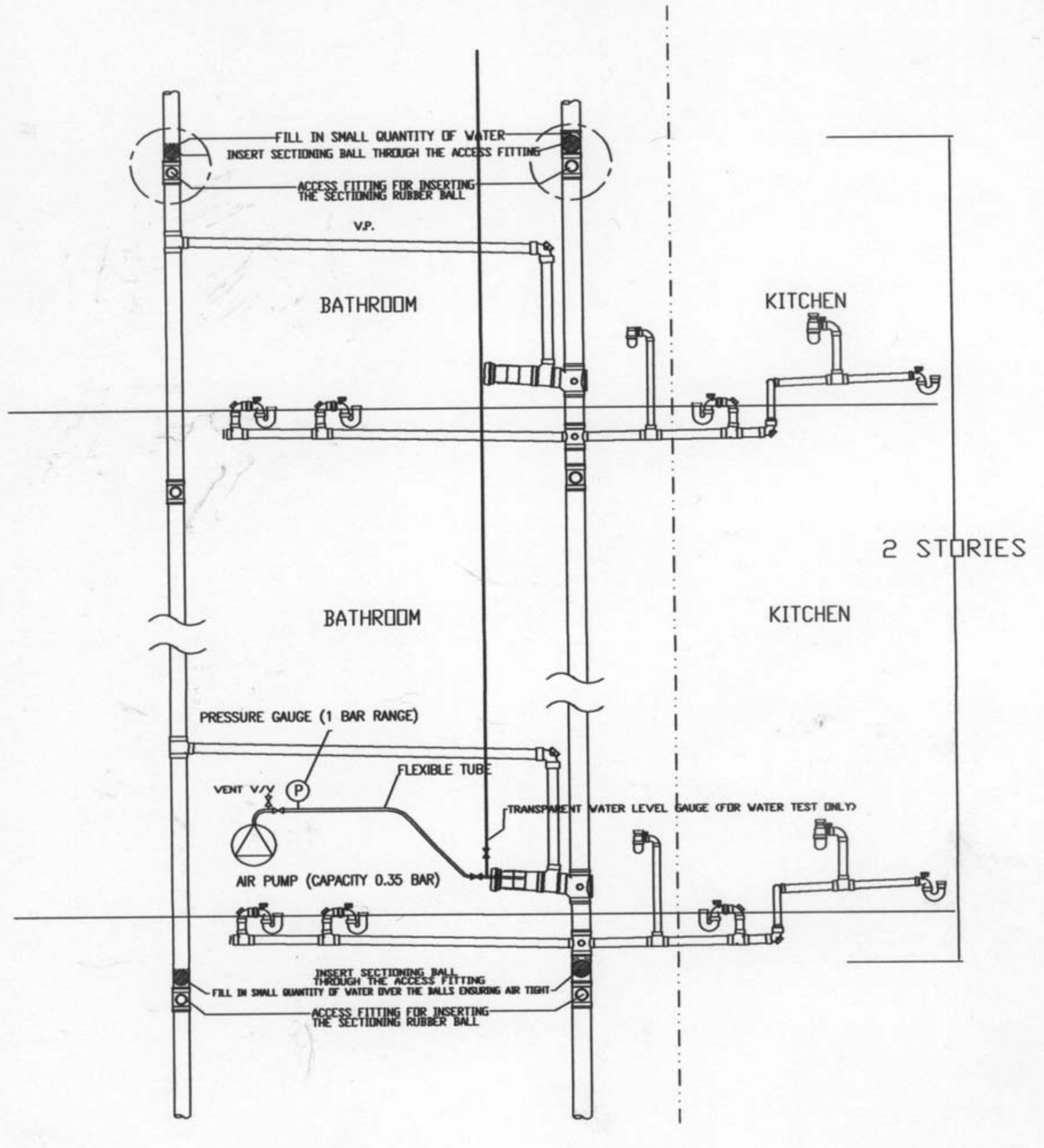
6. Reference

1. The functions and installation of PVC drainage traps with an anti-siphon valve by Chan Iat Keong, page 19, Journal of Hong Kong Engineer, June 2008

7. Presentation of Author

IK Chan is a member of CIPHE. His expertise is laboratory testing which are related to environmental hydraulic, heat and mass transfer and thermo-fluid. He presently is working in the Hong Kong Polytechnic University.

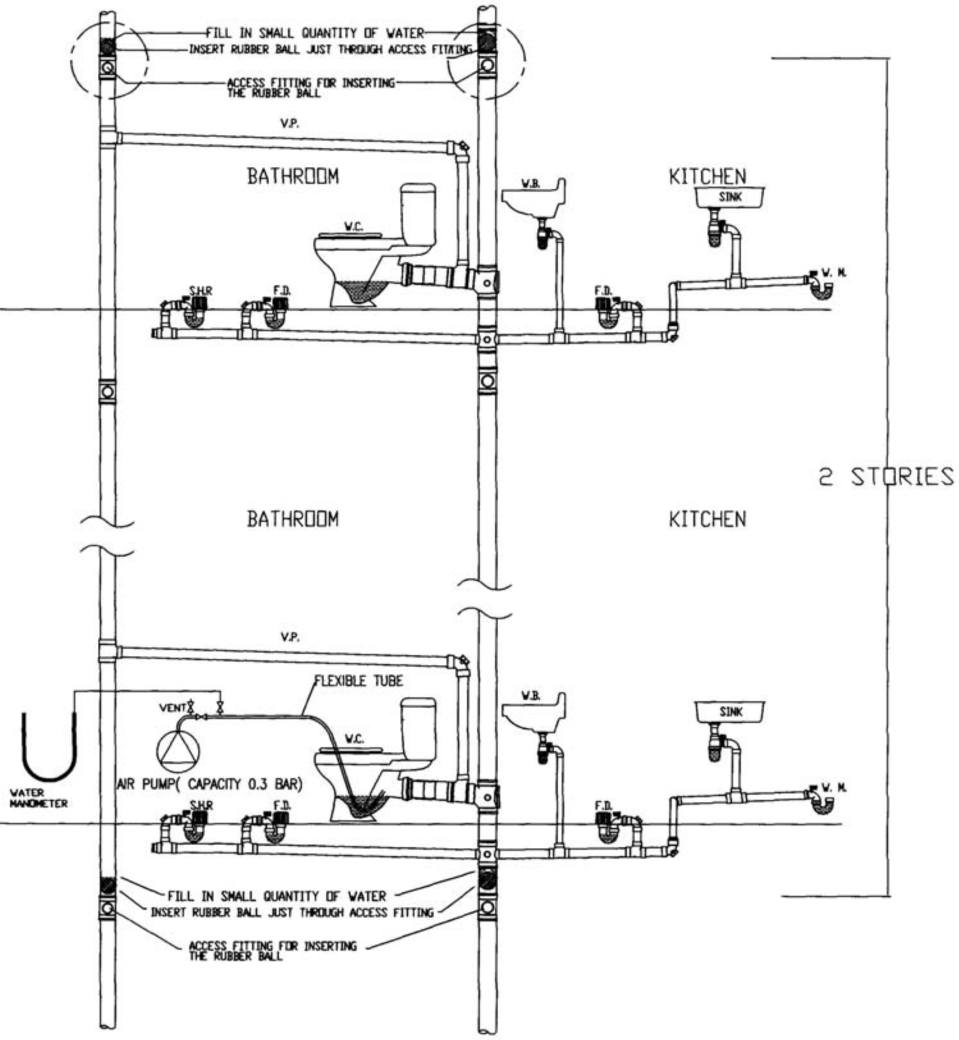
Appendix 1



AIR- LEAKAGE TEST FOR 2 STORIES

HIGH PRESSURE AIR TEST FOR TYPICAL
STACK OF SANITARY PIPEWORK

Appendix 2



LEAKAGE DETECTION FOR 2 STORIES

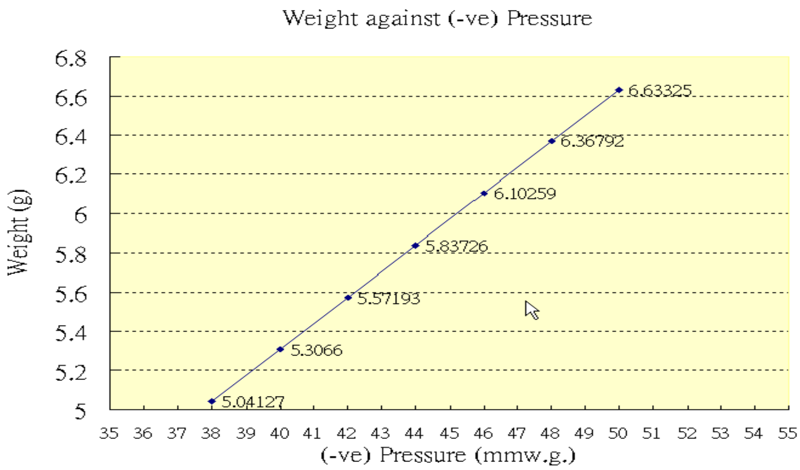
LOW PRESSURE AIR TEST FOR TYPICAL STACK OF SANITARY PIPEWORK

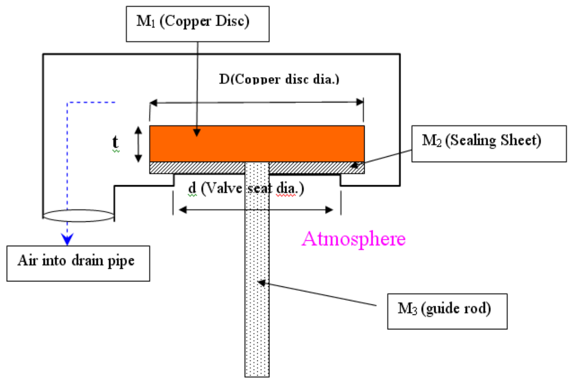
Appendix 3

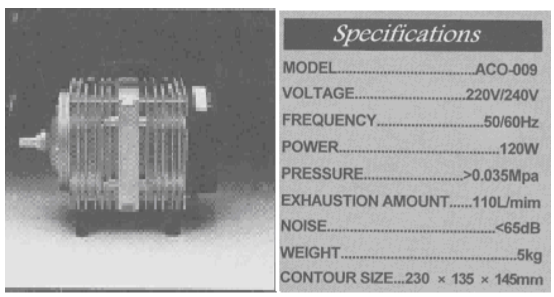
The weight of the anti-siphon valve disk, based on copper disc valve, was calculated as follows:
Based on the copper anti-siphon valve under test
M_1=Mass of copper disc in grams
M_2 =Mass of guide rod in grams = 1.17g
M_3 = mass of sealing sheet in grams = 0.26g
M=total mass of the anti-siphon valve=$M_1+M_2+M_3$
d = diameter of valve seat = 13mm
D = diameter of copper disc = 19mm
g = gravitational acceleration = 9.81m/s^2
At the time of valve opening,
Mg=Δp*area of valve seat
Δp=Mg/area of valve seat

$$\Delta p = \frac{(M/1000)*9.81}{\pi d^2/4} = \frac{M*9.81*1000*4}{\pi*13^2} \quad (\text{Pa or N/m}^2)$$

Δp=73.9M (Pa)
But 10Pa = 1mm w.g.
So thatΔp (mmAq) = 7.39*M







E5) Experimental Study on the Bluish Water Phenomena in Copper Piping Systems

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Abstract

The bluish water generated in hot water and cold water supply piping systems used the copper pipe was examined by the experimental study. The occurrence phenomena of bluish water were clarified, and it was proposed to take measures against the phenomena. It is shown that the phenomena occur with ease when the pH is low, the concentration of the free carbonic acid is high, and the concentration of the dissolution salts is high. The phenomena of bluish water are divided into the blue dirt to the bath equipments, dyeing to blue for the bath towels and laundry clothes, and looking blue to the water of bathtub and washbowl, etc. The following were clarified from the case studies and the experimental results. The bath equipments become dirty in blue by the products such as the copper soap or copper(II) carbonate hydrate. It is coloring of the clothes with the copper soap to dye in blue. The water of bathtub looks blue because reddish rays on the long wave length are selectively absorbed with water.

Keywords

Bluish Water, Bluish Stain, Cupper Ion, Cupper Soap, Copper(II) carbonate hydrate, Hot and Cold Water Cupper Piping System

1. Introduction

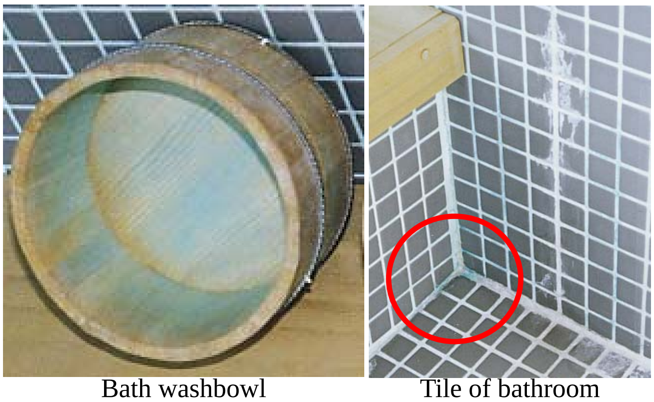
The use of copper tubing for hot and cold water supply piping can lead to certain 'bluish water' events occurring: bluish staining in bathtubs and plumbing fixtures; bluing of bath towels and laundry; and bluish coloration of bathtub water as soon as they enter service. It has been noted empirically that such events take in areas where the water pH is low and the free carbonic acid content of the water is high.[1] Experimentally, a water solution containing copper ions in high concentrations (at an acidic pH) turns bluish. It has been believed that bluish water events are due to the effect of copper ions dissolving out from the pipes.[2)] However, there has been little reported investigation or analysis of such events, such as analysis of the bluish stains deposited on plumbing fixtures, bluish -dyed laundry, or the bluish tinge given to water, and these bluish water phenomena have yet to be fully elucidated.[3)] With bluish water events still occurring where copper is used for piping systems and a need for measures to be taken, there is a need to analyze the phenomena in the context of actual conditions and propose suitable countermeasures. The overall phenomenon divides into several categories, so each category needs to be evaluated as quantitatively as possible. A cause and a mechanism need to be clarified for each variant of the phenomenon, taking into account environmental and usage conditions. In this paper, bluish water events and water quality tendencies are categorized and studied. To elucidate the mechanism of the phenomenon, cases of apartment houses that suffer a variety of bluish water events are analyzed. The bluish water events are categorized and a test is conducted to replicate each category. Based on the test results, each bluish water phenomenon is analyzed and the mechanism of the phenomenon is elucidated.

2. Analysis of bluish water events

Table 1 lists five cases of bluish water events in cold and hot water supply piping systems. Table 2 shows the results of water quality analysis. In each case, the bluish water events occurred as soon as the building entered service. The bluish coloring gradually faded over time in Case D but remained unchanged in the other cases. As listed in Table 1, discoloration in the form of bluish stains, such as in bathroom washbowls, bathtubs and bathroom tile joints (Figure 1), was observed in all cases. Discoloration of laundry and bath towels (Figure 2) was observed in Cases B and E. Bluish water was observed in the bathtub in Cases D and E. Discoloration of laundry and stains at the water level in a low down flush tank were observed in Case E. The cause of these phenomena is thought to be the copper tubing used for the water supply piping.

Table 1 – Various bluish water phenomenon in architectural equipment piping system

Building	**A**: Apartment house	**B**: School	**C**: Factory	**D**: College	**E**: Apartment house
Bluish water phenomenon	Bluish coloring of bath washbowl Bluish coloring of joint of tile in bathroom	Deposition of bluish stain on hot water sanitary fixture Bluish coloring of bath towel	Bluish coloring of joint of tile in shower room Bluish coloring of bath washbowl	Bluish hot water Deposition of bluish stain on bathtub	Bluish water in bathtub Deposition of bluish stain on dropping part of water from hydrant with bathtub Deposition of bluish stain on drainage fitting in washing place of bathroom Deposition of bluish stain on waterline in low down flush tank Bluish coloring of laundry



Bath washbowl Tile of bathroom

Figure 1 – Bluish phenomenon in bathroom (Case A)

After use Before use

Figure 2 – Bath towel dyed for bluishness (Left, Case B)

According to the results of water quality analysis listed in Table 2, copper ion concentrations in the water were high as a whole, but copper ions were not present in the raw water. Therefore it is thought that the copper was being dissolved out from the copper tubing. In Cases B and C, because the pH of the water was low and the free carbonic acid concentration was high, an oxide film did not form easily on the inside of the pipe. In Case E, because concentrations of chloride and sulfate ions, and therefore electric conductivity, were high, the level of protection provided by the oxide film on the surface of the pipe is considered low. In Cases A and D, the hardness and M-alkalinity (amount of acid consumed at a pH of 4.8) of the water were low and the water seemed to have a low tendency to form an oxide film on the pipe surface, though the pH or dissolved salts that might accelerate the dissolution of copper did not indicate this. In Case D, blue water was observed in the system when water consumption was low, which is thought to slow down the formation of an oxide film on the pipe surface. Categorizing the water quality data in these cases, the following tendencies are observed: (1) the pH of water was low and the free carbonic acid content in water was high, (2) the concentration of dissolved salts was high, and (3) the hardness and M-alkalinity of water were low.

Table 2 – Water quality of buildings that generated bluish water phenomenon

Analysis item	Unit	A	B	C	D	E	
		Hot water	Hot water	Hot water	Hot water	Tap water	Hot water
pH		7.1	6.3	6.5	7.3	7.2	7.7
Electric conductibity	mS/m	10.3	10.5	7.1	9.1	49.0	50.2
Free residual chlorine (Cl_2)	mg/L	-	<0.1	-	N.D.	-	-
M-alkainity (as $CaCO_3$)	mg/L	20	32	22	15	81	80
Free carbon dioxide	mg/L	7.2	31	13	1.5	9.9	3.1
Calcium hardness (as $CaCO_3$)	mg/L	22	11	-	18	20	18
Total hardness (as $CaCO_3$)	mg/L	23	14	18	22	29	26
Chloride ion (CL^-)	mg/L	11	11	4	10	60	63
Sulfate ion (SO_4^{2-})	mg/L	-	2	-	13	36	40
Soluble silicic acid (as SiO_2)	mg/L	14	40	-	19	6.7	6.4
Total residue	mg/L	-	80	-	-	301	327
Copper (Cu)	mg/L	0.71	0.66	0.56	1.1	0.20	0.77
Saturation Index (at 25℃)		-2.9	-3.4	-3.3	-2.4	-1.8	-1.3

Note) ND: Less than detection limit,-: No-measurement

3. Analysis of the bluish water phenomenon in Case E

The blue water events observed in the buildings in Table 1 can be regarded as common phenomena. All of the bluish water phenomena experienced in these buildings can be inferred from Case E, where all five categories of bluish water events were observed. For this reason Case E is analyzed below. Figure 3 shows the uses of cold and hot water in the Case E apartment house and the bluish water events observed. These were: (1) bluish stains deposited on the spout of a bathtub faucet(dropping part of water from hydrant), as shown in Figure 4, (2) bluish stains deposited at the water line of a low down flush tank, as shown in Figure 4, (3) bluish stains deposited on the floor drain fitting of a bathroom, (4) bath towels and laundry dyed bluish, and (5) the bluish water in a bathtub, as shown in Figure 5. These events can be further categorized: events (1), (2), and (3) involve the deposition of bluish stains, (4) is the discoloration of fabric, and (5) is the discoloration of water. These categories are analyzed below.

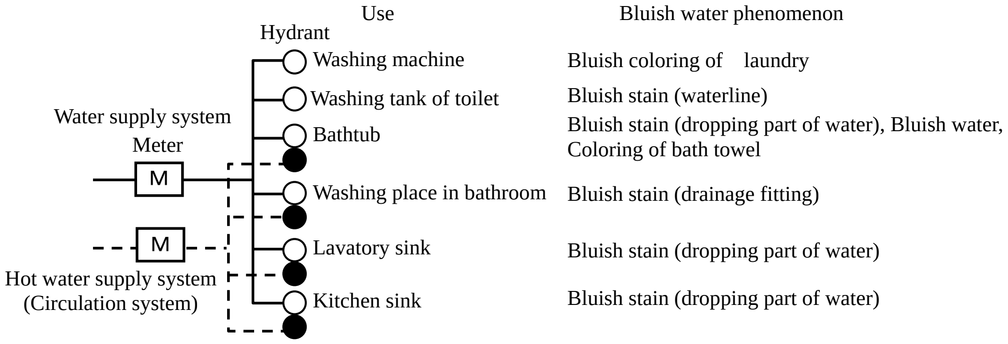
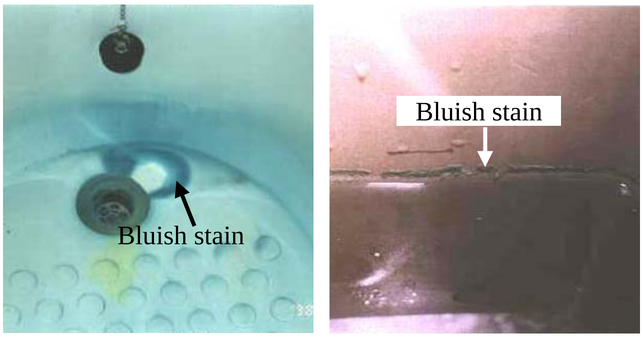


Figure 3 – Bluish water phenomenon according to usage of water supply and hot water supply in case E



Dropping part of water from hydrant with bathtub — Waterline in washing tank of toilet

Figure 4 – Bluish stain generated in bathtub and sanitary fixture

Tap water

Hot water

Figure 5 – Bluishness of water in bathtub (Case E)

3.1 Deposition of bluish stains on bathroom plumbing fixtures

3.1.1 Observation of bluish stains

The results of a visual inspection of dried samples are as follows: stains deposited on the spout of a bathtub faucet were greenish blue in powder form; Stain A at the water line of a low down flush tank was light blue slightly tinged with green in powder form; Stain B at the water line of another low down flush tank was bluish green in powder form; and stains on the floor drain fitting of a bathroom were different in texture from other stains and dark green in paste form. The results of a microscopic inspection of the samples are as follows: stains deposited on the faucet spout were dark blue flakes not more than 100 mm in particle size; Stain A at the water line of a low down flush tank was light blue and not more than 10 mm in particle size; Stain B at the water line of a low down flush tank was green and not more than 10 mm in particle size, partly mixed with blue particles; and the stains on the floor drain fitting were green in paste form, partly mixed with blue particles.

3.1.2 Component analysis of bluish stains

To determine the composition of the stains, a number of tests were carried out: a quantitative analysis of the elements using EDX (Energy Dispersive X-ray Spectroscopy); a determination of functional groups by FT-IR (Fourier Transform Infrared Spectroscopy); a determination of the chemical bonding of the component elements at a depth of a few nanometers by XPS (X-ray Photoelectron Spectroscopy); and an analysis of crystalline inorganic compounds by XRD (X-ray Diffractometry). The analysis results are listed in Tables 3 and 4 and illustrated in Figures 6 and 7. (XPS results are presented only for the stains deposited on the spout of a bathtub faucet.)

1) Stains deposited on the spout of a bathtub faucet

The EDX results in Table 3 indicate that the main elements making up the stains are carbon, oxygen, and copper, while the FT-IR analysis in Figure 6 shows that these elements form an inorganic carbonate. In Figure 7, XPS peaks for the carbonic acid and hydroxyl groups are seen and the copper is shown to be divalent. Together, these results suggest that the main component of the stains is most likely to be the hydrate of copper carbonate, $Cu_x(CO_3)_y•nH_2O$, and compounds such as basic copper (II) carbonate, $Cu_2(CO_3)(OH)_2$ (dark green, insoluble in water). In addition, a peak indicating trace amounts of sulfate (S/Cu ratio = 0.08-0.18) is present, as shown in Figure 7 and listed in Table 4. It is presumed from this result that copper sulfate (II) five hydrate, $CuSO_4•5H_2O$ (blue, readily soluble in water) or other similar substances giving a blue color are formed in trace amounts. It appears that this sulfate group is not visible in Figure 6 because the amounts are below measurable limits. As listed in Table 4, a phosphate group is also present although also in trace amounts (P/Cu ratio = 0.15-0.20). It is presumed that copper (II) phosphate three hydrate, $Cu_3(PO_4)_2•3H_2O$ (bluish green, insoluble or hardly soluble in water) or other similar substances are also present. There is also an extremely small amount of a chloride group (Cl/Cu ratio = 0.02-0.44), suggesting the formation of copper (II) chloride two hydrate, $CuCl_2•2H_2O$ (green, readily soluble in water). However, this material may not be a compound of copper because it is in extremely trace amounts. Incidentally, there are no clear peaks in the results of XRD analysis, so the samples are considered noncrystalline.

Table 3 – Qualitative analysis results of bluish stain by EDX

Sample / Presumption content	Bluish stain on dropping part of water from hydrant with bathtub	Bluish stain on drainage fitting in washing place of bathroom	Bluish stain on waterline in washing tank of toilet	
			A	B
Tens %	C O Cu	C O	C O Cu	C O Cu
Several %	Zn	Si Ca Cu	Si Zn	Si Fe Zn
Less than 1%	Al Si P S Cl Ni	Al Mg S Fe	Al P	Al P S Cl Ni

EDX:Energy Dispersive X ray Spectroscopy

These results demonstrate that the main component of the stains deposited on the spout of a bathtub faucet is a compound containing carbonic acid and hydroxyl groups. The color of the sample is due to a hydrate of copper carbonate; the sample may have a blue tinge due to the presence of copper sulfate (II) five hydrate or similar compounds.

Table 4 – Analysis results of bluish stain by XPS

Sample	Color	Item	Cu (2p3)	Cu (LMM)	C(1s)	O(1s)	Si(2p)	S(2p)	P(2p)	Cl(2p)	N(1s)	Zn (2p3)	Zn (LMM)	Na(1s)
Bluish stain on dropping part of water from hydrant with bathtub	Aqua-marine	Ratio to Cu(Atomic ratio) Content (Atomic%) Binding energy (eV)	1.00 7.4 932.8	916.2	6.9 51 284.6	4.9 36 531.1	0.21 1.6 101.6	0.08 0.61 168.4	0.15 1.13 132.9	0.04 0.27 199.2	0.14 1.03 398.9	0.12 0.92 1022.1	988.4	N.D.
As above sample	Aqua-marine	Ratio to Cu(Atomic ratio) Content (Atomic%) Binding energy (eV)	1.00 4.1 933.5	916.3	14.3 58 284.6	7.8 32 531.3	0.76 3.1 102.1	0.18 0.75 168.5	0.20 0.81 132.9	0.02 0.10 198.5	-	0.23 0.92 1021.3	988.8	0.11 0.45 1070.4
Bluish stain on waterline in washing tank of toilet A	Light blue	Ratio to Cu(Atomic ratio) Content (Atomic%) Binding energy (eV)	1.00 3.2 932.9	916.6	19 60 284.6	10.1 32 531.0	0.69 2.2 101.1	0.04 0.14 167.9	0.36 1.12 132.3	N.D.	0.47 1.47 399.1	0.05 0.17 1021.8	988.8	N.D.
As above sample	Light blue	Ratio to Cu(Atomic ratio) Content (Atomic%) Binding energy (eV)	1.00 2.7 933.9	916.3	22 58 284.6	13.1 35 531.2	0.74 2.0 100.7	0.11 0.30 162, 168	0.46 1.24 132.3	N.D.	-	0.04 0.11 1022.2		0.05 0.13 1068.7
Bluish stain on waterline in washing tank of toilet B	Tur-quoise	Ratio to Cu(Atomic ratio) Content (Atomic%) Binding energy (eV)	1.00 2.1 934.5	915.3	28 58 284.6	17.0 35 532.7	0.69 1.4 102.3	N.D.	1.18 2.4 133.1	0.09 0.19 201.2	-	0.08 0.16 1023.1	989.1	N.D.
As above sample	Tur-quoise	Ratio to Cu(Atomic ratio) Content (Atomic%) Binding energy (eV)	1.00 1.32 933.0	915.8	50 65 284.6	2.3 27 531.0	2.1 2.8 101.1	N.D.	0.69 0.91 132.4	0.16 0.21 199.2	1.77 2.3 399.3	0.03 0.04 1022.1	988.5	N.D.
Filter paper YFIL06		Content (Atomic%) Binding energy (eV)	N.D.		70 284.6	30 532.3	0.16 101.1	N.D.	N.D.	N.D.	0.23 398.5	N.D.		N.D.

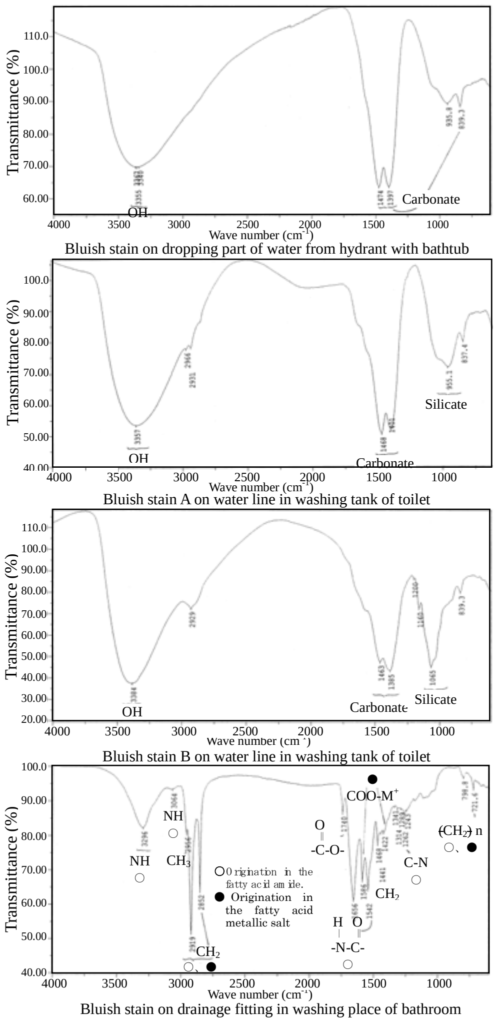
Note) The electorification correction did the binding energy value of Cls top peak as 284.6 eV.
Cu (LMM) and Zn (LMM) were shown by the kinetic energy, and another showed by the binding energy.
ND:Less than detection limit, -:No-measurement

2) Stain A at the water line of low down flush tank

The analysis indicates that the main components of the stains are carbon, oxygen, and copper, as listed in Table 3, and that these form an inorganic carbonate, as shown in Figure 6. Peaks for the carbonic acid and hydroxyl groups are detected and the copper is divalent, as can be seen in the XPS results. There are no clear peaks in the XRD analysis. Consequently, the main component of Stain A at the water line of a low down flush tank is thought to be a noncrystalline hydrate of copper carbonate, $Cu_x(CO_3)_y \bullet nH_2O$, while it is likely that compounds such as basic copper (II) carbonate are present, as is the case with the faucet stains. Further, the spectra obtained by XPS state analysis and the results listed in Table 4 indicate that trace amounts of sulfate and phosphate are involved in the stain, as is the case with the faucet stains. The reason for the lighter blue color of Stain A at the water line of a low down flush tank (close to light blue) as compared with the faucet stains is thought to be that the sulfate content is lower and the phosphate content higher. The results of the XRD analysis indicate that $Mg_2Al_4Si_5O_{18}$ is present and that an inorganic silicate compound, such as sand or stone, is also present in the stain. This seems due to trace components contained in tap water.

3) Stain B at the water line of low down flush tank

Once again, the analysis shows that the main components of the stains are carbon, oxygen, and copper, as listed in Table 3, and that these main components form an inorganic carbonate, as shown in Figure 6. Peaks for the carbonic acid and hydroxyl groups are detected and the copper is divalent, as can be seen in the XPS results. There are no clear peaks in the XRD analysis. As a result, the main component of Stain B at the water line of a low down flush tank is thought to be a noncrystalline hydrate of copper carbonate, $Cu_x(CO_3)_y \bullet nH_2O$, and it is likely that compounds such as basic copper (II) carbonate are also present, as in the case of Stain A at the water line of a different low down flush tank. The reason for the greenish color of the sample is thought to be the presence of copper (II) phosphate three hydrate, because phosphorus is detected in larger quantities than in other samples, or that other substances similar to basic copper (II) carbonate give the color tone.



○ Origination in the fatty acid amide.
● Origination in the fatty acid metallic salt

Figure 6 – Infrared adsorption spectrum of bluish stain

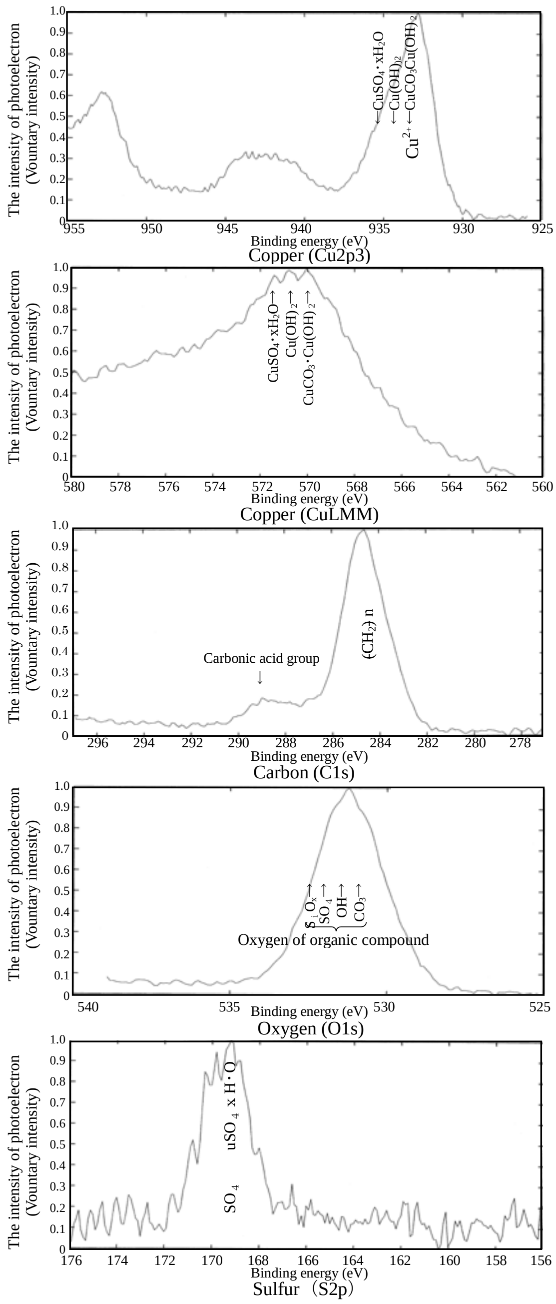


Figure 7 – Analysis spectrum of state by XPS with bluish stain on dropping part of water from hydrant with bathroom

4) Stains on the floor drain fitting of a bathroom

The analysis results identify two or more organic functional groups, as shown in Figure 6. As a result, it is inferred that the main components of the stains are organic substances. Further, peaks are detected for substances believed to be a fatty acid amide and a fatty acid metallic salt. Of the four types of stains investigated, this is the only one to consist mainly of organic compounds. Considering the sampling point, it is thought skin oils or the oil content of soap reacts with copper ions in the water to form fatty acid copper salts, which cause the discoloration.

3.1.3 Mechanism of bluish stains

1) Stains deposited on the spout of a bathtub faucet

The hot and cold water dripping from a faucet contains copper ions, Cu^{2+}, dissolved out from the copper tubing. These copper ions react with carbonate ions, CO_3^{2-}, formed when carbon dioxide, CO_2, from the air dissolves in the water, and hydroxide ions, OH^-, dissociated from the water to form compounds such as basic copper (II) carbonate, $Cu_2(CO_3)(OH)_2$. The copper ions also react with sulfate ions, SO_4^{2-}, which are contained in tap water, to form copper sulfate (II) five hydrate, $CuSO_4 \bullet 5H_2O$, or other similar substances. These add a blue color to the main component, basic copper (II) carbonate. With repeated wetting and drying at the dropping part of water from hydrant, the copper ion concentration increases and the reaction accelerates to form a precipitate. The reaction formulae are shown below.

[Copper ions formed by dissolution from copper tubing]

$Cu \rightarrow Cu^{2+} + 2e$

[Carbon dioxide dissolved in water and dissociation equilibrium of carbonic acid]

$CO_2 + H_2O \rightleftharpoons H_2CO_3$

$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$

$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$

[Formation of basic copper (II) carbonate]

$2Cu^{2+} + CO_3^{2-} + 2OH^- \rightarrow Cu_2(CO_3)(OH)_2$

[Formation of copper sulfate (II)]

$Cu^{2+} + SO_4^{2-} \rightarrow CuSO_4$

2) Stains A and B at the water line of low down flush tanks

Copper ions, having entered the water supply from the copper tubing, react with carbon dioxide that has dissolved in the water from the air near the water line of the tank to form basic copper (II) carbonate, $Cu_2(CO_3)(OH)_2$, or other similar compounds. Because the water is pulled up on the tank wall (forming a meniscus) due to capillary action near the water line, the concentration of copper ions rises as a result of local evaporation and this accelerates the reaction. Bluish stains, such as Stain A, contain a high proportion of copper sulfate (II) five hydrate or other similar compounds, whereas greenish stains, such as Stain B, contain a high proportion of copper (II) phosphate three hydrate or other similar compounds. The copper sulfate (II) five hydrate seems to be formed by the reaction of sulfate ions, which are present in large quantities in tap water, with the copper ions. The copper (II) phosphate three hydrate seems to be formed by the reaction of phosphate ions, present in trace amounts, with the copper ions. The reaction formula is shown below.

[Formation of copper (II) phosphate three hydrate]

$$3Cu^{2+}+2PO_4^{3-}\rightarrow Cu_3(PO_4)_2$$

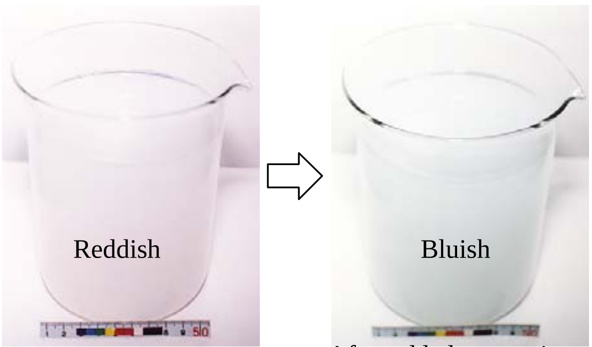
3) Stains on the floor drain fitting of a bathroom

Copper ions that have entered the water supply from the copper tubing react with soap or oils from human skin to form fatty acid copper salts (copper soap). To verify the formation of copper soap, a test was conducted as shown in Figures 8 and 9. A change of color was observed when a ionic copper aqueous solution was added to an aqueous soap solution (a solution prepared by immersing solid soap in 1 mL of tap water for 10 minutes, at a pH of 7.87). The aqueous soap solution was slightly reddish milky-white and turned bluish soon after the ionic copper aqueous solution was added (Cu^{2+}: about 2 mg/L, at a pH of 6.99), as shown in Figure 8. Further, when solid soap was immersed in the aqueous soap solution containing copper ions, the solution around the solid soap turned blue, as shown in Figure 9. The discoloration is due to the formation of copper soap through the reaction of copper ions with the components of the soap. The copper soap is thought to be the main cause of the formation of bluish stains on the floor drain fiting of a bathroom. The reaction formula for the formation of copper soap is shown below.

[Formation of copper soap by reaction of soap with copper ions]

$$2RCOONa+Cu^{2+}\rightarrow(RCOO)_2Cu+2Na^{+}$$ R: Alkyl group

Copper soap



Non-copper ion

After added copper ion (Cu^{2+}2mg/L)

Figure 8 – Generation of copper soap by reaction of copper ion and soapy water

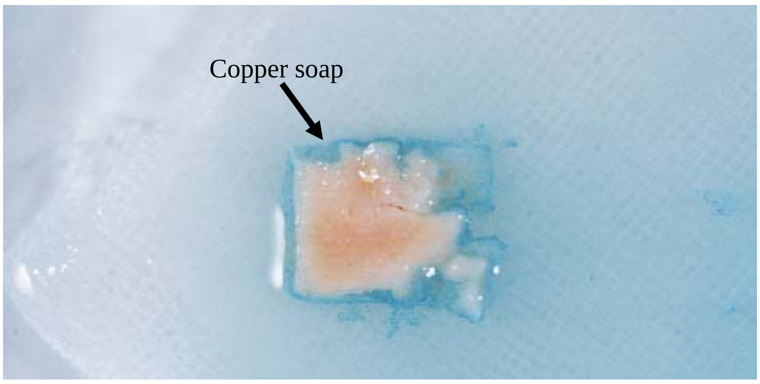


Figure 9 – Generation of copper soap by reaction of solid soap and copper ion

3.2 Discoloration of laundry and bath towels

The discoloration of bath towels is caused by the formation of copper soap through the reaction of copper ions with soap or oils from human skin; this is deposited on the fabrics. The discoloration of laundry is caused in the system consisting of laundry + water + soap. More specifically, copper ions in the water react with components in the soap or with oils deposited on the laundry to form copper soap; this then discolors the white laundry items bluish. Synthetic detergent consists primarily of an anion surfactant. Examples of anion surfactants include soap and alkyl benzene sodium sulfonate. Soap is the sodium salt of higher fatty acids, such as palmitic and stearic acids, and it reacts with copper ions to form copper soap which gives a bluish discoloration.

3.3 Discoloration of water in a bathtub

In both cases, where a bathtub was filled with hot or cold water, a bluish tinge was clearly identified, as shown in Figure 5. Even in the case where the bathtub was filled with potable water containing no copper ions, a comparable bluish color was identified. The bluish tint apparent with potable water in the bathtub was examined under different types of lighting, using incandescent and fluorescent (white and daylight) lamps. The bluish tint and color tone were about the same in all cases, as listed in Table 5. This suggests that copper ions are not the cause of this discolored water in the bathtub.

Table 5 – Examination results concerning color of bathtub water by presence of copper ion and kind of lighting

Lighting / Water quality	White light lamp	Fluorescent		Natural light
		White color	Daylight	
Tap water that contains Cu^{2+}	Bluish	Bluish	Bluish	-
Hot water that contains Cu^{2+}	Bluish	Bluish	Bluish	-
Tap water that doesn't contain Cu^{2+}	Bluish	Bluish	Bluish	-
Hot water that doesn't contain Cu^{2+}	-	Bluish	-	Bluish

-:No-measurement

To examine how bluish water appears with different copper ion concentrations, nine different concentrations of copper ions were added to normal temperature tap water (no containing copper ions) at two pH levels: 0, 0.5, 1 2, 5, 10, 20, 50, and 100 mg/L at pH 6.8-7.3 and 8.0-8.5. The bluish tint of the resulting water was observed. Ionic copper aqueous solution was prepared by dissolving copper with a purity greater than 99.999% in nitric acid and the pH of the resulting solution was adjusted by the addition of sodium hydroxide solution (30%). Figure 10 shows the outward appearance of the solution and Table 6 lists the results of observations. Immediately after preparation of the solution, the higher the copper ion concentration and the higher the pH, the greater the bluishness. A precipitate of blue-colored copper hydroxide, $Cu(OH)_2$, was formed on the bottom of the reagent bottle. The color of the precipitate was reflected in the reagent bottle in which the solution was prepared, with the supernatant in samples containing the precipitate in larger quantities appearing more clearly blue; this made it difficult to judge the color of the solution itself. Accordingly, 1,000 mL of the supernatant was moved into tall beakers for observation. As a result, a bluish tint to the water was identified at copper ion concentrations of not lower than 10 mg/L at a pH of 6.8-7.3 and not lower than 5 mg/L at a pH of 8.0-8.5. There was a hint of bluishness at a copper ion concentration of 5 mg/L and a pH of 6.8-7.3 and at a copper ion concentration of 2 mg/L and a pH of 8.0-8.5, as listed in Table 6. At a pH of 8.0-8.5, the bluishness was greatest at a copper ion concentration of 5 mg/L; it faded at higher copper ion concentrations. Further, the bluishness tended to fade over time and the color disappeared in three days, with a blue precipitate formed on the bottom.

Table 6 – Examination result concerning color of water by copper concentration

<table>
<tr><th>Cu concentration (mg/L)
pH</th><th>0</th><th>0.5</th><th>1.0</th><th>2.0</th><th>5.0</th><th>10.0</th><th>20.0</th><th>50.0</th><th>100.0</th></tr>
<tr><td rowspan="2">(Supernatant)
pH6.8-pH7.3
(Sample solution)</td><td colspan="4">Colorless</td><td>Barely bluish</td><td colspan="4">Bluish →</td></tr>
<tr><td colspan="6">Non-precipitation</td><td colspan="3">Bluish precipitation →</td></tr>
<tr><td rowspan="2">(Supernatant)
pH8.0-pH8.5
(Sample solution)</td><td colspan="3">Colorless</td><td>Barely bluish</td><td>Most bluish</td><td colspan="4">Bluish</td></tr>
<tr><td colspan="5">Non-precipitation</td><td colspan="4">Bluish precipitation →</td></tr>
</table>

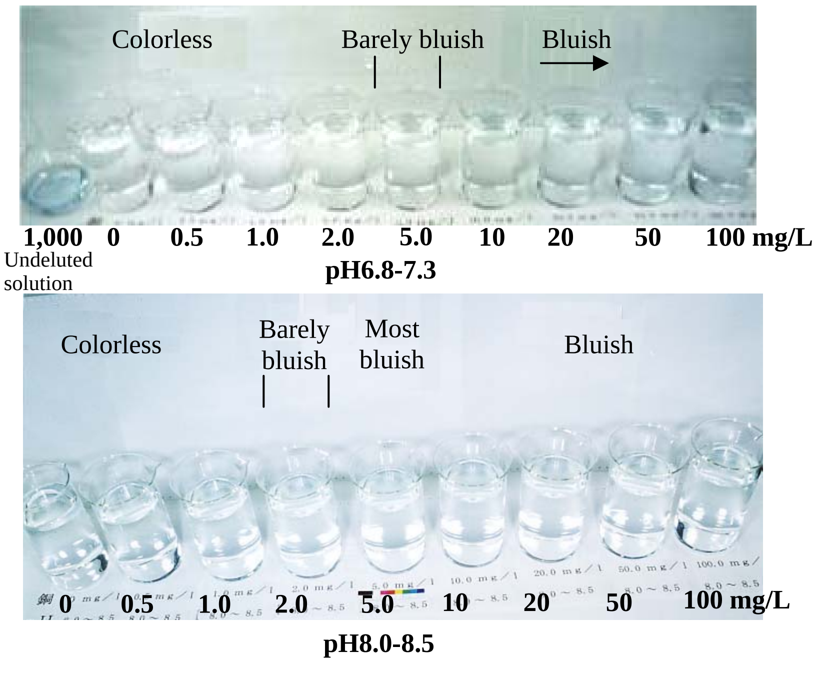


Figure 10 – Comparison examination concerning copper concentration and bluishness of water (Depend on the supernatant)

Figure 11 shows the copper ion concentration of the supernatant on the day of preparation (day 0: about 5 hours after preparation) and 10 days after preparation (day 10). The copper ion concentration showed a tendency to decrease over time, falling below the target concentration level even within the day of preparation. This tendency was strong at a copper ion concentration of 10 mg/L and higher. At a copper ion concentration of 5 mg/L and higher, the decrease was greater at a pH of 8 (a solution prepared at a pH of 8.0-8.5) than at a pH of 7 (a solution prepared at a pH of 6.8-7.3). The copper ion concentration at a pH of 7 and 8 decreased to about 1 mg/L or below within 10 days of preparation. The reason for this decrease is thought to be that the colloidal substances containing copper ions in the solution gradually associated over time to form flocs that precipitated out of the solution. More specifically, the results show that the reason for the solution appearing bluish is that products of reaction with copper ions were suspended in the water as colloidal fine particles. Further, the results indicate that these low-water-solubility colloidal substances (reaction products) became associated over time and precipitated out, resulting in the decrease in the copper ion concentration in the solution.

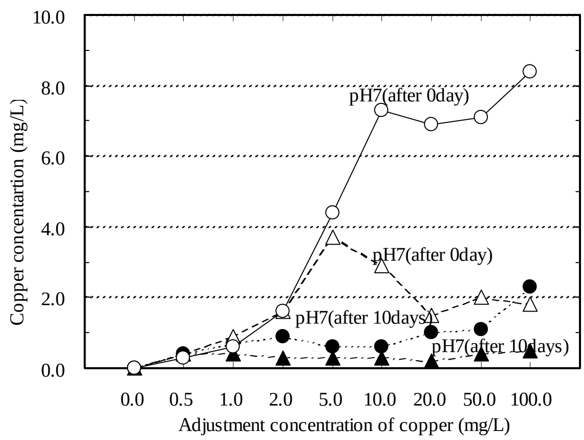


Figure 11 – Change of copper concentration over time with supernatant of solution adjusted for bluishness examination of water

These results indicate that the copper ion concentration in a solution decrease as the copper ions react with hydroxide and other ions at a pH of 6.8-8.5. The reason that the bluishness of water was greatest at a copper ion concentration of 5 mg/L at a pH of 8.0-8.5 and faded at higher concentrations, as indicated in Table 6, is thought to be that precipitation of colloidal substances containing copper ions reduced their concentration, as shown in Figure 11. Further, the reason for bluishness being identified at lower copper ion concentrations when the pH was 8.0-8.5 than when it was 6.8-7.3, as listed in Table 6, is that the product of the copper ion reaction, copper hydroxide, has a lower water solubility and is more readily precipitated at a pH of 8.0-8.5 than at a pH of 6.8-7.3.

Based on these test results and the analysis of water bluishness in a bathtub, as listed in Table 5, it is difficult to explain the bluishness in terms of colloidal compounds containing copper ions at the copper ion concentration listed in Table 2. An alternative explanation for the solution appearing bluish is a physical (optical) phenomenon resulting from interaction with light. More specifically, when light passes through the water in a bathtub, long-wavelength red light in the visible region is absorbed (in white light for example, light of 600-610 nm and 655 nm or longer wavelengths is absorbed by the water) and the remaining light wavelengths give the water a bluish color.[4] The bluish color becomes darker as the water level increases because visible light is absorbed in order of decreasing wavelength, from red through yellow and green to blue, so the proportion of blue in the remaining wavelengths increases, as shown in Figure 12.

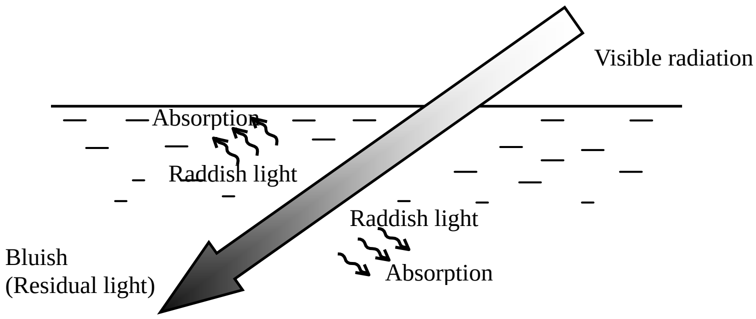


Figure 12 – Mechanism that water looks bluish

4. Conclusions

Phenomena involving bluish water have not always been quantitatively analyzed. In this paper, bluish water events occurring in piping systems using copper tube are categorized and bluish deposits resulting from the events are analyzed. A test to reproduce certain events is carried out. As a result, the causes of the events are elucidated. The mechanism of bluish water events is then studied. The principal results of this study are as follows.

1) The bluish stains deposited on bathroom and plumbing fixtures are of two types: fatty acid copper salts (copper soap) formed by the reaction of copper ions with soap or oils from the skin; and basic copper (II) carbonate, $Cu_2(CO_3)(OH)_2$, or other similar compounds formed by the reaction of copper ions with carbon dioxide dissolved in the water.
2) The discoloration of bath towels and laundry is caused by the formation of copper soap through the reaction of copper ions with soap or oils from the skin, which is then deposited on the fabrics.
3) The water in a bathtub appearing bluish is that, when light passes through the water, long-wavelength red light in the visible region is absorbed and the remaining wavelengths give the water a bluish color.

Bluish water phenomenon is caused by copper ions dissolved out from copper tubing. Possible measures against bluish water involve pH adjustment (removal of free carbon dioxide by aeration; addition of alkaline chemicals), deaeration (using membranes), and the addition of chemical agents promoting the formation of films, such as phytic acid (a food additive) to control the dissolution of copper ions out from copper tubing, as shown in Figure 13. Further, if an analysis of water quality indicates that copper ions are liable to dissolve out of copper tubing, other piping materials might be selected.

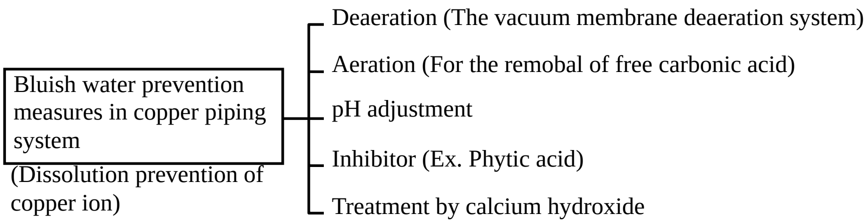


Figure 13 – Bluish water prevention measures in copper piping system

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6. Presentation of Author

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F1) CFD simulations of seal water oscillation in drain trap

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Abstract

To establish a testing method for evaluating the seal strength of a trap to induction siphoning, it is necessary to ascertain the oscillation response of trap seal water over pipe internal pressure. Moreover, improved seal strength requires prevention of resonance. It is therefore important to investigate oscillation response phenomena in detail also from this viewpoint. This study applied CFD analysis to seal water oscillation phenomena for comprehension of the fundamental response characteristic of trap seal water to the fluctuation of pipe internal pressure. First, free oscillation in a P trap was analyzed and compared to experimental results. Results show that water level fluctuations and the natural frequency obtained by CFD agree well with experimental results. Next, forced oscillation was analyzed, in which a single sine wave was impressed on trap seal water. A single sine pressure wave of the natural frequency induced resonance phenomena. Therefore, good agreement with the tendency in the experiment was verified. These results demonstrate that CFD might serve as a useful tool for analyzing seal water oscillation phenomena in a trap.

Keywords

Drain trap; Seal water oscillation; CFD simulation

1. Introduction

The drainage system of a building usually adopts the gravity type with no energy consumption: a drain pipe is connected directly to sewerage or a septic tank. A broken seal in a drain trap (hereinafter designated as a trap) might allow sewer gas and insanitary insects to invade into the room side, thereby causing health impairment or diffusion of infectious diseases. Induction siphoning is one cause of broken seals in a trap. Induction siphoning is the following phenomenon: pressure in drain transverse branch pipes and drain stack pipes fluctuates violently because of draining from water equipment; seal water responds to the pressure fluctuation and oscillates. Finally, seal water is lost. Seal water loss will result in a broken seal by induction siphoning.

Japanese regulations related to the performance of a trap in relation to induction siphoning states only that the allowable seal water loss of a trap shall be 25 mm or less to the allowable pipe internal pressure ±400 Pa in SHASE - S218 of the Society of Heating, Air-conditioning & Sanitary Engineers of Japan[2]. That is to say, the performance of a trap to induction siphon, i.e. pressure resistance, is not fully evaluated. Establishment of a testing method for evaluating the seal strength of a trap to induction siphon is therefore a pressing need.

To establish a testing method for evaluating the seal strength of a trap against induction siphon, it is necessary to ascertain the oscillation response of trap seal water over pipe internal pressure. Moreover, seal strength improvement necessitates prevention of resonance. It is therefore essential to investigate oscillation response phenomena in detail also from this viewpoint. The authors[1] have been conducting drain experiments on a real-scale tower experiment and pressure load experiments using a simplified pressure build-up system for the purpose of establishing a testing method for evaluating the seal strength of a trap.

Computer development has advanced studies that predict various flows inside air-conditioned rooms or machinery in a progressing situation using the Computational Fluid Dynamics (CFD) method. Especially, the progress made during this decade is remarkable: the analysis of air current behavior with steady-state CFD computation is established in air conditioning design processes[3]. Consequently, the CFD method has developed to play a part in major design methods used for building services and environmental engineering. Studies of drainage systems are also in progress. Knowledge of fundamental characteristics is now beginning to be accumulated after analyses by Tomonari, et al.[4] and Chang, et al.[5].

This study accordingly aims as a final goal at comprehending flow phenomena such as mutual vortices that are difficult to verify in experiments in CFD analysis, and examining the pressure resistance and broken seal characteristic of various traps. Inducion siphon is a forced oscillation phenomenon with pressure taking place within a drain pipe (hereinafter designated as a real pipe internal pressure) as a driving force, and trap seal water as a response object. Prevention of resonance, i.e. isolating the real pipe internal pressure and the frequency of trap seal water, is the key to its control. For that purpose, comprehension of the natural frequency and vibration response characteristics, the fundamental properties of a trap, is indispensable. Therefore, the CFD analysis to a seal water vibration phenomenon was applied as the first step of this study for comprehension of the fundamental response characteristics of trap seal water to pipe internal pressure fluctuation. Numerical analyses were carried out on the free and forced oscillations of a P trap, and comparison with experiments was performed: those results are reported in this paper. Experimental data for comparisons used in this analysis are based on a study of a performance test on a trap by Sakaue et al[6].

2. CFD analysis of free oscillation in P trap

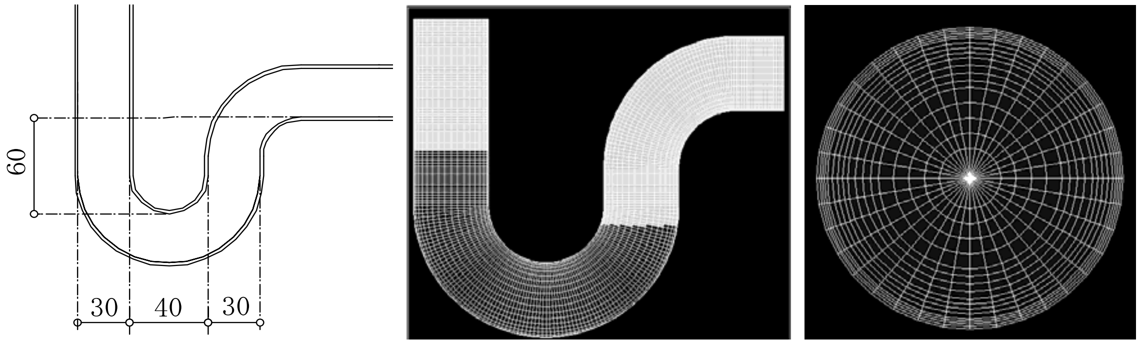
For this study, CFD analysis was carried out on the free oscillation of trap seal water, which is the most fundamental phenomenon, as a trial on 3-D analysis related to multi-phase flow of water and air. The object trap is a P trap.

2. 1 CFD analysis outline

Figure 1 portrays the P trap, the object in this analysis, a computation model for analysis, and a mesh layout. The amount of trap seal water was set at half the water level. Analysis was started at a condition that initial water level on the inflow side was higher by 15 mm than the rest equilibrium position (Fig. 1(b)), and was continued until the progress of 4 s. The experiment is also conducted on equivalent conditions.

The computation model adopts a cylindrical coordinate system to express the pipe cross section, where the cross section is divided into 612 meshes (radial direction, 17 divisions; circumferential direction, 36 divisions). The tube is equipartitioned at an interval of 1 mm in the trap flow direction with a rectangular coordinate system. An unequal interval mesh is used so that mesh division becomes dense near the wall. The total mesh number is 158,508.

The seal water vibration phenomenon, our study objective, is a phenomenon by which a multi-phase flow of water-air flows unsteadily. This study accordingly conducted transient analysis following the Pressure Implicit with Splitting of Operators algorithm (PISO)[7,8] using the Volume-of-Fluid (VOF) method[9], which is a computational method for a multi-phase flow of water-air. In addition, Re, the Reynolds number of the water phase on the experiment, varied corresponding to oscillation and dropped over time from about 5,000 at the maximum. Actually, Re was 2,000 or less for about 3 s within 4 s of the computational duration. Laminar flow analysis was applied in this computation for this reason.



(a)Section of P trap (mm) (b)Initial condition (c)mesh layout

Figure 1 - Analysis model of free oscillation on P trap

Surface tension was set at 0.072 N/m, a tension at a water temperature of 20°C for computation. The angle of contact between a trap wall and water was assumed as 90°. A pressure boundary condition was applied to the boundary surface at the trap ends open to the atmosphere, where water and air were free to flow in and out. The Multi-Interfaces Advection and Reconstruction Solver (MARS)[10] was used for the advective term of the equation of motion and the difference scheme of VOF; central difference was applied otherwise. The time differential interval was set to 0.1 ms (10,000 Hz) so that the Courant number at the time of the maximum flow velocity might be about 0.5, and analyses were carried out for 4 s in real time from the initial condition.

The number of the maximum collectors in one time step was set to 50 times and the mitigation coefficient to 0.8 in the PISO analysis. Analytical data were output at every 100 ms. A *Xeon 3.20 GHz* was used for the analysis. The computation required about 187 hour. Star-CD (ver. 3.24), general-purpose fluid analysis code, was used for the CFD analysis.

2.2 Free oscillation analysis results and discussion

Figure 2 shows the fluctuation of trap seal water level. Water level fluctuation is defined as a value at the inflow pipe center. Comparison between the experimental result and the CFD analysis result demonstrates good agreement up to about 2 s, when water level fluctuation is not less than ±5 mm. After 2 s, the difference between the experiment and CFD expanded up to about 3 mm at the maximum, which is considered to result from the effect of a float plate for laser reflection used for water level measurement during the experiments. The float plate, made of cardboard, might absorb water over time: its specific gravity thereby increased, such that it became insensitive to seal water fluctuation, which was therefore underestimated. Moreover, in the CFD side, the coarse computation mesh and the laminar flow analysis are considered to be causes of error.

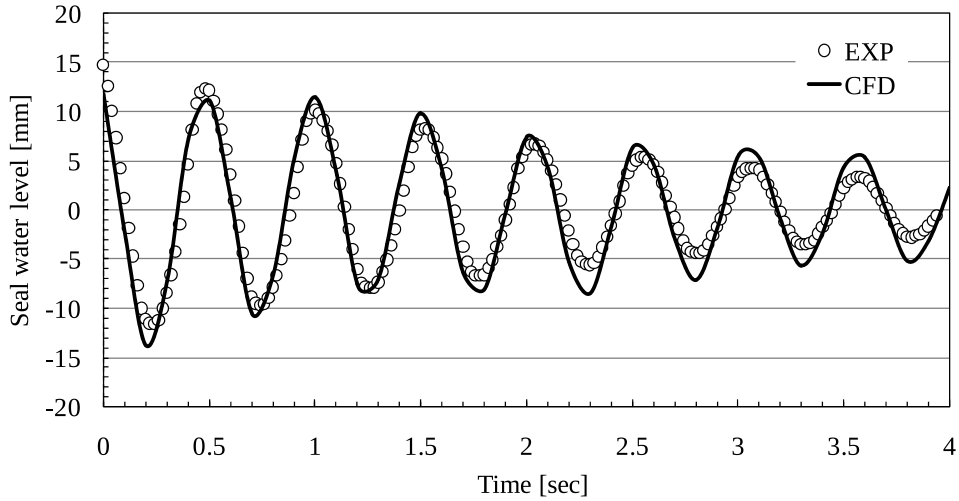


Figure 2 - Fluctuation of trap seal water level at free oscillation in P trap

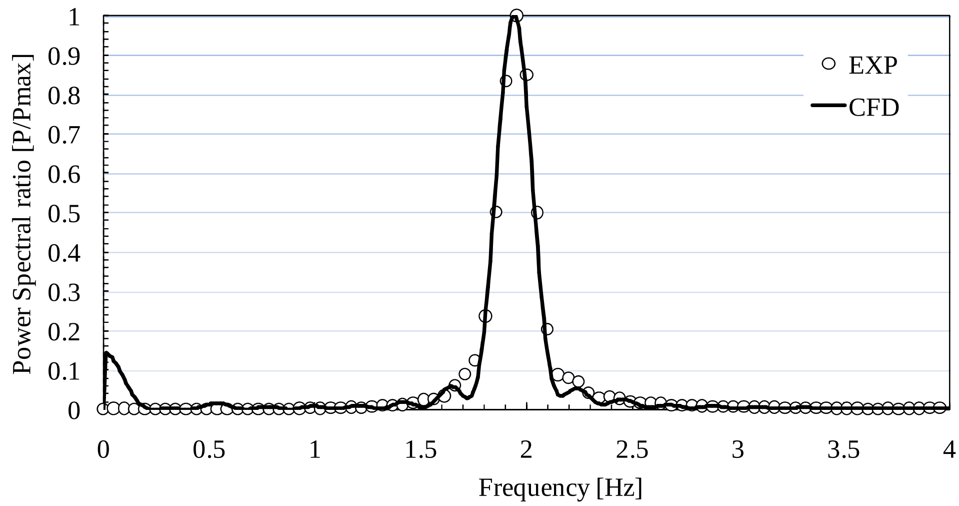


Figure 3 - Power spectral ratio obtained by FFT of a free oscillation wave

Figure 3 displays the density distribution of the power spectral ratio obtained by FFT of a free oscillation wave. The power spectral ratio is known to have an extremum near the natural frequency of a trap. A calculation method of a natural frequency is proposed by Sakagami et al.[11] as the following equation:

$$f = \sqrt{\{(1 + A_1/A_2)g\}/\{(1 + A_1/A_2)H + L \cdot A_1/A_0\}} \quad (1)$$

where, f signifies the natural frequency [Hz], A_0 represents the cross-sectional area of pipe [cm^2], g is the acceleration of gravity [cm/s^2], A_1 is the inlet cross-sectional area [cm^2], H denotes the rest equilibrium position [cm], A_2 is the outlet cross-sectional area [cm^2], and L is the inlet - outlet centerline distance [cm].

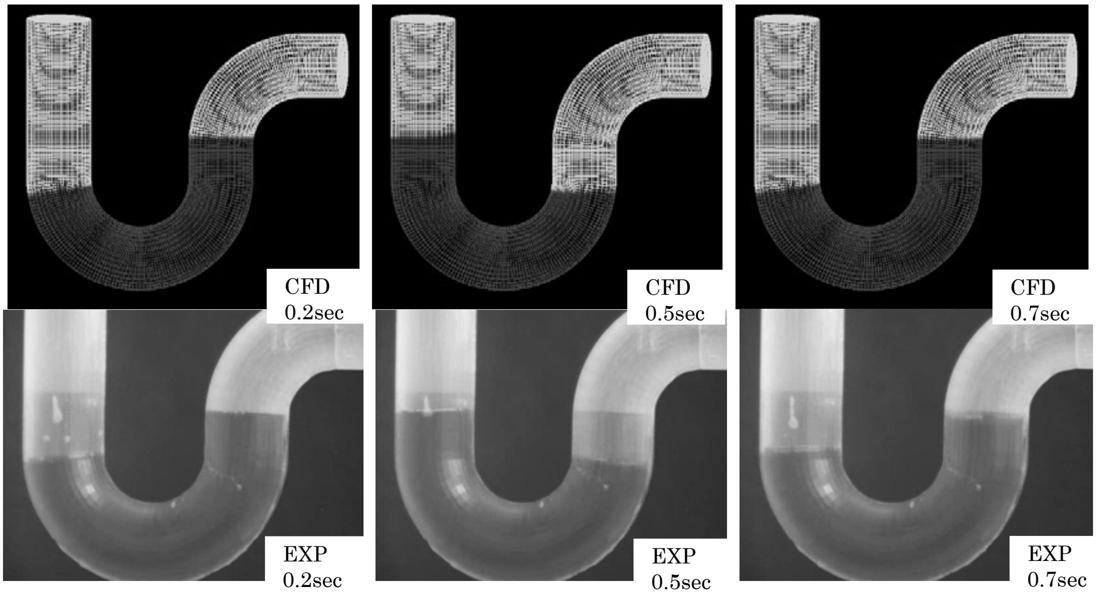


Figure 4 - Example of visualization image of CFD and experiment

This equation yielded the natural frequency of this trap at the half water level condition as 1.93 Hz, whereas the experiment and analysis provided respectively 1.95 Hz and 1.94 Hz. Consequently, it was verified that the estimated result of the natural frequency by the CFD is well in agreement with the experiment and computed values.

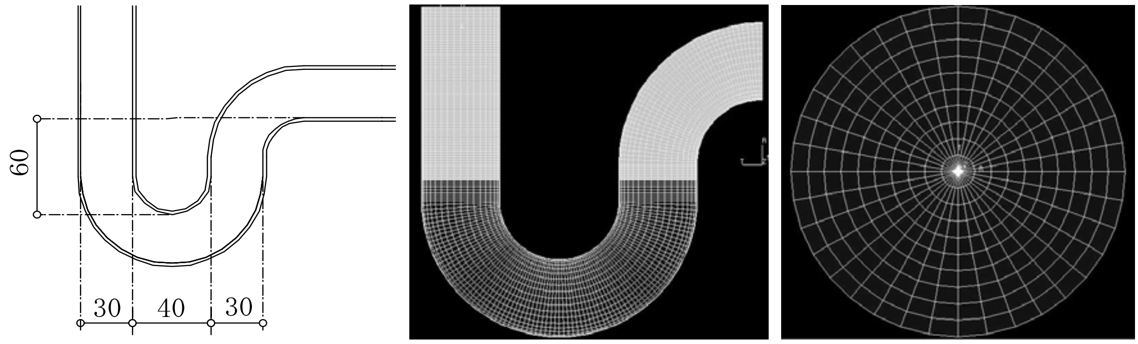
Next, the CFD analysis result is compared with the visualization image of the experiment. Figure 4 shows a part of the result. The water level and water surface inclination visualized using CFD analysis are well in agreement with the visualization images from the experiment. These results proved that the free oscillation of trap seal water can be reproduced in general using CFD analysis.

3. CFD analysis of forced oscillation on the P trap

Trap seal water moves by pipe internal pressure. Actual pipe internal pressure fluctuation depends on the property of a drainage system and includes complicated frequency components. Therefore, the CFD analysis of the oscillation of seal water when a single sine pressure wave is compulsorily impressed is conducted as the most fundamental seal water oscillation; comparison with the experimental results is performed.

3. 1 Analysis method

The object trap is identical to that described in the preceding section. However, because drift velocity is enhanced compared with the preceding section when a single sine



(a)Section of P trap (mm) (b) Initial condition (c) Mesh layout

Figure 5 - Analysis model of forced oscillation on P trap

pressure wave near a resonance frequency is input, pipe flow is presumed to be turbulent. A turbulence model was therefore applied and the analytical model was reconstructed.

A cylindrical coordinate system was adopted in the cylindrical cross section, where the cross section is divided equidistantly into 540 meshes (radial direction, 15 divisions; circumferential direction, 36 divisions). The tube is equipartitioned at an interval of 1 mm in the trap flow direction with a rectangular coordinate system. Star-CD (ver.3.26) was used for the analysis in this section. A standard k - ε model was used as the turbulence model. The VOF method is used as the computational method of multi-phase flow, as in the preceding section. The generalized log law by Launder[12] was applied to the wall surface boundary condition.

The amount of trap seal water was set at half the water level; the rest equilibrium position was used as the initial state (Fig. 5(b)). Single sine pressure waves of two types were impressed for forced oscillation: 2 Hz, the natural frequency of a P trap used for the experiment; and 1 Hz. The pressure wave was given to the outlet side boundary surface by the time series of 0.1 ms. The computation interval was 0.1 ms (10,000 Hz). The data output interval was 20 ms (50 Hz); computation for 2.5 s in real time was carried out for 1 Hz and 2 Hz. The water level fluctuation was determined at the location where the cross-sectional VOF becomes 0.5. Other analytical conditions are identical to those used in the preceding section. The computation times were, respectively, about 28 and 50 hour for 1 and 2 Hz.

3. 2 Analysis results and discussion

Figure 6 shows the pressure wave induced using a 1 Hz single sine pressure wave. Figure 7 depicts the water level fluctuation of trap seal water; Fig. 8 depicts the density distribution of the power spectral ratio obtained by FFT of a forced oscillation wave by a single sine pressure wave. The results for 2 Hz are presented in Figs. 9–11.

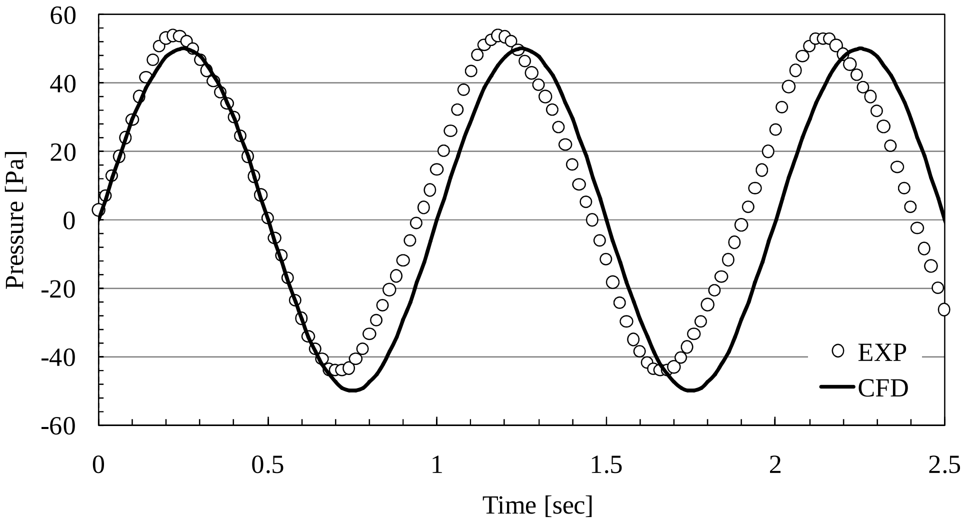


Figure 6 - Impressed sine pressure wave of 1Hz for forced oscillation

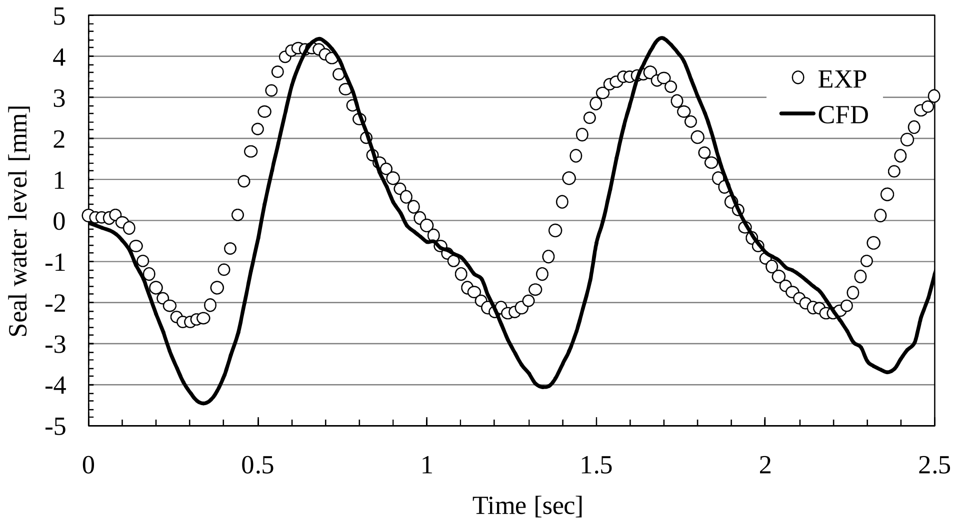


Figure 7 - Fluctuation of trap seal water level at forced oscillation (1Hz)

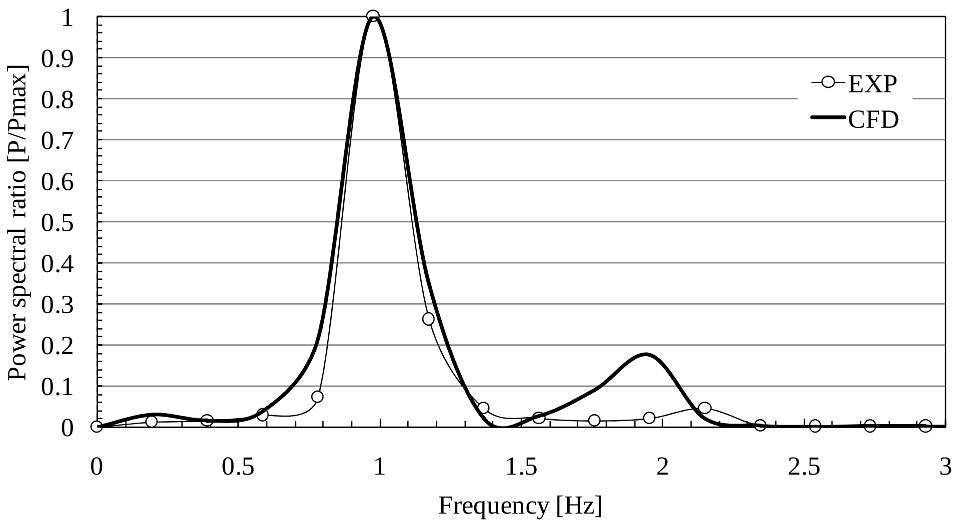


Figure 8 - Power spectral ratio obtained by FFT of forces oscillation wave (1Hz)

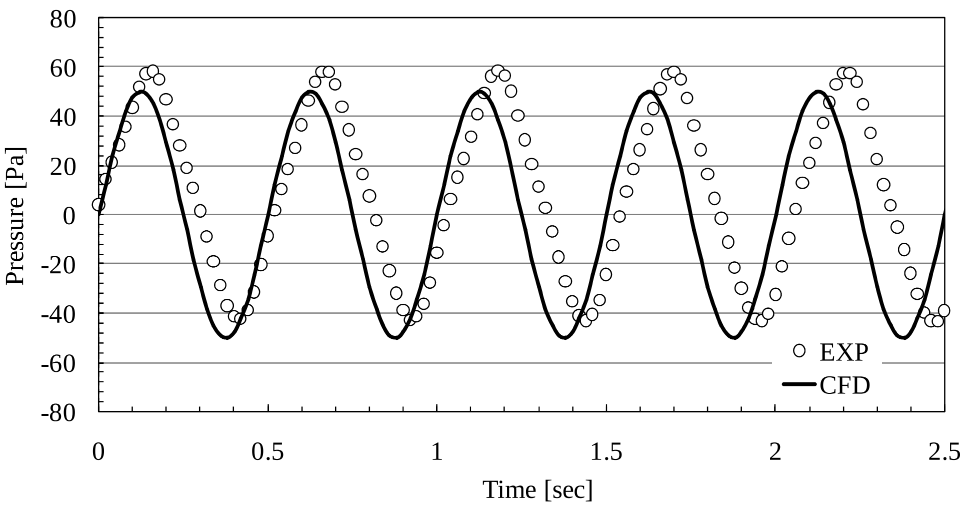


Figure 9 - Impressed sine pressure wave of 2Hz for forced oscillation

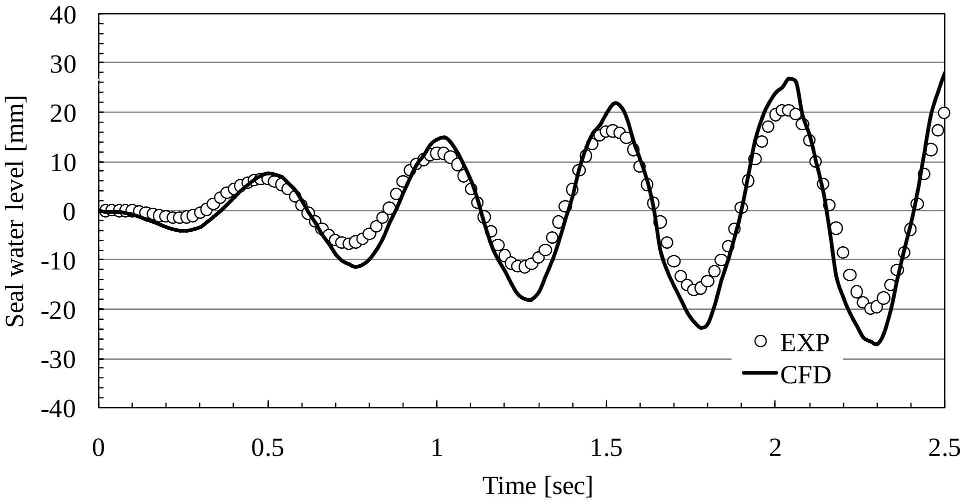


Figure 10 - Fluctuation of trap seal water level at forced oscillation (2Hz)

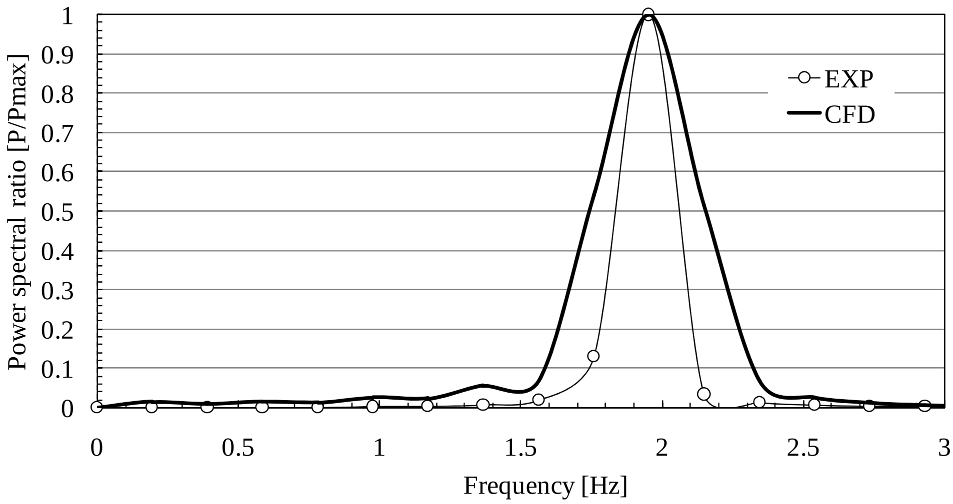


Figure 11 - Power spectral ratio obtained by FFT of forces oscillation wave (2Hz)

The pressure wave used in the experiment differs from a single sine wave slightly because of the control characteristic of the pressure device. A single sine wave of the mean amplitude in the experiment is used in the CFD.

Comparison between the experimental result on 1 Hz of a single sine pressure wave and the CFD analysis result revealed that the analysis value is slightly larger than the experimental value. The difference was about 2.5 mm at most, which was greater especially at a negative peak. The water level fluctuation in the experiment was -2 mm to 4 mm; values differ by the sign. The peak of water level fluctuation took place about 0.1 s before the peak of pressure fluctuation. Water level fluctuation diminished near the rest equilibrium position, about 1 s after the start. The peak locations of water level and pressure are not the same, which is assumed to reflect the effects of gravity acting on the seal water. It also seems that fluctuation near the rest equilibrium position decreased as a result of the peak location shift. Experiments might contain measurement error. The friction condition on the tube wall in the analysis differs from the actual condition, which is considered to be the cause of differences from the experiment values.

Next, the experimental result on a single sine pressure wave of 2 Hz, the natural frequency of the trap, used for the experiment, is compared with the CFD analysis result. The analysis did not reach the maximum response. The peak of water level fluctuation is delayed by about 1 s compared to the pressure wave peak. This tendency is also evident in the experiment. The analytical values were slightly greater than the experimental values. However, because the amplitude of water fluctuation is enhanced with time progress, resonance phenomena can be mostly reproduced. The difference peaked at about 7 mm at 2.5 s. Although continuous analysis might exaggerate error further, this remains as a subject for future study.

Regarding results of the power spectral ratio at 1 and 2 Hz, frequencies of the peaks in the experiment and analysis are mostly in agreement with those of a single sine pressure wave. It is therefore presumed that the CFD analysis can reproduce the forced oscillation phenomenon of trap seal water in general.

Water level fluctuation is enhanced gradually at the time of forced oscillation, especially when the pressure fluctuation of the natural frequency is given. Because the water level fluctuation per unit time is regarded as the flow velocity of seal water, this is equivalent to a gradual increase of Re. Frictional shearing stress and turbulence property on the wall surface change depending on Re. For that reason, analysis of resonance phenomena by free or forced oscillations with sufficient accuracy would require that a turbulent flow model applicable from a laminar flow to turbulent flow be applied. This analysis adopted either the laminar or turbulent flow analysis. Analysis with a low-Re type turbulence model and Large Eddy Simulation (LES) remains as a subject for future study.

4. Conclusion

To investigate the applicability of the CFD analysis to sealing water oscillation, the CFD analyses of the free oscillation and single sine-wave forced oscillation of sealing water in a P trap was conducted, and comparison with the experiment was carried out. The obtained results are as follows.

It is demonstrated that the CFD analysis can reproduce the free and forced oscillation phenomena of seal water in a P trap in general. A single sine pressure wave of 2 Hz, the resonant frequency, expands the amplitude of water fluctuation with time progress. This verifies that the CFD mostly reproduces resonance phenomena.

The water level fluctuation of trap seal water tends to be slightly greater in the CFD analysis than the experiments for both free and forced oscillations. This is presumed to be the result of the boundary conditions of the CFD, the selection of a turbulent flow model, and experimental accuracy. Accuracy improvement in analyses and experiments will be necessary.

The CFD analysis of traps of different configurations will be conducted, and the usefulness of the CFD will be investigated; improved accuracy is expected in the future.

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6. Presentation of Author(s)

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F2) CFD Simulation and Experimental Study of Flow Characteristic of Siphon Drainage System

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Abstract

This study adopts Computational Fluid Dynamics (CFD) analysis to elucidate the fundamental characteristics of siphon flow in a siphon drainage system. A relationship determined between the outflow head and horizontal pipe length is necessary to assure an effective equipment mean drain flow rate (qd = 0.5 *l*/s) as transport capacity from the result. Moreover, a fundamental calculation equation of the pipe internal velocity that is necessary for designing this system is proposed using this result.

Keywords

Siphon drainage system, Discharge flow, Terminal velocity , Experiment, CFD

1. Introduction

In a siphon drainage system, a drain flows according to the siphon principle through small diameter fixture drain pipe in a filled flow condition. This system, unlike a gravity drainage system, permits non-slope drainage and a small diameter, which drastically reduces piping space compared to conventional drainage piping. Moreover, it enables free piping design. However, siphon drainage systems have remained under development; various basic data have yet to be accumulated. Accordingly, this study adopts CFD analysis to elucidate the fundamental characteristics of siphon flow in a siphon drainage system. Its applicability is investigated through comparison with experimental results related to the trend of pipe internal velocity, the terminal velocity and terminal length in the outflow pipe of a siphon line.

2. Experiment and CFD analysis of the terminal velocity in a vertical outflow pipe

2.1 Objective

The terminal velocity and terminal length of a vertical outflow pipe are determined as a fundamental characteristic of a 20[A] rigid polyvinyl chloride (PC) pipe used for siphon drainage piping. The CFD analysis is also applied simultaneously; its reproducibility is verified. Results will indicate whether the CFD analysis is effective as an analytical tool of the two-phase flow of water-air.

2.2 Experiment

2.2.1 Outline of experiment

Figure 1 schematically depicts the terminal velocity experimental apparatus and an experimental model. The theoretical terminal velocity at the coefficient of velocity C = 150 was computed using Eq. (1), the Hazen-Williams equation. The vertical outflow pipe length necessary to reach terminal velocity was obtained using Eq. (2).

$$C=Q/(1.6712\times i^{0.54}\times D^{2.63}\times 10^{4}) \text{ --------- (1)} \qquad Lt=0.1444vt^{2} \text{ --------- (2)}$$

C: the coefficient of velocity, Q: flow rate [m/s], i:hydraulic gradient [mAq/m], D: pipe diameter [m], Lt: terminal length [m], v_t: terminal velocity [m/s]

This yields a terminal length of about 3m. The vertical outflow pipe length used for this experiment was set as 4.5 m in consideration of a safety factor of 1.5. A transparent plastic case of 395mm[L]×585mm[W]×300mm[H] was used as a water tank. The water storage height was 200mm from its bottom. The total head was 4,700mm as the sum of the water storage height and the vertical outflow pipe length. The outflow head pipe was filled with water in its open end, so that the terminal velocity was reached promptly after the start of measurement, thereby shortening the CFD analysis computation time. The pipe internal velocity was determined according to the water level change in the water tank, as measured using an ultrasonic water level sensor.

2.2.2 Experimental results and discussion

Figure 2 depicts the pipe internal velocity fluctuation (v_e), which indicates that terminal velocity was reached within about 2s after the start of measurement. The maximum pipe internal velocity was 4.70m/s; the mean velocity was 4.15m/s. The coefficient of velocity C = 138 was at that time.

2.3 CFD analysis

2.3.1 Outline of CFD analysis

CFD analysis conditions are shown in table 1. An analytical model was created according to the configuration and dimensions of the experimental model, as in Figure 1. The cross sectional cell of the vertical outflow pipe was divided into 80 meshes. The pipe was partitioned at an interval of 10mm in the height direction, so that was divided into 450 divisions. Regarding the water tank, the grid was finely divided gradually toward the unification section with the outflow head pipe, from a large 10mm cube mesh near the outer wall to a 2.5mm cube at the unification section. The total mesh number is 91,540. A dynamic model was constructed as a multi-phase flow of water-air, and the Volume-of-Fluid (VOF) method, an Euler-type method, was adopted as the computational method of a free surface in this analysis. Because the Reynolds number (Re) was anticipated as $10^4 \sim 10^5$, within the turbulence region, the standard k-ε model was adopted as a turbulence model. As a general-purpose fluid analysis tool, software (STAR-CD ver. 3.24) was used.

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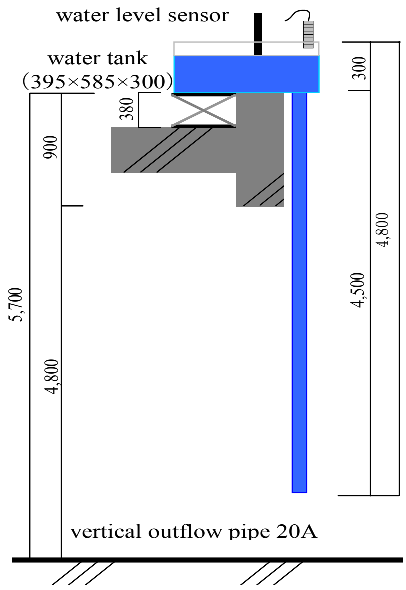


Figure 1- Experimental Apparatus for terminal velocity

Table 1- CFD analysis conditions

calculation method	free surface flow(VOF method)
fluid	the first fluid : air 、the second fluid : water
turbulent model	standerd k-ε2-equations model
solution	PISO,maxcimam number of collectors:50 relaxation coefficient:0.8
difference scheme	CICS,upwind difference(advective term), central difference(other terms)
boundary condition	wall degree of roughness 2×10^{-6}[m], experimental fixed number of Nikuradse
time step	2ms(500Hz)

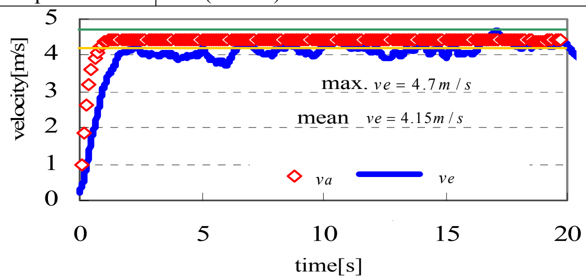


Figure 2- Analytical velocity v_a and experimental velocity v_e

2.3.2 CFD analysis results and discussion

Terminal velocity was reached within about 2s after the inflow start in the experiment; in the CFD analysis, it was reached within about 1s, as depicted in Figure 2. Although the mean terminal velocity was 4.15m/s in the experiment, it was 4.43m/s in the analysis, some discrepancy arose.

2.4 Comparison of experimental and CFD analysis results

Figure 2 presents a comparison of the temporal variation of the pipe internal velocity in the terminal velocity experiment (v_e) and CFD analysis (v_a). The terminal velocity in the vertical outflow pipe was about 4.2 ~ 4.4 m/s, with the coefficient of velocity C=140; the terminal length was about 2.7m. Although comparison between the experiment and CFD analysis revealed some differences in velocity variation from the outflow start to attainment of terminal velocity, and the values of terminal velocity themselves, sufficient agreement was observed in general. Therefore, the effectiveness of the CFD analysis was also verified.

3. Experiment and CFD analysis of the flow characteristics in siphon drainage piping

3.1 Objective

This experiment is intended to establish a method of evaluating the pipe internal velocity from piping configurations such as vertical and horizontal pipe lengths. For that purpose, a basic piping model without a trap or crossover piping is prepared indoors, and the flowing characteristic of siphon drainage piping is verified. Results verify whether the siphon phenomenon by a filled flow drain peculiar to a siphon drainage system is reproducible using the type of CFD analysis. A multi-phase flow of water-air with clean water containing no solid matter was assumed.

3.2 Outline of experiment and CFD analysis

3.2.1 Experiment

Figure 3 portrays a schematic drawing of the experimental apparatus. The line has no crossover piping or trap, which are indispensable in actual application, with minimal g water flow resistance as an elementary experiment. The open end was open to the atmosphere, also the confluence joint was not installed in drainage stack. A 20^{A} rigid PC pipe was used for siphon drainage piping and a bent pipe of R4D was used for the curved sections. Table 2 presents the line dimensions and configuration used for the experiment.

The experiment proceeded as follows. First, the water discharger was flooded so that the inflow head (*Hi*) was set to 700mm. Then, after checking that the predetermined water level was reached, the discharger plug was opened and water flow was released. For an experiment with horizontal pipe length (*Lh*) of 4,000mm, which was used for the comparison with the CFD analysis, the siphon drainage piping was also flooded to make the pipe internal velocity promptly steady and to shorten the analysis time. Pressure sensors were installed near the vertical and horizontal elbows, as portrayed in Figure 3, where deflection is remarkable. A water pressure sensor was installed in the drain characteristic measurement basin to determine the drain flow rate and flow velocity.

3.2.2 CFD analysis

The piping model of this analysis was created along with a siphon drain basic piping model without a trap or crossover piping used in the experiment. Calculation regions ranged from the free surface of the water discharger that was flooded initially in Figure 3 to the open end of the outflow head.

The structure meshes of the cross section of siphon drainage piping were 132. Figure 4-a schematically depicts the cross-sectional grid of the analytical model. Figure 4-b portrays the grid outline of the junction of the analytical model. The total mesh numbers are, respectively 144,128 and 157,592 at the minimum and maximum.

CFD analysis conditions are shown in table 1. This analysis assumed a multi-phase flow of water-air in an isothermal and transient flow field, and the Volume-of-Fluid (VOF) method, an Euler-type method, was adopted as the computational method of a free surface. Transient analysis was conducted using the Pressure Implicit with Splitting of Operators (PISO) algorithm, in which the windward difference of primary accuracy was used for the advective term as the difference scheme because the flow was one way. The generalized log law was applied to the wall surface boundary condition. The computational time unit was 2ms. Computation for 5.0s in the actual time was carried out.

3.3 Results and discussion

3.3.1 Experiment

The pipe internal velocity was minimal at EX 80-5 and maximal at EX 40-15. The pipe internal velocity was 1.20 ~ 2.08m/s. The *qd* value was ca. 0.5 l/s. Results verified that the flow rate varied according to the change in the pipe length (*Lh*) and outflow head (*Ho*).

3.3.2 CFD analysis

The maximum Courant number was about 4.0 or less in all CFD analytical models. Furthermore, y^+ ($=u^* \Delta y/\nu$) of the first cell on the wall surface was about 150. Therefore, it is considered that computation on this analysis was performed satisfactorily. Table 4 presents CFD analysis results and experimental results of the pipe internal velocity and pipe internal pressure in all piping configurations. The velocity and pressure values were on the stationary state. The pipe internal velocity evaluated in the CFD analysis

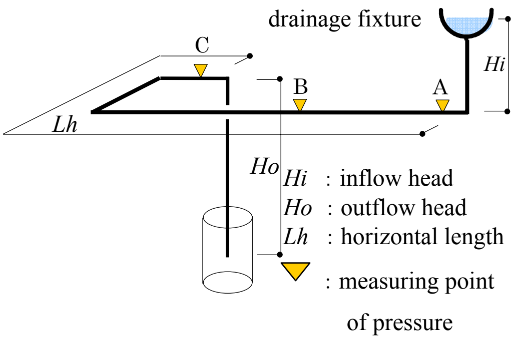
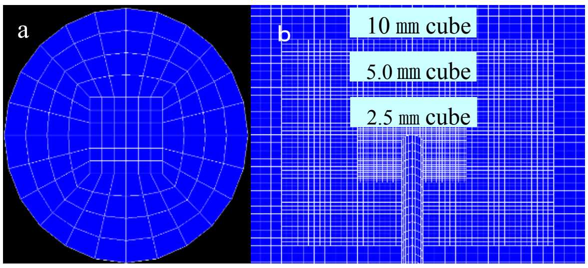


Figure 3- Experimental apparatus

Table 2- Pipe length and configuration for experiment

experiment No.	*Ho* [mm]	*Lh* [mm]	n. of bend
EX40- 5	4000	500	2
EX40-10		1000	2
EX40-15		1500	2
EX60- 5	6000	500	2
EX60-10		1000	2
EX60-15		1500	2
EX80- 5	8000	500	4
EX80-10		1000	4
EX80-15		1500	4



(a : section, b : junction)

Figure 4- Cells of CFD model

Table 3- Pipe length and configuration for CFD

Lh [mm]	*Ho* [mm]	*Lt* [mm]	n. of bent
4,000	500	5,200	2
	1,000	5,700	2
	1,500	6,200	2

differ from experimental values respectively by about 5% and the pipe internal pressure evaluated about 500Pa at the maximum. This is considered a satisfactory result considering the resolution of the pressure sensors.

Figure 5 depicts the transient distribution of mean pipe internal velocity and pipe internal pressure at the *Ho*: 1,500 mm. The mean velocity distribution was different between the experimental and analysis values by 0.5 m/s at the maximum for 1 ~ 2s after the outflow start. However, mean pipe internal velocity agreed well with the experiment shown since 2.5s after the outflow start, when flow velocity settled into a constant value. A rapid pipe internal negative pressure by a siphon phenomenon was also reproduced in a satisfactory manner. Furthermore, the mean pipe internal velocity was compared with the theoretical value obtained using the flow velocity theoretical equation derived from experimental values at the pipe length (*Lh*) of 4,000mm and the kinetic energy conservation law. Each parameter used for these analytical conditions ($\lambda = 0.024$, $d = 0.02$m, $\zeta = 0.5$) is substituted for the theoretical equation Eq(3). The hydraulic gradient is assumed as $I = Ht / Le$ (where Le =1.2l + 0.5). Consequently, the relationship between the flow velocity and hydraulic gradient can be expressed as Eq (4).

$$v_t = \sqrt{2gH_t \Big/ (\lambda \frac{l}{d} + \sum \varsigma + 1)} \quad \text{---------} \ (3), \qquad v_t = 4043\sqrt{I} \quad \text{--------------} \ (4)$$

v_t: velocity of theory[m/s], Ht: total water head[m], l:equivalent pipe length [m], λ:friction factor [-], d: diameter [m], ς:loss coefficient[-], I:hydraulic grade [-]

Table4-CFD analysis and experiment results of velocity and prwssure

Ho		500[mm]		1,000[mm]		1,500[mm]	
method		analysis	experiment	analysis	experiment	analysis	experiment
velocity[m/s]		1.59	1.67	1.89	1.81	2.1	2.02
pressure[Pa]	A	2,567	2,478	1,403	1,602	358	191
	B	245	56	-1,791	-1,956	-3,160	-3,188
	C	-3,594	-3,954	-7,206	-7,770	-10,306	-1,088

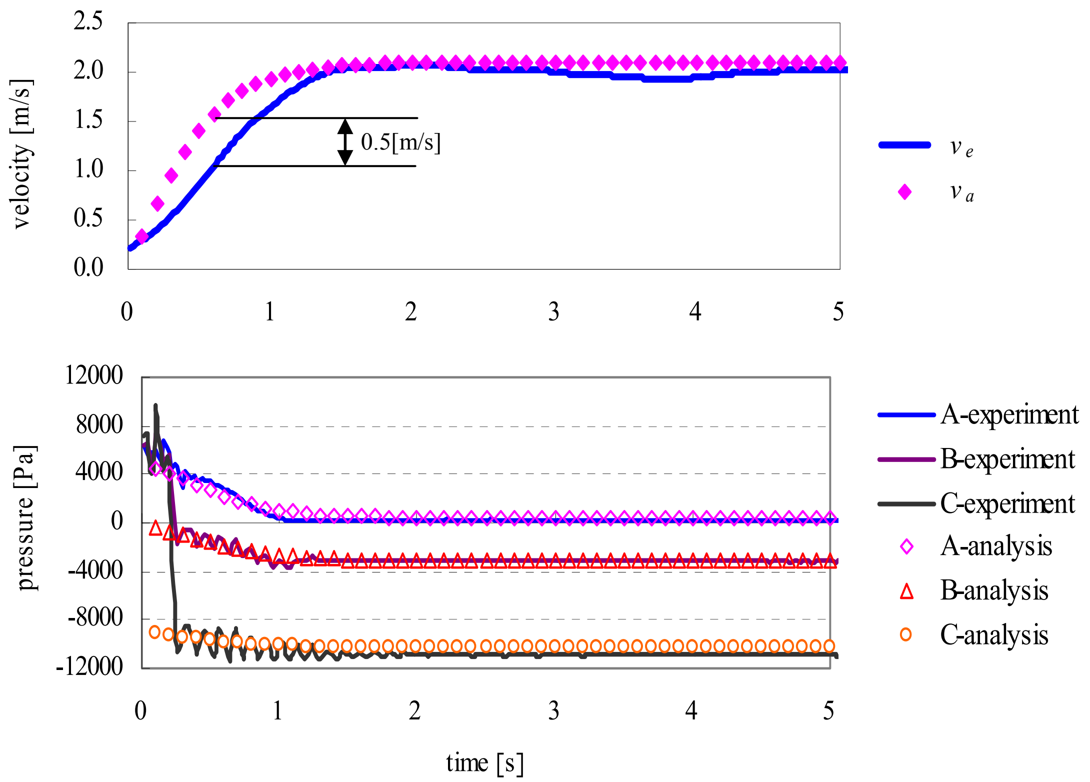
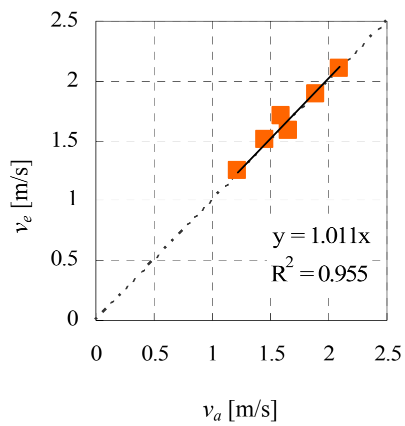


Figure 5- Comparison of CFD and experiment on velocity, pressure
(*Lh* = 4,000mm, *Ho* = 1,500mm)



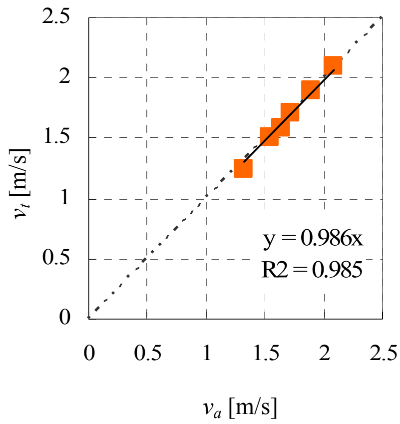


Figure 6- Comparison of v_a of v_e **Figure 7- Comparison of v_a of v_t**

Figures 6 and 7 respectively represent the correlation of pipe internal velocity between the CFD analysis values and the experimental and theoretical values. The CFD analysis values exhibited a high coefficient of determination. They very closely approximated the experimental and theoretical values. Consequently, the CFD analysis was verified as effective for these analysis conditions.

4. Flow characteristic of siphon drainage basic piping model

4.1 Objective

In response to the satisfactory analysis results obtained using CFD in the preceding section, a piping configuration for which it is difficult to conduct an indoor experiment is analyzed. Flow characteristics for diverse piping are investigated in this section.

4.2 Outline of CFD analysis

The inflow head (*Hi*) of the piping configuration of this analysis was identical to that used in the preceding section. In all, conditions of 24 types were assumed from four types of the horizontal pipe length (*Lh*) —2,000, 4,000, and 8,000 or 12,000 mm—and six types of the outflow head (*Ho*)—0, 500, 1,000, 1,500, 2,000 or 2,500 mm.
The configuration of the cross sectional grid and analysis conditions were the same as those reported in the preceding section. The total mesh numbers are, respectively, 111,392 and 274,412 at the minimum and maximum.

4.3 Results and discussion

Table 5 presents the pipe internal velocity for all piping configurations. Figure 8 shows the relationship between the horizontal pipe length (*Lh*) and the pipe flow rate from the CFD analysis result. Therefore, it is assumed that the equipment mean drain flow rate is *qd* = 0.5 *l*/s, which assures that no problem in a common residence when the following conditions are met when the inflow head (*Hi*) is 700mm: the horizontal pipe length of 2,000mm, and 0mm of the minimum of outflow head (*Ho*) is allowable; when the horizontal pipe length is 12,000mm, the minimum of outflow head (*Ho*) is 2,000mm.

This engenders the following argument: the horizontal pipe length (*Lh*) that is not shorter than 15m renders it difficult to acquire sufficient drain capacity merely by the siphon force of the outflow head according to the floor height of one story. Therefore, it is likely that no conveying force other than the siphon force is necessary.

Figure 9 compares the square root of hydraulic gradient (I) with flow velocity from the CFD analysis (v_a), the theoretical flow velocity (v_t) derived from the kinetic energy preservation law, and flow velocity from the experiment (v_e). The regression coefficient in the CFD analysis was 4.33, which very closely approximates to 4.43, the proportionality factor of the theoretical equation, and 4.22, the regression coefficient by experiment. Furthermore, the flow velocity from CFD analysis was compared to the experimental and theoretical values shown in Figures 10 and 11. High coefficients of determination in both cases prove the propriety of the analysis.

Table 5- Velocity for all piping configurations

velocity [m/s]		*Ho* [mm]					
		0	500	1,000	1,500	2,000	2,500
Lh [mm]	2,000	1.6	1.98	2.28	2.51	2.69	2.84
	4,000	1.24	1.59	1.9	2.1	2.28	2.43
	8,000	0.94	1.25	1.51	1.7	1.87	2.02
	12,000	0.75	1	1.21	1.41	1.61	1.73

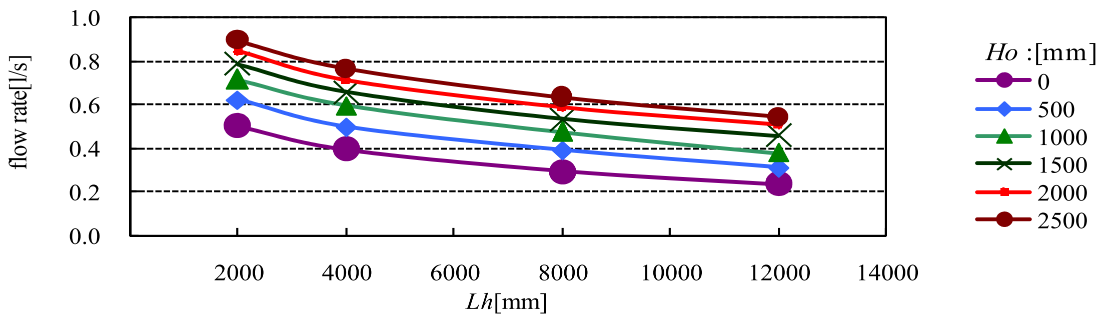


Figure 8- Flow rate with *Ho* and *Lh*

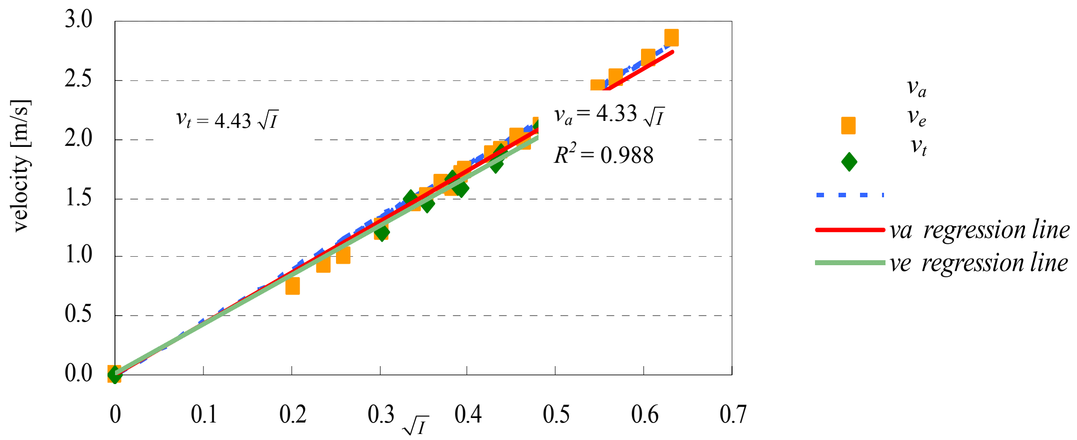


Figure 9 - Comparison of square root (*I*) and v_a, v_e, v_t

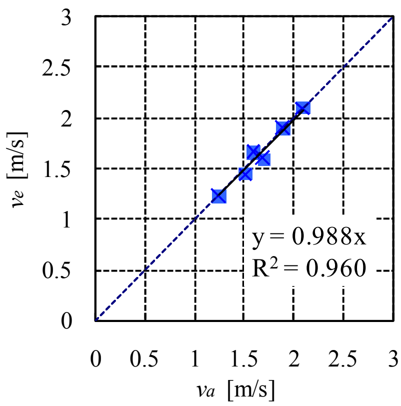


Figure 10- Comparison of *va* of *ve*

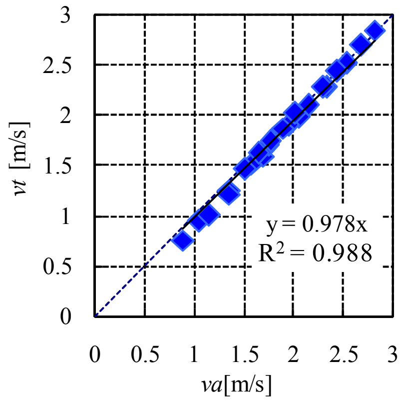


Figure 11- Comparison of *va* of *vt*

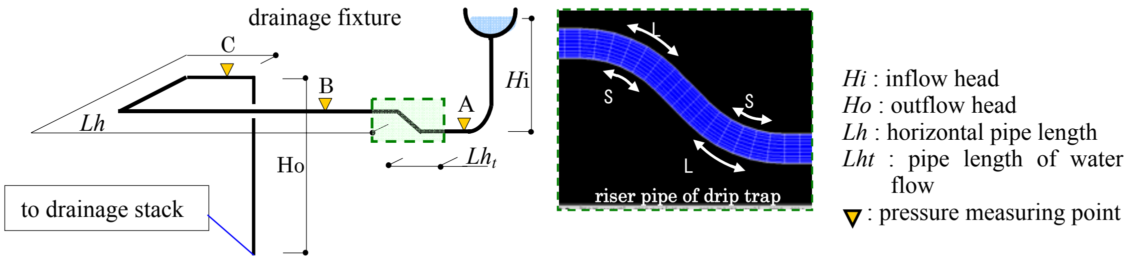


Figure 12- Siphon drainage piping trap

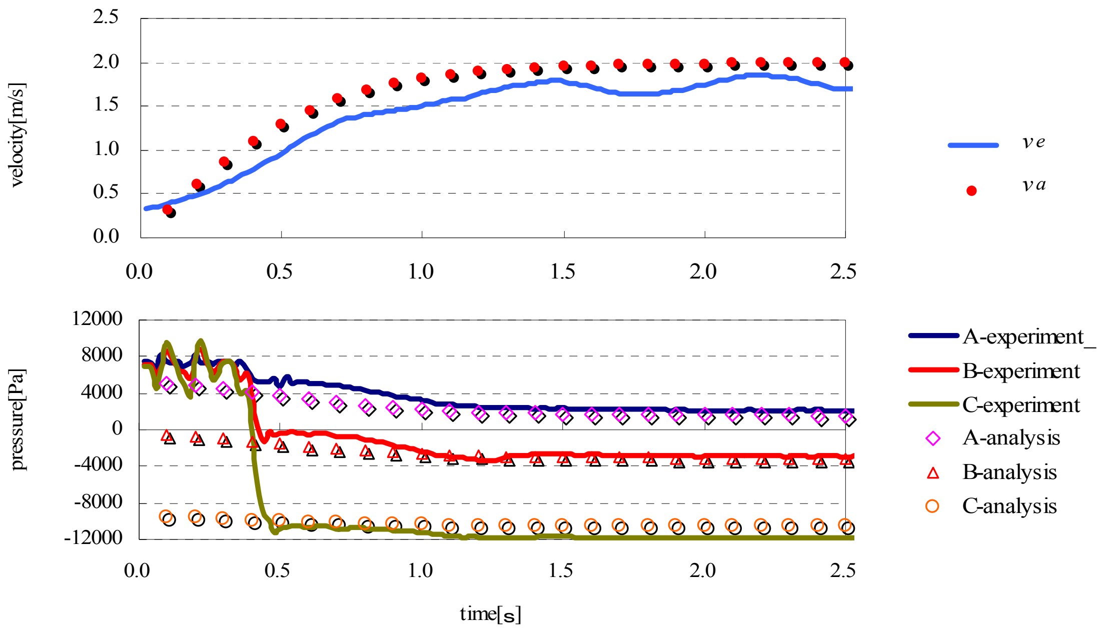


Figure 13- Comparison of CFD and experiment on velocity, pressure
(*Lh* = 4,000mm, *Ho* = 1,500mm)

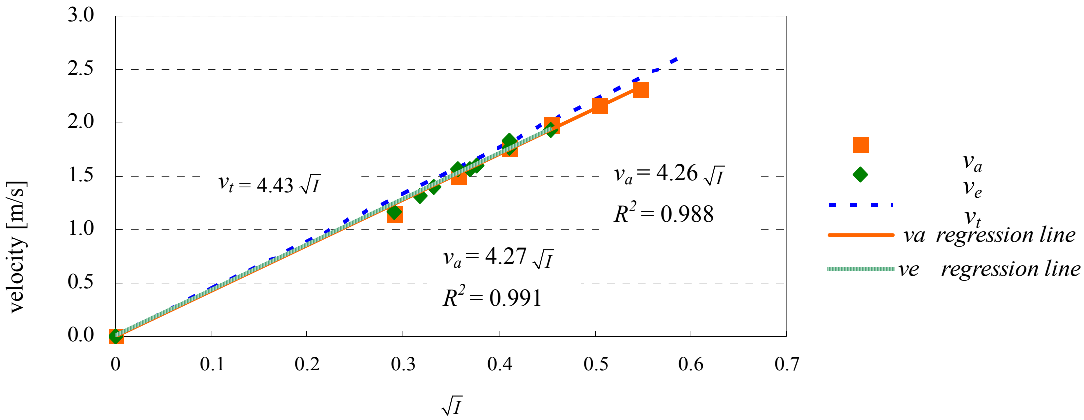


Figure 14- Comparison of square root (*I*) and v_a, v_e, v_t

5. Flowing characteristics of a piping trap drainage piping model

5.1 Objective

The flow characteristics of a piping model with a piping trap installed are investigated presuming a real application, which identifies the effectiveness of the CFD analysis in a piping model with many elbows. At the same time, this investigation aims at expanding the comprehension of the flow characteristics of siphon drainage piping considering local resistance.

5.2 outline of CFD analysis

This analysis considers a siphon drainage piping trap model with a line trap (water flow length 500mm, seal depth 50mm), with *Hi* of 700mm and *Lh* of 4,000mm, using six outflow head types with *Ho* of 0, 500, 1,000 and 1,500, and 2,000 or 2,500mm. Figure 11 schematically depicts the siphon drainage piping trap model.

The calculation region is initially a flooded region. The standup section of the trap was equipartition of the longitudinal direction using an interval of 8mm, and was slightly more finely divided compared with 10 mm of the straight section. The configuration of the cross sectional grid (see Figure 4), analysis conditions (see Table 1), and the calculation method of pipe internal velocity were the same as those described in the preceding section. The total mesh numbers are, respectively, 146, 372 and 179, 900 at the minimum and maximum. Computations for 2.5s in actual time were carried out.

5.3 Results and discussion

The maximum Courant number was about 6.0 or less for all analytical models: *y+* was about 140. Figure11 presents the hourly variation of pipe mean velocity and pipe internal pressure at outflow head (*Ho*) 1,500mm. The analytic values of pipe mean flow velocity were greater by about 0.2 m/s compared to experimental values terminal. An almost identical tendency in velocity distribution confirms a satisfactory CFD analysis result. Moreover, the reproducibility of the pipe internal pressure is as satisfactory as the CFD analysis in the preceding section.

Figure 12 compares the CFD analysis result, experimental values, and theoretical values on the siphon drainage piping trap model. This yields a regression coefficient in CFD analysis of 4.26, which differs from the constant of proportion of the theoretical equation by about 4%. However, it was very close to the regression coefficient obtained through experimentation. The regression coefficient in the CFD analysis was 4.33 in the siphon drainage basic piping model; it was 4.26 in the siphon drainage piping trap model. A slight decrease in the regression coefficient was observed for the relationship between pipe internal velocity and the square root of a hydraulic gradient with and without a piping trap. This is the result of some deviation from the proportionality factor of the theoretical equation. It is considered to occur because only six piping patterns were used in these CFD analysis models. It is necessary to increase piping patterns in the siphon drainage piping trap model and to carry out data expansion and accumulation in the future.

6. Conclusion

Analyses of the flow characteristics of siphon drainage piping and the pipe internal velocity equation were carried out using CFD, which provided the following knowledge based on those results.

The CFD analysis was verified with excellent reproducibility in the siphon drainage basic piping model for an isothermal and transient flow field and for the multi-phase flow of water-air. Moreover, the analysis of various piping configurations demonstrated the effectiveness of the pipe internal velocity equation derived from the kinetic energy preservation law.

Furthermore, for the siphon drainage piping trap model, by adding the loss resistance for a piping trap to the equivalent pipe length, it was identified that the flow velocity equation using the view of a hydraulic gradient is effective. However, the regression coefficient in the CFD analysis resulted from the proportionality factor of the theoretical equation, although only slightly. This is considered to occur because only a few piping patterns were used in the analysis model. Consequently, expansion of piping patterns is a pressing need for further investigation.

This study investigated the flow characteristics with clean water (water-air two-phase flow) using the CFD. It is expected however, that introduction of solid matter contained in drainage and the viscosity change of water in an actual wastewater would degrade flow characteristics. Accordingly, the flow characteristics of wastewater (water-air miscellaneous matter three-phase flow) close to the actual draining state must also be investigated, and flow characteristics and the trend of pipe stagnation of solid matter are expected to be investigated as subjects of future studies.

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8. Presentation of Author

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F3) Modelling low amplitude air pressure transient propagation in building drainage and vent systems to allow system analysis and control.

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Abstract.

Low amplitude air pressure transients propagate as a result of any appliance discharge within a building drainage and vent system. The resulting transient pressures may be sufficient to deplete appliance trap seals and provide a cross contamination route into habitable space. These effects may be modelled through the use of established mathematical methods drawn from the wider field of pressure surge control and suppression. This paper will demonstrate the application of these modelling techniques, based on the Method of Characteristics, to local Active Control to minimise the effect of transients on appliance trap seals and as a means of assessing the most appropriate control strategy. The effect of both negative air pressure transients, generated by increases in system water flows, and positive air pressure transients, generated by surcharge events, will be demonstrated, together with the effect of introducing passive venting solutions and / or active solutions based around the use of Air Admittance Valves and flexible containment chambers to minimise positive transients. Historic links to surge control will demonstrate that low amplitude air pressure transients obey the rules of surge propagation, dependent upon the rate of change of flow conditions and the characteristic reflection and transmission properties of system terminations and junctions.

Keywords
transient propagation, vent systems, cross infection, defect identification.

1. Transient propagation.

The prevention of cross contamination via depleted trap seals has been a design consideration over the past 100 years. The invention of the water seal trap in the 18th Century - a ‘U ‘bend’ immediately downstream of the appliance with a water depth of 50 - 75 mm - has remained the most effective barrier to sewer gasses. Traps respond to network pressure so system failure involving cross infection may follow the depletion of trap seals by air pressure transient propagation. Modern design, water conservation and the need to economise demands a re-evaluation of drainage design that recognises the unsteady nature of system flows and the effects of pressure transient propagation. Demands on urban living space that increase system loading due to occupation levels in excess of those envisaged at the design stage, will compromise drainage operation. Pressure transient propagation leading to system failure is associated with destructive forces in complex fluid systems. While the definition of failure is system dependent, the underlying principles of surge propagation, suppression and control remain constant. Transient propagation communicates flow demand - negative transients demand an increase in flow while positive transients reduce flow and increase pressure.

Figure 1 illustrates a single stack conveying appliance discharges as annular water flow, of 6-10 mm thick in stacks up to 150 mm diameter that reaches terminal velocity based on flowrate, stack diameter and roughness, within two floors and entrains air that enters via the open stack termination, generates a frictional pressure drop in the dry stack and pressure losses at discharging branch to stack junction airpath occlusion. Shear forces between the annular water and the air core, due to 'no-slip', generates an entrained airflow. If this airflow exceeds that appropriate to the shear force in any section of the stack the air pressure reduces as the air is drawn past the water film. At stack base the transition to free surface flow generates a water curtain, resulting in the generation of a 'back' or positive pressure. This overall mechanism depends on water flow and network parameters, increasing stack diameter decreases entrained airflow velocity; sweeping the stack base decreases back pressure; sweeping branch entry to the stack reduces airpath occlusion. Negative stack pressure draws trap seal into the system while positive pressure may lead to 'bubble through' from the system to habitable space.

This appreciation of system operation, developed in the UK at BRE and in the US at NBS, was empirical and exclusively steady state, Applications of fluid mechanics analysis in the 1950s, (Lillywhite and Wise 1969), was limited to steady state and remained so until the advent of computer based simulation. Appliance discharges are time dependent and random so the water downflow displays temporal and spatial unsteadiness. Flow conditions also depend on external pressure perturbations from the remainder of the building, the downstream sewer network and wind shear over roof level terminations. While the complex nature of these flow conditions was recognised, the lack of an accessible theoretical basis for design led to 'rule of thumb' practices that ignore the fact that the laws of physics transcend national frontiers.

Drainage systems display classic unsteady flow, variously described as pressure surge or waterhammer. Joukowsky (1900) investigating waterhammer in the St Petersburg Water Works, laid the foundations of modern transient theory, identifying the importance of wave speed and the reflection and transmission of transients at system boundaries that applies to the air pressure transients propagated in building drainage systems due to sudden increases in annular water downflow or reductions in entrained airflow that travel throughout the system. Joukowsky's fundamental relationship

$$\Delta p = - \rho c \Delta u \qquad (1)$$

indicates that an increase in airflow of 1 m/s would generate a -40 mm water gauge transient when air density and an acoustic velocity of 320m/s are system characteristics. Equation 1 introduces the first rule of surge protection – reduce the rate of change of the flow velocity.

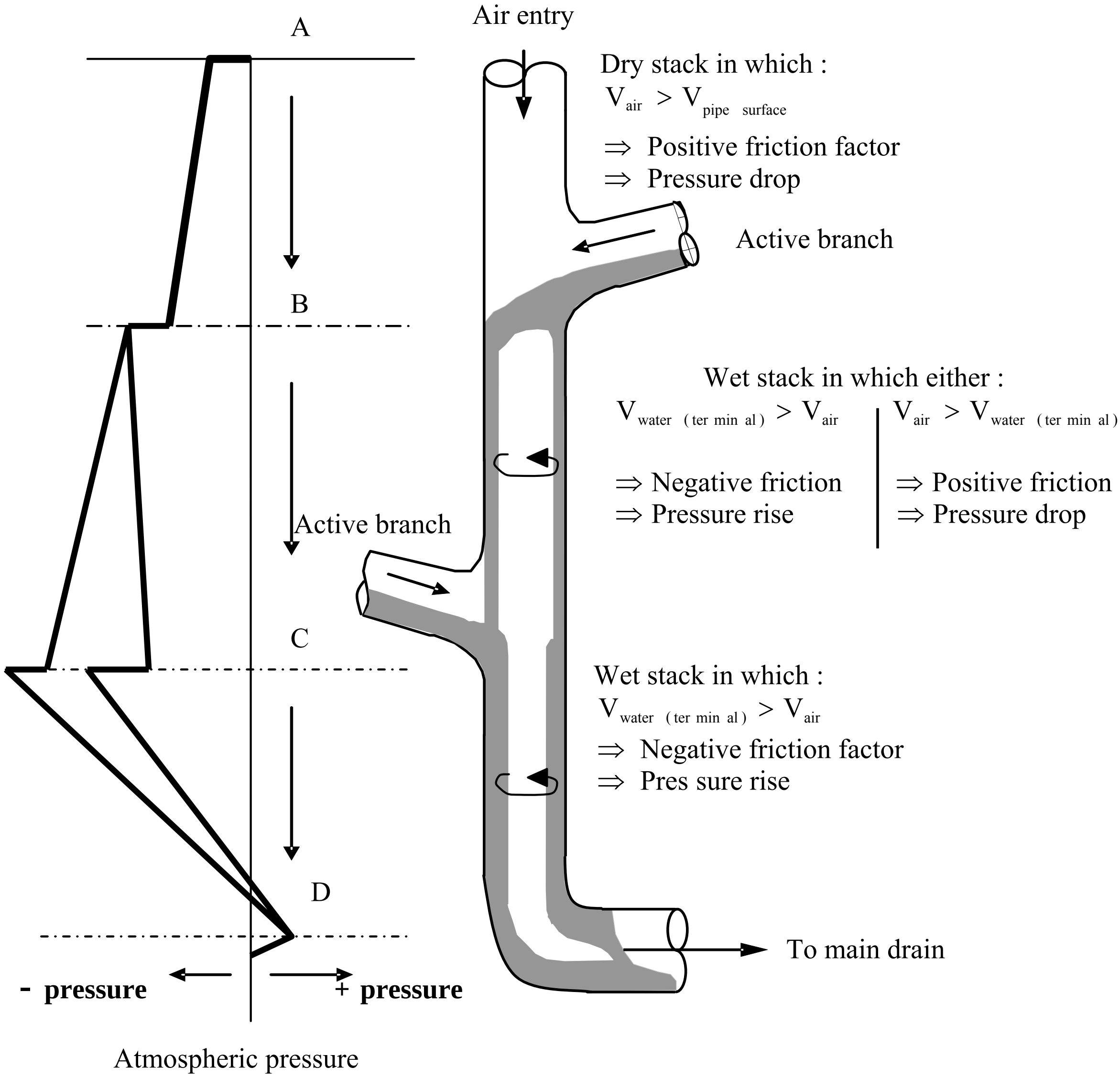


Figure 1 - Water and entrained airflows in a drainage vertical stack, illustrating the possible pressure regime established under steady flow conditions. Note concentrated losses at A, B and C and the 'back pressure' at D, the sewer entry.

Interruptions to the airpath may occur at the base of the stack, or at offsets, if a rapidly increasing annular water downflow causes local surcharging. A 'severe' positive transient could force air through the appliance trap seal – 'bubble through'- or displace the trap seal water upwards leaving the trap wholly or partially depleted. Where the positive pressure displaces the trap seal sufficiently to allow air bubbles to pass through to the appliance, trap seal depletion may occur on cessation of the positive pressure as the trap seal water is allowed to flow into the trap. Once generated a transient will continue to propagate throughout the network displacing every trap seal it encounters until relieved. This introduces the second rule of surge protection – position the relief device between the source of the transient and the item to be protected.

2. Mathematical basis for a vent system simulation.

Network air pressure transients depend on the rate of change of water flow and interrupted airflow. Air pressure transient propagation belongs to a family of unsteady flow conditions described by the St Venant equations of continuity and momentum solvable via the Method of Characteristics, introduced in the 1960s, (Lister 1960, Streeter and Wylie 1967). Jack (2000) introduced a 'pseudo-friction factor' model of the annular water to entrained air core interface that drives the simulation of combined discharge flows and air entrainment. This analysis includes the case of airflow entrained by high water flows in the lower levels of the wet stack exceeding that appropriate to the water flow in the upper levels. This allows the modelling of increasing pressure in the lower levels and decreasing pressure further up the stack as the air is drawn past the slower moving upper level water film that impedes its passage.

The St Venant equations link mean airflow velocity and wave speed as air pressure and density are interdependent. These quasi-linear hyperbolic partial differential equations are transformed via the Method of Characteristics into finite difference relationships, equations 2 to 5, linking conditions at a node one time step in the future to current conditions at adjacent upstream and downstream nodes, Figure 2.

For the C^+ characteristic : $$u_P - u_R + \frac{2}{\gamma - 1}\left(c_P - c_R\right) + 4 f_R u_R |u_R| \frac{\Delta t}{2D} = 0 \qquad (2)$$

when $$\frac{dx}{dt} = u + c \qquad (3)$$

and the C^- characteristic : $$u_P - u_S - \frac{2}{\gamma - 1}\left(c_P - c_S\right) + 4 f_S u_S |u_S| \frac{\Delta t}{2D} = 0 \qquad (4)$$

when $$\frac{dx}{dt} = u - c \qquad (5)$$

where the wave speed c is given by $c = (\gamma p/\rho)^{0.5}$ (6)

and local pressure is calculated as $p_{local} = [(p_{atm} / \rho_{atm}) (\gamma/c^2_{local})^{\gamma}]^{1/(1-\gamma)}$ (7)

Time step and internodal distance are governed by the Courant Criterion, defined as $\Delta t < \Delta x/(u+c)$. In the dry stack f_R and f_S are determined from Colebrook White. In the wet stack they are functions of time, location and annular water downflow and drive the simulation by generating the entrained air flow, Jack (2000).

Only one characteristic exists at each boundary so an additional equation is required at each pipe termination, e.g. airflow vs. pressure for AAVs, constant pressure for open terminations, zero velocity at dead ends, a combination of these for PAPA^{TM}s, partial reflection and transmission coefficients at pipe junctions or the momentum equation describing trap seal motion. An unique feature is the pseudo friction factor that drives the entrained airflow condition, effectively a distributed boundary condition with variable friction factor values at each node. Boundary conditions may be active or passive - pressure relief by vent connection to atmosphere is a passive boundary while active boundaries include AAVs, where inflow depends on local pressure differentials, or variable containment volumes that open in response to local positive pressure.

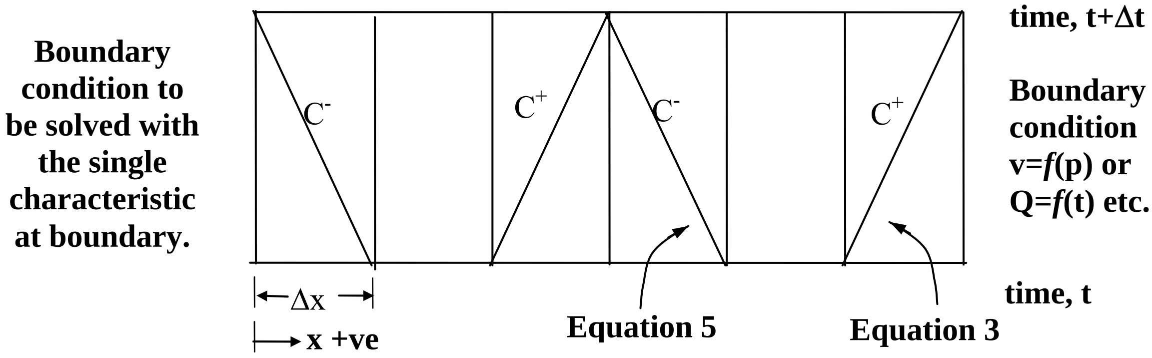


Figure 2 - St Venant equations of continuity and momentum allow airflow velocity and wave speed to be predicted on an x-t grid. Note $\Delta x<1.0$ m, $\Delta t < 0.003$s.

3. Air pressure transient control and suppression – traditional ‘passive’ venting.

While the propagation of low amplitude air pressure transients is a natural and unavoidable consequence of appliance discharge to a building drainage system, the protection of appliance trap seals is dependent on the control and suppression designed into the system. From the late 19th century, this control and suppression depended upon fixed venting running parallel to the wet stacks. The earliest ‘two pipe’ systems separated foul from general waste flows with each appliance independently vented. In the 1930s the ‘one pipe’ system discharged all appliances to a common wet stack but again separately vented appliances. In the 1970s the UK introduced a ‘single stack’ system that dispensed with separate vents although above 30 floors a parallel vents stack cross connected into the wet stack was introduced. All these designs featured vent stacks smaller in diameter than the wet stack and all represent ‘passive’ control and suppression as there is no interaction between the control mechanism, the fixed in place vent, and the transient. Two basic rules of surge suppression have been identified –

1. Transients may be attenuated by reducing the rate of change of flow velocity. This follows from equation 1 and implies that flow should be diverted in the case of a positive transient or, in the case of a negative transient added through an adjacent inlet.

2. The second basic rule is that the surge alleviation should be positioned between the source of the transient and the equipment to be protected.

While the fixed in place vent solution provide a degree of flow diversion or addition, criteria 1 above, its efficiency in this role is limited by fundamental misunderstandings of the operating mechanism of the vent stack currently embedded in the codes.

Fixed in place vents do not meet the second criteria in any way. The source of any relief to offset the pressure regime imposed on the system by the passage of the transient is the reflection of the transient at the upper open termination of the vent system. Thus the potentially trap seal depleting transient has already passed all the traps to be protected before any relieving reflection can be generated by the open termination. The pressure transient transmission and reflection coefficients at junctions may be determined from the following expressions (Swaffield and Boldy 1993)

$$C_{Transmission} = \frac{2\frac{A_1}{c_1}}{\frac{A_1}{c_1}+\frac{A_2}{c_2}+\frac{A_3}{c_3}} = \frac{2}{1+\frac{A_2}{A_1}+\frac{A_3}{A_1}} = \frac{2}{1+\frac{A_{Branch}}{A_{Incoming}}+\frac{A_{Continuation}}{A_{Incoming}}} \quad (8)$$

$$C_{Reflection} = \frac{\frac{A_1}{c_1}-\frac{A_2}{c_2}-\frac{A_3}{c_3}}{\frac{A_1}{c_1}+\frac{A_2}{c_2}+\frac{A_3}{c_3}} = \frac{1-\frac{A_2}{A_1}-\frac{A_3}{A_1}}{1+\frac{A_2}{A_1}+\frac{A_3}{A_1}} = \frac{1-\frac{A_{Branch}}{A_{Incoming}}-\frac{A_{Continuation}}{A_{Incoming}}}{1+\frac{A_{Branch}}{A_{Incoming}}+\frac{A_{Continuation}}{A_{Incoming}}} \quad (9)$$

It will be seen from equations 8 and 9 that the wave speed in each pipe or duct is included in the coefficient determination, however in the case of low amplitude air pressure transient propagation in building drainage and vent systems the pipework may be taken as rigid and the wave speed in air as constant, simplifying the equations.

Similarly it will be seen that the transmission and reflection coefficients depend upon the identification of the pipe carrying the incoming transient. The junction will present different coefficients for transients arriving along the branch or the continuation pipe. Thus equations 8 and 9 have been re-cast in terms of the pipe carrying the incoming transient (pipe 1 in Figure 3), the branch (pipe 2 in Figure 3) and the continuation pipe (pipe 3 in Figure 3) as this will make calculation of the coefficients easier.

The transmission coefficient at a junction of three equal diameter pipes is 66% of the incoming wave, Figure 4. A -33% reflection of the incoming is also generated. If the branch vent, Pipe 2 in Figure 3, is reduced in diameter then the transmitted wave strength increases – e.g. if the vent is half wet stack diameter then the transmitted wave is increased to 90% of the incoming wave. This offers no reduction in the transient propagating up the wet stack. If the vent has a greater diameter than the wet stack then the vent system starts to have an influence on the transient propagated up the building, e.g. if the vent stack is double the wet stack diameter then the transmission reduces to 33%. Note that the diameter of the cross vent, Figure 3, is as important as the vent diameter in restricting wave attenuation.

All national plumbing suggest equal or smaller diameter vent stacks compared to the wet stack, hence there is a fundamental misunderstanding of the mechanism of surge protection embedded in the design codes.

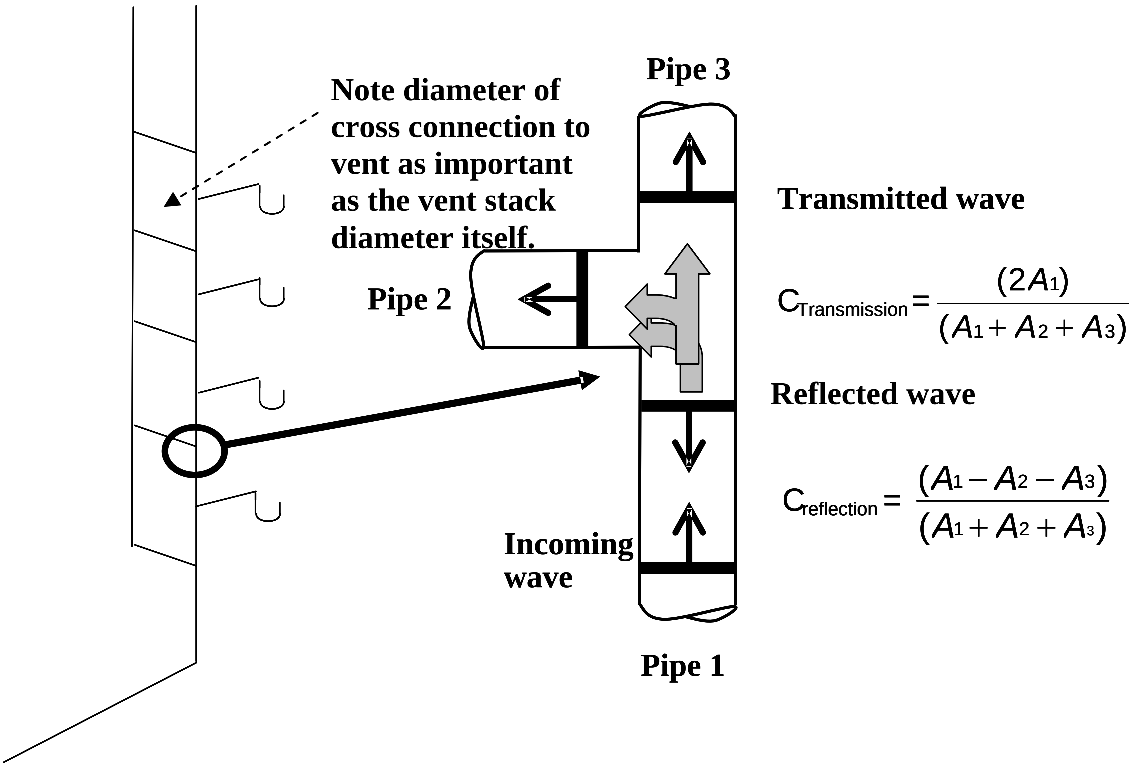


Figure 3 – transmission and reflection of a transient at a three pipe junction.

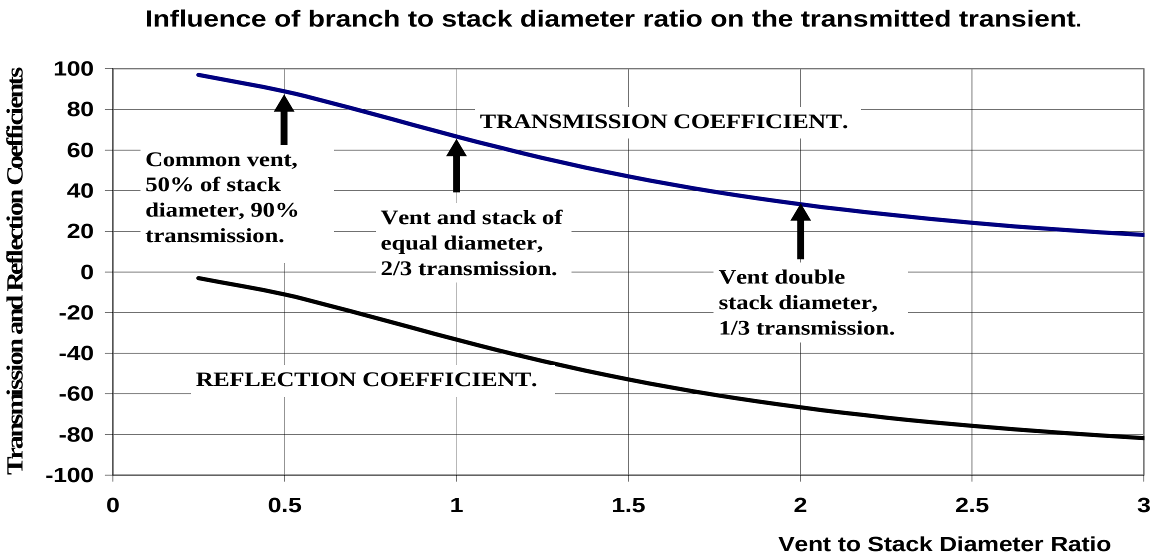
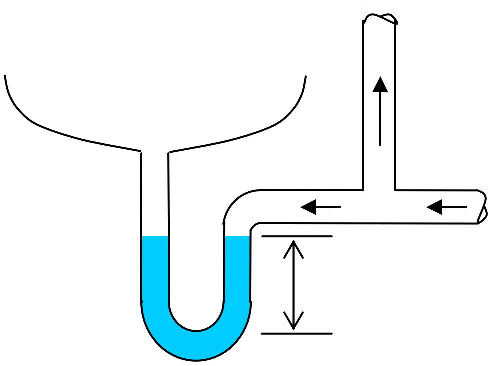


Figure 4 – The transmission and reflection coefficients at a three pipe junction depend upon the relative area ratios of the joining pipes. Figure 3 illustrates the necessary equations defining these coefficients.

It is the ratio of the pipe cross sectional areas that determines the coefficients rather than actual pipe diameters. If the traditional passive venting of individual traps back to the vent stack is considered, Figure 5, then it will be appreciated that a small diameter vent connected into the trap branch will have little effect.



Diversion of incoming transient depends on area ratio of the vent pipe cross sectional area to that of the trap branch.

To be effective in reducing pressure applied to the trap seal the vent should be greater in cross section than the branch.

Figure 5 – Passive vent connections applied locally to protect trap seals also require a larger vent diameter to be effective.

4. Air pressure transient control and suppression – active control.

The need to minimize external pipework and the advent of taller buildings led to the introduction of the single stack system in the 1970s. Further reductions from the mid 1980s introduced Air Admittance Valves installed within the habitable space to allow inwards air pressure relief. Active transient control extends this approach to include both positive and negative transient suppression to provide trap seal retention and prevent cross contamination of habitable space. Figure 6 illustrates an air admittance valve, AAV, and the positive air pressure attenuator, PAPA™ or flexible containment

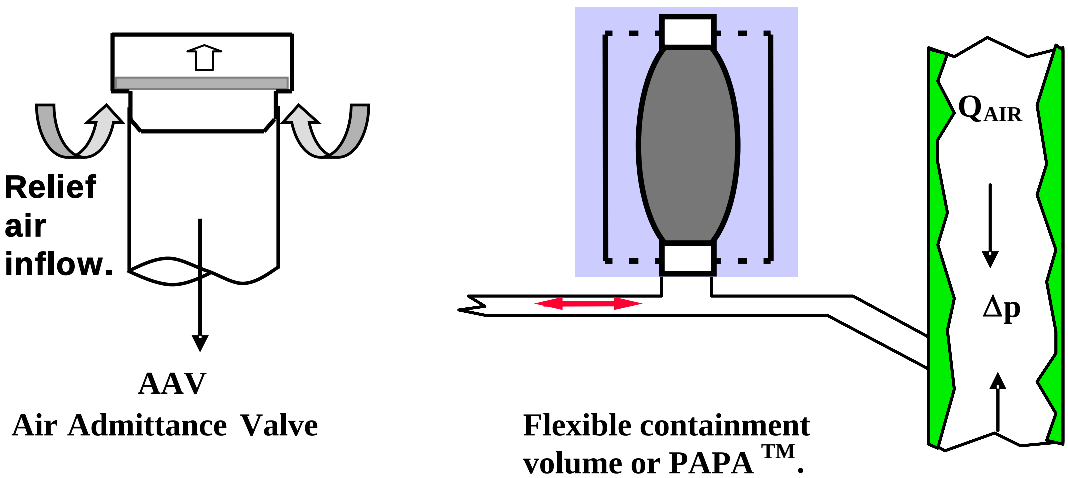


Figure 6 - Active air pressure transient suppression devices to control both positive and negative surges.

volume, capable of absorbing transients until pressurized. The principle of operation of. the AAV is to open whenever the local air pressure falls below a predetermined level in the local network allowing allowing an air inflow that does not require the transient to travel the whole height of the building to the first roof line open termination

The PAPA^{TM} allows entrained airflow to be diverted into the containment volume and reduces the rate of airflow deceleration by providing a diversion path. The pressure rise associated with the flow stoppage (Swaffield et al 2005) is therefore reduced. Thus it may be appreciated that Active control and suppression meets both the criteria.

5. Evaluation of Active and Passive control and suppression strategies for a simulated network.

Figure 7 illustrates a network that will allow the direct comparison of several design solutions - All stacks and branches 100 mm diameter, the trap is a 50 mm seal and the vent stack is initially 80 mm diameter. Interfloor height is 5 m. The applied water flow is a 2 litre/s flow with a 0.8 rise time from 1.0 seconds. This trial will impose a negative transient on the network and will test the ability of the Active control AAV installation compared to various Passive venting solutions with differing vent stack diameters. The base of the stack is surcharged from 3.5 to 4.0 seconds to impose a positive air pressure transient onto the network to test the ability of the Active control PAPA^{TM} installation compared to various Passive venting solutions with differing vent stack diameters.

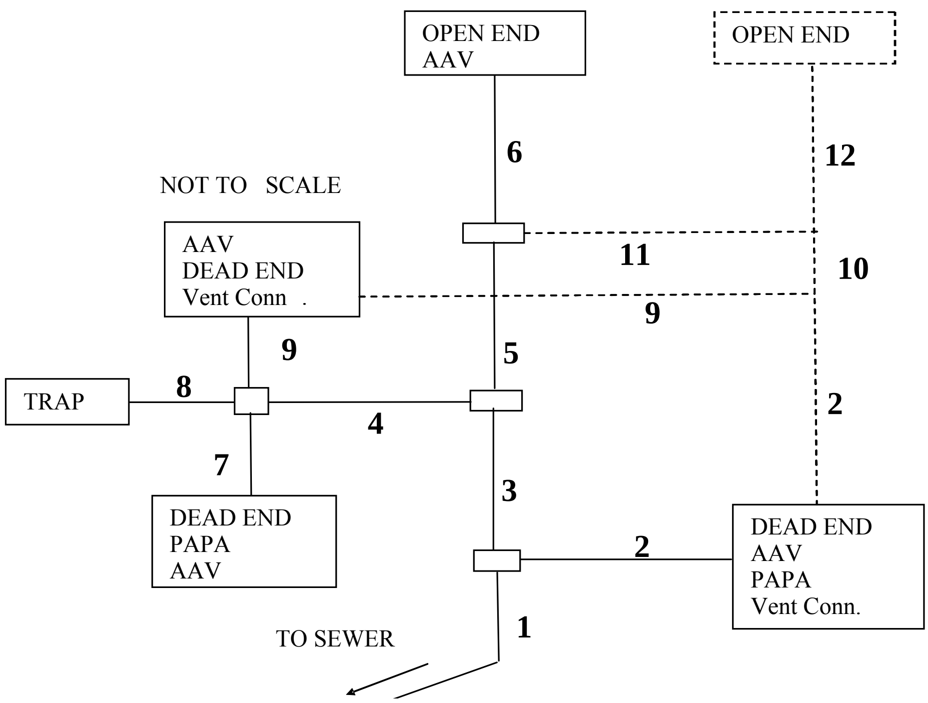


Figure 7 – a drainage and vent system to allow the evaluation of the relative performance of an Active or Passive transient control and suppression strategy.

Thus this single simulation includes both the possibility of induced siphonage and trap seal loss following a system surcharge dependent on system characteristics. Figure 8 illustrates the system operational conditions for two design cases, namely an Active Control application including distributed AAVs and a PAPA™ at pipe 2 and a traditional scheme using an 80 mm diameter parallel vent. Trap seal water is lost as the imposition of the annular water downflow generates negative stack air pressure. Seal loss is dependent on the waterflow acceleration – 2.5 litre/s^2 is a challenging criteria. Stack base surcharge results in a positive transient propagation, however the inclusion of the PAPA™ Active Control device prevents any additional trap seal loss. The parallel vent system does not control the positive transient and a secondary trap seal loss is experienced. Air pressure values in pipe 3 indicate that Active Control was more efficient at reducing the propagated positive transient following stack base surcharge

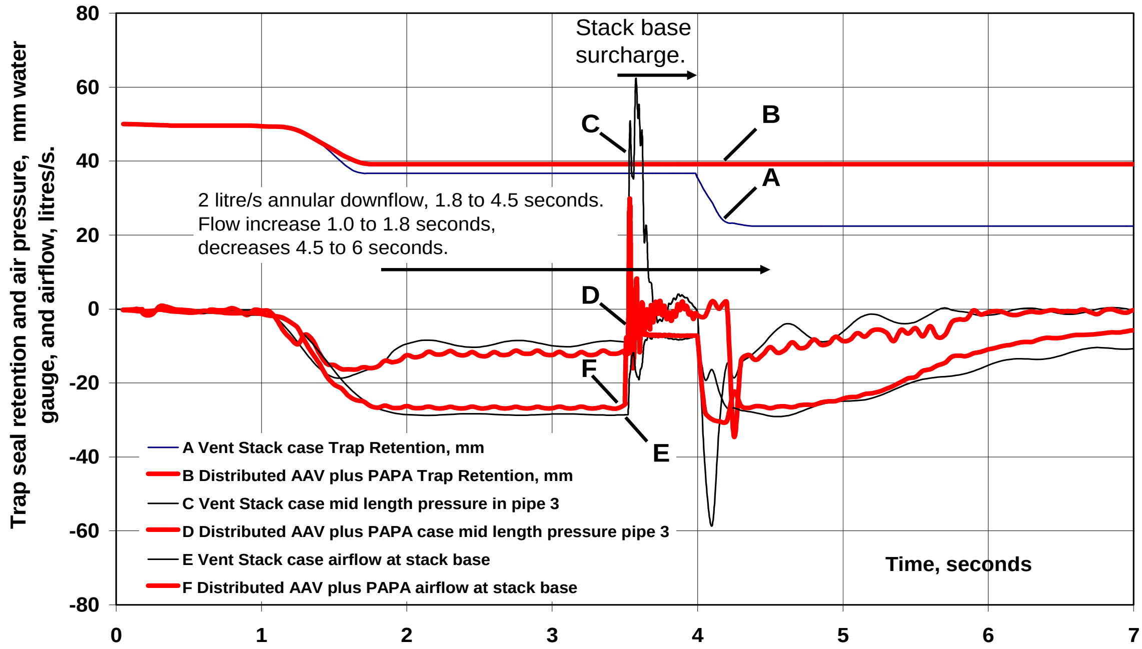


Figure 8 - Active Control through AAV and PAPA™ units compared to a standard parallel vent system.

Table 1 compares trap seal retention and peak pressure following surcharge for all cases. Active Control results in improved trap seal retention. Introducing AAVs alone reduces the positive transients experienced as the airflow into the network is reduced and so the stack base surcharge acts on a lower entrained airflow, generating a weaker transient. Table 1 indicates that for a parallel vent system to have a similar performance, the vent diameter would have to be twice that of the wet stack diameter at 200 mm, a result justified by the transient transmission relationship for junctions.

Reducing vent diameter increases the transmission coefficient and reduces attenuation. A 200 mm vent stack diameter reduces the transmission coefficient to 0.33 and allows greater diversion of the airflow that would have been brought to rest by the surcharge, thus conforming to the concept of surge protection already discussed – a similar but less efficient mechanism to that used by the PAPA^{TM} (Swaffield et al 2005).

Network description, Figure 4	Trap seal retentior	Trap seal retention	Maximum pressure
	mm water gauge.	mm water gauge.	mm water gauge.
	at 3.5 seconds.	at 7.0 seconds.	mid length pipe 3
Parallel Vent Stack, 200 mm dia. with 100 mm dia. cross vents.	45.68	41.25	16.85
Single Stack, Distributed AAV pipes 6, 7, 9, 3, PAPA pipe 2.	39.20	39.20	28.16
Parallel Vent Stack, 200 mm dia. with 50 mm dia. cross vents.	41.82	36.38	22.18
Single Stack, AAV pipe 7 and 9, PAPA pipe 2.	35.08	35.08	18.90
Single Stack, AAV pipe 7 and 9, PAPA pipes 2 and 7.	34.48	34.34	18.39
Single Stack, AAV pipe 9, PAPA pipe 2.	33.49	31.12	20.90
Single Stack, AAV pipe 9, PAPA pipe 2 and 7.	33.54	30.67	18.13
Single Stack, Distributed AAV pipes 6, 7, 9, 2.	39.74	26.74	51.70
Parallel Vent Stack, 80 mm dia. with 50 mm dia. cross vents.	36.70	22.44	62.40
Single Stack, AAV pipe 7 and 9 no PAPA.	35.08	17.44	48.41
Single Stack, PAPA on pipe 2.	28.07	13.32	20.83
Single Stack, AAV on pipe 9.	34.00	12.82	55.94
Single stack, no AAV, PAPA or paralel vent.	27.80	1.58	62.43

Table 1 - Comparative system performance for various levels of Active Control and parallel vent sizing.

The modelling capability provided by the Method of Characteristics and the application of pressure surge analysis to building drainage and vent systems presents an opportunity to re-evaluate drainage design to reduce both complexity and labour and equipment costs while providing effective protection against cross contamination via the depletion of trap seals.

6. Conclusions.

Building drainage and vent system design relies on codes that in the main have been developed from practice 'rules of thumb' or steady state experimental research, much now dated or, as demonstrated by this paper, based on a fundamental misunderstanding of the mechanisms of transient control and suppression based on passive, fixed in place, vent networks – the traditional basis of system venting. There is a need to re-evaluate the design of these networks against current criteria, including water conservation, an escalation in building complexity, increased occupation levels, enhanced concerns as to cross contamination and ever increasing building height. Reliance on codes is no longer sufficient. There is a need to move drainage design into the same arena as other building services system design where validated simulation techniques provide a background to allow designers and consultants to deal with applications that lie outside the specific range of cases dealt with in codes. The Method of Characteristics driven simulations presented in this paper, along with the Active Control design opportunities, provide a basis for this re-evaluation that rests on extensive research as well as drawing on over a century of analysis and practice in the area of pressure surge theory. It is hoped that this paper will encourage the drainage design community to undertake this re-evaluation.

7. References.

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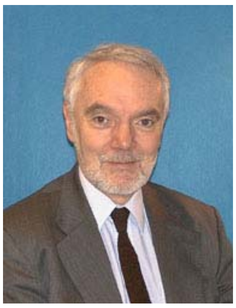
8. Nomenclature.

A	Pipe cross section, m^2.	C^{+-}	Characteristic equations.
c	Wave speed, m/s.	f	Friction factor
p	Air pressure, N/m^2	Q	Air/water flowrate, m^3/s.
t	Time, seconds.	u	Mean air velocity m/s.
V	Stack water, air velocity m/s.	x	Distance, m.
γ	Ratio specific heats.	μ	Viscosity kg/ms.
Δp	Pressure change, N/m^2	Δt	Time step, s.
Δu	Velocity change, m/s.	Δx	Internodal length, m.
ρ	Density, kg/m^3	atm	Atmospheric pressure
R,S,P	Nodal points.	$t+\Delta t,t$	Conditions at node at a time.

9. Presentation of Author



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F4) Experimental Studies on Flow Characteristics of Siphon Drainage System

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Abstract

The drainage system with drain pipes with diameter of 20mm, which makes use of siphon effect, creates full discharge flow of considerable speed to draw out subsequent discharge. On the other hand, drainage systems currently in general use have open channel flow requiring in horizontal sloping drain pipes for effective discharge. The siphon drainage system may successfully cope with problems associated with wavy piping and cross piping as it does not require slope for discharging. Small diameter pipes used in the system also contributes to downsizing of pipe space and greatly expand the freedom of designing piping layouts. In this study we conducted experiments simulating the siphon drainage system in apartment buildings with a view to collecting basic data for designing siphon drainage systems, and examined resistances and flow characteristics of factors such as bending piping, straddling piping and piping trap.

Keywords

Siphon drainage system, Basic design data, Piping trap, Straddling piping, Experiment

1. Introduction

The above-ground drainage system currently in use is highly valued as an ultimate energy saving system as it operates on gravity requiring no external energy sources. However, its horizontal drain pipes, relying on the difference of head created by slope for transportation, have a weak performance of transport causing various problems as poor drainage and clogging, etc. The drain pipes used in the system also, having larger diameters than water and hot water supply pipes, become an obstacle to integration of piping. In addition, the system requires a large space for piping, and severely limits a freedom of piping installation with problems associated with cross piping and securing slope.

In Japan modern apartment houses have a history of approximately 40 years, and now the overhaul and renewal of drain piping are under way at an enormous cost. On the other hand, constructions of super long life apartment houses that are expected to last 100 to 200 years have been promoted as part of efforts to create a recycle-oriented society. In developing these houses the concept of Skelton Infill house (SI house) is playing an important role. In the Skelton Infill concept the building body is designated as Skelton, and the interior finishing and building service as Infill. Infill is expected to be modified freely whenever necessary. Changes in arrangements of plumbing fixtures necessitate changes in the length of horizontal drain pipes. In some cases the horizontal sloping drain pipes may not be adequately obtained due to limitations of space. Given the architectural conditions mentioned above, the drainage system seems to be the sole obstacle to the SI house concept, but the siphon drainage system has prospects of removing that obstacle.

The use of siphonic rain water drainage system in particular has been extensively studied having a considerable track record[1]. But when it comes to application of the siphon drainage system to general indoor drainage, it was the study by N. Tsukagoshi in 1999 that paved the way[2]. Since then multi-faceted research has been undertaken by various organizations including Urban Renaissance Agency, piping manufacturers, house makers, Meiji Univ. and general contractors. The contents of such undertakings were summarized and presented by Tsukagoshi at Symposium of CIB W062 in 2007[3].

In this study we conducted experiments simulating the siphon drainage system in apartment buildings with a view to collecting basic data for designing siphon drainage systems, and examined resistances and flow characteristics of factors such as bending piping, straddling piping and piping trap.

2. Characteristics values of siphon drainage piping

We examined partial resistance (pressure loss) of bend pipes that compose the siphon piping, and obtained their equivalent pipe lengths.

2.1 Outline of Experiment

The experimental apparatus is shown in Figure 1. As shown in Table 1, we made four piping models, and filled the pipes with full flow after relieving air. We then measured pressure in each piping model to obtain basic data of the siphon piping system from the differences in pressure at points of measurements. In each piping model measurements were made at three points in the order of A, B and C from upstream, and flow rates were set at 30, 25 and 15ℓ/min. The components used for the experiment of partial resistances are shown in the figure 1. In this study pressure was measured with a diffusion semiconductor type pressure sensor.

2.2 Results and Discussion

2.2.1 Pressure loss in socket

After the initial experiment, we examined pressure loss caused by sockets in the experiment with the piping model 1 as we intended to use drainage sockets at connections of piping, but found no pressure loss at connections. Therefore we gave no further thought to the influence of sockets in later experiments.

2.2.2 Loss grade and velocity coefficient

Using the piping model 1, we calculated loss grades in unplasticized polyvinylchloride pipes at each flow rate. We also calculated coefficients of velocity using the transposition equation of Hazen-William formula (Table 2), and compared the loss grades and velocity coefficients we obtained from our experiments with those described in the flow rate charts for unplasticized polyvinylchloride pipes in SHASE-S206[4] (Table 3). Regardless of flow rates, the loss grades obtained from our experiments were smaller than the standard values in SHASE-S206. In contrast, the coefficients of velocity in our experiments tended to be slightly larger (C=134~145) than the standard velocity coefficient (C=130) though there were some variances at different flow rates.

2.2.3 Partial resistance (Pressure loss)

Next we obtained pressure loss caused by the curvature of siphon piping (Table 4) by using bend pipes with radius of curvature R5D (R100) at four curved sections between A and B in the piping model 2, and those with R4D (R80) at four sections between B and C (Figure 2). The results showed little difference between R5D bend pipes and R4D bend pipes. The pressure loss caused by bend pipes was found to be approximately 1.3 times the loss caused by straight pipes of equivalent lengths.

2.2.4 Pressure loss in piping with multiple bends

The piping models were designed in such a way that each model had the different number of bends from others. The comparison of three piping models: piping model 2

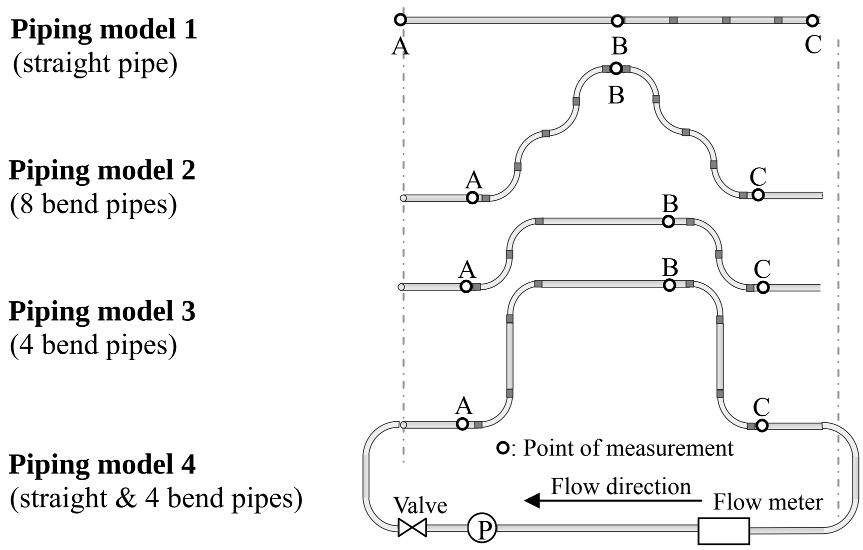

Figure 1 - Experimental apparatus and piping models

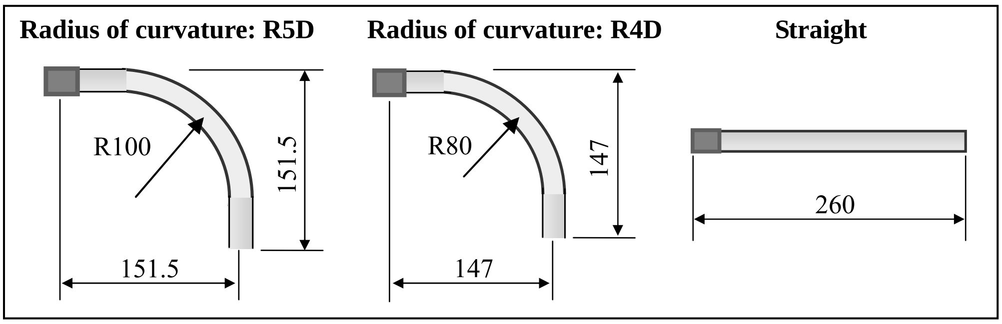

Figure 2 - Piping compositions

Table 1 – Piping composition of piping models

Piping model	Piping composition	
1	Straight pipe	A-B: without socket, B-C: with socket
2	8 bend pipes	A-B : R5D (R100), B-C : R4D (R80)
3	4 bend pipes	A-B : R4D (R80), B-C : R4D (R80)
4	Straight pipe & 4 bend pipes	A-B : R4D (R80), B-C : R4D (R80)

Table - 2 Transposition equation of Hazen-Williams formula

$$C = Q / (1.6712\, C \times i^{0.54} \times D^{2.63} \times 10^4) \ldots\ldots (1)$$

C : velocity coefficient [-] Q: flow rate [ℓ/ min]
i : loss grade [mAq/ m] D : pipe diameter [m]

Table 3 - Loss grades and velocity coefficients

Loss grade/ Velocity coefficient		Flow rate [ℓ/min]		
		30	25	15
Loss grade [mmAq/m]	Experiment value	1504	1056	374
	Value of SHASE-S206	1842	1314	510
Velocity coefficient [-]	Experiment value	145	142	134
	Value of SHASE-S206	130		

Table 4 - Pressure losses of piping compositions

Piping composition	Pipe length	Flow rate [ℓ/min]		
		30	25	15
R5D (R100)	260	492 (1.25)	360 (1.30)	150 (1.44
R4D (R80)	260	504 (1.28)	362 (1.31)	132 (1.31)
Straight	260	394 (-)	277 (-)	104 (-)

[Note] ( ): ratio of pressure loss of bend pipe to it of straight pipe

Table 5 - Pressure loss of piping models

Piping model	Number of bent pipes	Flow rate [ℓ/min]		
		30	25	15
2	4	504	362	132
3	2	471	328	125
4	1	529	368	146

(4 bends between A and B), piping model 3 (2 bends between A and B), piping model 4 (1 bend between A and B) is shown in Table 5. For all piping models bend pipes with R4D radius of curvatures were used. Little difference was found in pressure loss among the piping models, which indicates that multiple bends in the piping has practically no influence on pressure loss.

3. Resistance coefficient of straddling piping and piping trap

In this phase of the experiments we intended to define the resistance coefficients of straddling piping and piping trap.

3.1 Outline of Experiment

Piping trap, P trap and straddling piping used in the experiment are shown in Figures 3 and 4, and the experimental apparatus in Figure 5. A straddling piping was set up in such a way that the seal depth of the traps and the height of the straddling piping were 50mm. The water level of the kitchen sink and heads between the horizontal fixture drainage pipes were kept constant at 750mm to prevent air bubbles from flowing into the pipes, and discharges were made. Pressures were measured in each trap, at both ends of the straddling piping, and in the measurement tank.

3.2 Results and Discussion

We calculated resistance coefficient from the measured pressure data, and the results are shown in Table 6. Resistance coefficients for straddling piping, piping trap and P trap were 0.95, 0.82, 1.02 respectively and the friction factor for straight piping was 0.024. Equivalent pipe lengths of straddling piping, piping trap and P trap were 0.29, 0.68 and 0.85. Both resistance coefficients and equivalent pipe length of piping trap were smaller than those of P trap. Therefore the effects of piping trap on siphon discharge were found to be relatively small compared to those of P trap and straddling piping.

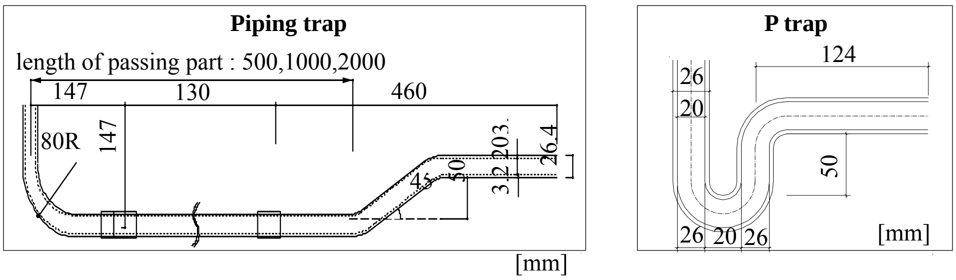

Figure 3 – Piping trap and P trap

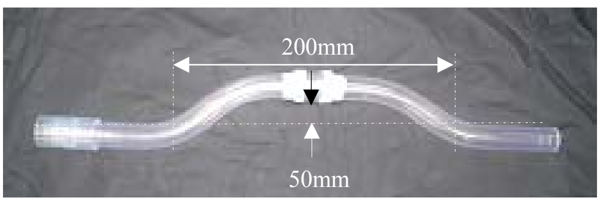

Figure 4 - Straddling piping

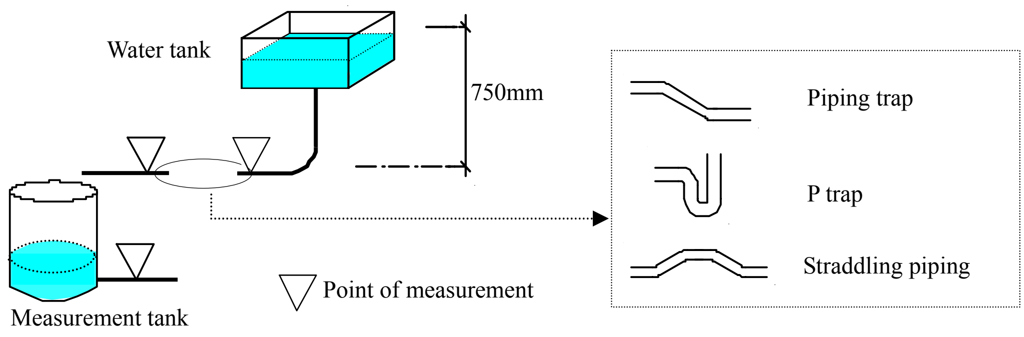

Figure 5 - Experimental apparatus for partial resistance (pressure loss)

Table 6 - Resistance coefficients and friction factor

Coefficient / Factor	Piping composition			
	Straddling piping	Piping trap	P trap	Straight
Resistance coefficient ζ	0.95	0.82	1.02	-
Friction factor λ	-	-	-	0.024

4. Flow characteristics of siphon drainage basic piping model

This phase of the experiment was intended to examine flow characteristics of the siphon drainage basic piping model without traps or straddling piping.

4.1 Outline of Experiment

The definitions of basic components of the siphon drainage system: inflow head (H_i), length of horizontal pipe (L_h), outflow head (H_o), and siphon head (H_t) are shown in Figure 6. As is shown in Figure 7, a siphon drainage model with basic piping ("basic piping model") was constructed as the test drainage fixture simulating a water basin to accommodate variable settings: the distance from the bottom of the fixture to the horizontal piping = 560mm; length of horizontal pipe L_h = 4,000, 6,000, 8,000mm; outflow head H_o = 500, 1,000, 1,500mm. Unplasticized polyvinylchloride pipes (diameter: 20mm) were used, and bend pipes of R80 were placed at two sections in L_h: 4,000mm pipes, and four sections in L_h = 6,000 and 8,000mm pipes. A water tank with the dimension of 430×600×320 was used as a drainage fixture. Flow rate and velocity was calculated from pressure values read by a sensor placed in the measuring tank.

As shown in Table 7, two styles of discharge, one with running water and the other with filled water were adopted. In discharge with running water, water was supplied continuously at the flow rates of 4, 8, and 12ℓ/min., which were thought to simulate the real life flow rate conditions. In discharge with filled water, water was filled to the depth of 160mm, and continuously supplied at the rate of about 40ℓ/min. to keep the water level constant (H_i = 700mm).

4.2 Results and Discussion

Flow rates and phases of flow varied depending on the styles of discharge. Figure 8 shows phases of flow and Figure 9 indicates flow rates and accumulated water volumes.

4.2.1 Discharge with running water

The phases of flow varied depending on the rate of water supply with the average value of discharge flow rate being about the same as that of supply flow rate, but were not affected by the length of horizontal pipe or outflow head. Discharge flow rate was constant with supply flow rate of 4ℓ /min., turbulent with supply flow rate of 8ℓ/min., and became stable again with 12ℓ /min. The phase in which the flow rate became stable with the supply rate of 4ℓ /min. is referred to as "partial full flow, the turbulent phase with the supply rate of 8ℓ /min. as "intermittent flow", and the last phase where the flow returned to a stable state as "bubble flow" below.

4.2.2 Discharge with filled water

In all piping models siphon effect operated with no air bubbles mixed in, and full discharge flow ensued. Discharge flow rate was constant (Figure 9). Based on the principle of conservation of kinetic energy, we clarified the relationship of total head and piping with each loss of head, and created an equation for calculating velocity (Table 8). If we assign each parameter (λ: 0.02, d: 0.02m, ζ: 0.5) to the equation, and denote loss grade I as $I = H_t / L_e$ (where $L_e = 1.2m + \Sigma\zeta + 1$), the relationship of velocity and loss grade can be expressed by Equation (6). In this way we compared the theoretical velocity, v_t with the experimental velocity, v_e (Figure 10). The constant of

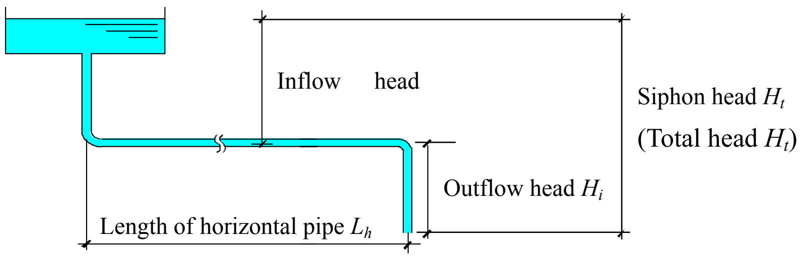

Figure 6 – Definition of basic composition of siphon drainage system

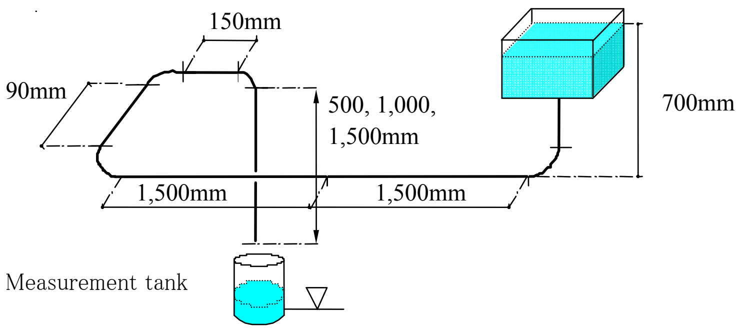

Figure 7 – Example of siphon drainage model with basic piping (L_h = 4,000mm)

Table 7 – Experimental conditions

Length of horizontal pipe L_h [mm]	4,000, 6,000, 8,000	
Inflow head H_i [mm]	500, 1,000, 1,500	
Discharge style	Discharge with running water	4, 8, 10 [ℓ/min]
	Discharge with filled water	Inflow head H_i = 700 [mm]

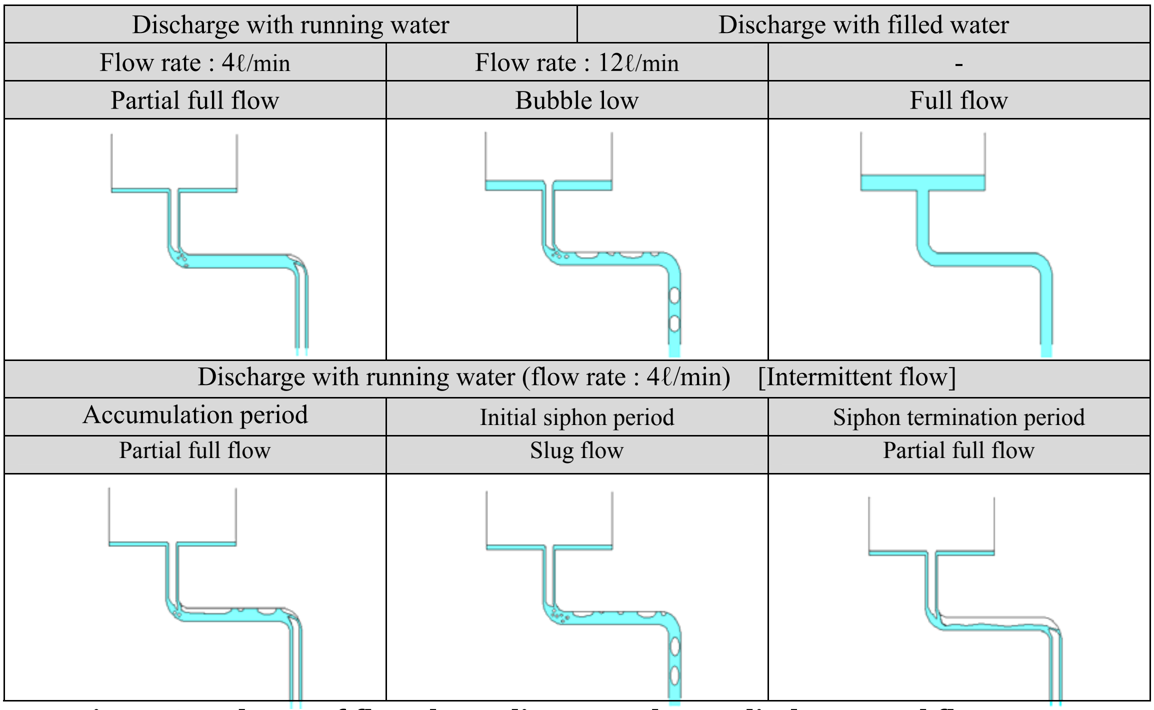

Figure 8 – Phases of flow depending on styles on discharge and flow rates

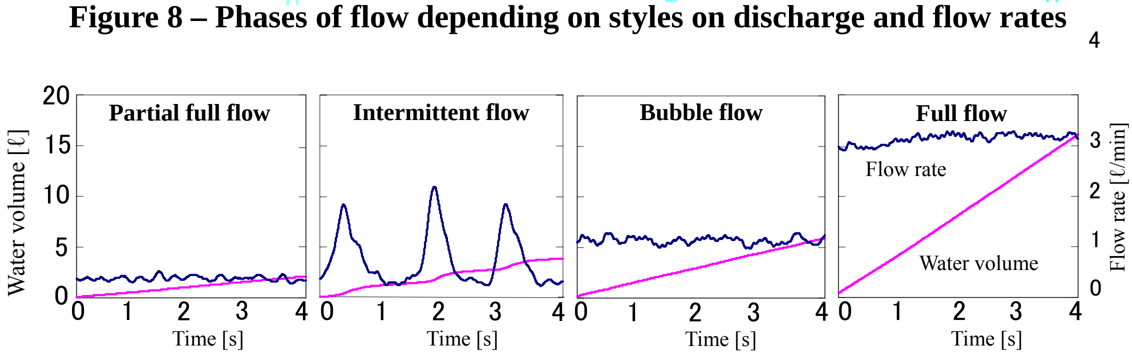

Figure 9 – Flow rates and accumulated water volumes by phases of flow

Table 8 – Equations for calculating velocity

$$H_t = \lambda \frac{l}{d} \cdot \frac{v^2}{2g} + \left(\sum \zeta\right) \frac{v^2}{2g} + \frac{v^2}{2g} \quad \cdots\cdots\cdots (2)$$

$$v_t = (\, 2\, gH \,/\, (\, \lambda \frac{l}{d} + \sum \zeta + 1\,)^{1/2} \quad \cdots\cdots\cdots (3)$$

$$L_e = 1.2l + \sum \zeta + 1 \quad \cdots\cdots\cdots (4)$$

$$I = H_t / L_e \quad \cdots\cdots\cdots (5)$$

$$v_t = 4.43\sqrt{I} \quad \cdots\cdots\cdots (6)$$

d : pipe diameter [m]
g : acceleration due to gravity [m/s^2]
I : loss grade [m/m]
H_t : total head [m]
l : pipe length [m]
L_e : equivalent pipe length [m]
v_t : velocity [m/s]
ζ : partial resistance [-]
λ: friction factor [-]

proportion: 4.33 derived from the theoretical formula and regression coefficient: 4.22 obtained from the experiment were found to be extremely close to each other. From this we can safely conclude that flow velocity in piping of a basic drainage system without piping traps or straddling piping can be predicted by Equation (6) when discharge is made with filled water.

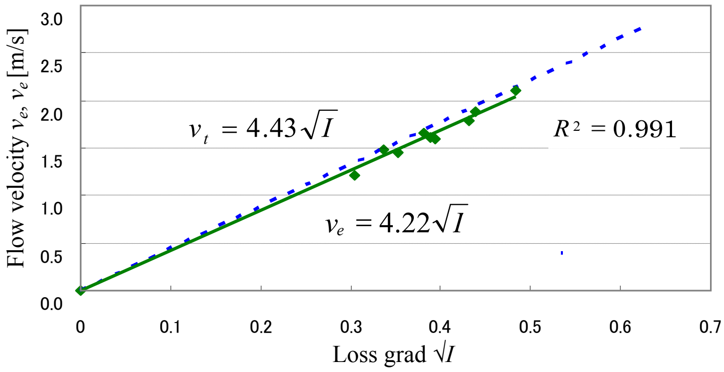

Figure 10 Relation between v_t or v_e and $I^{1/2}$

5. Flow characteristics of siphon drainage variant piping models

This phase of the experiment was intended to examine flow characteristics of the siphon drainage piping models with piping trap and both piping trap and straddling piping.

5.1 Outline of Experiment

5.1.1 Piping model with piping trap

We attached piping trap (length of passing part: 500mm, H_i: 630mm) to the experimental apparatus shown in Figure 7 in this phase of the experiments. Experiments were conducted under the following conditions: length of passing part = 500mm; length of horizontal piping from piping trap = 4,000, 6,000, 8,000mm; outflow head H_o = 500, 1,000, 1,500mm. Actual measurement values were calculated in the same way as 4.1. Discharge was made with running water at the rate of 4, 8 and 12ℓ/min. and with filled water by supplying water to a discharging apparatus until the water level reached the prescribed height (H_i: 700mm) and removing the plug to start discharging.

5.1.2 Piping model with piping trap and straddling piping

We attached piping trap and straddling piping (piping length = 500mm, piping height = 50mm) to the experimental apparatus shown in Figure 7 in this phase of the experiments. Straddling piping was installed at 1,000mm from the piping trap. The experimental methods were the same as *5.1.1*.

5.2 Results and Discussion

5.2.1 Piping model with piping trap
(1) Discharge with running water
The average value of discharge flow rate was about the same as that of supply flow rate. Even with piping trap attached, a supply flow rate of 4ℓ/min. created partial full flow, 8ℓ/min. created intermittent flow, and 12ℓ/min. bubble flow.

(2) Discharge with filled water
Water was discharged in full flow in the same way as the siphon drainage basic piping model without traps. 0.27, the value obtained by subtracting resistance caused by friction of pipe (pipe length: 460mm) from the coefficient of resistance was added to $\Sigma\zeta$, and the theoretical velocity v_t and experimental velocity v_e were compared in Equation (6) (Figure 11(a)). The constant of proportion derived from the theoretical formula was 4.43, which was extremely close to the regression coefficient, 4.22 obtained from the experiment. From this we can safely conclude that flow velocity in piping of a drainage system with piping traps can be predicted by Equation (6) when discharge is made with filled water.

5.2.2 Piping model with piping trap and straddling piping
(1) Discharge with running water
The average value of discharge flow rate was about the same as that of supply flow rate. Even with piping trap and straddling piping attached, a supply flow rate of 4ℓ/min. created partial full flow, 8ℓ/min. created intermittent flow, and 12ℓ/min. bubble flow.

(2) Discharge with filled water
Water was discharged in full flow in the same way as the siphon drainage basic piping model without traps. 0.27 and 0.35, the values obtained by subtracting resistance caused by friction of pipe (pipe length: 460mm) from the resistance coefficient were added to $\Sigma\zeta$, and the theoretical velocity v_t and experimental velocity v_e were compared in Equation (6) (Figure 11(b)). The constant of proportion derived from the theoretical formula was 4.43, which was extremely close to the regression coefficient: 4.36, obtained from the experiment. From this we can safely conclude that flow velocity can be predicted by Equation (6) in this case as well.

(a) Piping model with piping trap and straddling piping

(b) Piping model with piping trap and straddling piping

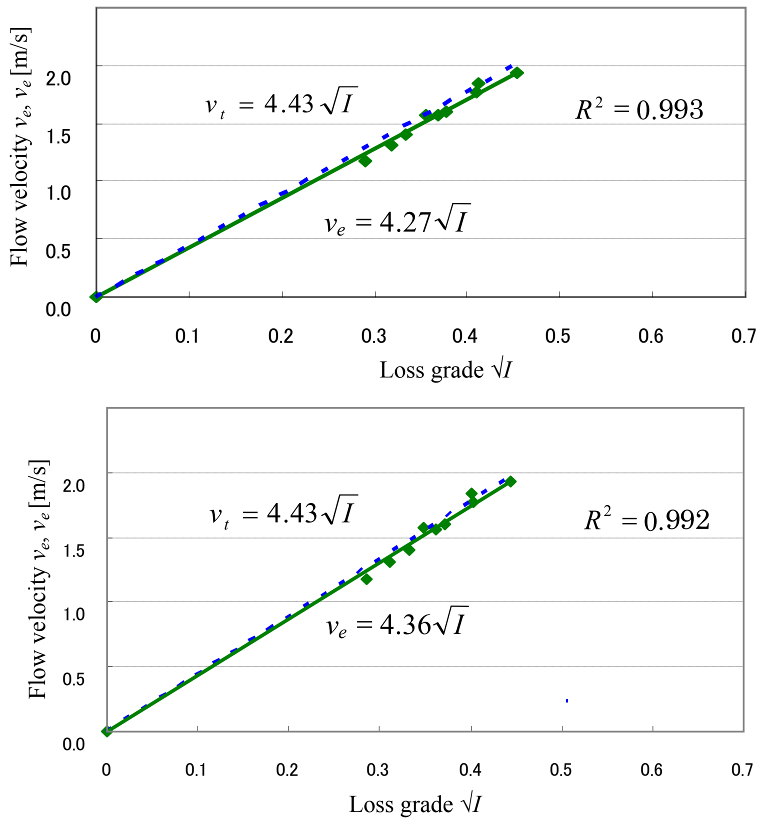

Figure 11 Relation between v_t or v_e and $I^{1/2}$

6. Conclusion

The results of experiments described above can be summarized as follows:
(1) The pressure loss caused by R5D (R100) and R4D (R80) bend pipes was found to be approximately 1.3 times the loss caused by straight pipes of equivalent lengths, and the use of multiple bends in piping had no effect on pressure loss. This seems to indicate that curvatures in fixture drainage pipes (horizontal drainage pipes) have little effect on their discharge performance.

(2) Various flow phases in discharge with running water have been clarified. It also became clear that the velocity in discharge with filled water could be obtained from Equation (6) for each of the piping models: the basic piping model without trap or straddling piping and varied piping models with trap and straddling piping. Some of the future challenges for effective application of the siphon drainage system include:

1) To clarify flow characteristics in various types of fixtures and piping patterns; bathtubs with low inflow head and drain pans for washing machines in particular.
2) To examine seal strength of piping traps.
3) To examine performance such as discharging conditions in real buildings.
4) To come up with ways to cope with problems such as clogging of drainage pipes with wastes and ways to clean drainage pipes.
5) To clarify the effects of drainage stacks on pneumatic pressure.

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8. Presentation of Author(s)

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F5) Study of the Prediction of Influences of Different Air Admittance Valves on the Drainage Capacity of the Drainage Stack System
-The examination of prediction results according to different pipe diameters

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Abstract

This report uses the results of the experiment, which was explained at the CIBW062 Symposium 2007 (held in Brno, the Czech Republic), which used a simplified apparatus with different types of air admittance valves, to actually predict influences of such air admittance valves on the drainage capacity of the drainage stack system with the purpose of examining the effectiveness of the prediction method.

To be more specific, the report focuses on the following three points:
1. From the results of the experiment, which used a simplified apparatus, the air flow characteristics of air admittance valves with different pipe diameters were each identified.
2. The previously-proposed drainage capacity prediction method was explored further so that the method could also be applied with many different pipe diameters.
3. The results acquired from 1 were applied to 2, the drainage capacity of the drainage stack system was predicted using different pipe diameters, and the prediction results were compared with the actually measured results.

Keywords

Air admittance valve (AAV); drainage capacity; prediction of pipe pressure;
airflow resistance; air flow rate

1. Introduction

In Japan, subsequent to the revision of the Building Standards Law 2000, it is now allowed to install AAVs with a back-flow prevention function to the end of vent pipes of drainage systems, and some new products have been introduced from overseas, many products have been developed domestically and many AAVs are currently available for sale. However, it is necessary to implement various performance tests when applying AAVs in the design of drainage stack systems. With these facts as a background, this study aims to propose a method which enables the implementation of a simple drainage performance test for the drainage stack system, which incurs the most labour and cost among the items to be tested for the evaluation of AAV performance.

As shown in **Fig.1** Flow of the Study, five commonly available types of AAVs were evaluated, with reference to the results of a simple airflow characteristic test and by using the drainage capacity prediction method proposed by the past study[1)], to see how they each would influence the drainage capacity of the drainage stack system as well as to examine how effective it would be to apply the prediction method. The previous study[2)] also looked at the effectiveness of the prediction method using an experimental AAV of 100A diameter. This study furthers the previous study with the intention of widening the application of the method to various types of drainage stack systems and AAVs of different diameters (50A, 65A, 75A, 100A, 125A). To be more specific, this study focuses on the following three points:

(1) From the results of a simple airflow characteristic test, the airflow resistance coefficients of the AAVs, which can be used with many different pipe diameters, are formulated using airflow rates and two parameters of each pipe-diameter. The formulated coefficients are presented as reference for the design of vent pipes.
(2) The previously proposed drainage capacity prediction method is expanded so that it can be applied to many different pipe diameters and the evaluation of influences on the drainage capacity is estimated within a practically effective scope.
(3) The drainage capacity is compared between when a bellmouth is installed, which is standard in design, and when the AAVs are installed to the vent section of the drainage stack system.

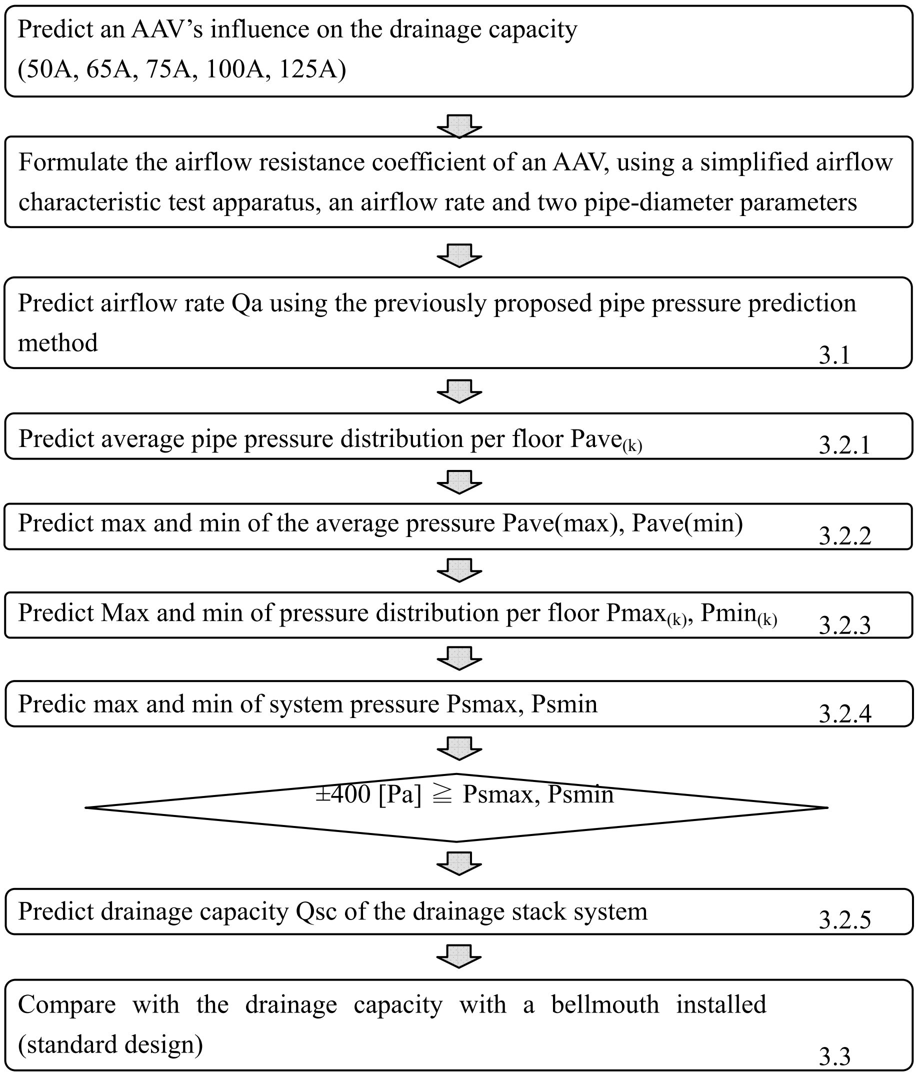
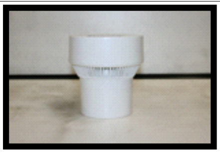


Figure 1 - Flow of the study

2. Testing methods

Table 1 shows the various types of AAVs and different diameters that were used for experiments. In the previous study[2)], an airflow characteristic test was conducted using an AAV with 100A diameter, and with reference to the results of the test, the AAVs are divided into Group1 (type A – C), Group2 (type D) and Group3 (type E) for this study.

Table 1-Experimental AAVs and their characteristics

Group	Type	Photo	Diameter [A]					Characteristic
			125	100	75	65	50	
1	A		*	*	*	*	*	Eccentric core type
	B		*	*	*	*	*	Common type
	C			*	*	*	*	Rail type
2	D			*	*	*	*	Spring type
3	E			*				Insect screen type

2.1 Airflow characteristic test

Using the simplified airflow characteristic test apparatus (**Fig.2**), which was suggested in the previous study[2)], the airflow characteristic test was implemented on the experimental AAVs with diameters applied (50A, 65A, 75A, 100A, 125A) which are listed in **Table 1**. With reference to the airflow rates acquired and the actual measured values of pipe pressure, airflow resistance coefficient ζ of each of the AAVs was calculated using **formula (1)**. Also, for each Group, airflow resistance coefficient ζ was acquired using airflow rate Qa and inside pipe diameter D [mm] as parameters.

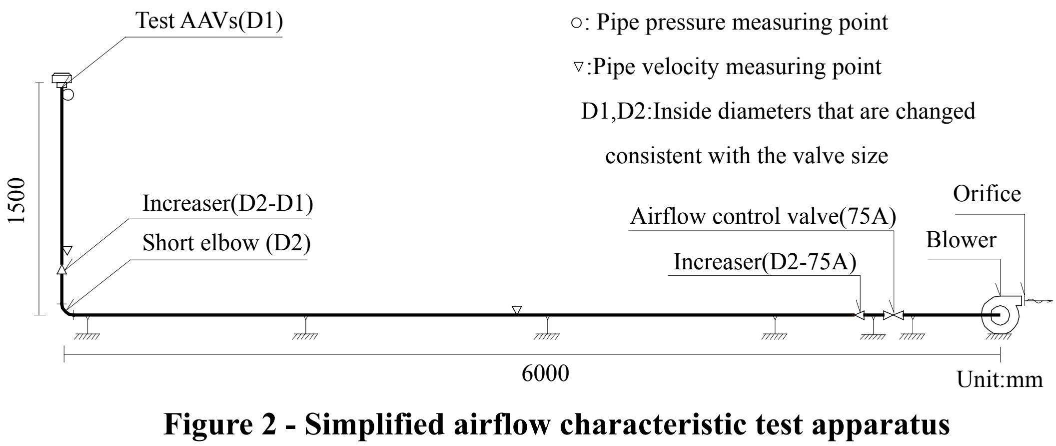


Figure 2 - Simplified airflow characteristic test apparatus

$$P = \zeta \frac{\rho}{2} \left(\frac{Qa}{A} \right)^2$$ ... **Formula (1)**

P: Inside pipe pressure [Pa]

ζ: Airflow resistance of air-admittance valve

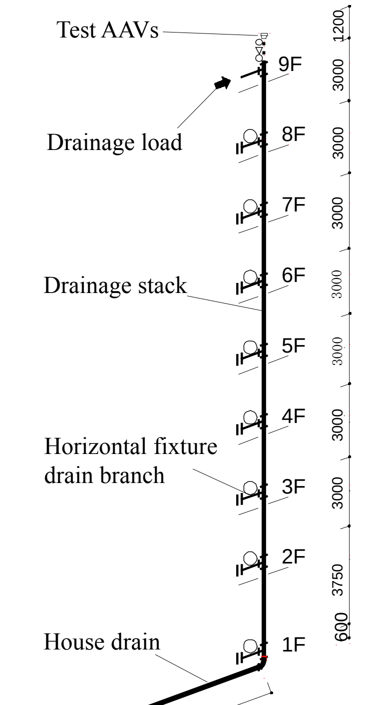
ρ: Air density [kg/m^3]

Qa: Airflow rate [L/s]

A: Pipe sectional area [m^2]

2.2 Drainage capacity test

The environmental experimental construction simulation tower (26.5m high, **Fig.3**) at Kanto Gakuin University was used for the drainage capacity test and the test was carried out consistent with SHASE-S218 "Testing Method of Flow Capacity for Drainage System in Apartment Houses[3]. The experimental drainage stack employs a vent pipe system using five types of JIS-DT fittings with the pipe diameters in the table (50A, 65A, 75A, 100A, 125A). In addition, a horizontal fixture drain branch and a house drain were integrated and their gradients were specified as shown in **Fig.3**. The maximum and minimum system pressure, Psmax and Psmin, of the fluctuation of pipe pressure which is generated on each floor were acquired and they were determined to fall within the criterion value of ±400Pa[4]. The maximum drainage flow rate when reaching the criterion value was acquired as drainage capacity Qsc[L/s]. The main items to be evaluated by the tests in **2.1** and **2.2** are the airflow rate of the vent pipe and the fluctuation of pressure in the horizontal fixture drain branch on each floor. The measuring points are as shown in the diagram.



Note

○:Pipe pressure measuring point

▽:Pipe velocity measuring point

Drainage stack system outline

Test AAV , Drainage stack	Drain branch	House drain
125A	75A 1/50	150A 1/200
100A	75A 1/50	125A 1/150
75A	75A 1/50	100A 1/100
65A	65A 1/50	75A 1/100
50A	50A 1/50	65A 1/50

Drainage load

Drainage load floor: 9F
Drainage load flow: 1.0,1.5,2.0,2.5L/s

Items for evaluation, measuring instruments

Pipe centre velocity: Pressure sensor
Pipe pressure fluctuation : Hot-wire anemometer

Unit :mm

Figure 3 - Experimental drainage stack system

2.3 Drainage capacity prediction method

This study intends to apply the drainage capacity prediction method which was proposed by the past study[1]. To be more precise, as shown in **Fig.4**, using the direct current circuit theory, the total airflow resistance value of the drainage stack system is balanced with the total suction of airflow and the relationship between them is created to predict the airflow rate. Based on the predicted airflow rate, the drainage capacity of the drainage stack system is predicted and compared with the actual measured value. The effectiveness of this prediction method in practical terms is then examined. The calculation formulas are as shown in **Formulas (2)**, **(3)** and **(4)**.

$$P_{(1),(2),(3)} = \zeta_{(1),(2),(3)} \times \frac{\rho}{2} \times \left(\frac{Qa}{A_S}\right)^2$$ **...Formula (2)**

$$P_{(5)} = \zeta_{(5)} \times \frac{\rho}{2} \times \left(\frac{Qa}{A_S}\right)^2$$ **...Formula (3)**

$$\frac{P}{L} = \left(\frac{P}{L}\right)_{(4)} \times Z$$ **...Formula (4)**

ζ: airflow resistance of each zone

Qa: airflow [L/s]

(P/L): suction/1m stack [Pa/m]

Z : height from the house drain [m]

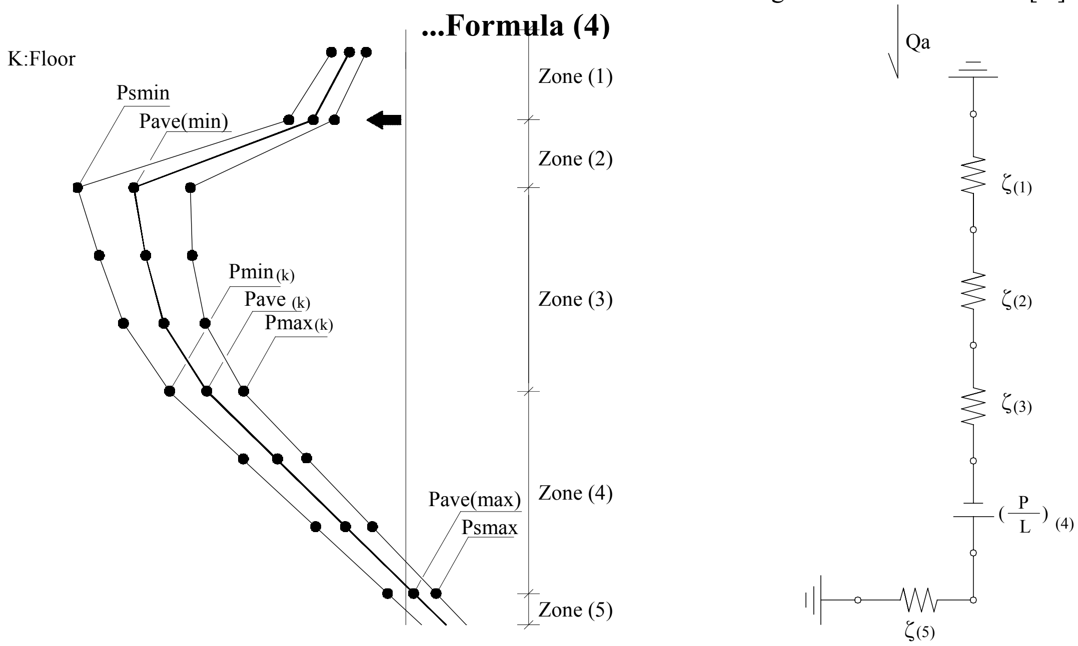


Figure 4 - Concept of pressure distribution and a pipe network model for the prediction of pressure distribution

3. Results and considerations

3.1 Understanding the airflow characteristics of the AAVs

By the simplified airflow characteristic test, airflow resistance coefficient $\zeta_{(1)}$was calculated and its relationship with airflow rate Qa and pipe diameter D was acquired (**Fig.5**). Further, from this diagram, the relationship of airflow resistance $\zeta_{(1)}$ of each of the AAV groups1-3 with airflow rate Qa and actual diameter D[mm] was also acquired. It was assumed that if the diameter and airflow rate of a vent pipe were acquired with each type of AAV, the pressure loss in the AAV section could be estimated. Also, using the same formulas, the drainage capacity can be predicted with each pipe diameter.

Regression equations of airflow resistance coefficients :

Group 1	$\ln\zeta_{(1)} = 0.01(\ln Qa)^{-1.20}(\ln D)^{4.53}$
Group 2	$\ln\zeta_{(1)} = 0.41(\ln Qa)^{-0.41}(\ln D)^{1.79}$
Group 3	$\ln\zeta_{(1)} = 0.01(\ln Qa)^{-0.39}(\ln D)^{3.87}$

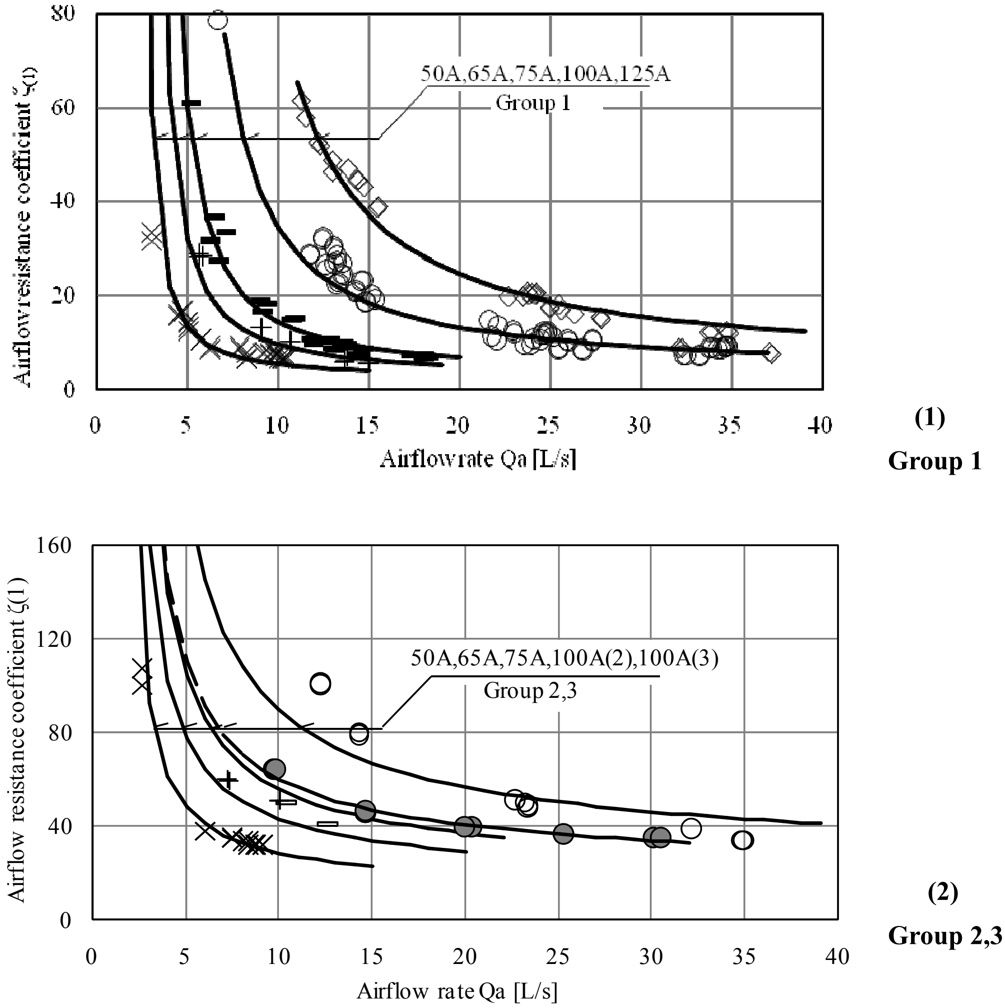
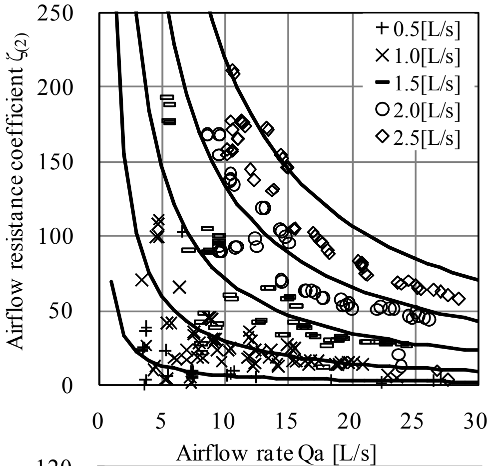


Figure 5 - Relationship between airflow rate Qa and airflow coefficient

3.2 Prediction of drainage capacity

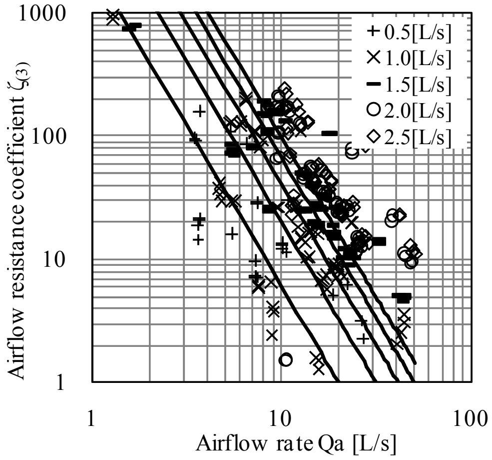
3.2.1 Prediction of airflow rate Qa

Resistance coefficients $\zeta_{(2)}$, $\zeta_{(3)}$ and suction P/L, as shown with the pipe network model in **Fig.4**, are arranged in **Fig.6** using three parameters; airflow rate Qa, pipe diameter D, and drainage load flow rate Qw. The same formula was used as for acquiring $\zeta_{(1)}$ and the values are as shown in the graphs. Based on this, the total resistance was balanced with the total suction from which airflow rate Qa was predicted. The predicted values and the actual measured values are compared in **Fig.7**. Consequently, it was found that when using pipe diameters of 50A, 65A, 75A, 100A and 125A, the difference between the estimated airflow rates and the actual flow rates was more or less within 10%.

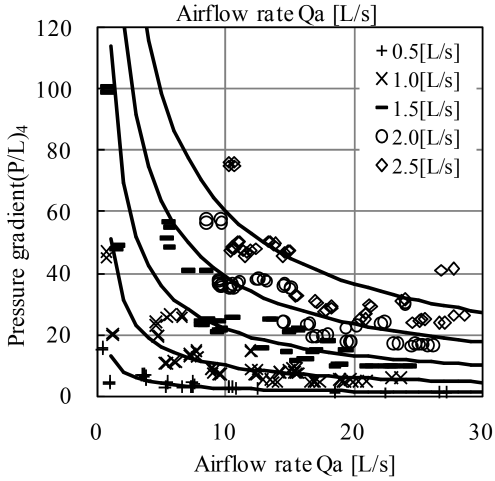


Regression equations:

$\zeta_{(2)} = 645.93 \times Qa^{-1.04} \times (Qw \times 10)^{2.13} \times D^{-1.28}$
$\zeta_{(3)} = 3.0 \times 10^{-5} \times Qa^{-2.61} \times (Qw \times 10)^{1.73} \times D^{3.52}$
$(P/L)_4 = 3.19 \times Qa^{-0.72} \times (Qw \times 10)^{1.98} \times D^{-0.41}$

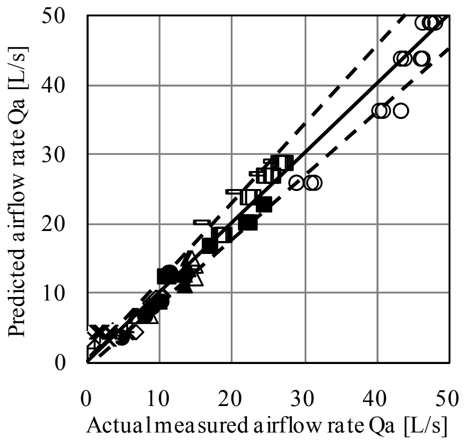


(2) Airflow Resistance Zone 3



(3) Suction($P/L)_4$

Figure 6 - Relationship between airflow and airflow resistance



	125A	100A	75A	65A	50A
Group1	○	□	△	◇	×
Group2		■	▲	◆	+
Group3		−			

Figure 7 - Comparison between airflow rate Qa and the predicted values

3.2.2 Prediction of average pressure/floor $Pave_{(k)}$

Using the method which was proposed by the past study[1)], average pressure/floor $Pave_{(k)}$ was calculated and compared with the actual measured value. The results are shown in **Fig.8**. There is little difference between each predicted value and each actual measured value and they actually match. The prediction of average pressure/floor $Pave_{(k)}$ is therefore deemed to be very possible.

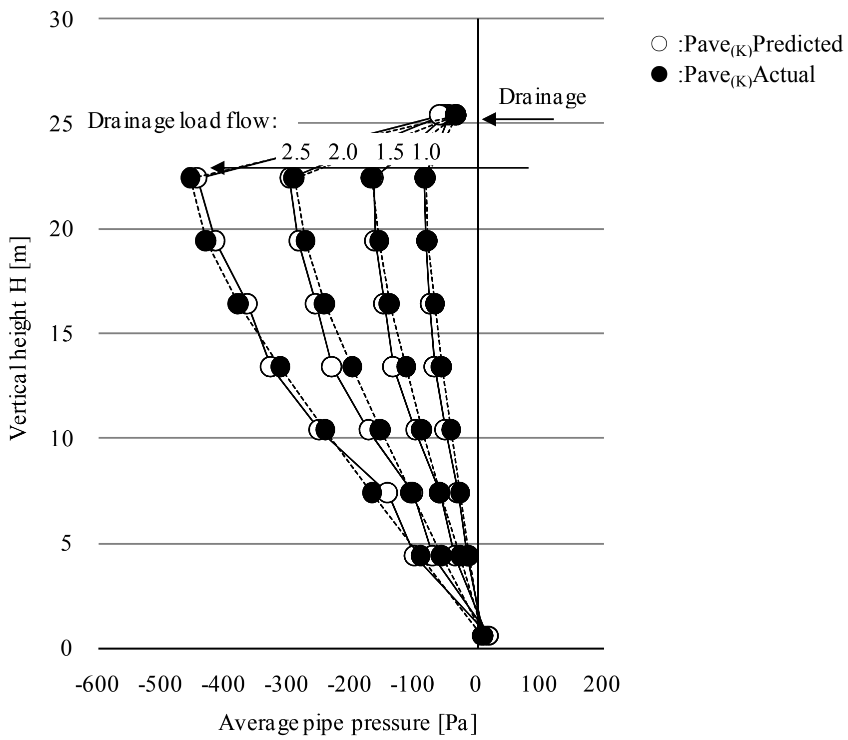


Figure 8 - Average pressure/floor $Pave_{(k)}$ – comparison between predicted values and actual measured values（C-type, 100A nominal diameter）

3.2.3 Prediction of max. pressure/floor $Pmax_{(k)}$ and min. pressure/floor $Pmin_{(k)}$

Max. pressure/floor $Pmax_{(k)}$ and min. pressure/floor $Pmin_{(k)}$ were calculated using **formulas (5)** and **(6)**. Shown in **Fig.9** is the relationship between standard deviation σ and the pipe pressure and it was found that different pipe diameters affected the pressure fluctuation component little. Therefore, the pipe diameters were treated as one; $N_{1(k)}$ =2.79, and using $N_{2(k)}$ = -3.71, $Pmax_{(k)}$ and $Pmin_{(k)}$ were acquired and the predicted values and the actual measured values were compared. An example is shown in **Fig.10**.

$$Pmax_{(k)} = Pave_{(k)} + \sigma_{1(k)} \times N_{1(k)}$$ **... Formula (5)**

$$Pmin_{(k)} = Pave_{(k)} + \sigma_{2(k)} \times N_{2(k)}$$ **... Formula (6)**

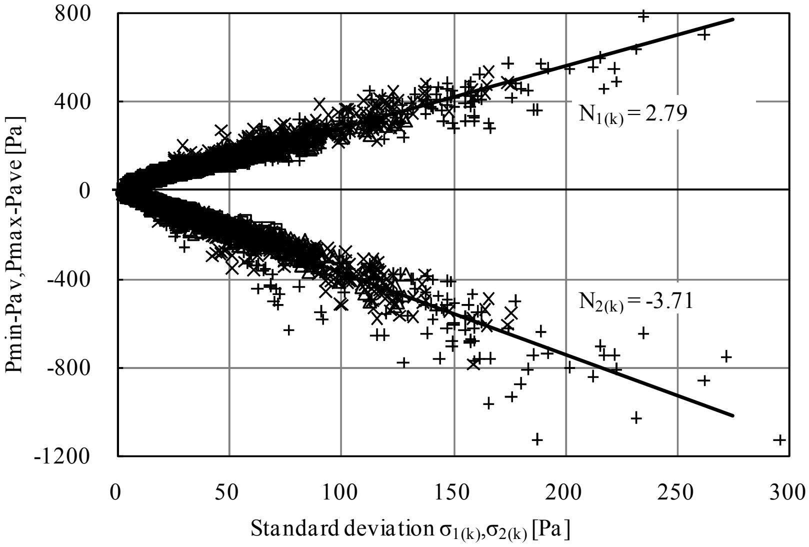
$Pmax_{(k)}$: max. pressure/floor [Pa]

$Pmin_{(k)}$: min. pressure/floor [Pa]

$Pave_{(k)}$: average pressure/floor [Pa]

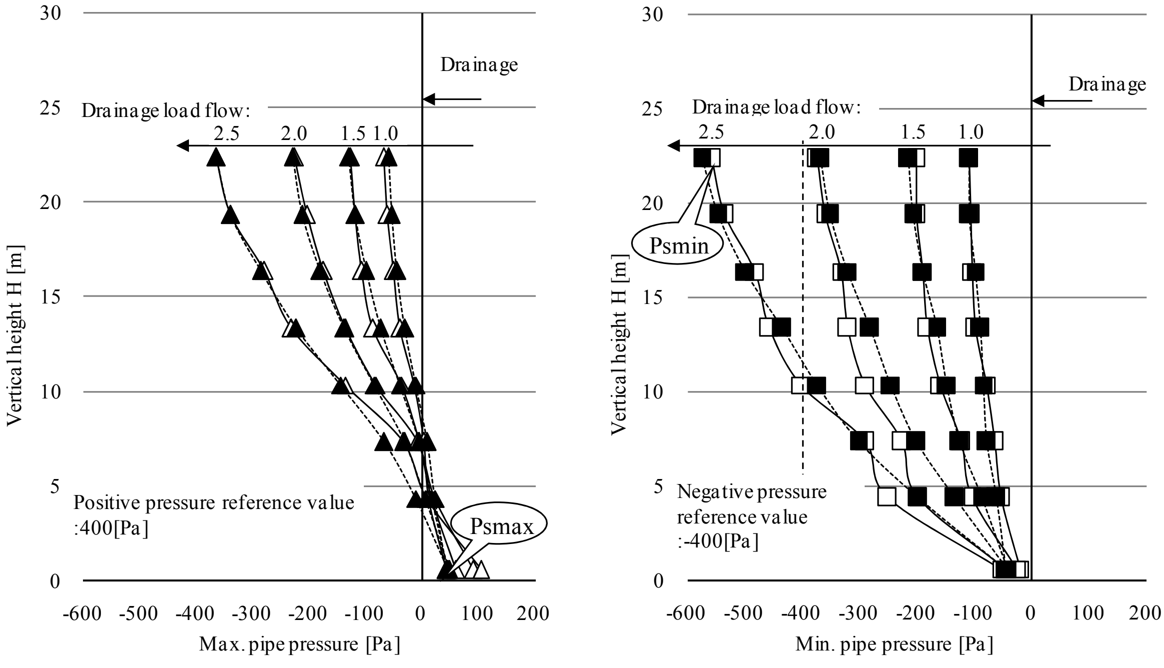
$\sigma_{1(k)}$, $\sigma_{2(k)}$: standard pressure deviation/floor [Pa]

$N_{1(k)}$, $N_{2(k)}$: constant



Diameter	Symbo
125A	○
100A	□
75A	△
65A	×
50A	+

Figure 9 - The relationship of $\sigma_{1(k)}$ and $\sigma_{2(k)}$ with $Pmax_{(k)}$-$Pave_{(k)}$ and $Pmin_{(k)}$-$Pave_{(k)}$

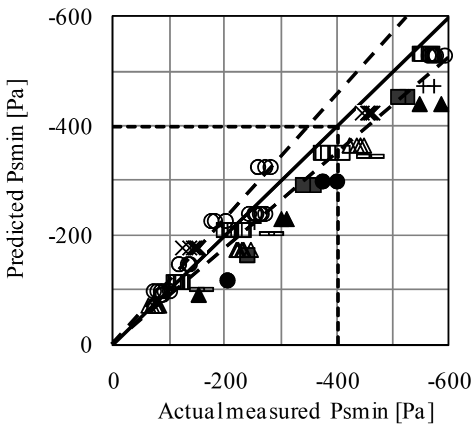


(1) $Pmax_{(K)}$ **(2) $Pmin_{(K)}$**

Figure 10 - Max. and min. pressure/floor distributions – comparison between the actual measured values and the predicted values（C type, 100A nominal diameter）

3.2.4 Prediction of min. system pressure Psmin

As in **Fig.9**, all the patterns were also calculated. Especially, the predicted and actual measured values of min. system pressure, which provides an index for drainage capacity, are compared in Fig.11 to show the relationship between them. Within the reference value of pipe pressure, -400[Pa], the difference between the predicted and actual measured values for Group 1 is roughly ±10% but as for Groups2 and 3, the difference between the values is more noticeable. This is speculated to be related to the structural difference of the AAVs.



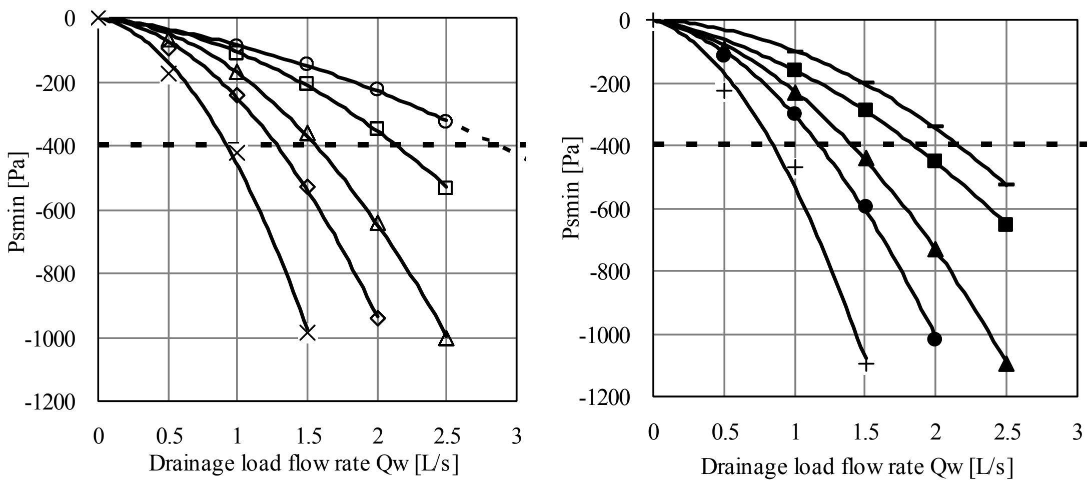
	125A	100A	75A	65A	50A
Group1	○	□	△	◇	×
Group2		■	▲	◆	+
Group3		−			

Figure 11 - Comparison of the actual measured and predicted Psmin

3.2.5 Prediction of drainage capacity Qsc

Based on the predicted values of Psmin, drainage capacity curves for Groups 1, 2 and 3 were created as shown in **Fig.12**. Based on this together with the reference value of -400[Pa], drainage capacity values were acquired as shown in the same diagram. According to this, the estimated values and the actual measured values are almost identical, suggesting that the drainage capacity prediction is possible. Therefore, the previously proposed drainage capacity prediction method is still effective when using it for predicting the drainage capacity of the drainage stack system with various pipe diameters.

Drainage capacity value [L/s]	Group1					Group2				Group3
	125A	100A	75A	65A	50A	100A	75A	65A	50A	100A
	○	□	△	◇	×	■	▲	◆	+	−
Actual measured value	3.31	2.07	1.45	1.25	0.92	1.63	1.18	0.98	0.77	1.86
Predicted value	2.86	2.14	1.56	1.28	0.92	1.84	1.41	1.18	0.85	2.16



(1) Group1 **(2) Group2,3**

Figure 12 - Drainage capacity curves

3.3 Drainage capacity in comparison

Fig.13 shows a comparison of predicted drainage capacity values when installing a bellmouth and an AAV to the end of a vent pipe. Compared to the drainage capacity with a bellmouth installed, which is a standard design, the drainage capacity with an AAV installed is assumed to decrease by approximately 7% with Group 1 and by approximately 15% with Group2. The decreasing ratio of drainage capacity, when compared to the standard system, was also identified.

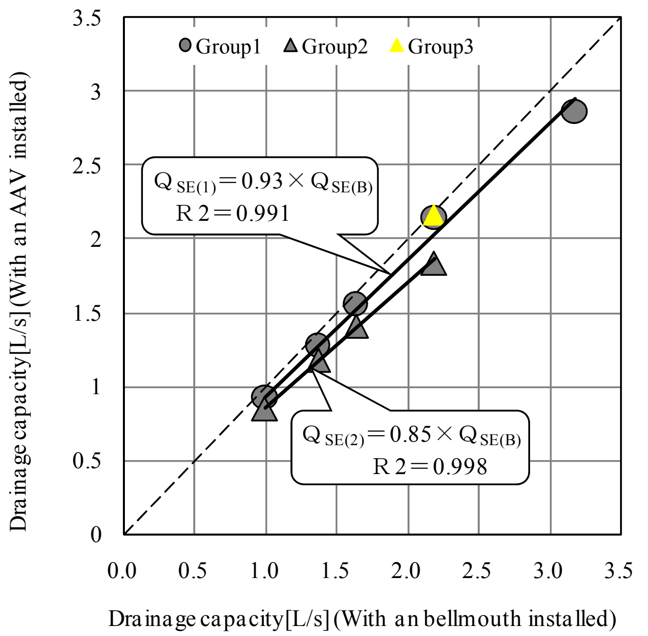


Figure 13 - Drainage capacity values in comparison

4. Conclusion

The following conclusions were drawn from the study of predicting the influence of AAVs on drainage capacity when installing each of five different types of AAVs to the vent pipe of the drainage stack system with JIS-DT fittings using different pipe diameters (50A, 65A, 75A, 100A, and 125A).

(1) Based on the results of the airflow characteristic test, the relationship of airflow resistance coefficient ζ with airflow rate Qa and pipe diameter D was formulated and presented as reference for vent pipe design.
(2) By expanding the application of the previously proposed drainage capacity prediction method, it was found possible to estimate such influence on the drainage capacity of the drainage stack system within a practical and effective scope when using many different pipe diameters.
(3) The drainage capacity decreases by 7 to 15% when an AAV is installed to the vent pipe compared to when a bellmouth is installed to the vent pipe.

5. References

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6. Presentation of authors

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F6) Characteristics of air transient pressure at drainage stacks: a statistical modelling study

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Abstract

The maximum transient air pressure at a discharging drainage stacks is an important design parameter for the drainage system in high-rise buildings. As the pressure fluctuated, measurements of the inside of the drainage stacks at coarse sampling intervals would defeat the data quality; however, ultra fine sampling frequency would not be practically cost justified. This study examines the air pressure variations characteristics in a discharging drainage stack of a full-scale drainage experiment tower at steady flow rates. The pressure was described in terms of the fluctuation frequency, the maximum pressure, and the average pressure with its standard deviation. Correlations between physical parameters were investigated. In particular, mathematical expressions were proposed to correlate the maximum transient air pressure with the probability density function of the measured pressure. Good correlations with the measured results were reported. This study enhanced the understanding of transient air pressure characteristics at a discharging drainage stack and the result would be useful for air pressure measurements at drainage stacks of high-rise buildings.

Keywords

Drainage stack; transient air pressure characteristics; full-scale experiments; high-rise.

1. Introduction

Trap seals were used to prevent the ingress of foul gases into a habitable space. Trap seal depletion may result from the air pressure transients generated in a poorly-designed drainage stack in a high-rise building. Control of the transient air pressure in drainage stacks of high-rise buildings has been identified as an important factor to ensure the performance of a building's drainage system (Swaffield, 2006).

Apart from simulation studies, the transient air pressure with partially-filled unsteady pipe flow has been investigated intensively through laboratory tests (Cheng *et al.*, 2005, Swaffield *et al.*, 2006). As a key parameter for drainage system design, mathematical expressions were proposed for determining the maximum air pressure in drainage stacks due to some flushing operations from the experiments (Cheng *et al.*, 2005, Swaffield, 2006, Jack *et al.*, 2006). Air pressure fluctuations in a discharging stack is transient; however, the measured maximum pressure at sampling frequencies of choice would be subject to certain uncertainties. Measurements at ultra fine sampling frequency would not be practically cost justified for the entire drainage stacks but coarse sampling would defeat the data quality (Wong and Mui, 2006; He *et. al.*, 2007).

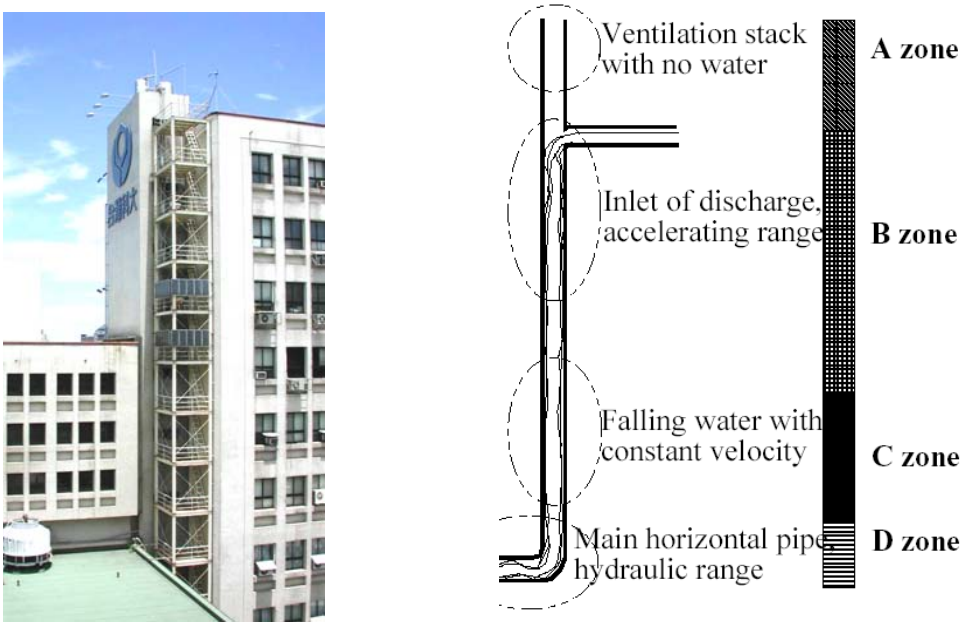
This study examines the air pressure variations characteristics in a discharging drainage stack of a full-scale drainage experiment tower and proposes statistical expressions for the probable maximum air pressure in the discharging stack. The result would be useful for measuring the maximum air pressure at discharging drainage stacks of high-rise buildings with consideration of measurement uncertainties due to the sampling frequency.

2. Methodology

Transient air pressure of a high-rise discharging drainage stack was measured at an experimental tower at NTUST, Taiwan (Jack *et al.*, 2006). The NTUST tower consists of 13 floors above ground and is approximately 38.4 m high as shown in Figure 1. The testing facilities comprise a main drainage stack of 100 mm diameter and of height 37.4 m measured from the stack base, which is connected to a second 75 mm diameter ventilation stack using 50 mm slop vents, and has water discharging points at 5 levels (from level 2 to level 12 of the stack) served by a re-circulatory water supply. Ball valves were installed on all ventilation cross-connections so that the test rig can be adapted to yield network designs with varying degrees of ventilation provision. The pipework is acrylic, and a hot wire anemometer is used to measure airflow in the upper region of the stack.

In this study, 11 pressure sensors were installed evenly along stack at locations between 3 and 33 m above the stack base. Transient air pressures at these pressure sensors were measured at a steady flow rate of 1, 2, 3 or 4 Ls^{-1} discharged into the stack at level 12 (i.e. 33 m above the stack base). In each of the four discharge scenarios, the measurement of air transient pressure was made for 30 s at a sampling frequency of 0.01 s.

The drainage stack transient air pressure characteristics can be described by a vertical zonal model as shown in Figure 1, with empirical coefficients determined from experiments at a full-scale drainage experimental tower (Cheng *et al.*, 2005). Using the discharge flow direction as a reference, i.e. from the stack top to its bottom, 'zone A' is the upstream part of the stack vent from the discharge entrance, i.e. this zone starts at the stack vent and ends at the discharge entrance, and the pressure drops below the atmospheric pressure due to the incoming airflow. ‘Zone B’ is between the discharge entrance and the downstream point of atmospheric pressure in which the air pressure profile reached its negative peak. ‘Zone C’ is the downstream part of the positive transient air pressure of ‘zone B’. In this zone, airflow gains energy as a form of static pressure increment through the deceleration against the falling water. ‘Zone D’ is located at the connection point to the horizontal pipe. Due to the hydraulic jump at the connection point of the vertical stack pipe to the horizontal drain pipe, air resistance of this zone is similar to ‘zone A’. In this study, the transient air pressures at ‘zone B’ and ‘zone C’ were measured for the subsequent analysis.



(a) (b)

Figure 1 – Drainage stack; (a) Full-scale testing facilities at the NTUST; (b) stack zoning

3. Results and discussions

For the test period during which water was discharged at the drainage stack, the discharge flow rate at the stack remained unchanged. The transient air pressure was measured at the minimum sampling time interval of 10 ms for about 30.3 s when a water flow rate 1, 2, 3 or 4 Ls^{-1} was discharged into the stack at level 12 (i.e. at a height H_θ=33 m above the stack base). A total of n=3030 pressure measurements in each case were recorded. The instantaneous transient air pressure was measured, θ_i as a time series from data number from i=1…n.

In the time series of the transient air pressure, the ‘sign’ changes of the air pressure gradient, i.e. from positive pressure to the negative pressure or vice versa, at a measurement location were counted to determine the transient air pressure frequency ω

(Hz), where $\sum_{i=1}^{n-2}\phi_i$ is the number counts of the pressure gradient change of sign, τ (s) is the total time period of measurements,

$$\omega = \frac{\sum_{i=1}^{n-2}\phi_i}{2\tau}; \ \phi_i = \begin{cases} 0 & ;\xi_i \geq 0 \\ 1 & ;\xi_i < 0 \end{cases}; \ \xi_i = (\theta_{i+2} - \theta_{i+1})(\theta_{i+1} - \theta_i) \quad \ldots (1)$$

Figure 2 shows the transient air pressure frequency ω (Hz) at a height H_θ (m) measured from the stack base. The frequencies measured in zones B and C of the stack would be approximated by a geometrical distribution (p>0.05), with a geometric mean of 21 Hz and a geometrical standard distribution of 1.4 Hz. The maximum frequency in zone B of 29 Hz was measured at 1-level below (H_θ=30 m) the discharge location. The frequency was decreasing downstream of the discharge level at a rate of about 1 Hz m^{-1} (R=0.88, p<0.0001). The frequency measured in zone C was 20 Hz to 28 Hz. The maximum frequency of 35 Hz was measured at the transitional location between zones B and C.

The instantaneous transient air pressure at a time θ(t) (m water gauge or denoted as 'm wg.') at the drainage stack, relative to the atmospheric pressure outside the connected water seals to the stack, can be expressed by an equation below, where $\overline{\theta}$ (m wg.) is the average air pressure over the period, θ' (m wg.) is the instantaneous air pressure fluctuation at time t.

$$\theta(t) = \overline{\theta} + \theta'; \ \sum \theta' = 0 \quad \ldots (2)$$

The instantaneous pressure over the period would be approximated by a normal distribution function N with the mean pressure $\overline{\theta}$ (m wg.) and the standard deviation υ (m wg.) as the predictors of the distribution function.

$$\tilde{\theta} = N(\overline{\theta}, \upsilon) \quad \ldots (3)$$

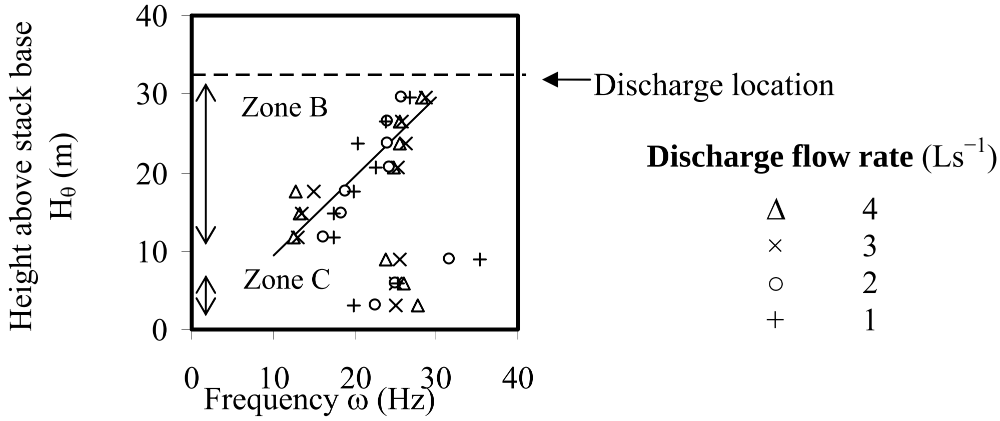


Figure 2 – Frequency of transient air pressure in a discharging stack

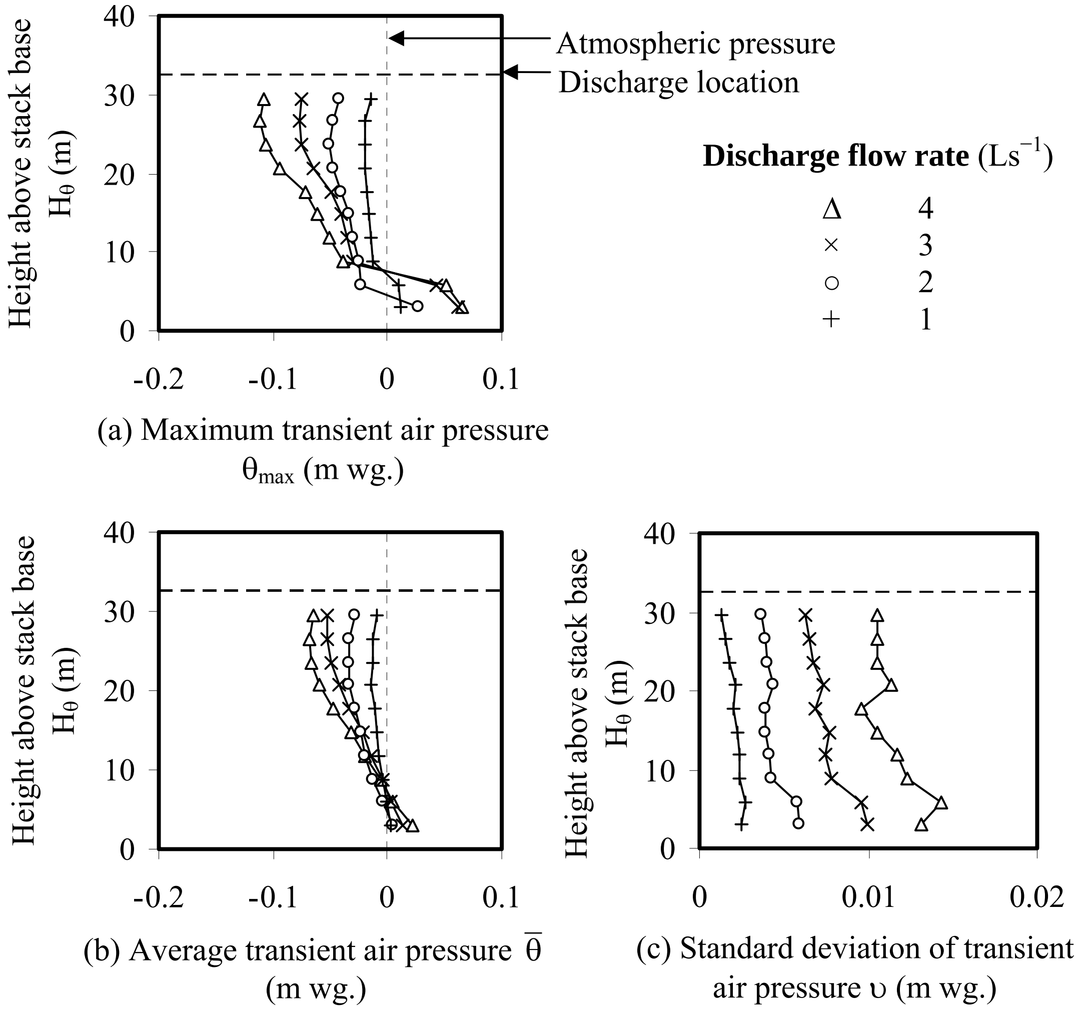


Figure 3 – Transient air pressure at the NTUST discharging stack.
(a) maximum; (b) average; (c) standard deviation

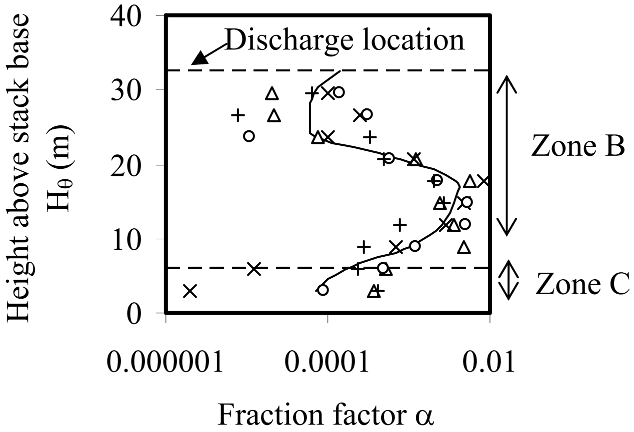


Figure 4 – Fraction factor of air transient pressure density function

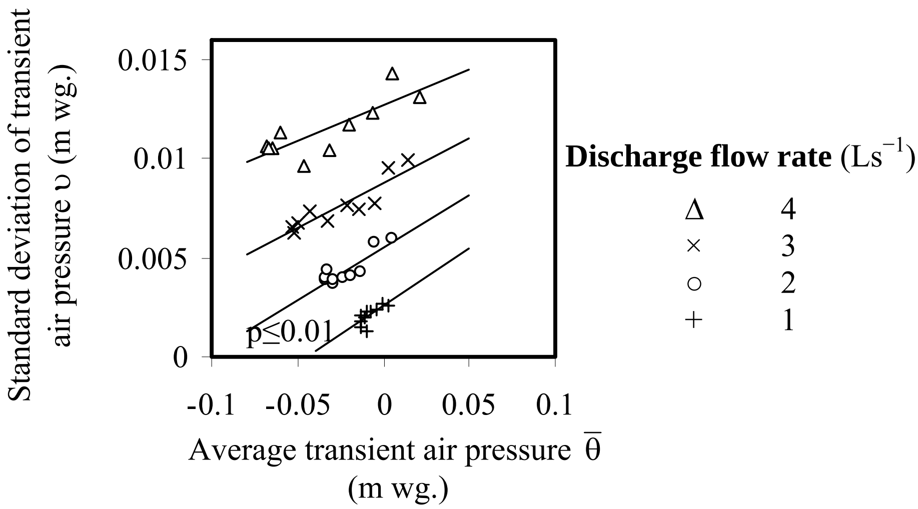


Figure 5 – Transient air pressure variations as a function of the average air pressure

The transient air pressure characteristics were presented as the maximum air pressure θ_{max} profiles and the average pressure $\overline{\theta}$ profiles with the standard deviations υ as shown in Figure 2. It was reported that both the maximum and the average air pressure were proportional to the discharge flow rate as shown in Figures 3(a) and 3(b). It was noted that the flow rate was an explanatory parameter of the maximum air pressure in an earlier study (Cheng *et al.*, 2005). The pressure variations were expected to be proportional to the discharge flow rate as shown in Figure 3(c).

The first expression of the maximum transient air pressure (both the maximum positive θ^+ and negative pressures θ^- measured at the stack) was the fraction factor α, which can be expressed by a probability density function of the air pressure $\widetilde{\theta}$ at an allowable failure rate of the probable maximum pressure limits,

$$\alpha = \begin{cases} \int_{-\infty}^{\theta^-} \widetilde{\theta}\, d\theta & ;\theta \le \theta^- \\ 1 - \int_{-\infty}^{\theta^+} \widetilde{\theta}\, d\theta & ;\theta \ge \theta^+ \end{cases} \qquad \ldots (4)$$

Figure 4 showed the fraction factors ranged from 8×10^{-6} to 0.009 for zone B. The fraction factors of zone C, ranged from 2×10^{-6} to 5×10^{-4}, were significantly lower than that in zone B (p=0.07). It would be approximated by a geometric distribution ($p\geq0.1$) with a geometric mean (GM) of 4.7×10^{-4} and geometric standard distribution (GSD) of 7 for zone B, and 1×10^{-4} and 7.8 for zone C respectively. As the fraction factor would vary along the stack, the choice of the allowable failure rate needs adaption for the maximum air pressure at a discharging stack.

Alternative approximation of the maximum air pressure would be obtained from the probable correlations of the average air pressure and its standard deviation. The standard deviation of the pressure variations was plotted as a function of the average air pressure as shown in Figure 5. It was reported that, at a test water discharge flow rate, the standard deviation was correlated with the mean air pressure for all the test cases with a correlation coefficient between 0.75 and 0.91 ($p \leq 0.01$, t-test).

Figure 6 shows the transient air pressure characteristics evaluated with the fraction of the maximum absolution pressure and the probability density function of the normalized air pressure given by, where $\overline{\vartheta}$ and ν are the average and standard deviation of the normalized air pressure,

$$\vartheta_i = \frac{\theta_i}{\max|\theta_i|} ; \ \tilde{\vartheta} = N(\overline{\vartheta}, \nu) \qquad \dots (5)$$

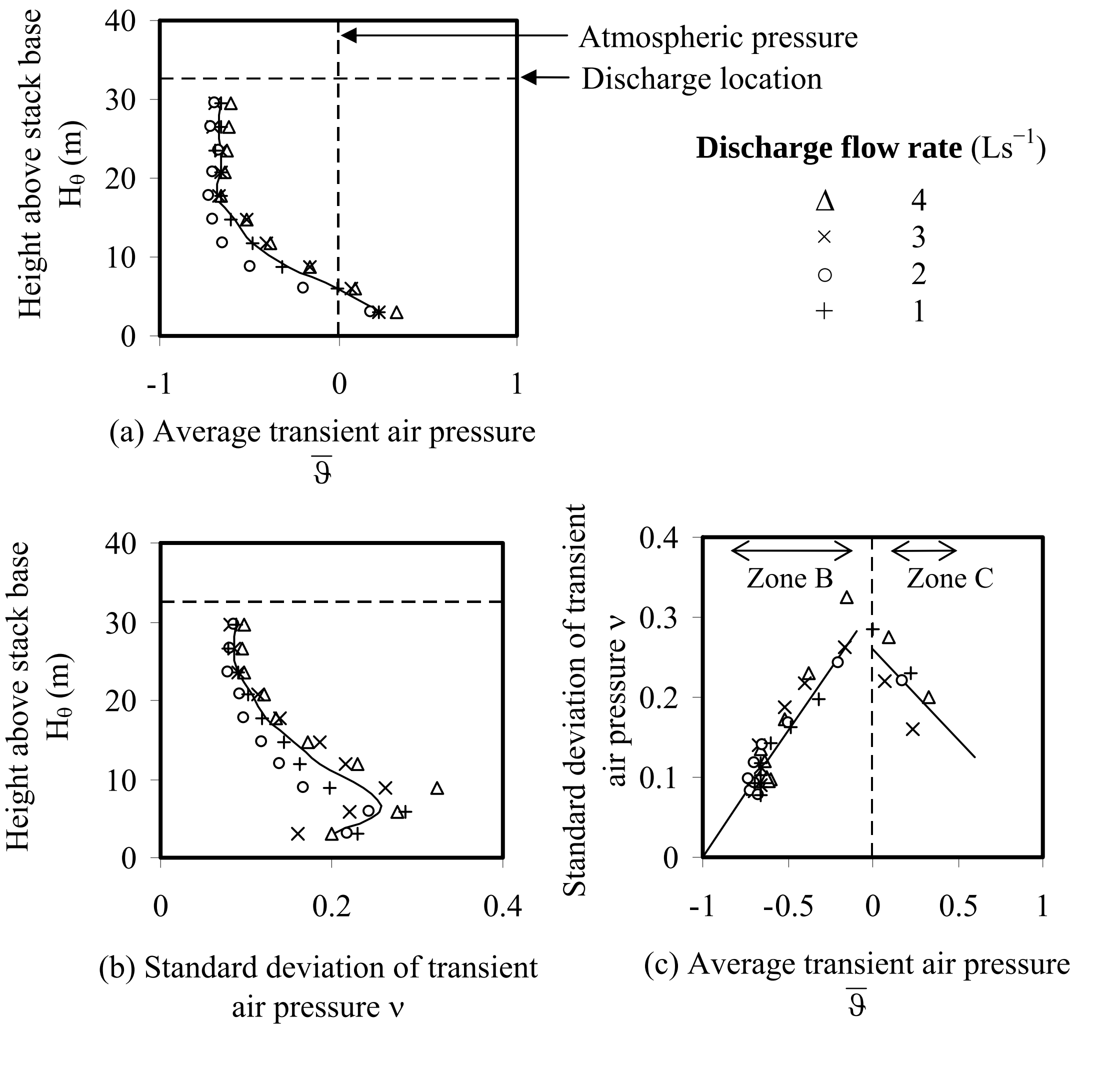


Figure 6 – Transient air pressure characteristics at a discharging stack.
(a) average; (b) standard deviation; (c) standard deviation as a function of average

In zone B at 30 m$\geq H_\theta \geq$18 m, the maximum normalized air pressure downstream to the discharge level was relatively 'steady' at a range from −0.66 to −0.68. The maximum normalized air pressure in zone C was 0.23 to 0.33 as shown in Figure 6(a). Figure 6(b) showed the normalized standard deviation was 0.08 to 0.3. Compared with Figure 5, Figure 6(c) showed that the standard deviation of the normalized air pressure was correlated with the average normalized air pressure for all test water discharge flow rates, where a_0=[0.31, 0.26] and a_1=[0.31, −0.23] were the regression coefficients for zones B and C, ξ was the residuals expressed by the standard error ε of 0.023 and 0.031 for zones B and C respectively. It was noted that the regression for zone B was significant (R=0.93, p<0.0001) but more measurements would be required to confirm the probable correlation for zone C (R=0.6, p=0.2).

$$\nu = a_0 + a_1\overline{\vartheta} + \xi(\varepsilon) \qquad \ldots (6)$$

Combining Equations (5) and (6), the maximum transient air pressure in the discharging stack would be determined from the measured average transient air pressure and its standard deviation,

$$|\theta_{max}| = \frac{\upsilon - a_1\overline{\theta}}{a_0 + \xi(\varepsilon)} \qquad \ldots (7)$$

Using the average prediction as a reference, i.e. ξ=0, Figure 7 indicates the goodness-of-fit of the proposed statistical model by comparing the measured and predicted maximum transient air pressure. It was noted that the negative pressure in zone B was measured and the absolute pressure was shown in the figure for presentation. By visual expression, reasonable predictions of the proposed model were reported. The correlations were further examined with the prediction of the maximum air pressure near the discharge level, i.e. level 12 and the results were shown in Figure 7.

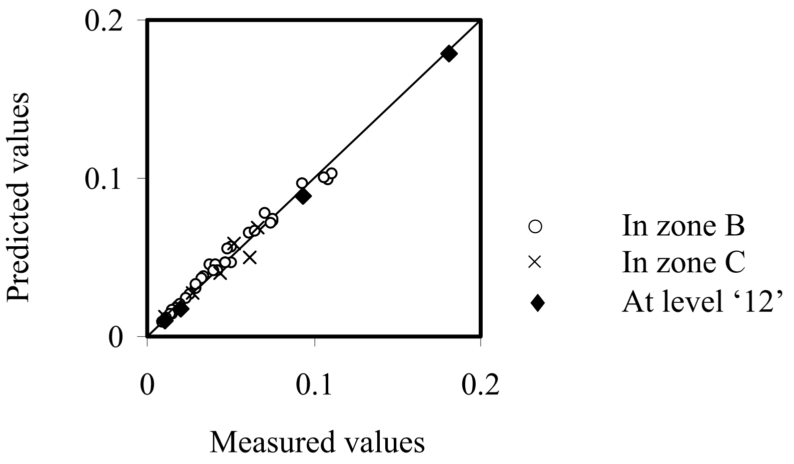


Figure 7 – Comparison between the predicted and measured absolute maximum transient pressure in a discharging stack $|\theta_{max}|$

4. Conclusion

The maximum transient air pressure is one of the important design parameters of drainage stacks in high-rise buildings. The transient air pressure characteristics at two discharge characteristic zones (B and C) in a full-scale discharging drainage stack of height 38 m at constant water discharge flow rates discharged at 33 m above the stack base were investigated. This study reported that the transient air pressure would be described in terms of the fluctuation frequency, the maximum pressure and the average pressure with its standard deviation. The air pressure frequency would be approximated by a geometrical distribution. The maximum frequency of 35 Hz was measured at the transitional location between zones B and C. For zone B, the maximum frequency of 29 Hz was recorded at one level below the discharge level and the frequency was found decreased downstream at a rate of about 1 Hz m^{-1}. The frequency measured in zone C was between 20 Hz and 28 Hz. The maximum air pressure was expressed as a failure rate (known as a fraction factor) of the probability density function; this study showed that fraction factor would vary from 8×10^{-6} to 0.009 for zone B and from 2×10^{-6} to 5×10^{-4} for zone C.

The standard deviation of the pressure variations would correlate with the average air pressure. Mathematical expressions were proposed to correlate the normalized pressure standard deviation with the normalized average pressure, and were found useful in predicting the probable maximum transient air pressure at the discharging stack. The predicted maximum transient air pressure was compared with the measured values and was used to predict the maximum transient air pressures. Good correlations were reported and the results would be useful for future investigations of air pressure characteristics of a discharging drainage stack.

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6. Presentation of Authors

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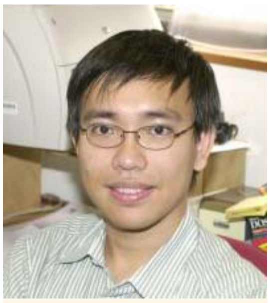

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G1) Performance evaluation and a design method for the horizontal fixture drain branch system comprising drain headers that can be adapted to long-life housing

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Abstract

Housing complexes in Japan used to be constructed using the “scrap & build” method, but the construction of long-life housing that lasts for as long as 200 years has been started in tackling global environmental issues with the aim of reducing environmental impact and controlling CO_2 which is emitted during the process of design, construction, demolition and disposal of housing.

The construction of long-life housing adopts the concept of providing a plumbing layout which can be flexibly adapted to a resident’s lifestyle, and in order to materialize this concept, much consideration is required in terms of construction planning while it is necessary to develop a horizontal fixture drain branch system which can be installed to a section (infill within a dwelling unit) available for the updating of the plumbing layout.

This study discusses the technique of plumbing planning for long-life SI (Support & Infill) housing complexes and the characteristics and advantages of the horizontal fixture drain branch system which uses drain headers and which is installed in the privately owned section (“horizontal fixture drain branch system with drain headers” hereafter). To be more specific, the study focuses particularly on the following four points:
(1)The technique of plumbing planning for SI housing complexes and its characteristics
(2)The length of the horizontal fixture drain branch and the drainage characteristics of sanitary fixtures in relation to the reduction of drainage load
(3)The drainage characteristics of sanitary fixtures in relation to the carrying performance
(4)The reduction of induced siphonage which is caused by combined drainage from multiple sanitary fixtures and the effect of backflow prevention

Keywords

Drain Headers, Support & Infill, Long-life Housing, The Horizontal Fixture Drain Branch System, Drain Headers

1. Introduction

The objectives of this study are as follows:
(1)To clarify important points when constructing long-life SI housing complexes and planning drainage facilities for them
(2)To identify design and planning advantages of the horizontal fixture drain branch system with drain headers for SI housing and to specify the points to bear in mind when implementing performance evaluation.

There are two advantages when designing and planning the horizontal fixture drain branch system with drain headers for SI housing. Firstly, the infill is much more adjustable depending on the plumbing planning by installing the drainage stack and the pipe shaft in the common use section instead of in the privately owned section as it often used to be, and the drainage pipes of the system have higher maintainability and updatability. Secondly, longer pipe distances, to connect sanitary fixtures to the drainage stack, help reduce the drainage load which is caused to the drainage stack while providing more options when selecting a drainage stack system.

There are two points to bear in mind when implementing performance evaluation. Firstly, because of the long pipe distance and the low pipe pitch, it is important to ensure that the carrying performance of the horizontal fixture drain branch is reasonably good. Secondly, it is also important to ensure that the trap seals do not break by induced siphonage created by combined drainage from multiple sanitary fixtures which are connected to the horizontal fixture drain branch in the privately owned section. Especially, backflows must be prevented from entering the traps that are installed close to the floors (in low positions), otherwise drained water could spill out of the drain outlets.

2. The characteristics of plumbing design and planning for SI housing

2.1 The concept of SI housing design

Fig.1 shows the image of a plumbing layout that is appropriate for SI housing. As shown in Fig.1, typical SI housing comprises a so-called “support” (or a “skeleton”), a collective term for a building frame and a common use section, which has a long useful life (100 years or longer). Also, the privately owned section adjustable for a plumbing layout that may need to be updated is called “infill” and has a short useful life (20 years max.). It is distinctive that the intended use of the support and the infill and their expected performance are taken into consideration when plumbing is designed and planned for SI housing. For this study, a pipe shaft and a drainage stack, which should be highly updatable and maintainable with a long useful life, are installed in the support section. A horizontal fixture drain branch system with drain headers, which is flexible with the change of plumbing layout, is also installed in the infill.

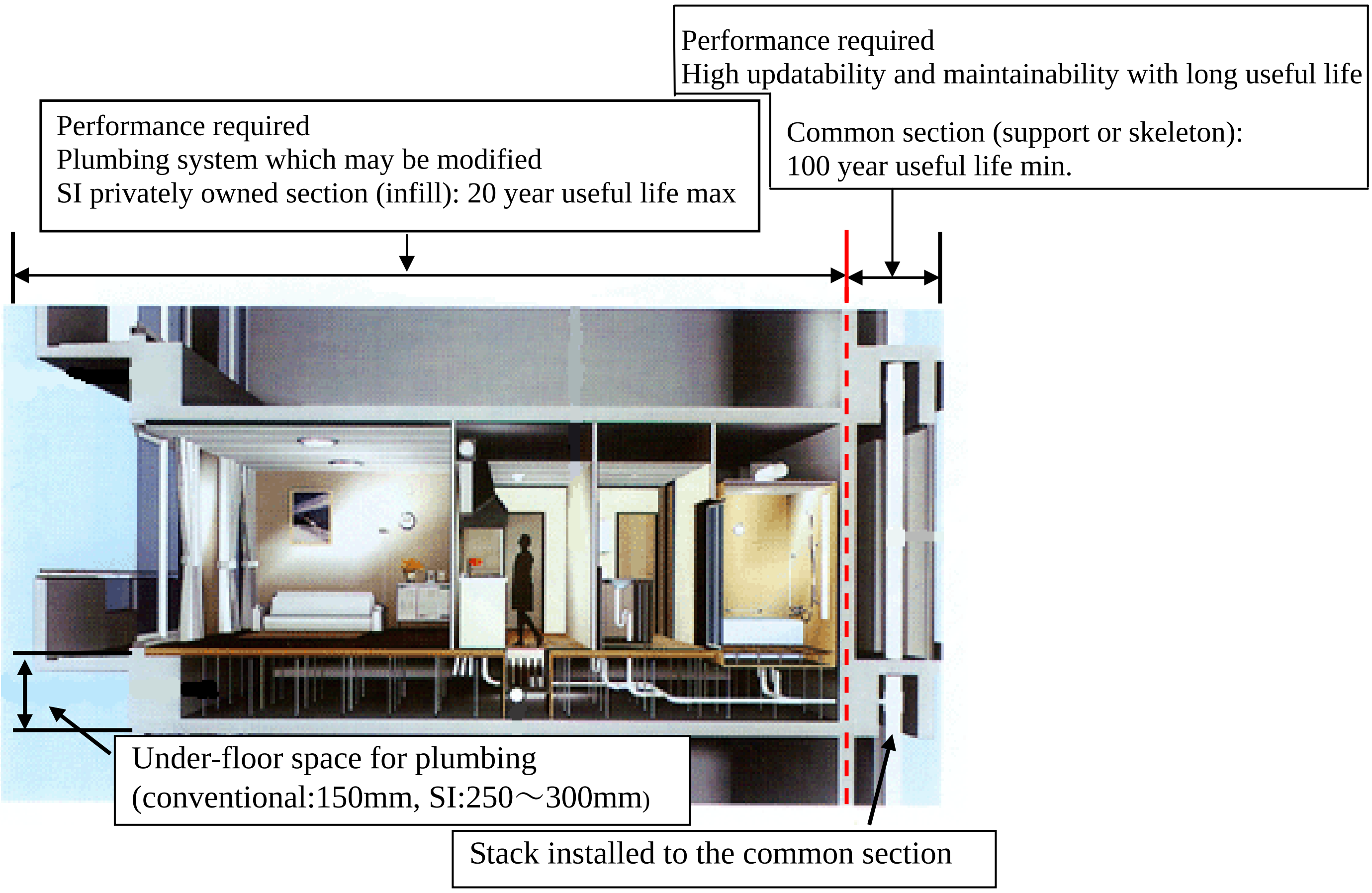


Fig.1 SI (Skeleton & Infill) plumbing layout and performance required

2.2 Pipe shaft and drainage stack planning

Fig.2 shows a horizontal fixture drain branch system installed in the infill of conventional housing. For conventional housing complexes, a pipe shaft is installed in the infill with a drainage stack running through the pipe shaft. Therefore, as shown in Photo 1, the maintenance and updating of the drainage stack requires a major operation including destroying the pipe shaft as well as the walls and floors around it. In addition, the residents of conventional housing complexes have no choice but to evacuate their homes and be relocated during such updating work. There have also been cases in which drainage systems were out of order for a long period of time, causing inconveniences to residents.

Meanwhile, Fig. 3 shows a horizontal fixture drain branch used on the horizontal fixture drain branch system with drain headers. As shown in Photo 2 (1) and (2), for SI housing, the pipe shaft is installed facing the common use corridor with the drainage stack running through in the same place. This eliminates maintenance and updating work by entering the infill, thus not disturbing residents' daily life too much.

Fig.4 shows how a horizontal fixture drain branch can be housed in the under-floor space of SI housing. As shown in Fig.4, the under-floor space (a distance between the upper surface of concrete slab and the finished floor surface) of SI housing for accommodating a horizontal fixture drain branch used to be approximately 150mm but it has been expanded to 250 to 300mm, consequently enabling drainage along a comparatively long distance; approximately 10 to 15m, while securing a pipe pitch which is lower than the pitch specified by the standard.

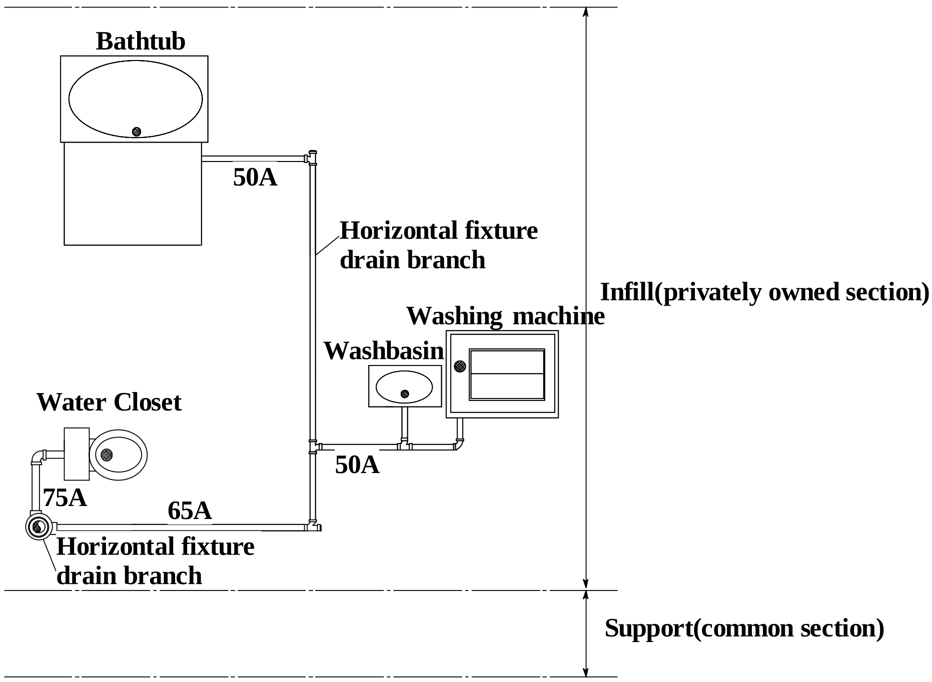
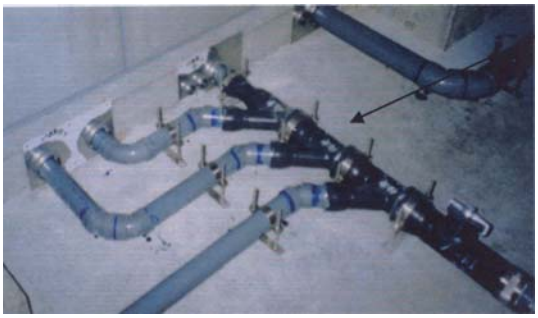


Fig.2 Conventional horizontal fixture drain branch system

Photo 1 Updating work on the drainage stack and horizontal fixture drain branch in the privately owned section



(1)Horizontal fixture drain branch with drain headers

(2) Pipe shaft installed in the common section

Photo2 Horizontal fixture drain branch with SI housing-compatible drain headers

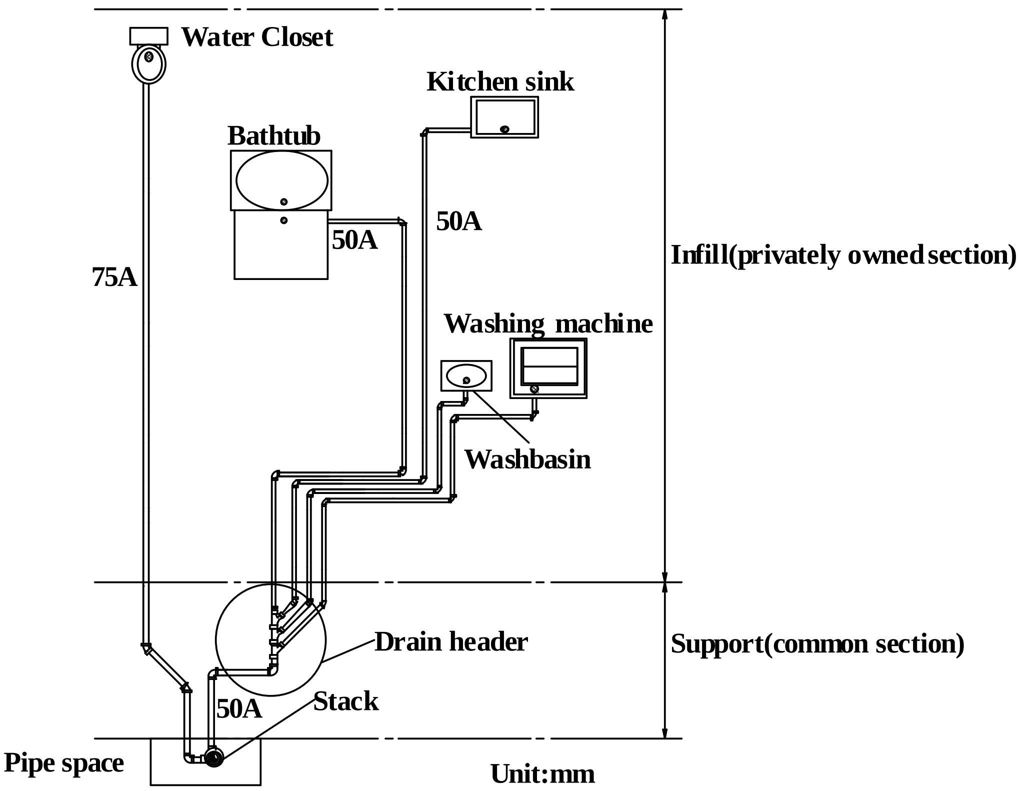


Fig.3 Horizontal fixture drain branch with drain headers for SI housing

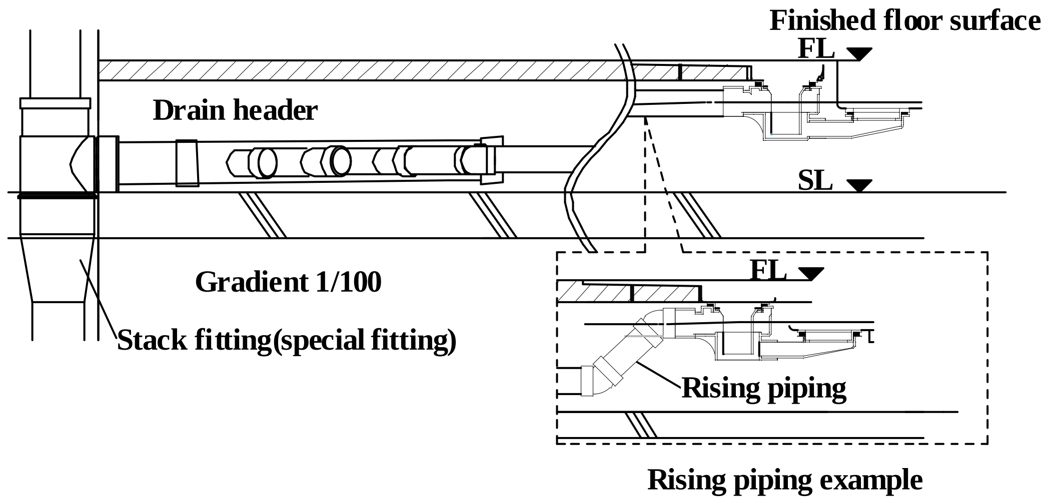
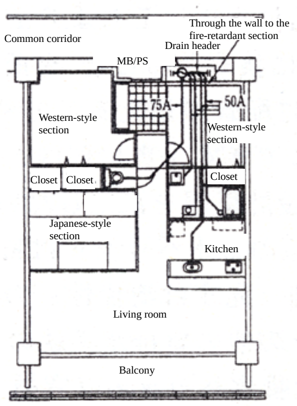


Fig.4 Under-floor space for installing a horizontal fixture drain branch for SI housing

2.3 The characteristics of the horizontal fixture drain branch system with drain headers that are compatible with different types of SI housing

The horizontal fixture drain branch system with drain headers is a drainage system by which the wastewater drained from various sanitary fixtures, which are connected to the miscellaneous drainage system in the infill, is combined at the drain header section and drained further to the drainage stack. As shown in Table 1, there are three different configurations which are actually used depending on how the drain headers and the drainage stack are connected as well as on where to install the drain headers. The characteristics of each configuration are also shown in Table 1. Types A and B are adopted by the Urban Renaissance Agency. They comprise drain headers which are housed in the common use section PS. A miscellaneous drainage system is connected to the drain headers whereas a sewage water system is installed separately and the wastewater from both systems is combined at the stack fitting section. These types each require five connecting points through the wall to the fire-retardant section, which is quite a few. Nonetheless, these types make it easy to clean the horizontal fixture drain branch from the drain headers which are housed in the common use section. Meanwhile, type C is configured with drain headers which are installed near the entrance of the privately owned section and the miscellaneous drainage water collected in this section is drained to the drainage stack using one horizontal fixture drain branch. A sewage water system is plumbed separately to provide a drainage route to the stack fitting section. Type C is a more sophisticated system than types A and B in the sense that it requires only two connecting points through the wall to the fire-retardant section, thus better constructability. It should be noted, however, that the horizontal fixture drain branch needs to be cleaned from the drain headers which are housed near the entrance of the privately owned section. This study focuses on type B.

Table 1 SI housing-compatible horizontal fixture drain branch systems and their characteristics

<table>
<tr><th></th><th>Type A</th><th>Type B</th><th>Type C</th></tr>
<tr><td>Type</td>
<td>
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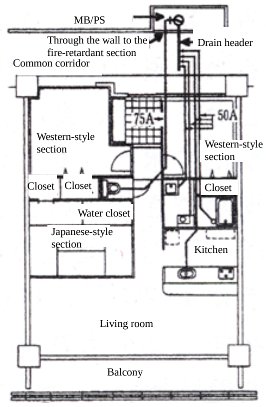
<td>
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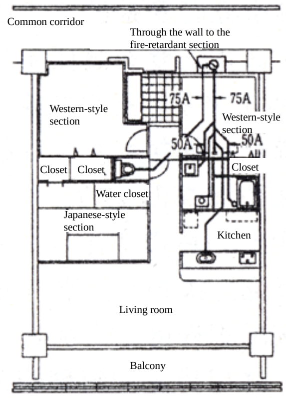
<td>
</td></tr>
<tr><td>Characteristics</td>
<td>○ Maintainable (cleaning) from the common section
○Large pipe shaft space
○Difficult connection through the wall to the fire-retardant section
○Adjust the pipe shaft position to save frontage space</td>
<td>○ Maintainable (cleaning) from the common section
○tand-alone pipe shaft is required
○Stand-alone pipe shaft is required
○Finished floor is required above the corridor
○Long pipe length to go along the corridor
○Pipe shaft design</td>
<td>○Maintainable from the privately owned section
○Not quite maintainable from the common section
○Access panel is required in the floor above the header
○Small pipe shaft space
○ Easy drainage on the lowest floor
○ Easy connection through the wall to the fire-retardant section</td></tr>
</table>

2.4 The length of the horizontal fixture drain branch and the drainage characteristics of sanitary fixtures in relation to the reduction of drainage load

Fig.5 shows different pipe lengths in relation to different fixture drainage characteristics when the horizontal fixture drain branch system with drain headers for SI housing is used with a siphon-jet type Water closet. Compared to the conventional system, the horizontal fixture drain branch system with drain headers for SI housing uses a longer horizontal fixture drain branch to connect a sanitary fixture to the drainage stack, and the fixture drainage characteristic curves, which represent the fixture drainage load, therefore change gradually from waveforms with sharp rises and drops to gentler forms as the pipe length increases. Based on this fact, when calculating the flow load in the drainage stack using a steady flow rate method under SHASE-S206, it is legitimate to think that the drainage load is less with the horizontal fixture drain branch system with drain headers for SI housing than with the conventional system. The advantage from the design perspective is that the diameters of the pipes used for the drainage stack system could possibly be reduced.

Similarly to Fig.5, Fig.6 presents fixture drainage characteristic curves showing different drainage pipe lengths in relation to different drainage flow rates, qd values, of various sanitary fixtures. The definition of qd value and how to calculate it were clarified at CIB-W062 Symposium[4)] last year. The curves indicate that the qd value of each Water closet decreases drastically as the pipe length increases. However, the qd values of the other sanitary fixtures, including the bathtub, are hardly affected by the pipe length as the Water closet are, and it is characteristic that these qd values remain more or less the same.

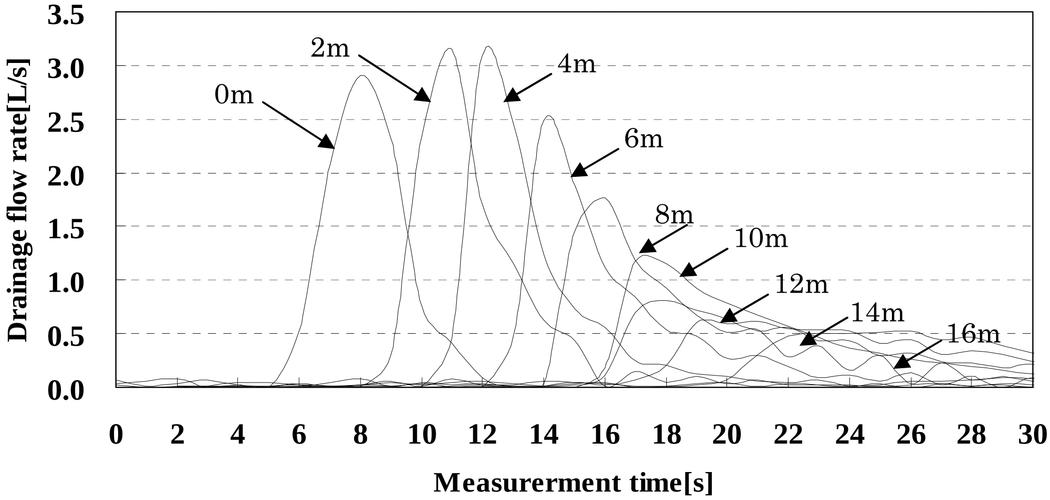


Fig.5 Transition of characteristics of fixture drainage (in the case of a siphon-jet water closet)

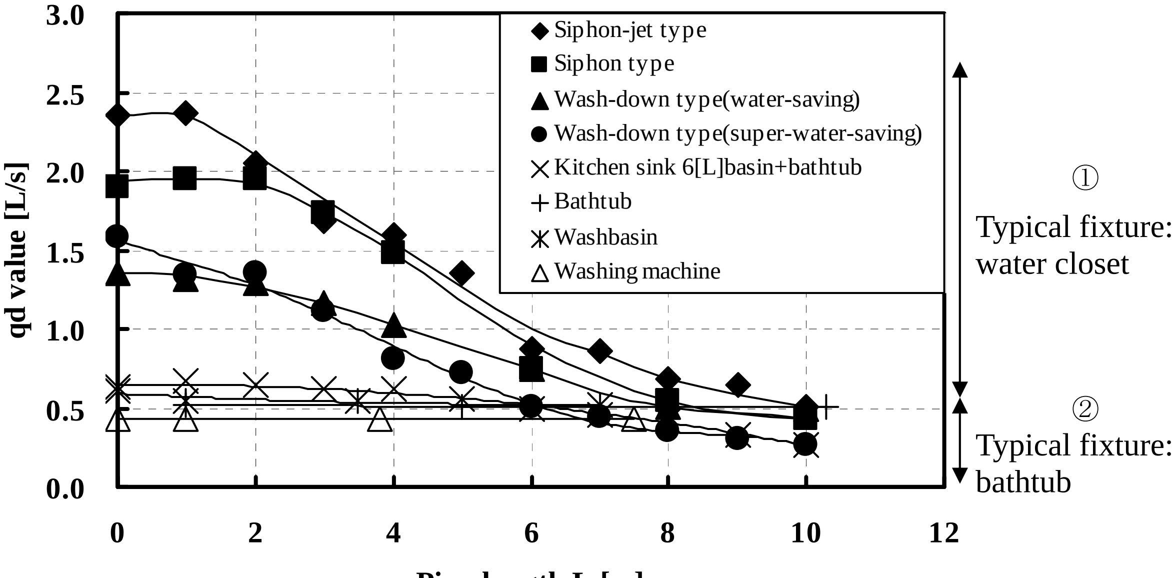


Fig.6 Change of the average fixture drainage flow, qd value, in relation to the pipe length

Next, Fig.7 shows the flow of how to calculate the drainage load and the pipe diameter using a steady flow rate method under SHASE-S 206 (plumbing code). Using the flow, the steady pipe flow, Q, is estimated and a sanitary fixture with the largest qd value is selected as a typical fixture. Using the qd value, the drainage load flow rate to the drainage stack is determined with reference to the pipe diameter curves in Fig.8. Toilet bowls are common nominees to be typical sanitary fixtures for these calculations but as shown in Fig.6, the qd values of the Water closet decrease as the pipe length increases and even become smaller than the qd value of the bathtub at a pipe length of 6 to 8m.

As it is clear from Fig.8, a longer pipe length is used with the horizontal fixture drain branch system with drain headers for SI housing than with the conventional system and the qd values of typical fixtures used for the drainage load calculation therefore become smaller, enabling the reduction of drainage load as a result. Fig.9 shows the drainage load curves along with different pipe lengths in relation to the drainage performance curves of a drainage stack system with special fittings when a siphon-jet type Water closet and a bathtub are used as typical sanitary fixtures. The drainage stack system comprises a stack with diameters of 100mm and 125mm and special fittings. Each height applied is also calculated to correspond to each pipe length. Based on the results shown in Fig.9, Fig.10 shows different heights and different numbers of floors applied that correspond to various lengths of the horizontal fixture drain branch when toilet bowls that apply different flush systems and a bathtub are used as typical sanitary fixtures.

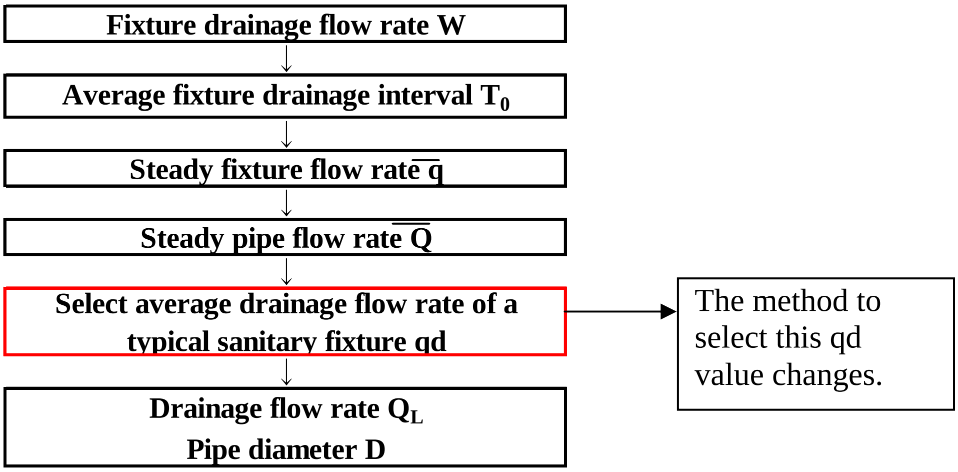


Fig.7 Flow of how to determine the pipe diameter using a steady flow rate method under SHASE-S 206 (plumbing code)

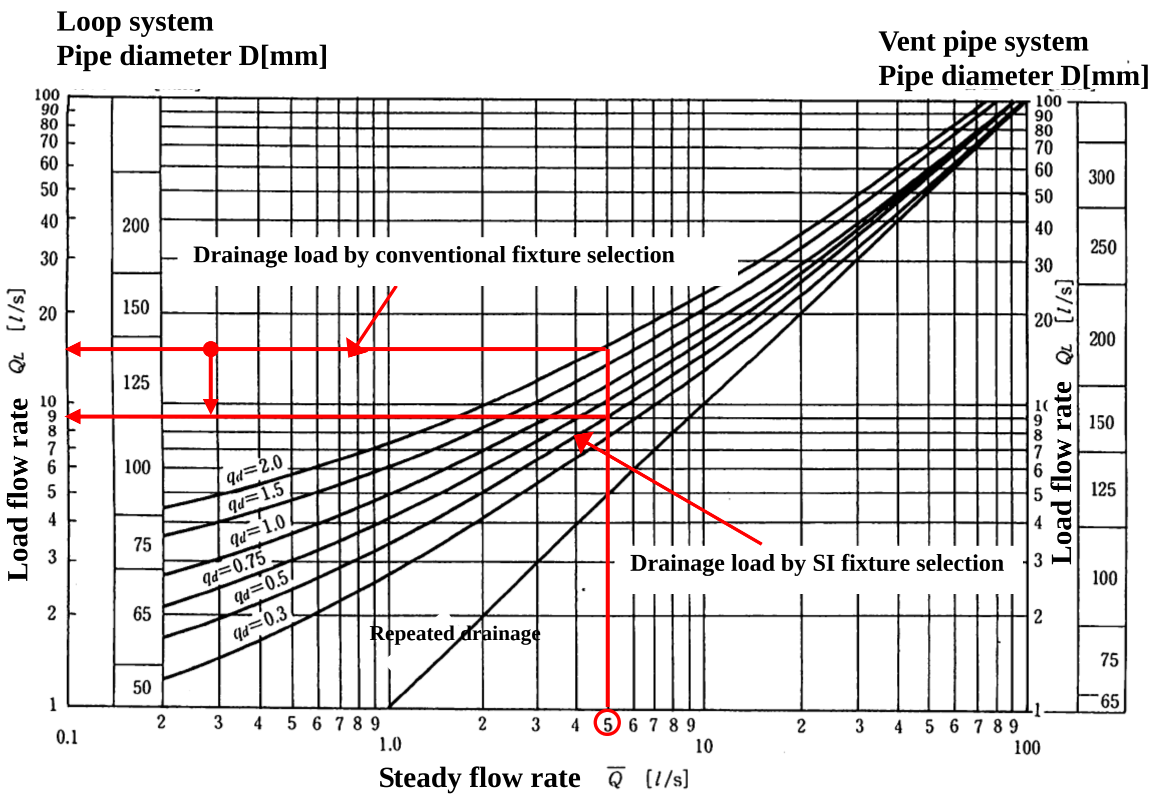
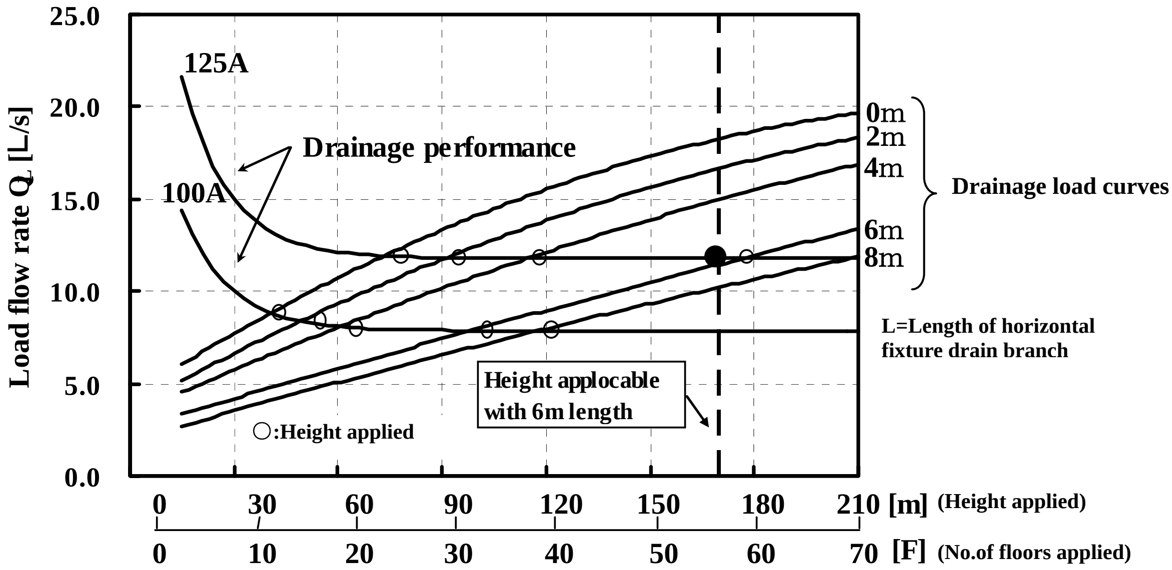
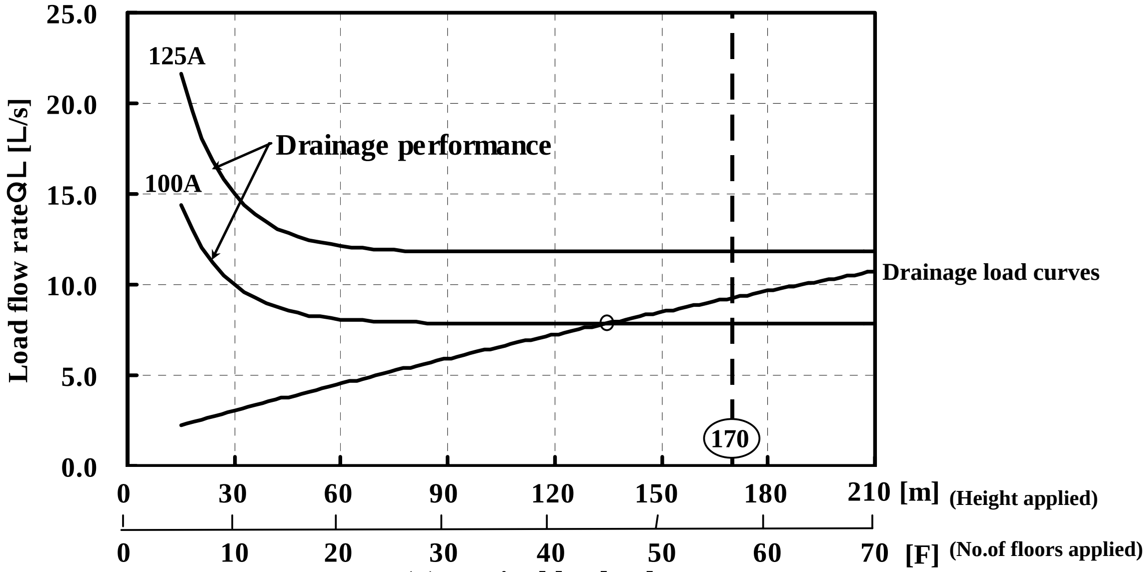


Fig.8 Calculation of drainage load in relation to pipe diameters (SHASE-S 206)



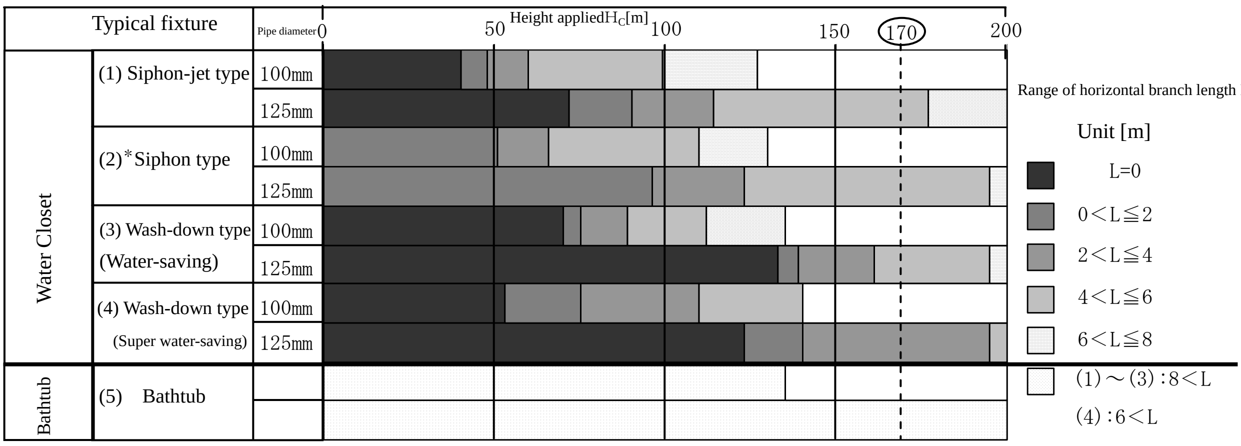
(1) Typical siphon-jet type sanitary fixture



(2) Typical bathtub

Fig.9 Drainage load curves and drainage performance curves of different sanitary fixtures

According to Fig.10, when using the siphon-jet type toilet bowl, for instance, if the pipe length is approximately between 4 and 6m, a drainage system with special fittings with a pipe diameter of 125A can be used, which also means that the horizontal fixture drain branch system with drain headers for SI housing can be applied to super high-rise housing complexes with a height of 170m. It is therefore right to say that compared to the conventional system with a short horizontal fixture drain branch generating large drainage load, the horizontal fixture drain branch system with drain headers for SI housing can reduce the drainage load to the drainage stack, which is a big advantage of the system.



*: The heights applied with the siphon type when L=0～2m made no difference, thus being regarded as identical.

Fig.10 Heights applied with different types of sanitary fixtures and different pipe lengths

3. Point to bear in mind when implementing performance evaluation

3.1 Fixture drainage characteristics in relation to the ability to carry waste

Compared to the conventional system, the horizontal fixture drain branch system with drain headers for SI housing allows more under-floor space (between the upper surface of the concrete slab and the finished floor surface) for housing the horizontal fixture drain branch, but as explained previously, the pipe pitch cannot be secured as to meet the specification. Hence, wastewater has to be drained along the horizontal fixture drain branch with a gentle pitch. This condition lowers the ability to carry waste especially from Water closet, possibly causing trouble, such as blockage, to the pipework. Therefore, performance evaluation needs to be implemented.

Shown in Fig.11 is an experimental horizontal fixture drain branch system used on the sewage water system and Fig.12 shows waste substitutes for the experiment. A carrying performance test was implemented using these items and the results are shown in Fig.13. The results clarified applicable carrying distances (pipe lengths) and the applicable number of pipe bends. For instance, using a super water-saving Water closet with a flush water volume of 6L, the applicable pipe length is approximately 6m, allowing the maximum of five bends created along the pipe. Fig. 14 shows the relationship of qd values, which were measured at the end section of the horizontal fixture drain branch, with flow velocity V and water depth H. To set conditions to determine a carrying limit value, it is necessary to ensure that the decreased qd value is 0.42L/s or above, water depth H is 15 to 20mm or above, and flow velocity V is 0.5m/s or above. These values are considered to be the requirements for maintaining good carrying performance.

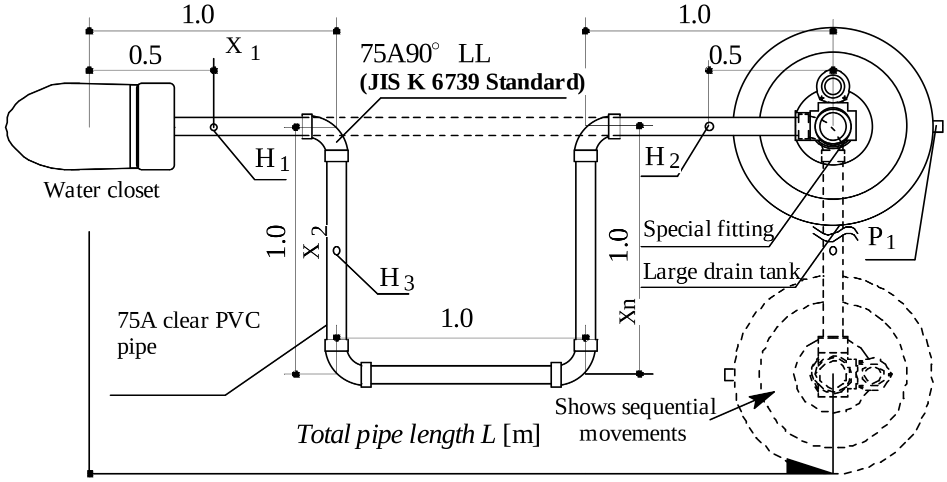


Fig.11 Experimental horizontal fixture drain branch system (sewage water system)

Substitute material for waste	BL Standard		BL Recommended		Standard by Fukuoka City
	A	A'	B	B'	C
Sponge	PVA Sponge:2 pieces	PVA Sponge:2 pieces	Toilet paper rolled:6m(1-ply)	Toilet paper rolled:6m(2-ply)	PVA Sponge:4 pieces
Paper	Toilet paper crumpled:4 pieces (1-ply)	Toilet paper crumpled:4 pieces (2-ply)			Toilet paper crumpled:7 pieces (1-ply)
Photo					
Waight [kg]	0.23	0.27	0.12	0.22	0.4
Volume $\times 10^{-5}$[m^3]	23.2	28.8	11.3	21.7	42.1
Density [kg/m^3]	996	931	1050	987	937
Acting force [N]	2.27	2.74	0.91	2.83	3.43

Fig.12 List of waste substitutes

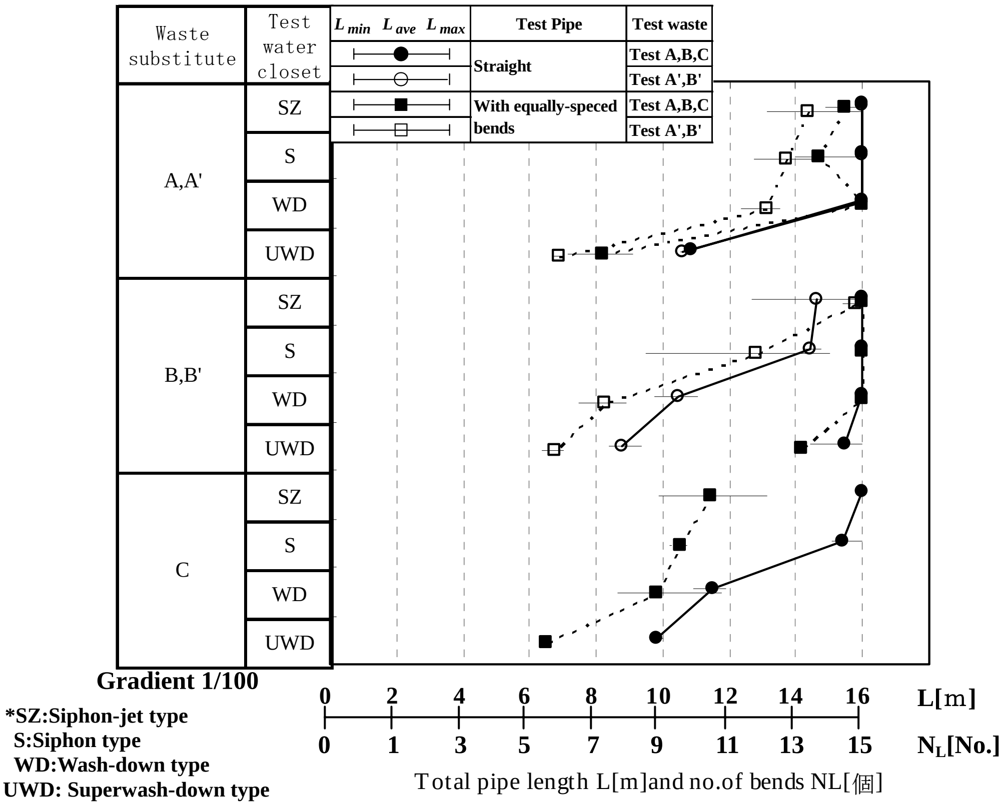


Fig.13 An example result of the carrying performance test on a sewage water system

＊L: total length, N_L: no. of pipe bends

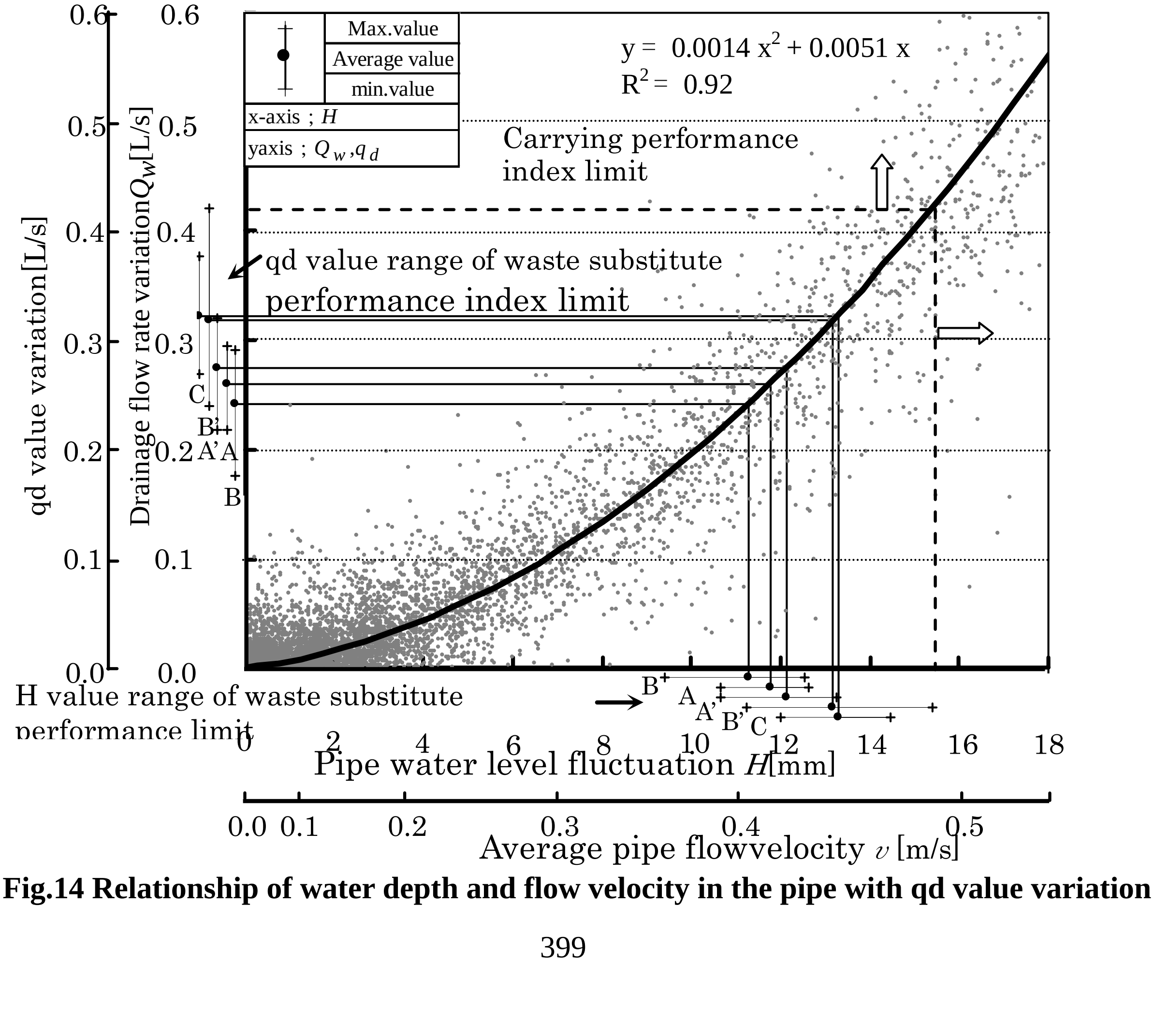


Fig.14 Relationship of water depth and flow velocity in the pipe with qd value variation

3.2 The reduction of induced siphonage by combined drainage from multiple sanitary fixtures and the effect of backflow prevention

Fig. 15 shows the maximum and minimum values of pressure in the horizontal fixture drain branch when wastewater from multiple sanitary fixtures, which are connected to the horizontal fixture drain branch, is combined and drained together. The results are shown in comparison between the conventional system and the system for SI housing. When combined drainage water is generated from two fixtures or from three fixtures, the pipe pressure variation exceeds −400Pa on the conventional system but it is kept within ±100Pa on the system for SI housing. This suggests that the pressure variation is much likely to stay within ±400Pa, the limit specified by SHASE-S 218, ensuring that there is no risk of trap seals broken by induced siphonage created by combined drainage water. It has therefore been confirmed that the horizontal fixture drain branch system with drain headers for SI housing is much safer to adopt than the conventional system.

Furthermore, it is visibly clear that there is hardly any risk of combined drainage water backflowing to the floor drain traps which are installed in low positions near the floor surface. This is because, as shown in Fig.4, the horizontal fixture drain branch system with drain headers for SI housing allows more under-floor space (between the slab surface and the finished floor surface) which prevents backflows, if they occur, from reaching the floor traps.

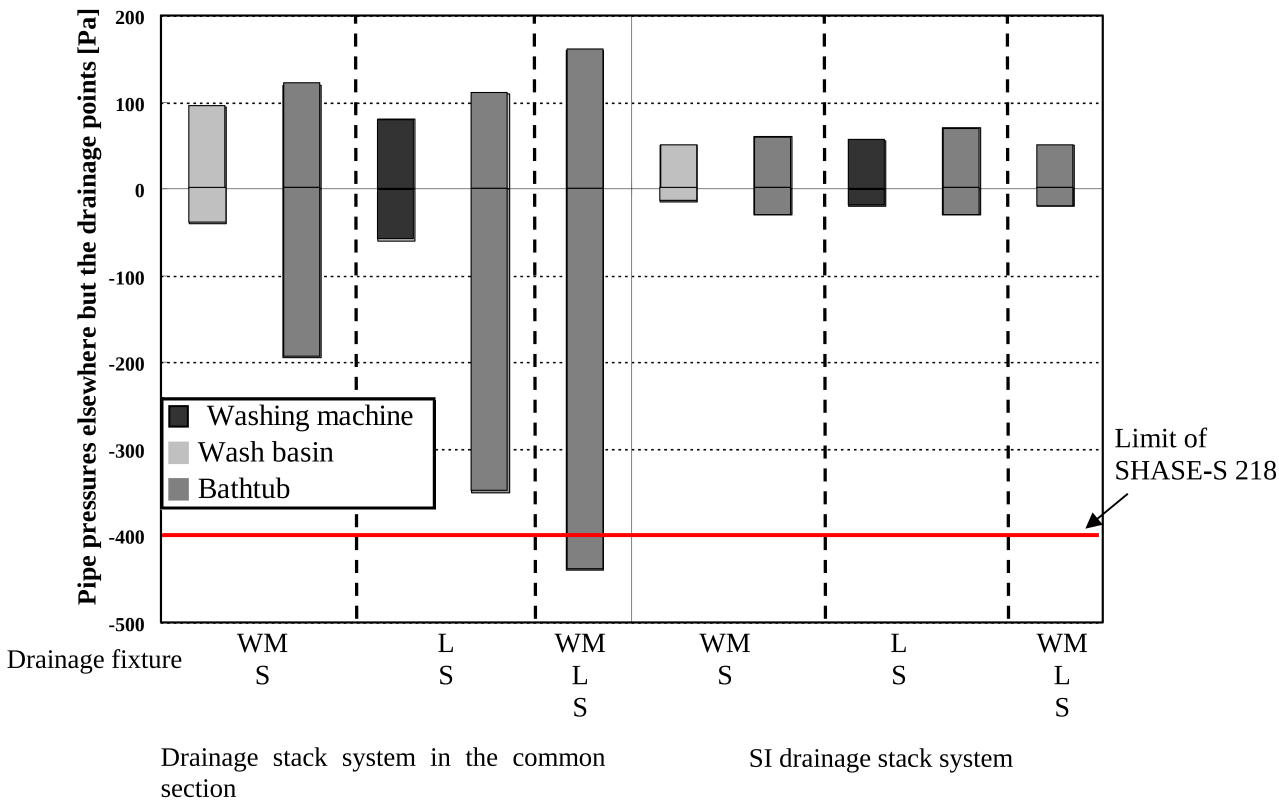


Fig.15 Comparison of drainage pipe pressure by combined drainage

4. Summary

This study examined the horizontal fixture drain branch system with drain headers for SI housing, which has improved updatability and maintainability for long-life housing complexes, and reached the following conclusions mainly in terms of design and planning advantages and points to bear in mind when implementing performance evaluation.

(1)The drainage stack was installed in the support section and under-floor space was secured sufficiently. This improved the updatability of pipework while confirming that this is a system design which enables the easy modification of plumbing layout in the infill.

(2)The relationship between the length of the horizontal fixture drain branch and the average fixture drainage flow rate, qd value, was identified. The length variation and the qd value variation were then used for the steady flow rate method under SHASE-S206 to calculate the drainage flow load to the drainage stack. The results indicate that compared to the conventional system, the horizontal fixture drain branch system with drain headers for SI housing can reduce the drainage load to the drainage stack.

(3)Especially as for the horizontal fixture drain branch which is connected to the Water closet, the relationship between the variation of the average fixture drainage flow rate, in-pipe water level and in-pipe flow velocity was figured out to determine the level of ability to carry various types of waste substitutes. The conditions to limit these values were also clarified.

(4)It is certain that backflows are not caused to traps that are connected to the pipework even when wastewater from multiple sanitary fixtures is combined and drained together and that the pipe pressure variation, which is the cause of induced siphonage, remains below the reference value of ±400Pa. Therefore, the horizontal fixture drain branch system with drain headers for SI housing is superior to the conventional system from the performance point of view.

Acknowledgement

During this study, part of the Academic Frontier Promotion Project “Strategic Development Research of Symbiosis Technologies to Achieve Urban Building Stock Refurbishment”, which is supported by the Ministry of Education, Culture, Sports, Science and Technology, was kindly provided for reference.

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6. Presentation of author

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G2) Study of the proportion of the pipe length in siphon drainage system

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Abstract

For amending the limited of gravity drainage slop and pipe diameter, this study refers to the research by Arthur and Sakaue to discuss the influence factors in a siphon drainage system. According the research results, the primary conditions for the siphon system is priming, and other influence factors are full bore flow velocity, proportion of the pipe length, and push height. The minimum bore flow velocity should be controlled against the air mixing into fluid, and the maximum flow velocity should be concerned with the strong siphon suction to damage the trap functions. The proportion of the horizontal pipe length corresponds with its vertical pipe length, and the push height is the key point for the horizontal pipe primed or barred back.

This study discusses the siphon drainage performance with primed conditions in 3 different influence factors by theory reviews and experiments. The purpose is to find out the suitable proportion of the pipe length and push height under bore flow velocity control to reach the perfect siphon drainage efficiency. And the results not only predict the efficiency of siphon drainage system, but also provide the standard of siphon drainage piping system design.

Keywords

Siphon drainage, Primed system, Full bore flow velocity, Proportion of pipe length, Push height

1. Introduction

Siphon drainage systems use a small diameter pipe to drain water, and it can reduce the floor height when drainage pipe is installed in the floor and increase the soil moving distance without extra equipment. According to Tsukagoshi and Sakaue published “A study on the siphon drainage system" in CIBW62-2007[1], the soil is drained by a siphon drainage system without extra energy consumption and moving longer. The methodology used experiments to find out the phenomenon and efficiency, and it also supports us to analyze the drainage process. The result helps us to think the direction of this study and the conclusion brings up that the drainage efficiency is influenced by the height of vertical siphon pipe and length of horizontal drainage pipe, the study result is shown as Fig. 1.

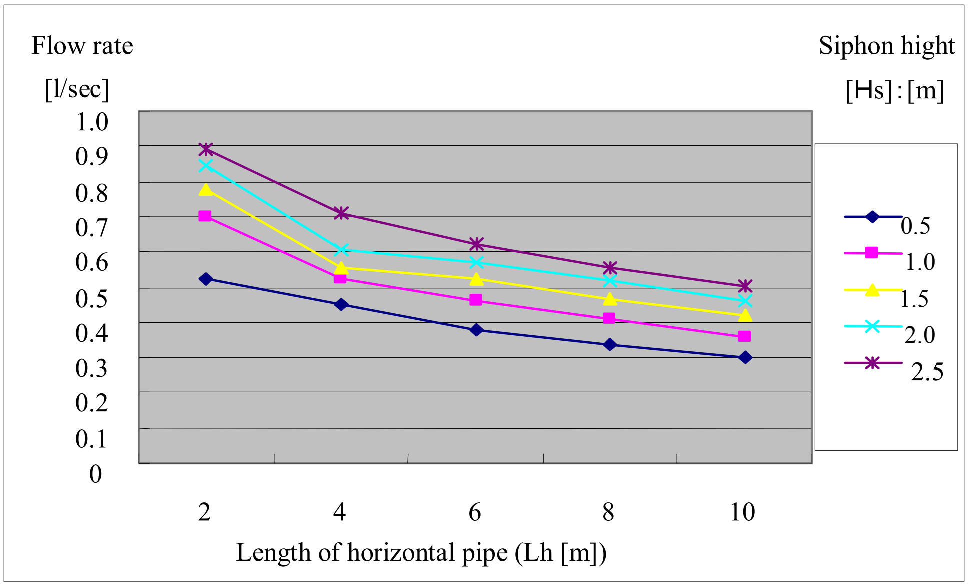

Fig. 1 Discharge flow rate by length of horizontal pipe (Lh) and siphon height (Hs)[1]
(pipe diameter 20mm (internal diameter: 19mm),Push height [Hp]:500 mm)

The publication "The priming focused design of siphonic roof drainage" by Arthur in CIBW62-2007[2], discusses the design standard of the siphon rain water drainage system. It discusses the influence factors, such as depth of flow, friction of pipe material, partial flowing energy lost, and instant flowing out velocity in the end of pipe.
Based on these publications, this study considers all influence factors in a siphon drainage system and tries to simulate the velocity and work in the total drainage process by fluid mechanics. Following the simulation results, we try to find the proportion of the length between horizontal drainage pipe and vertical siphon pipe, and simplify the complex calculations into a simple equation. This simple equation will provide the drainage system designer or operator to easily check the proportion.

2. Methodology

2.1 Bernoulli's Equation

An important theorem concerning fluid flow may be derived when the fluid is incompressible and non-viscous and the flow is steady and laminar. The work done by the pressure forces equals the change in energy of the pipe volume of fluid. The changes in the potential and kinetic energies, and these changes are brought about by the net work done on the system, as Eq.1.

$$W = \Delta U + \Delta K = (P_1 - P_2)\Delta V = \Delta mg(h_2 - h_1) + \frac{1}{2}\Delta m(v_2^2 - v_1^2) \quad \text{Eq.1}$$

Since the density is $\rho = \Delta m / \Delta V$, we can modify Eq.1 into Eq.2.

$$P_1 + \rho g h_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g h_2 + \frac{1}{2}\rho v_2^2 . \quad \text{Eq.2}$$

The fluid flowing through a pipe whose cross section decreases, the pressure in the narrower pipe, where the pressure is high, and the speed is low. This lowering of the pressure where the speed is greater is called the Bernoulli effect. From the equation of continuity, we can have $A_1 v_1 = A_2 v_2$, and the velocity as Eq.3.

$$v_2^2 = \frac{2A_1^2(P_1 - P_2)}{\rho(A_1^2 - A_2^2)} \quad \text{Eq.3}$$

Since v_2^2 must be positive, it is necessary that $P_1 > P_2$

2.2 Incompressible Flow

The fluid in the horizontal drainage pipe is incompressible flow, and the flow is steady and laminar. The velocity of fluid inside the horizontal pipe is distributed by a parabola as show in Fig.2, and the velocity is calculated by Eq.4. The average velocity is calculated by integral in cross section, as Eq.5.

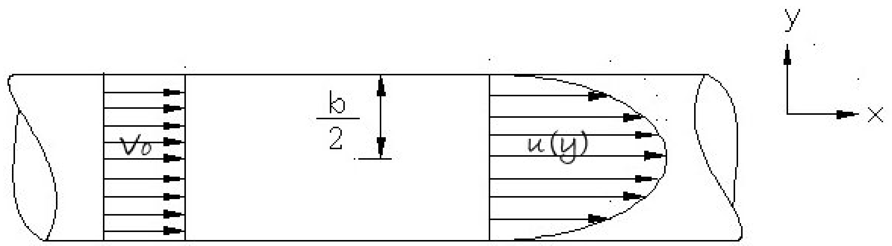

Fig. 2 Velocity distribution in laminar flow

$$u(y) = v_0 \left[1 - \left(\frac{y}{b/2} \right)^2 \right]^n \quad \text{Eq.4}$$

$$\bar{v} = \frac{1}{A}\int u dA = \frac{1}{\pi(b/2)^2} \int_0^{b/2} v_0 \left[1 - \left(\frac{y^2}{(b/2)^2} \right) \right]^n (2\pi y) dy = \frac{v_0}{n+1} \quad \text{Eq.5}$$

2.3 The Energy Equation

In the flowing system, the total energy is not only considered at potential energy (PE) and kinetic energy (KE), but also considered at flowing energy (FE) and other energy (such as chemical reaction energy, magnetic energy, etc.). In this system, we ignore other energy with simple flowing, and just focus at PE, KE, and FE, as Eq.6.

$$E = PE + KE + FE = mgh + \frac{1}{2}mv^2 + \frac{mP}{\rho} \qquad \text{Eq.6}$$

3. Simulation

3.1 Concept

In the past, the drainage system is considered in Open-channel flow with wide pipe, the drainage water mixes with air inner pipe and flows out. The concept of siphon drainage system is assumed and the air pressure equal in both ends of diameter drainage pipe. A basin filled with water is set up at the high end of the piping. As drainage begins, the water flows into thin horizontal pipe, which causes the air in the pipe to move forward past the push height (U-pipe), eventually pushing all air out of the piping system. When water flows over the top of high raise pipe (U-pipe), water drops fast by gravity and a vacuum is created that sucks the remaining water in the pipe forward. As water steady flows out, the entire piping system is filled with water due to gravity (siphon), and the slope is calculated from basin to the end of vertical pipe. After most of the water flows out, air mixes into pipe again, water inside the pipe will repeat the beginning drainage step to prime and suck again.

To satisfy this concept, the siphon drainage system is shown as Fig. 3, and we separate 5 partitions in basin, vertical downspout, length of horizontal pipe (Lh), push height (Lp), and length of vertical pipe (Lv) to analysis the draining condition.

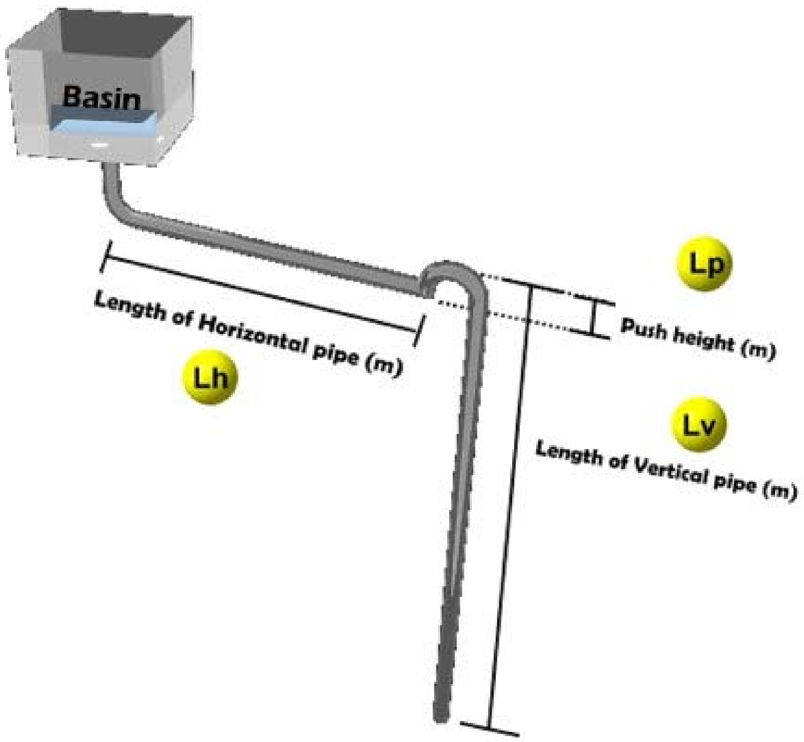

Fig.3 Concept of siphon drainage system

3.2 Analysis

Design a siphon drainage system should analyze the velocity of drainage water and the applicable proportion of the pipe length α . The velocity of drainage water is the point to satisfy the priming pipe and siphon action. If the velocity is too slow, the flowing water can not push air away to prime the pipe that causes Open-channel flow. If the velocity is too fast, the steady flowing water starts gravity drainage, and cause turbulent flow inner pipe easily.

The proportion of length between horizontal drainage pipe and vertical siphon pipe is also the point to cause siphon action. If the length of the horizontal drainage pipe is very long, when compared to the vertical siphon pipe, the siphon action may not happen, and the air will back flow into pipe to cause eddy current with drainage water. Ideally the horizontal drainage pipe should be shorter in length than the vertical siphon pipe; the siphon force is too large to damage water trap function.

3.3 Calculation

3.3.1 Partition

There are 5 partitions in siphon drainage process, each partition has its own actions and conditions. We separate these 5 partitions in 5 sections as Fig. 4 to calculate the velocity and energy in each section, and collect the equations in Table 1.

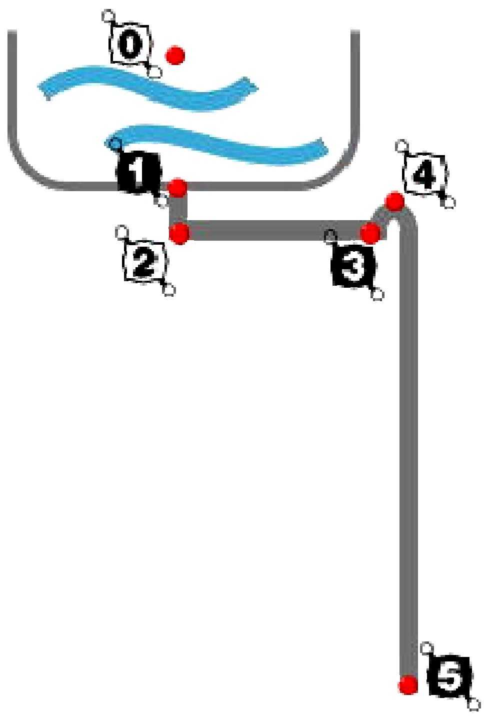

Fig.4 5 sections in siphon drainage process

1st section (0→1) is water flowing from the basin to sinkhole. There is no energy consumption, and drainage velocity is calculated by Bernoulli's Equation.

2nd section (1→2) is water flowing from the sinkhole flowing through vertical downspout. The energy consumption includes potential energy, kinetic energy, and flowing energy. The drainage velocity is calculated by Newton's 2nd Law of motion in $v = v_0 + at$.

3rd section (2→3) is water flowing through horizontal pipe. The energy consumption only includes kinetic energy and flowing energy. The drainage velocity is calculated by the steady and laminar flow in Eq. 5.

4th section (3→4) is water flowing raise inner U-pipe. The energy consumption is the summary of negative potential energy, kinetic energy and flowing energy. The drainage velocity is calculated by Torricelli's theory in $v = \sqrt{2gh}$.

5th section (4→5) is water flowing through vertical siphon pipe. The energy consumption also includes potential energy, kinetic energy, and flowing energy. The drainage velocity is calculated by acceleration of gravity, and it also follows Newton's 2nd Law of motion in $v = v_0 + at$.

Table 1 Equations of velocity and energy in 5 sections

Section	Velocity (m/sec)	Energy (*J) PE+KE+FE*
0→1	$v^2 = \frac{2A_1^2(P_1 - P_2)}{\rho(A_1^2 - A_2^2)}$	Non energy consumption
1→2	$v = \sqrt{2gh}$	$mgL_h + \frac{1}{2}mv^2 + \frac{mP}{\rho}$
2→3	$v = \frac{v_0}{n+1}$	$\frac{1}{2}mv^2 + \frac{mP}{\rho}$
3→4	$v^2 = 2gh$	$-mgL_p + \frac{1}{2}mv^2 + \frac{mP}{\rho}$
4→5	$v = \frac{v_0}{n+1}$	$mgL_v + \frac{1}{2}mv^2 + \frac{mP}{\rho}$

3.3.2 U-pipe push height

U-pipe push height stops water flowing faster than air, and it is for pipe priming to reach siphon action. The push height has a limit for steady drainage velocity, it can not be too high to stop water passage, and it also can not be too low to lose its function. The height is calculated by energy balance, when kinetic energy is greater than potential energy, water inner horizontal pipe is primed and flows over push height. We assume that the potential energy equals kinetic energy, and we modify the equation as Eq.7. Use the average velocity in 1 m/s to calculate Eq.7, L_p is about 5cm.

$$L_P = \frac{v^2}{2g} \qquad \text{Eq.7}$$

3.3.3 Critical siphon force

To avoid large siphon force damages to the water trap function, we have to calculate the maximum siphon force and the length of vertical siphon pipe. The force is generated by gravity, so the siphon force is calculated by Newton's 2nd Law of motion in Eq.8.

$$F = mg \qquad \text{Eq.8}$$

When the calculated force that changes into the stress inner pipe is larger than atmospheric pressure, it would damage the water trap. We have to control the stress under atmospheric pressure, and we get the length of vertical siphon pipe in 10.3m by trial-and-error. Therefore, the maximum length of vertical siphon pipe is 10.3m.

3.3.4 Range of velocity

The velocity has to be controlled. Minimum velocity is needed to prime the pipe, and not exceed maximum velocity to avoid lager siphon force damaging the water trap function. The minimum velocity is close to the maximum open-channel flow (max. open-channel flow is close to priming flow), as Eq.9. The maximum velocity is close to the damage water trap function in Eq.10. L_p is used 5cm, and L_v is used 10.3m to calculate Eq.9 and Eq.10. When the vertical length of pipe is 3m, and the horizontal length of pipe is 2m, the calculated velocity range is between 0.2987m/sec and 17.33m/sec. ($0.2987 < v < 17.33$ m/sec)

$$\frac{1}{2} m_{2\to3} v^2 = m_{4\to5} g L_P \qquad \text{Eq.9}$$

$$\frac{1}{2} m_{2\to3} v^2 = m_{4\to5} g L_V \qquad \text{Eq.10}$$

4. Simulation Results

4.1 Energy consumption

After simulation, we get the energy consumption in the 5 sections, shown as Fig.5. The energy consumption trend goes up during the 1-2 and 2-3 section, and goes down during the 3-4 section in raising U-pipe, after that the trend goes up again in 4-5 section in siphon action. If the energy trend in the 4-5 section is lower than 2-3 section, the drainage system will not occur siphon action.

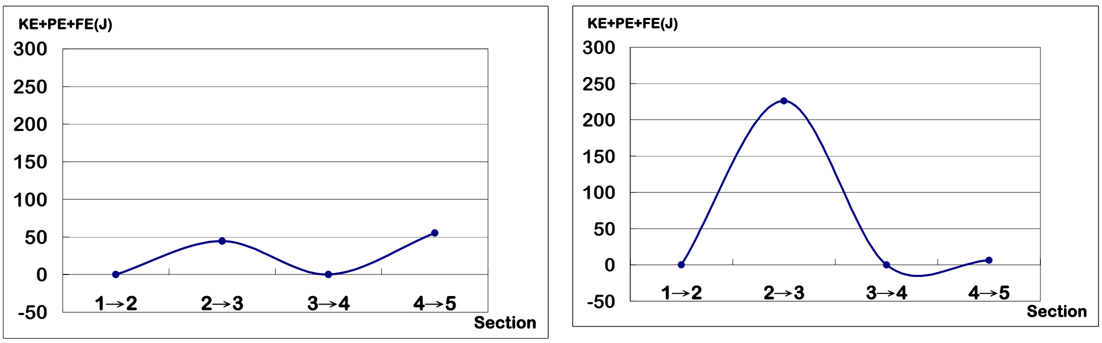

Fig. 5 Energy consumption trend (left side occurs siphon action but right side not)

The energy consumption trend in the same horizontal length, different vertical lengths is results in a different trend, as shown as Fig. 6. Long vertical pipe causes large siphon forces, and a high proportion of pipe length also results in a large siphon force.

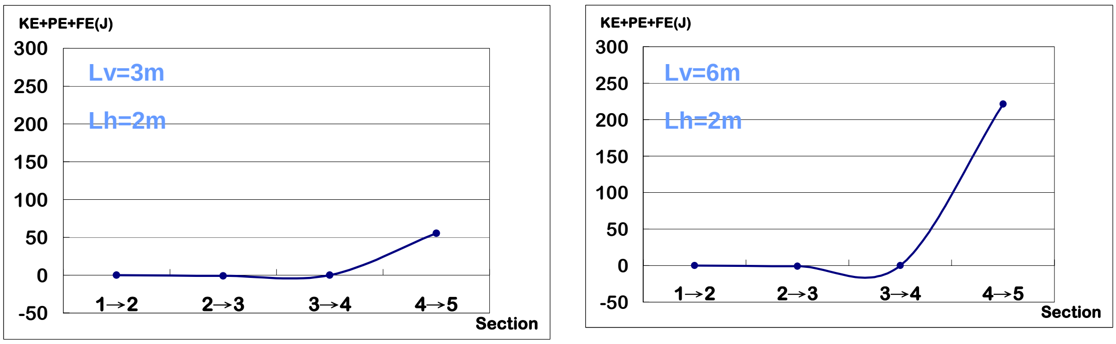

Fig. 6 Energy consumption trend in same horizontal length different vertical

The energy consumption trend in the same vertical length, different horizontal length, the siphon force in short horizontal length is better than the longer one, shown as Fig.7.

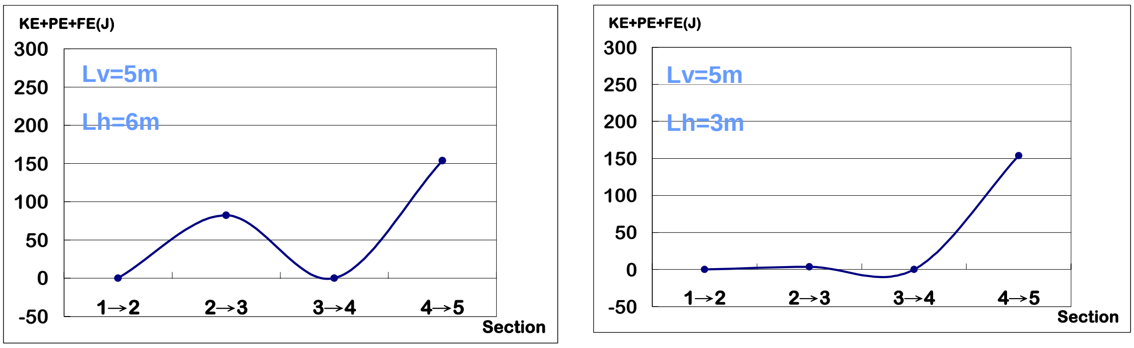

Fig. 7 Energy consumption trend in same vertical length different horizontal length

4.2 Proportion of pipes

Based on energy consumption trend, we may know the proportion α of pipe length influences the siphon force and drainage velocity, shown as Eq.11. And it is also the key component of design and operation. We try to use a simulation to finish a diagram of proportion of pipe length as shown in Fig.8, and we get the regression equation to simplify the 5 sections calculation. We just know the horizontal length or vertical length, and we can calculate via this regression equation, Eq.12, to get the other one.

$$\alpha = \frac{L_V}{L_h} \qquad \text{Eq.11}$$

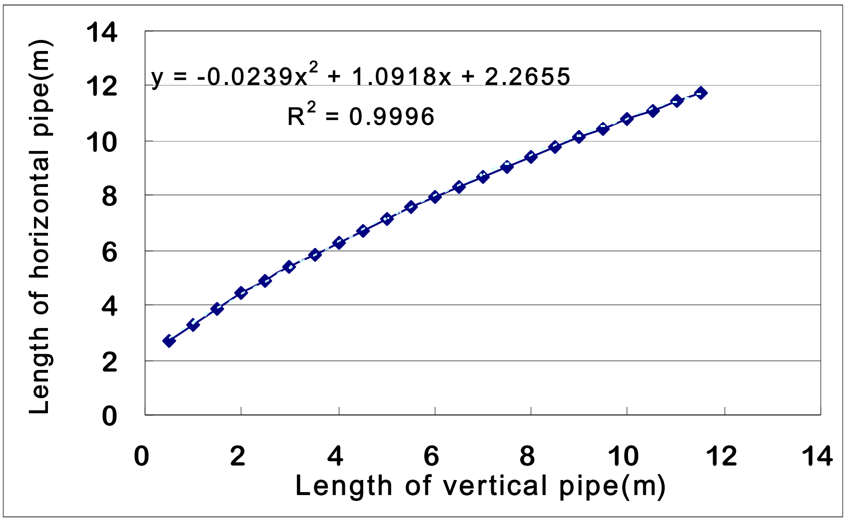

Fig.8 Proportion of pipe length in horizontal and vertical pipes

$$L_h = -0.0239L_V^{\,2} + 1.0918L_V + 2.2655 \qquad \text{Eq.12}$$

Consider at maximum vertical pipe length in 10.3m for non water trap damaging, the effective range of siphon drainage system is shown as Fig. 9. The curve in Fig. 9 is the trend line, and the left side is effective range.

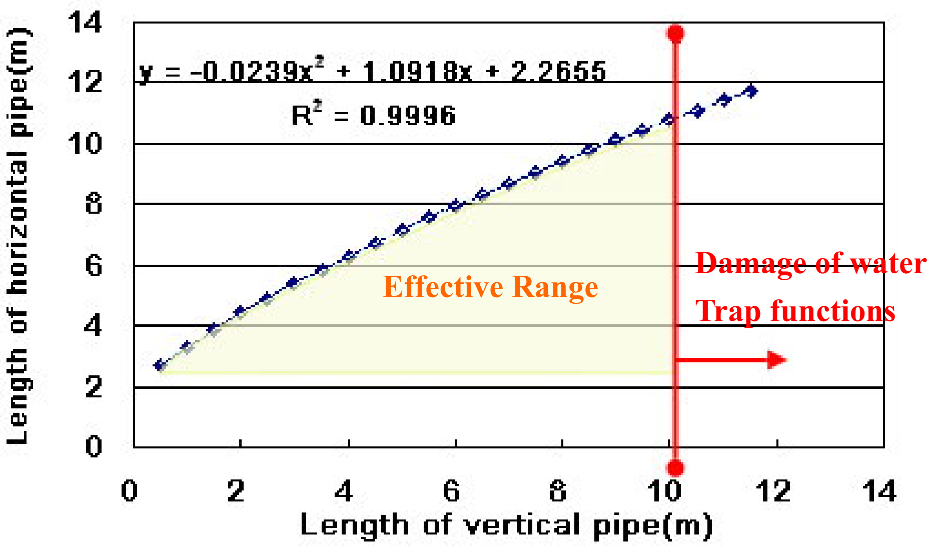

Fig.9 Effective range in proportion of pipe length

5. Discussion

The push height of U-pipe is about 5cm in 20mm pipe diameter. The length of vertical siphon pipe is shorter than 1m, the energy consumption in the horizontal pipe is not stable. If the length of vertical siphon pipe is longer than 10.3m, the siphon force will be too strong and will damage the water trap function. Therefore, the design length of the vertical siphon drainage pipe system should be limited between 1m to 10.3m , we can use Eq.12 to calculate the design length under this range, as shown in Fig.9.

The simulation results compare with the study result by Tsukagoshi [1], it shows the siphon energy is larger when the length of vertical siphon pipe is longer or the length of horizontal drainage pipe is shorter in the same length vertical pipes. The siphon force will not be sufficient when the length proportion α is under or over the critical value.

In this study, we assumed the length proportion under the ideal conditions in the system, and the diameter of drainage pipe is 20mm. The best design is short vertical pipes with longer horizontal pipes under the range of length proportion.

6. Conclusion

The length proportion is the important basis of siphon drainage design, and this study offers an easy check diagram in the length of siphon drainage pipe. The design length must follow the critical values, such as length of pipes, drainage velocity, push height, diameter of pipe, for siphon force.

The simulation in this study is under ideal conditions, we want to check the results or modify the parameters by real site experiment in the near future. The simulation condition is considered at basin with small and simple soil. For toilet use, there may be a need to design a buffer zone or disposer to break down hard excrement and quickly discharge the toilet water.

7. Nomenclature

A	Cross section	m^2	$m_{2\to3}$	Mass in 2-3 section	kg
a	acceleration	m/s^2	$m_{4\to5}$	Mass in 4-5 section	kg
b	Diameter	m	P	Pressure	N/m^2
F	Siphon force	N	v	Velocity	m/sec
g	Acceleration of gravity	m/s^2	y	Distance between water flow	m
L_h	Length of horizontal	m	E	Energy	J
L_V	Length of vertical	m	PE	Potential energy	J
L_{pU}	Push height in U-pipe	m	KE	Kinetic energy	J
m	Mass	kg	FE	Flowing energy	J
n	Coefficient in 1 / 7	-	ρ	Density	kg/m^3

8. Reference

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9. Presentation of Author

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G3) Implications of grey water re-use on solid transport in building drainage systems.

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Abstract

Grey water re-use has presented real benefits in terms of water conservation of domestic and commercial potable water supplies in recent years. While the benefits of water usage reductions are clear, the costs are less obvious and require a more detailed investigation. One such cost is the possible increased likelihood of maintenance due to the blockages caused by the reduction in water available to transport solids away from the building drain to the main public sewer. One particular problem concerns the re-use of large volume drain cleansing discharges such as those from baths. In the grey water re-use scenario this bath water is used to flush a WC, thus replacing a surge wave of long duration with a series of much smaller amplitude surge waves from a WC discharge. In this research the implications of grey water re-use have been assessed in a number of installation scenarios, from single dwellings to a small housing estate with a common collection drain leading to the public sewer. The numerical model 'DRAINET' was used to model the scenarios incorporating known and assumed usage patterns. These simulations lead to conclusions that, in the main, grey water re-use does not have a major impact on the solid transport characteristics of a drainage system. There are however significant exceptions and great care should be taken in mitigating against the increased risk of blockages associated with these cases. The simulations also confirm the importance of correct pipe diameter selection in order to maximize system efficiency and reduce risk of failure.

Keywords

Grey water re-use, solid transport modelling, building drainage systems.

1. Introduction

Water recycling systems offer many benefits, such as reducing the strain on the freshwater supplies and reducing the amount of wastewater entering the sewage pipes. This research aims to investigate the impact that water recycling systems, in particular grey water recycling systems, have on domestic drainage systems and to assess the implications of this water conservation method.

In recent years, the topic of global warming and climate change cannot have gone unnoticed amongst the general public regardless of their personal stance on the issue. While the issue of Climate Change is often seen as 'carbon' issue, and this is not in dispute any more, the consequences of a seemingly inevitable change in climate are as much to do with 'water' as carbon. In some places too much water exists, in the case of flooding, and in others, there is too little water. This has led some to proclaim that 'water is the new carbon' [1] as adapting to more erratic climate conditions falls easily under the remit of the practicing Engineer.

Water agencies around the world are rapidly realising the benefits of treated recycled water, especially with the increasing pressures on water resources due to growing populations, increase in the numbers of households and water wastage [2] It has been shown that the issues of water reclamation, recycling and reuse constitute an important part of water and wastewater management [2], [3]. Angelakis & Bontoux highlight that the benefits of using recycled water which include the protection of water resources, prevention of coastal pollution, recovery of nutrients for agriculture, savings in wastewater treatment, and sustainability of water resource management [4]. Despite the diversity of the benefits of recycled water, care should be taken to ensure that water recycling systems are implemented in conjunction with other water conservation measures [2].

The re-use of grey water for flushing WCs and other non-drinking purposes such as irrigation has become more commonplace in recent years. Current WCs use 6 litres of water to flush and pressure exists to push this down even further. The transportation distances of waste material from WCs is dependent mainly on the volume of water used in the flush. In many ways building drains (especially those with long horizontal runs) depend on contributing flows from other appliances to achieve self-cleansing. In many cases these flows are of longer duration (e.g. a bath or a continuously draining shower) and therefore assist in cleaning drain lines with much more efficacy than a short duration WC flush. The removal of grey water as a 'contributing flow' may compromise this self-cleansing. This research seeks to quantify the effect of removing grey water, with it's original discharge characteristics, and re-using it in a much less efficacious manner.

2. Water consumption and conservation

It is widely accepted that using high quality potable water within some appliances, such as WCs, is a waste of a resource, especially in countries where water of such a high quality is in rare existence and reasonably inaccessible [5], [6]. It is also true to say that arid countries would benefit from reducing the amount of high quality potable water used by these appliances.

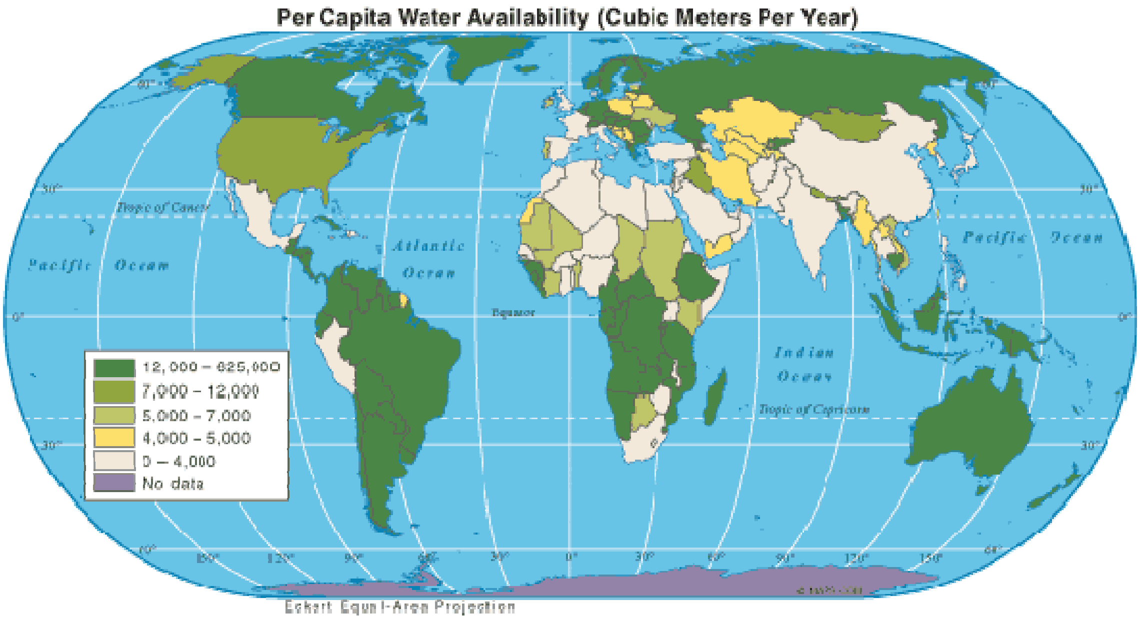

Figure 1 – Per Capita Water Availability (Source: WWDR)

Water consumption has increased over the years. Moran *et al*, present figures that suggest an increase of 35% in the supply of water between 1971 and 2001 for unmetered properties [7]. In the UK, the average domestic water consumption is 149 litres per person per day [8]. There are factors such as climate, culture and economy that will have an impact on the domestic water consumption in different countries as discussed by Lazarova *et al*, who also discuss the factors that result in variable per capita consumption, which include age, sex, type of domestic appliances and metering arrangements [9]. It is also true that as a result in these increases in water consumption, that many areas have suffered and endured “periods of man made drought, depletion of environmental flow in natural water systems and the decrease in the quality of drinking water reservoirs, including groundwater systems” [6].

3. Grey water recycling systems

In many applications the largest savings in mains water are likely to be obtained by using reclaimed water for toilet flushing [10]. Low public acceptance of using grey water for activities such as watering vegetables has been widespread, and it could be suggested that users may prefer to use rainwater for such activities and use grey water for non-personal activities such as toilet flushing. This would certainly improve the acceptability of water recycling systems, especially since it has been suggested that public acceptability improves after exposure to such systems [11]. It would also fit in with the views of Dolnicar *et al*, who want to exploit the powers of word of mouth and use influential people to endorse and publicise these alternative systems [6].

It has been suggested that there is a “cumulative flow balance” between the grey water collected and the volume of water required for the WCs [3],[12]. Jefferson further explains that although there is this "cumulative flow balance", grey water is generated over short time periods and not always in tandem with toilet flushing, which occurs more consistently throughout the day [3]. Figure 2. depicts these variations in times of supply and demand, that will generally result in a deficit in water during the afternoon and later evening [13], which therefore require the recycled water to be stored to balance out the variations between generation and use [12]. However, it should be noted that residence time in systems dramatically affects the characteristics of grey water and care should be taken to ensure that grey water is not stored for long periods of time. An investigation by Dixon et al into storage tanks found that a $1m^3$ tank was suitable for a wide range of occupancy scales [14]. Jefferson et al found that increases in storage capacity over $1m^3$ provided marginal rises in water saving whilst also enhancing problems associated with grey water degradation and disinfection reliability, due to prolonged storage [3],[6].

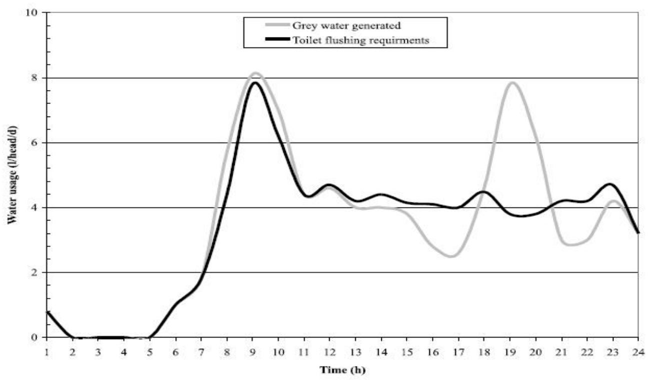

Figure 2 – Grey water Collected v WC Flushing Requirements
(Source: Jefferson *et al*, 2000 courtesy of Surendran & Wheatley, 1998)

4. Simulation of systems using DRAINET: building types and usage scenarios

It is of great importance to consider the different types of buildings and the habits of their occupants (scenarios) in order to gauge their water consumption and therefore assess the implications of grey water re-use. Although there are stated volumes of water associated with different activities such as showering, it can be difficult to ascertain the exact amount of water used by an individual. It is true to say that lifestyle choices and personal attitudes towards environmental issues will differ from person to person. Despite increased promotion of the benefits of saving water, it cannot be assumed that everyone will follow this advice. Hence, the values used in these simulations will be based on the usage patterns of a person who is not environmentally conscious. It can be said, however, that in reality these values may vary and thus have an impact on the outcome.

Each of these scenarios will be simulated using the numerical model DRAINET and the first simulation will be run with all the water (waste and grey) entering the sewerage system to assess solid transportation distances and to determine whether or not the entire system will be self cleansing. The scenarios will then be run again, with only the wastewater from the WCs entering the drainage system. This will allow a comparison of the final transportation distances of the two simulations and determine the impact of removing the grey water from the drainage system.

The results from the individual households will be input into the fourth scenario, which will simulate a ten house estate, and will allow an assessment to be made on the implications of grey water reuse on the operation of the drainage system. To investigate this issue further, the ten-house estate scenario will be re-run (for both grey water reuse and all water to drain) with differing pipe sizes.

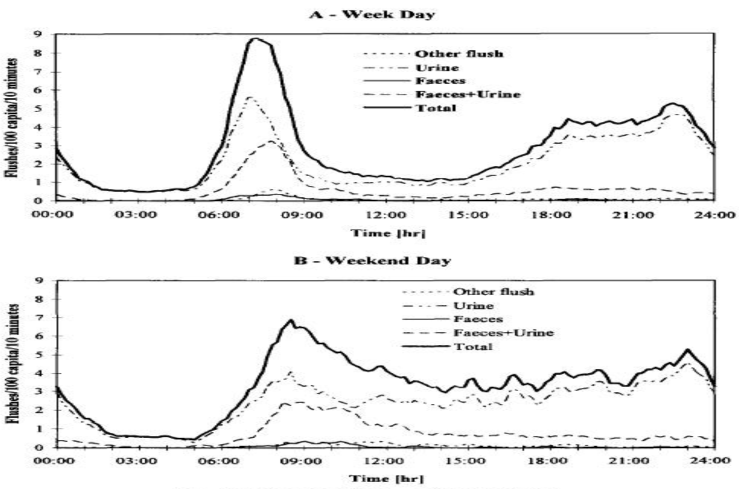

Figure 3 – WC modes of use - diurnal patterns
(Source: Friedler *et al*, 1996)

Within each scenario, the week has been divided into typical weekday and weekend usage. Figures by Friedler [15] and assumptions were used to generate a table of the typical appliances and their associated usage. While it is possible to divide the day into three distinct time zones, morning, day and evening, the simulations run in DRAINET will be based only on the morning peak time between 6am and 9am, by which time the house will be vacated for the working day. Simulating the morning will give a good indication of the usage patterns of each appliance and assess the requirements of the drainage system. Figure 3 depicts weekday and weekend WC modes of use found from the survey undertaken by Friedler [15].

Each of the scenarios/households had the same appliances and pipe layout to aid comparisons and to eliminate any extra parameters that could impact on the operation of the drainage system. The system was designed to meet European standard EN12056:2000 [16]. Figure 4 depicts the domestic appliance and drainage layout – It should be noted that pipe 19 connects to the main sewer, and the two crossed boxes at pipes 7 and 9 represent a washing machine and dishwasher respectively.

It has been assumed that all buildings are single storey and are attached to mains sewerage. It is also assumed that all houses will have 1m^3 grey water recycling storage tanks as suggested by [3]. Table 1 indicates the assumed quantities of water consumed by domestic appliances.

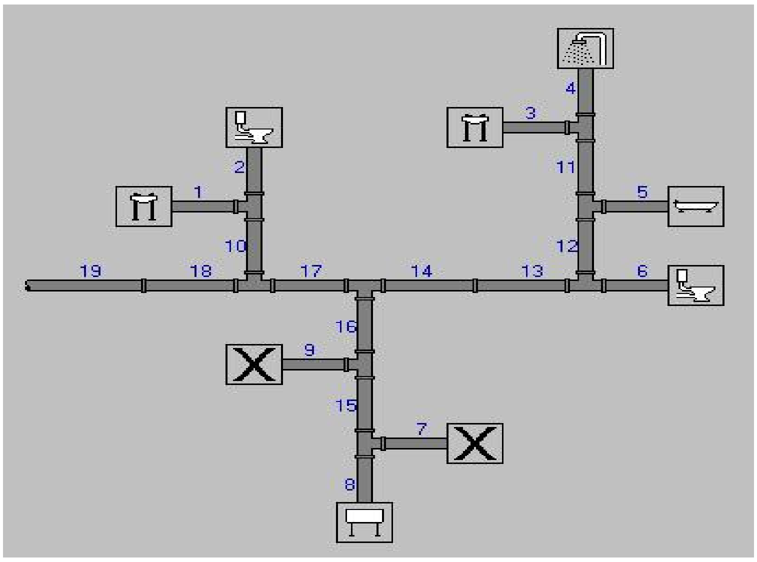

Figure 4. Domestic Appliance & Drainage Layout

Table 1 – Appliances & Associate Volume of Water Used

Appliance	Water Used (litres)	Dishwasher	15
Bath	75 to 90	Sink	6 to 8
Shower	5 to 7 per min	Wash face & heads	3 to 9
WC	6	Teeth cleaning (tap on)	5 to15
Washing Machine	50	Teeth cleaning (tap on/off)	1 to 2

(Source: The Water School)

5. Usage Scenarios

5.1 Scenario 1 (Single Occupant)

The first scenario is a single house with one occupant. The gender and age of the occupant has not specified, however it is noted that the domestic WC usage patterns could be affected by these parameters [15]. For all scenarios, the simulation of each scenario in DRAINET will be based on the timeframe 6am-9am.

Table 2 illustrates which appliance the occupant uses and when. This information can then be used to determine how much water will be entering the drainage pipe and when. This information will be important in ascertaining whether or not the pipe will self-cleanse.

Table 2 – Morning Water Usage for Single Occupant Household

Appliance	Morn Uses	6-6.30	6.30-7	7-7.30	7.30-8	8-8.30	8.30-9
		0-1800	1800-3600	3600-5400	5400-7200	7200-9000	9000-10800
Bath	0						
Shower	1				1		
WC 1	1	1					
Basin 1	1	1					
WC 2	1					1	
Basin 2	1		1			1	
Washing Machine	1		1				
Dishwasher	1						
Sink	1			1			

5.2 Scenario 2 (Standard Household)

The second scenario represents a house with a group of four occupants. It is presumed that all four occupants will be out of the house by 9am, with activities happening at various times between 6 and 9am. Table 3 below shows the number of times each appliance in the house is used between 6 and 9am. In order to simulate these in DRAINET, the morning has been subdivided into 6 half hour slots and the second part of the table lists the appliances used in each half hour timeslot and how many times. It could be suggested that despite installing two WC's in each house, one WC may be used more often than the other. It is assumed that the two WC's are equally popular, especially as the larger the household, the more likely one or other bathroom will be occupied.

Table 3 – Morning Water Usage for Standard Household

Appliance	Morn Uses	6-6.30	6.30-7	7-7.30	7.30-8	8-8.30	8.30-9
		0-1800	1800-3600	3600-5400	5400-7200	7200-9000	9000-10800
Bath	1					1	
Shower	3	1	1	1			
WC 1	4	1		1	1	1	
Basin 1	6	1		1	1	1	2
WC 2	4	1	1	1	1		
Basin 2	6	1	1	1	1		2
Washing Machine	1	1	1				
Dishwasher	1		1	1			
Sink	6		1		1	2	2

5.3 Scenario 3 (Large Household)

This scenario looks at the usage patterns of a household that is occupied by 6 people. This was to incorporate larger families or households with a number of unrelated persons such as student accommodation or young professionals. Although it is expected that the number of smaller household would increase in future years in the UK, it is still important to assess the water consumption and usage patterns of a variety of household dynamics hence the inclusion of the multi-occupied household.

Table 4 – Characteristics of sample households

Household size distribution			
Number of occupants	Household No.	Sample %	U.K.*
1	32	24	23
2	62	46	32
3	14	10	17
4	19	14	18
5+	8	6	10

Household age distribution			
Age range	Sample No.	Sample %	U.K.†
0–14	59	18.8	19.4
15–29	64	20.4	21.5
30–44	107	34.1	21.2
45–59	63	20.1	17.3
60–74	10	3.2	13.7
75+	1	0.3	6.9
Not indicated	10	3.2	—

(Source: Friedler *et al*, 1996)

The same methodology was used to determine the contribution of each appliance to overall drainage flows due to the assumed usage patterns. Table 5 shows the results of this exercise for the large household.

Table 5 – Morning Water Usage for Large Household

Appliance	Morn Uses	6-6.30	6.30-7	7-7.30	7.30-8	8-8.30	8.30-9
		0-1800	1800-3600	3600-5400	5400-7200	7200-9000	9000-10800
Bath	1			1			
Shower	5		1	1	2	1	
WC 1	6	1	1	2		1	1
Basin 1	9	1	1	2		3	2
WC 2	6			3		1	2
Basin 2	9			4		1	4
Washing Machine	1						1
Dishwasher	1						1
Sink	6			1	1	2	2

5.4 Scenario 4 (Ten-House Estate)

The fourth scenario investigated a housing estate of ten houses. A mix of single occupant, single family and multi-occupant households made up this estate. Having investigated the effects of water consumption and grey water recycling on the domestic drainage system within the actual house, it was imperative to ensure that once all the houses were connected to the main sewerage system, that there would be adequate flow to avoid blockages. In order to simulate this scenario, the results for the first 3 scenarios were used to make up the profile for the estate and were run twice as previously discussed.

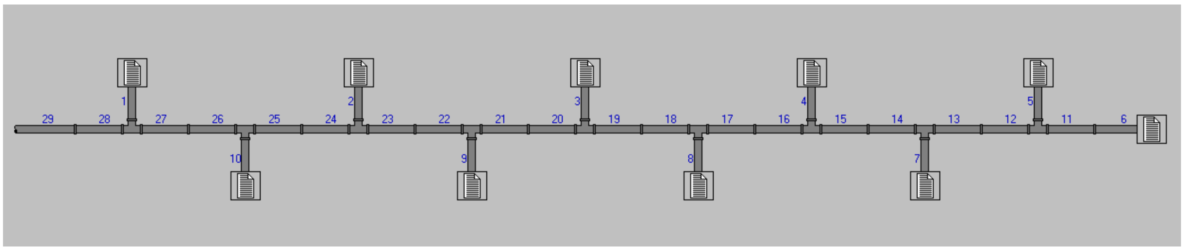

Figure 5 – Scenario 4 simulation layout

6. Results and discussion

The rationale behind this research was to establish whether removing grey water from the drainage system completely would increase the risk of blockages occurring in the house drain and collection drains for houses in different configurations. Simulations of solid transport were carried out on different house types and combinations to assess this risk.

6.1 Solid transport in the house drain

Figure 6 shows the results obtained from the assessment of solid transport within each of the house types described above. Since the usage scenarios describe many appliance operations with combinations of WC flushes with and without solids, the approach taken was to assess whether or not solids leave the house drain and enter the main sewer as a result of all the appliance activity during the peak period of 6 am to 9 am. In order to assess this all solid transport distances were calculated in relation to the distance to the main sewer i.e. actual transport distance (m) / distance to main sewer (m). This produces a transport index where greater than 1 represents solid which clear the house drain and an index of less than 1 are solids which remain in the house drain despite the significant activity during these peak hours.

It can be seen from Figure 6 that the only house type/usage scenario of concern is the single occupancy house where all the grey water is recycled, all other scenarios clear the house drain during these peak hours.

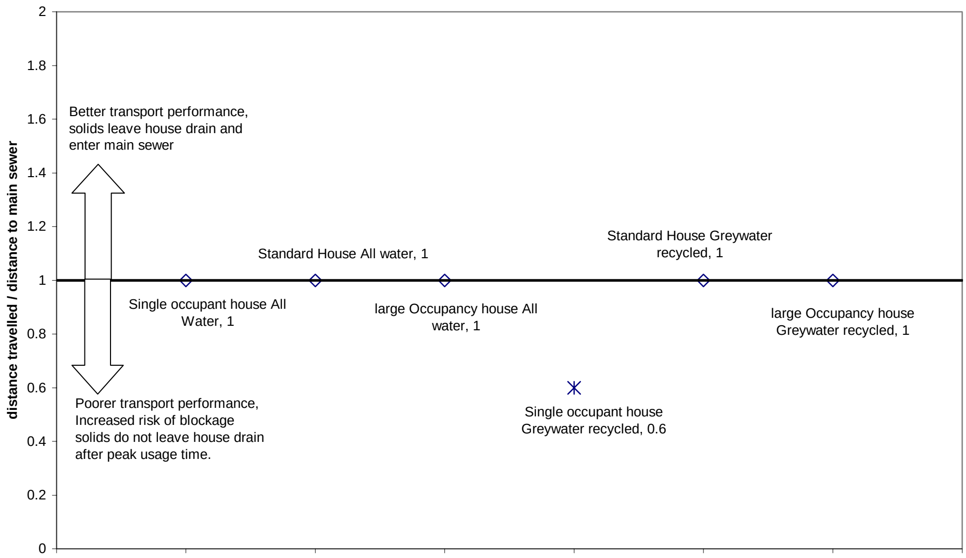

Figure 6 – Assessment of solid transport distances for individual house drain scenarios.

6.2 Solid transport in the main collection drain

The transport of solids away from the building and into the public sewer network is also of significance when assessing the risk of blockages in relation to the quantities of water available to ensure drain self-cleansing. An assessment of solid transport distances was carried out in the configuration of 10 houses as shown in Figure 5 above. In this assessment the critical issue is one of contributing flows from the different houses. Solids need to travel far enough so that they can be moved on from flows from adjacent houses. So a critical transport distance is the distance between houses. Again, as in the case with the house drain above, a solid transport index is a useful tool for assessing the risk of blockages. In this case transport distances are cast in terms of the number of adjoining flows contributing to the final transport distances for a particular scenario i.e actual transport distance (m) / distance between adjoining flows (m). The critical number for this index again is 1. A scenario producing an index of less than 1 is at an elevated risk of blockage, since it has travelled its maximum distance (no further transport possible due to upstream flows) and not yet reached a point where an adjoining flow could assist transport further.

It can be seen from Figure 7 that as pipe diameter decreases solid transport performance increases, and as would be expected, as the quantity of water available for solid transport decreases so solid transport performance decreases. Figure 7 also shows the critical transport index of 1 and the only scenario which falls below this is the case where all grey water is recycled and the main collection drain is 150 mm.

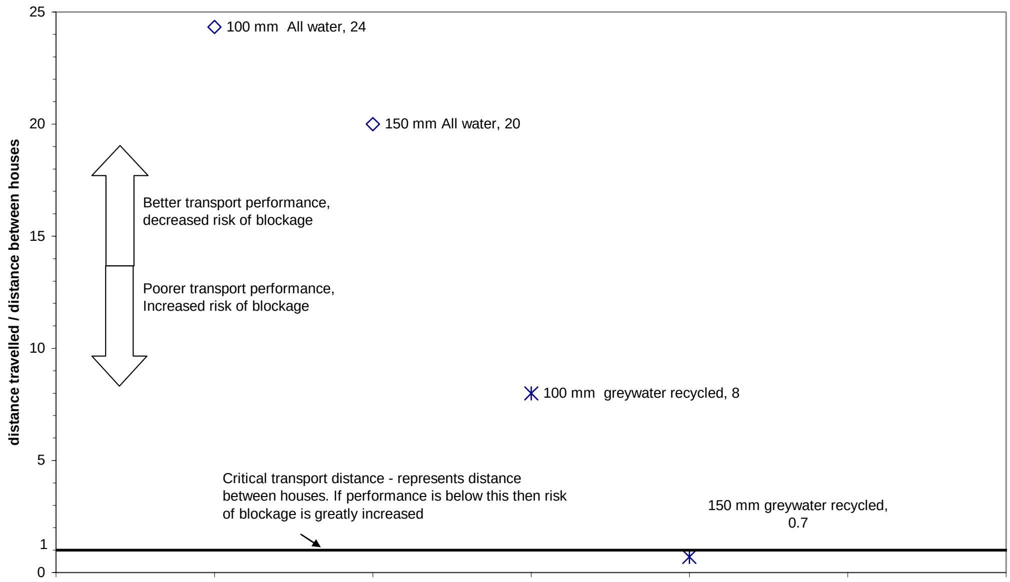

Figure 7 – Assessment of solid transport performance in multi – house configuration (scenario 4)

7. Conclusions

This research has shown that it is possible to recycle grey water whilst minimizing the risk of blockages in house drains and main collection drains between houses in U.K. configurations. Areas of concern are clearly properties where there is little activity due to the small number of occupants. Another cause for concern is the over specification of pipe diameter, with performance being severely reduced where larger diameter pipes are used with smaller quantities of water.

The introduction of solid transport performance indices linking transport distances to known limiting parameters such as distances between adjoining flows and maximum distance to the collection drain from a house installation has proved very useful in assessing risk of blockage and system performance.

Overall the research has confirmed that, with some exceptions, 100% grey water can be tolerated in terms of maintaining adequate flows for the transport of solids in the system. The research has also confirmed that the choice of pipe diameter is crucial in minimizing the risk of blockages and maximizing performance under water conservation criteria.

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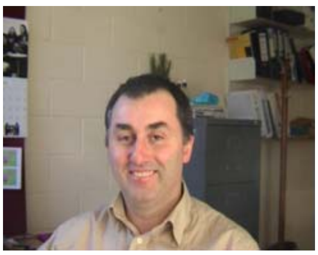

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G4) Reducing the risk of infection spread from the building drainage system through identification of depleted appliance trap seals using the reflected wave technique

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Abstract

The loss of an appliance trap seal can pose a serious risk to public health. Depleted appliance trap seals were shown to be a causal factor in the rapid spread of the SARS virus in Hong Kong in 2003. Without a method of monitoring the condition and status of the appliance trap seals, they can often lie empty for a considerable time unnoticed. This paper presents a method for identifying depleted appliance trap seals using the reflected wave technique which uses the arrival time of the first reflected wave from an open trap to determine its location within the system.

For the first time, the reflected wave technique has been tested within a fully occupied office building. These investigations have not only shown that the technique to can be easily applied to real building situations but has shown that up to six single stacks in the same drainage network can be tested from one test location. Also, a new trap recognition programme is presented which is capable of automatically detecting and locating a depleted trap seal within any building drainage system.

Keywords

Building drainage system, trap seal depletion, cross-contamination, reflected wave

1. Introduction

The building drainage system is designed to convey human and domestic wastewater to the sewer quickly and safely, while simultaneously ensuring foul sewer gases are prevented from entering the building. Recent evidence has shown that a failure in the building drainage system can pose a very serious, and potentially fatal, risk to public health by facilitating the spread of dangerous disease and infection. This was demonstrated by its facilitating role in the rapid spread of the severe acute respiratory syndrome (SARS) virus at the Amoy Gardens housing complex in Hong Kong in 2003 where a total of 321 residents were infected with the airborne virus resulting in 41 fatalities. A number of factors were attributed to the spread of the virus[1] but none as contributory as the depletion of several trap seals serving the bathroom floor drains within the building. Designed to provide protection from the foul sewer gases prevalent within the drainage system, the physical barrier created by the water filled trap seal can be lost through excessive pressures generated within the drainage system following normal appliance discharge, or through evaporation due to lack of use or poor maintenance[2], thus forming a route for cross-contamination between the drainage system and the occupied space.

Such a catastrophic event could have been avoided if a regular and routine maintenance regime had been in place to monitor the condition and status of each appliance trap seal. By promptly identifying and repairing a trap failure the spread of infection could have been limited and the risk to public health minimized. However, the practicalities of current maintenance methods make this difficult to achieve as they are reliant on visual inspection of the trap seal which is not only time consuming, but sometimes difficult or impossible to implement due to the scale of the building or inaccessible trap seals. A new and innovative technique to detect and locate depleted appliance trap seals using a remote and non-invasive system test has been presented in previous papers[3, 4, 5, 6]. The reflected wave (RW) technique is based on the temporal analysis of the first reflected wave returned from a depleted trap in response to the arrival time of a controlled low-amplitude sinusoidal pressure wave. This paper extends this work further by presenting results from an extensive field investigation which, for the first time, allowed the RW technique to be tested within a fully occupied and operational office building. In addition to addressing the practical issues of testing within a real building, these field trials allowed the working range of the RW technique to be examined as the drainage system used for testing consisted of multiple single stacks.

Firstly, the basis of the RW technique will be presented, followed by an overview of a computer programme developed to identify the depleted trap reflected wave through automatic analyse of the system pressure response. Finally, the findings of the field investigations will be presented.

2. Reflected wave technique

Pressure transients occur within the drainage system following rapid changes in flow conditions and are normally considered a problem as they are a potential cause of trap depletion. However, since transient pressure waves propagate back and forth in the pipeline and, at the same time are affected by the presence of system boundaries, such transients carry information about features of the pipeline[7]. The resultant system response is, therefore, specific to that system and the different boundaries within it. Every boundary has a characteristic reflection coefficient which alters the system pressure response. A fully primed trap (similar to a closed end) will generate a positive reflection (equal in magnitude and sign to the incident wave) while a depleted trap (similar to an open end) will generate a negative reflection (equal in magnitude but opposite in sign to the incident wave). Figure 1 demonstrates the difference between the measured reflection for both a closed and open ended pipe.

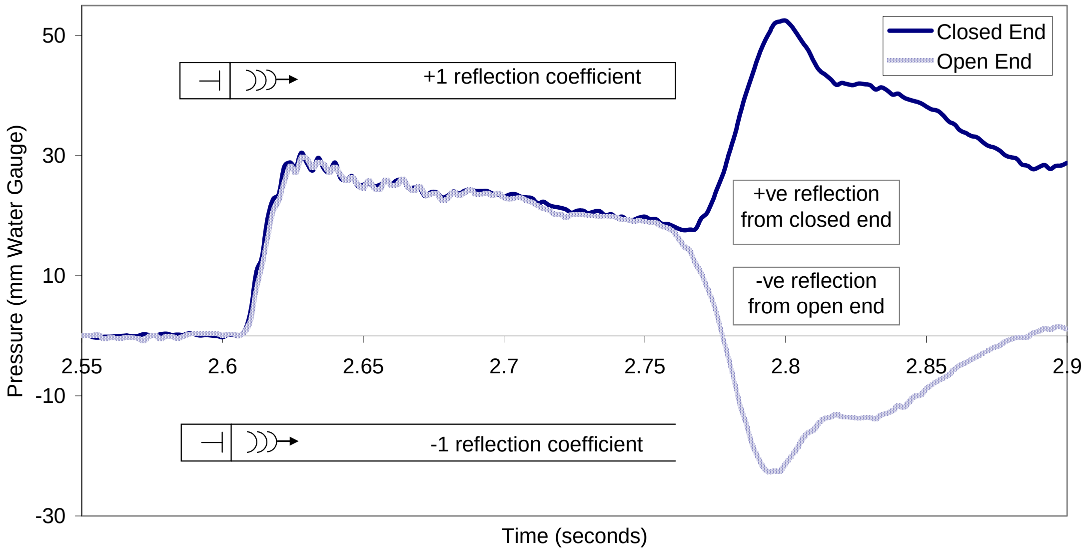

Figure 1 –Demonstration of the +1/-1 reflection coefficients encountered at a closed and open end termination of a single pipe subject to a positive pressure pulse

The RW technique operates by comparing a test system response with a previously obtained defect free baseline. If a trap seal becomes depleted then this will be characterised by a pressure drop in the test system response and the two traces will diverge at a time specific to the location of that trap within the system.

The time of divergence, t, can be used to determine the distance to the depleted trap from the pressure measurement point, X_D, as this correlates to the time taken for the incident wave to arrive at the depleted trap, be reflected, and arrive back at the pressure measurement point:

$$X_D = \frac{t \times c}{2} \qquad (1)$$

where c is the wave propagation speed which can be calculated from the following equation[2]:

$$c = \sqrt{\frac{\gamma p}{\rho}} \qquad (2)$$

where γ is the ratio of specific heat, p is the absolute air pressure and ρ is the air density. Equation (2) assumes isentropic flow, however, this is a valid assumption for drainage system application as the changes in temperature and pressure are extremely small during transient propagation. For air at 20 ^{o}C, c = 340 m/s. Wave propagation speeds calculated theoretically are approximate and are only for preliminary tests. For improved accuracy the true wave propagation speed is measured on site.

Test Equipment

Previous work[5, 6] has shown that a 10Hz sinusoidal pressure wave does not compromise the integrity of the trap seals as the time duration that the cyclic transient waves are in contact with the trap surface are insufficient to overcome the inertia of the water column, thus, providing a completely non-invasive test transient. Additionally, optimum delivery of the sinusoidal pressure wave into the drainage system is achieved via a 3-port valve located within the upper stack allowing directional control of the test transient and removing the potential problem of mirrored reflections[4]. These requirements have lead to the development of the test equipment combination shown in Figure 2. In addition to these requirements, this equipment, measures the system pressure response via the integrated pressure transducer and can be easily installed into any new or existing building drainage system.

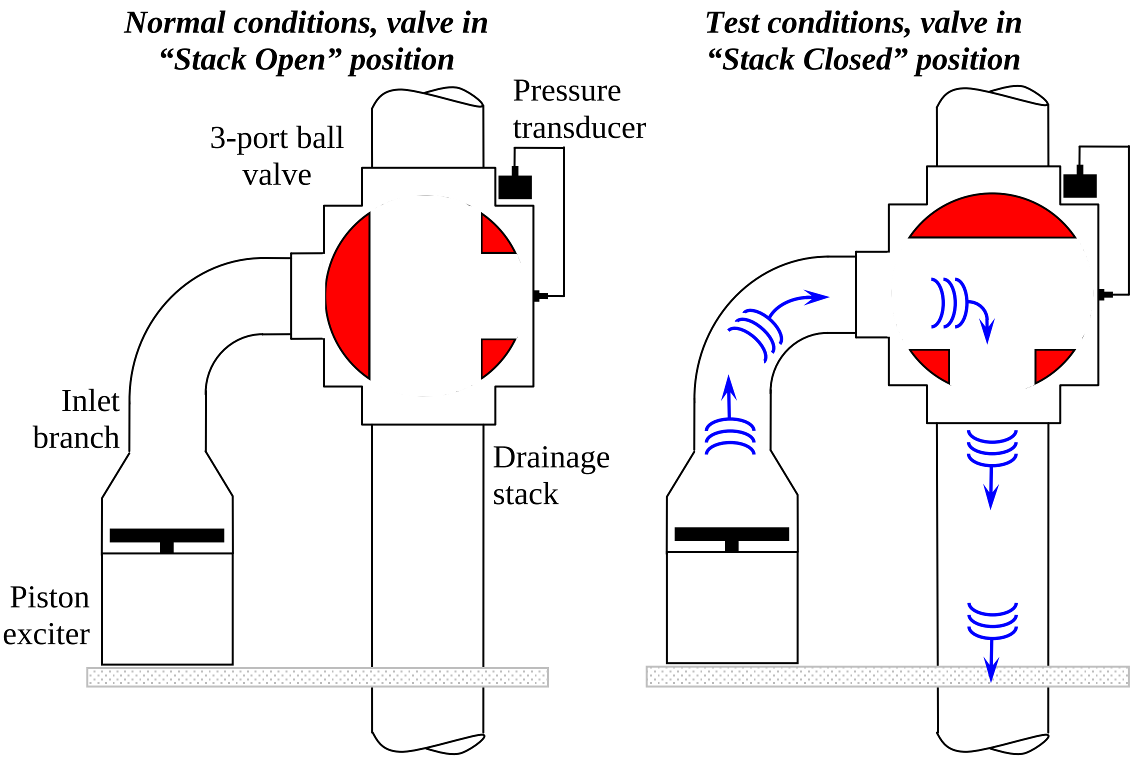

Figure 2 – Test equipment combination providing transient generator, transient directional control and system pressure response measurement

The 3-port valve remains in the "stack open" position during normal conditions and is switched to the "stack closed" position during test conditions. The valve is controlled by a relay controlled actuator which has a failsafe reset function which returns the valve to the "stack open" position in the event of a power failure.

3. Automatic depleted trap detection and location

An Excel-based computer programme has been developed to read, analyse and display the system response measured by the pressure transducers (data collection rate = 2kHz). Applying the numerical data analysis detailed below, the programme allows automatic detection and location of depleted trap seals within any building drainage system. The trap recognition programme allows comparison of consecutive test traces by identifying the start of the system pressure response as the time when the pressure from at least four consecutive data points is > 1 mm water gauge.

The RW technique uses the return time, t, of the negative reflection from a depleted trap seal to locate that trap. Comparing a test trace with the defect free baseline allows t^* to be determined easily from the time that the two traces diverge. Firstly, ensuring that all traps are fully primed, the defect free baseline, mSp_{DF}, is determined by averaging the data for N number of defect free traces using:

$$mSp_{DF} = \frac{mSp_1 + mSp_2 + ... + mSp_N}{N} \quad (3)$$

The defect free baseline and any subsequent test trace, mSp_{TEST}, are then analysed to determine the time of divergence using the Absolute Compliance Factor (ACF) which calculates the absolute difference between the two traces point-by-point:

$$ACF = \left| mSp_{DF} - mSp_{TEST} \right| \quad (4)$$

The ACF provides a measure of the relationship between the defect free baseline and the test trace. The closer the two traces match, the smaller the ACF. For a perfect system ACF = 0 at every data point. However, in real systems where noise and natural signal variations must be considered, it is necessary to determine a threshold, h_{MAX}, to distinguish between signal variations caused by normal signal drifts and those caused by depleted traps. This is calculated as the maximum deviation between the defect free baseline and each of the N number of defect free traces measured previously:

$$h_{MAX} = \left| mSp_i - mSp_{DF} \right|_{i=1}^{i=N} \quad (5)$$

The time, t^*, when ACF > h_{MAX} is recorded as the wave arrival time and is substituted into Equation (1) to determine the location of the depleted trap seal.

The parameters required for the successful operation of the trap recognition programme are as follows: (i) distance to each trap, X_D^{true}; (ii) defect free baseline, mSp_{DF}; (iii) system threshold, h_{MAX}; (iv) wave propagation velocity, c. These will be specific to each system but can be easily and quickly determined during initial test commissioning.

4. Field validation

Tests were carried out on the drainage system of a fully occupied 7-storey insurance building in Glasgow to assess the practical considerations of applying the RW technique to detect depleted trap seals in real building situations. This compliments earlier testing conducted within an unoccupied building in Dundee and in a Heriot-Watt University building in Edinburgh[4, 5, 6]. Figure 3 shows a schematic of the drainage system used for testing. This multi-stack system consisted of six 100 mm diameter cast iron single stacks, each connecting to a common horizontal drain pipe at high level within the basement, and each terminated with an air admittance valve. Stack 2 and Stack 5 served WCs only, whilst the other stacks served wash-hand-basins only.

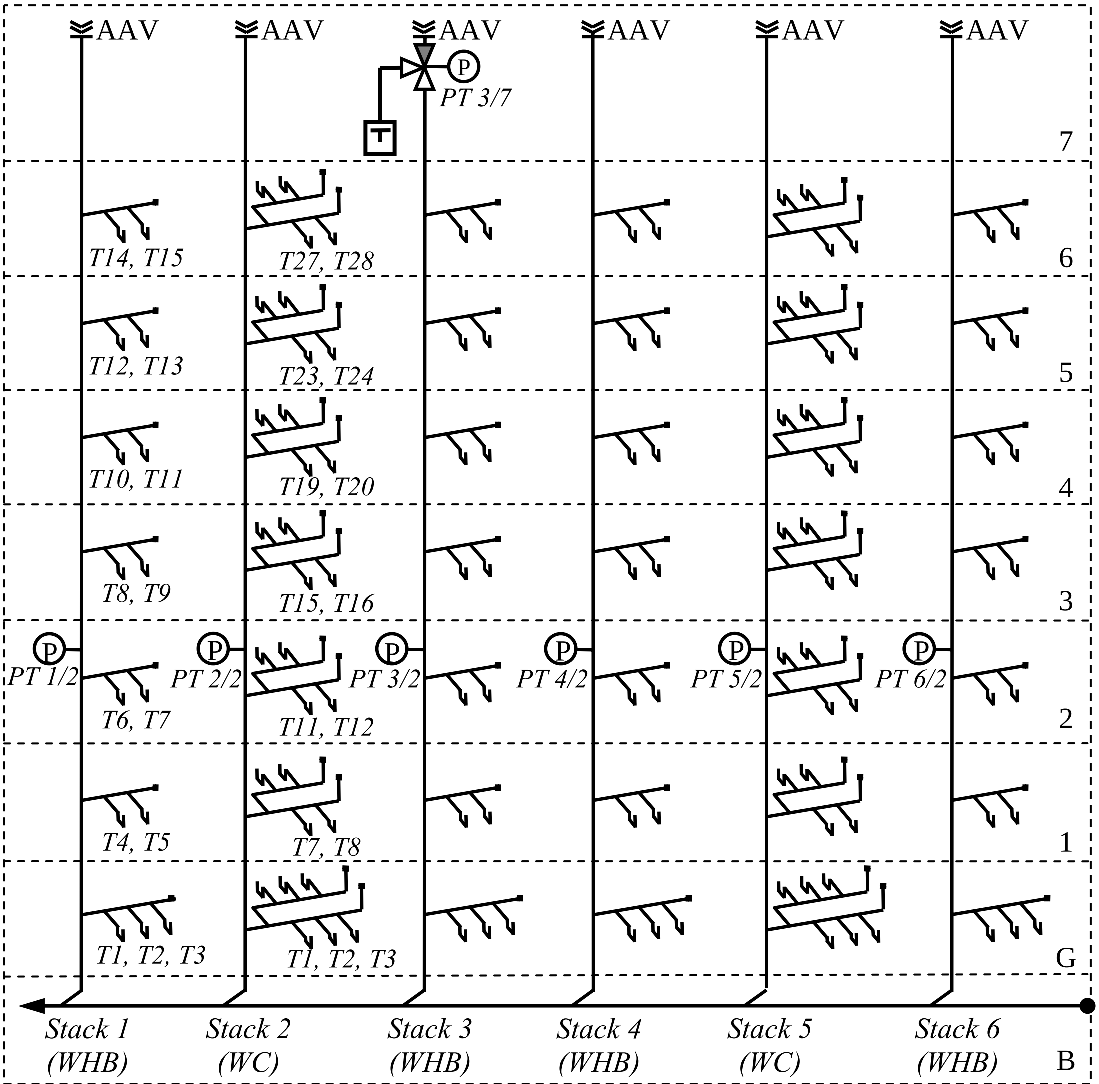

Figure 3 – Schematic of multi-stack drainage system used for field investigations showing location of the test equipment combination and pressure transducers

One stack was selected to mount the test equipment combination, from where the whole system would be tested to examine the working range of the RW technique. Stack 3 was selected and the equipment was installed within the upper stack section on Floor 7. Pre-test analysis was carried out using the Method of Characteristics based computer model, AIRNET, developed previously at Heriot-Watt Univeristy[8, 9]. Capable of simulating the RW technique in any building drainage system, AIRNET, allows optimum pressure measurement points to be identified within the system. In addition to the pressure transducer included in the test equipment combination, PT 1, a further transducer was required at the base of each of the remaining stacks. However, due to issues of accessibility these transducers were located at Floor 2. Each transducer is designated by its *stack number* and *floor number*, i.e. PT 1/2 for a transducer on Stack 1 and floor 2, and each trap is designated by its *stack number* and *trap number*, i.e. T 2/12 for a trap on Stack 2 and number 12.

To begin the test process, firstly, the system characteristics in terms of configuration and dimensions were collected, allowing X_D^{true} to be input to the trap recognition programme. Next, the defect free baseline, mSp_{DF}, and the system threshold, h_{MAX}, were determined from a sample of 20 system pressure responses using Equations (3) and (5) respectively. Figure 4 shows mSp_{DF} and h_{MAX} for each of the six stacks.

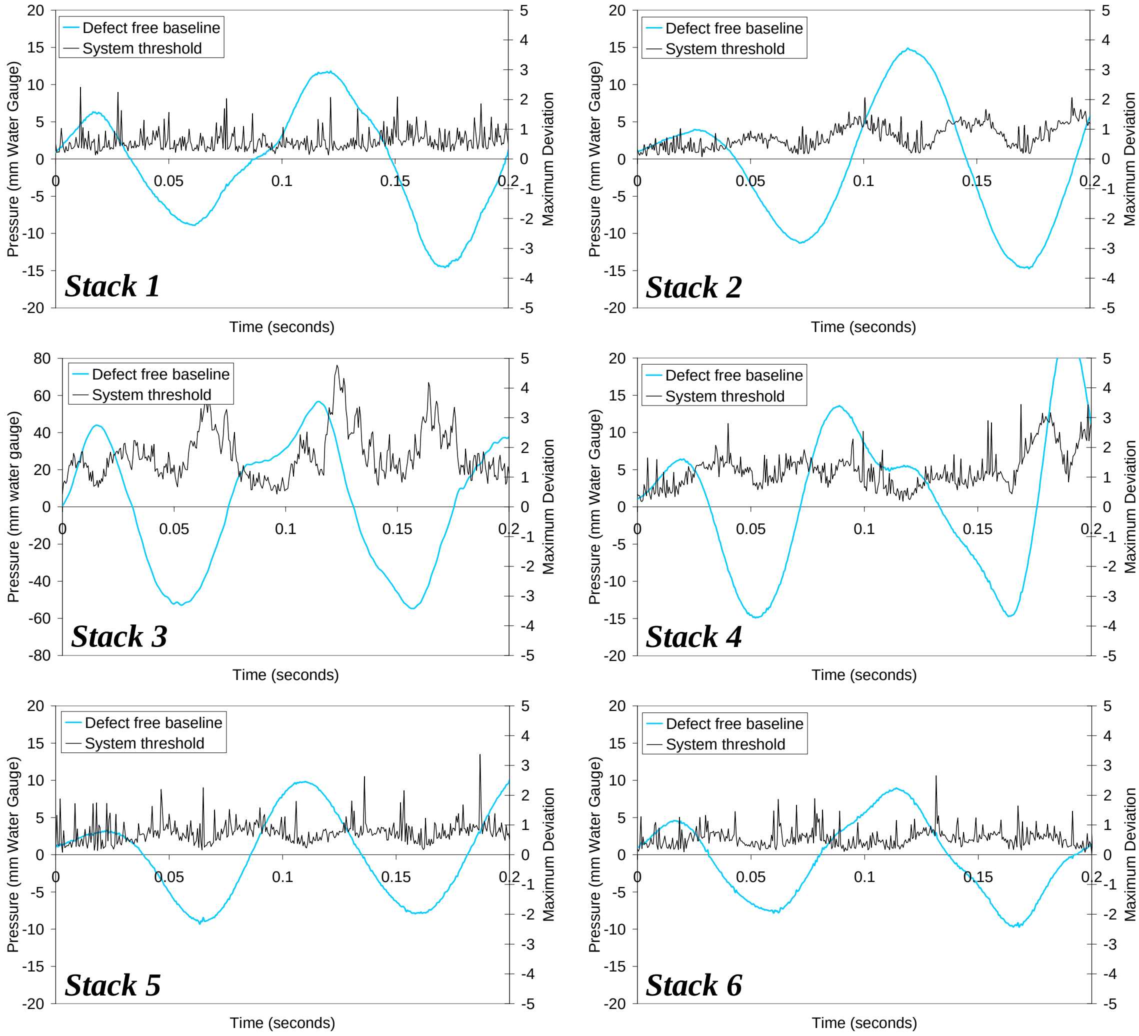

Figure 4 – Defect free baseline, mSp_{DF}, and system threshold, h_{MAX}, for each stack in response to a 10Hz control transient applied to Stack 3 at Floor 7

The magnitude of the system pressure response measured at PT 1 on Stack 3 is between 7 and 10 times greater than that measured at Floor 2 on any of the other stacks. This is due to the effect that the system junctions have on the travelling transient. On arriving at a junction the transient will be partly reflected backwards while the remainder will be transmitted forwards. The magnitude of the reflected wave for a three-pipe junction is defined by the following general expression[10]:

$$C_R = \frac{A_1 - A_2 - A_3}{A_1 + A_2 + A_3} \quad (6)$$

where C_R is the reflection coefficient and A is the cross-sectional pipe area. Neglecting energy losses along the pipeline, the reflected wave subtracted from the incident wave equals the transmitted wave with a transmission coefficient, C_T, derived from:

$$C_T = \frac{2A_1}{A_1 + A_2 + A_3} \quad (7)$$

Note that the above expressions have been simplified by omitting the wave propagation speed as this is assumed to be constant for all connecting pipes. It is clear from Equations (6) and (7) that the reflection and transmission coefficients are reliant on the area ratios of the pipes within the junction. A 3-pipe junction will always generate a 1/3 reflection and a 2/3 transmission as long as all pipes are of equal diameter.

Once all the parameters were input to the trap recognition programme, depleted traps were created by removing the water seal from a selection of traps on each of the six stacks. Figure 5 shows an example of the test system response, obtained while a depleted trap existed at trap T4.12. The test system response is compared with the defect free baseline and the time at which the two traces diverge indicates the return time of the reflected wave from the depleted trap. It can be seen that there is a small discrepancy between the perceived return time, t^*, (identified by the trap recognition programme) and the predicted return time, t, (calculated using Equation 1 and based on the true trap location, X_D^{true}).

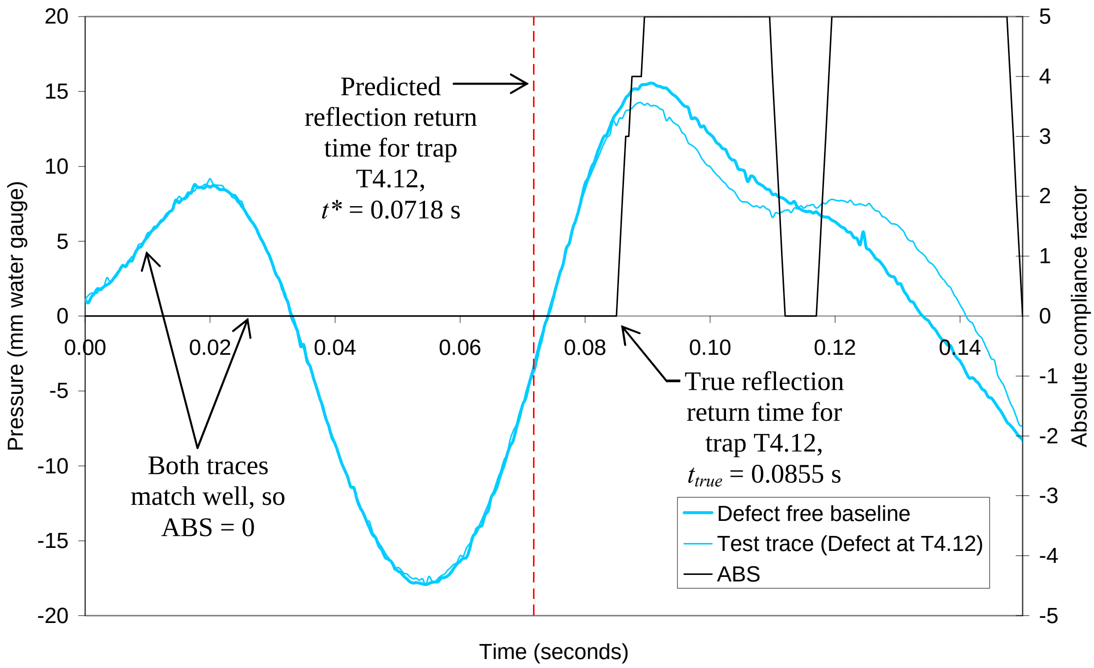

Figure 5 – Typical graphical output from the trap recognition programme showing test trace compared to defect free baseline and resultant absolute compliance factor. In this case for a defect at trap T4.12

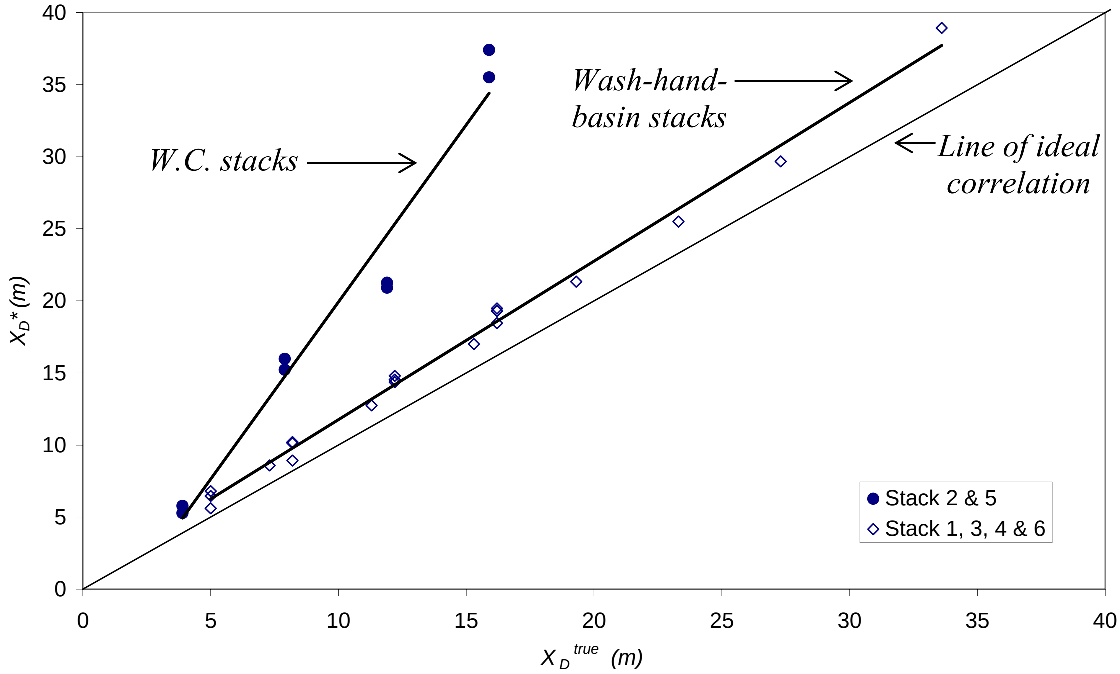

Figure 6 – Comparison of the predicted, X_D*, and true, X_D^{true} , depleted trap locations for all 6 stacks

In every test t* was found to be greater than t, resulting in an *overestimate* of the predicted trap location, X_D*. Figure 6 compares X_D* with X_D^{true} for every depleted trap tested where it can be seen that the difference increases with trap distance. Not only that, but the magnitude of difference varies distinctly between the W.C. stacks and the wash-hand-basin stacks. This phenomenon points to a possible wave attenuation caused by the pipe junctions. A local junction loss coefficient, C_j, would explain the delay in the perceived return time of the reflected wave and would also explain the variation between the W.C. stack and the wash-hand-basin stack owing to the different branch-to-stack area ratios that are specific to each. The W.C. stack has a 100mm diameter stack with 100mm diameter branches, therefore, generating reflection and transmission coefficients of 1/3 and 2/3 respectively at each junction, whereas the wash-hand-basin stack has a 100mm diameter stack with 50mm diameter branches, generating reflection and transmission coefficients of 1/9 and 8/9 respectively. The larger reflection generated at each junction in the W.C. stack could be responsible for the larger variation between X_D* and X_D^{true}.

To identify the effect of the junctions C_j must first be quantified as follows:

$$C_j = \frac{X_D * - X_D^{true}}{2n} \qquad (8)$$

where n is the total number of junctions that the transient wave encounters as it travels from the measurement point to the depleted trap. From the collected data, average values of C_j were calculated for both the W.C. and wash-hand-basin stack and were found to be 0.97 and 0.21 respectively. The equivalent pipe length, J_ε, attributed to the presence of these junctions in the pipeline can now be determined:

$$J_{\varepsilon} = 2n \times C_j \tag{9}$$

which can then be used to calculate an adjusted predicted trap location, X_D^{adj}, taking account of the local loss coefficient at each junction within the system:

$$X_D^{adj} = X_D * - J_{\varepsilon} \tag{10}$$

Table 1 compares the true depleted trap location, X_D^{true}, with the predicted trap location, X_D*, calculated using Equation (1) and the adjusted predicted trap location, X_D^{adj}, calculated using Equation (10). The depleted trap location can be accurately estimated using Equation (10) with trap location errors, ε_{loc}, ranging from only 0.2% to 7.5%. In comparison, Equation (1) has slightly higher uncertainties with errors ranging from 3.1% to 16.3% for the wash-hand-basin-stacks and 36.6% and 46.8% for the W.C. stack. Depleted trap locations obtained using Equation (8) are very accurate, returning trap locations within 10% of the stack height.

Accuracy can be increased further by simply using the RW technique itself to map the trap locations during system calibration to directly determine $t*$ for each possible depleted trap. This is made possible as each trap has a fixed location within the system, thus returning a value of $t*$ which is specific to that location. This method removes the need to measure the distance to every trap to determine X_D^{true} and has been found to be highly accurate and repeatable in identifying the correct depleted trap location.

Table 1 – Assessment of the depleted trap location using the RW technique

Trap	Depleted trap detected?	X_D^{true} (m)	t (s)	$t*$ (s)	X_D* (m)	ε_{loc} § (%)	X_D^{adj} (m)	ε_{loc} § (%)
T1.8	Yes	5.0	0.029	0.033	5.6	*3.1*	4.3	*3.3*
T1.12	Yes	12.2	0.072	0.085	14.4	*10.8*	12.2	*0.2*
T1.14	Yes	16.2	0.095	0.115	19.5	*16.3*	16.9	*3.6*
T2.19	Yes	7.9	0.046	0.094	16.0	*40.4*	8.3	*1.8*
T2.23	Yes	11.9	0.070	0.123	20.9	*45.1*	11.2	*3.3*
T3.2	Yes	33.6	0.198	0.229	38.9	*15.2*	35.1	*7.5*
T3.7	Yes	23.3	0.137	0.150	25.5	*6.3*	22.5	*3.9*
T3.13	Yes	11.3	0.066	0.075	12.8	*4.1*	11.0	*1.3*
T4.8	Yes	5.0	0.029	0.038	6.5	*7.3*	5.2	*0.9*
T4.12	Yes	12.2	0.072	0.086	14.5	*11.7*	12.4	*1.0*
T4.14	Yes	16.2	0.095	0.109	18.4	*11.2*	15.9	*1.5*
T5.19	Yes	7.9	0.046	0.090	15.2	*36.6*	7.5	*2.1*
T5.23	Yes	11.9	0.070	0.125	21.3	*46.8*	11.6	*1.6*
T6.8	Yes	5.0	0.029	0.040	6.8	*9.0*	5.5	*2.6*
T6.12	Yes	12.2	0.072	0.087	14.8	*13.0*	12.7	*2.3*
T6.14	Yes	16.2	0.095	0.114	19.3	*15.5*	17.2	*4.8*

§ $\varepsilon_{loc} = |X_D - X_D^{true}|/L$, where L = total stack height.

5. Conclusion

This paper has presented the findings of an extensive field investigation into the application of the RW technique to detect and locate depleted appliance trap seals within the building drainage system. The RW technique allows the condition and status of trap seals to be regularly monitored using a remote and non-invasive method by determining the arrival time of the reflected wave from a depleted trap seal. The accuracy of the RW technique depends on the accurate estimate of both the arrival time of the reflected wave and the determination of the wave propagation speed. A new trap recognition programme has been presented which is capable of automatically identifying depleted trap seals by comparing the test system response with a previously obtained defect free baseline to determine the arrival time of the reflected wave.

The results presented have confirmed the RW technique as a successful and accurate method to detect and locate depleted trap seals and has demonstrated its applicability to multi-pipe and multi-stack systems. During these investigations the technique was capable of accurately detecting and location every trap tested within a six stack system (containing 112 traps).

The presence of pipe junctions within the system has been shown to affect the perceived arrival time of the reflection returned by the depleted trap which gives an overestimate of the predicted trap location. However, it has been shown that by including an equivalent length term based on the local junction loss coefficient the true location of the depleted trap can be determined with accuracy.

This technique not only provides a fast and accurate method of identifying depleted appliance trap seals but has the added benefit of requiring very little set up time, operates using a relatively small amount of equipment.

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7. List of Symbols

A	flow cross-sectional area	N	number of defect free traces
c	wave propagation speed	p	absolute air pressure
C_j	junction loss coefficient	t	reflection return time
C_R	reflection coefficient	t^*	perceived reflection return time
C_T	transmission coefficient	X_D	trap distance
h_{MAX}	system threshold	X_D^*	predicted trap distance
J_ε	equivalent junction pipe length	X_D^{true}	true trap distance
$_mSp_{DF}$	defect free baseline	X_D^{adj}	adjusted predicted trap distance
$_mSp_{TEST}$	test system pressure response	ε_{loc}	depleted trap location error
n	number of junctions	ρ	air density

8. Presentation of Author

David is a Research Associate in the Drainage Research Group at Heriot-Watt University in Edinburgh. His interests include the modelling of the system response and transient behaviour of the building drainage system when subject to both naturally occurring and imposed pressure transients.

G5) Development of Smart Floor Trap for Enhanced Seal Protection

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Abstract

SARS outbreak in 2003 has imposed a threat on a communicable infection which human body has little or no immunity. However, it has triggered an intensive research on how it spreads within the building space. The report by an investigation delegate from World Health Organization on the plague occurred in Amoy Garden concluded that the SARS virus transmitted via the re-entrants and drainage stacks of the residential buildings. Since then, it has become a common sense for citizens that traps and floor drains in drainage systems should be kept filled up by water all the time.

Floor traps in the bathrooms and kitchens are short falls in keeping them filled up because people now only mop floors for cleaning rather than wet it. More often, floor traps are left dry when the occupants take a week long vacation. It reduces the risk of contaminated air flow from drainage stacks into indoor spaces if the floor drains can hold water for a longer drying period without increasing the currently adopted size of the drain in practice. This paper describes a new design of floor traps which increases the drying period. This paper also describes the design of a test rig which facilitates the test of floor traps for its drying up performance.

Keywords

Floor traps; evaporation; test rig

1. Introduction

Outbreak of the SARS in 2003 was absolutely a tragedy. The main cause of the Amor Garden tragedy was due to the spread of the virus via the drainage pipe as the U-shape water trap is dry out. The U-shape water seal is not quite reliable. People are unaware of it as it is located outside the building. Some even blamed that the resident should be responsible for the tragedy as they have not regularly kept the U-trap filled with water.

Excess drainage stack air pressures can decrease water seal of floor trap; however, even there is no effect of air pressures, evaporation must be considered as another main factor which dry out water seal of the trap.

2. Evaporation

Hong Kong has a sub-tropical climate, with cool dry winters and hot wet summers. In summer, the highest temperatures often exceed 32 ^{o} C. Many tall buildings are constructed closely to each other, so that natural ventilation by wind is not sufficient to decrease heat load on surface of building. Buildings absorb heat and convent to floor slab and wall. When air-conditioning adjusts cooler temperature inside the flat, it causes high temperature difference inside and outside the building. Floor traps being heated outside have a higher evaporation rate and are easy to get dry.

Figure 1 - High and Density Residential Buildings

Figure 2 - Floor trap installed outside a building

3. Type of floor traps

3.1 Traditional floor traps are P trap, S trap and bottle trap

P Trap P Trap Bottle Trap

Figure 3 - P, S and bottle traps

These designs (U trap outside the wall, easily blocked but difficult to clean) are widely used in Hong Kong.

Many people aware about the height of water seal which is decreased by excess air pressure inside the drainage stack. The deep water seal is recognized as 70 mm and the minimum is 50mm. However, many people ignore floor trap which can be dried because of evaporation.

3.2 Innovative design-water loss prevention in the water seal –smart trap

Smart trap is a bell type floor trap. The most significant difference with the above-mentioned one is that it has larger buffer space to recover the loss of evaporation.

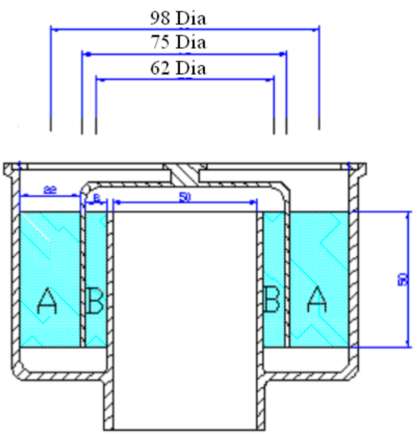

Figure 4 - Bell type floor trap

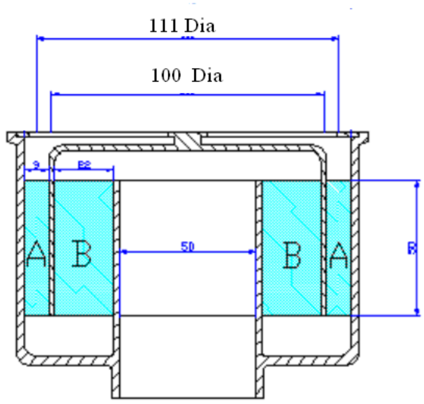

Figure 5a - Smart Bell type floor trap

Figure 5b - Elevation of Smart trap

Figure 5c - Top of Smart trap

Smart trap introduce a new concept: Safety of floor trap not only depends on the height of water seal. It considers the contact surface of water to atmosphere. An innovated design of minor consumed trap is illustrated above. The appearance of floor traps in Fig4 and Fig 5a are the same, but they vary in their ability of water retention. From 5a, Smart trap possess front (A zone) and back (B zone) water seals. They have different volume of water seal and have different retention duration of water seal.

3.2.1 Making a calculation in figure 4: (Bell type D = 75mm)

Area of water seal	$F_A = 22 \times 98 \times 3.14 = 6769.84 mm^2$
	$F_B = 8 \times 62 \times 3.14 = 1557.44\ mm^2$
Total area of water seal	$F_T = 6769.84 + 1557.44 = 8327\ mm^2$
Total consumption of water seal	$\omega_T = F_T \times 50 = 416364\ mm^3$
Total suction of water seal	$\omega_S = F_A \times 50 = 6769.84 \times 50 = 338492\ mm^3$
Daily evaporation of water seal	$\omega_E = F_A \times 2 = 6769.84 \times 2 = 13539.7\ mm^3$
Residue of water seal after suction	$\omega_R = \omega_T - \omega_S = 77872\ mm^3$
Safety period of water seal	Day = $\omega_R / \omega_E = 77872 / 13539.7 = 5.8$

3.2.2 Making a calculation in figure 5a: (Smart Bell type D = 100mm)

Area of water seal	$F_A = 8 \times 111 \times 3.14 = 2788.3 mm^2$
Total area of water seal	$F_T = 6769.84 + 1557.44 = 8327\ mm^2$
Total consumption of water seal	$\omega_T = F_T \times 50 = 416364\ mm^3$
Total suction of water seal	$\omega_S = F_A \times 50 = 2788.3 \times 50 = 139415\ mm^3$
Daily evaporation of water seal	$\omega_E = F_A \times 2 = 2788.3 \times 2 = 5576.64\ mm^3$
Residue of water seal after suction	$\omega_R = \omega_T - \omega_S = 276949\ mm^3$
Safety retention period of water seal	Day = $\omega_R / \omega_E = 276949 / 5576.64 = 49.7$

All of them have 50mm discharge pipes. From calculation, higher water seal loss is found in traditional bell trap and efficiency of recovery is low. The smart bell trap is improved by means of cascaded arrangement. It owns 2 tiers water seals, the front tier (F_A) is smaller contact surface for evaporation and the back tier (F_B) possess larger water seal. F_B is to backup and compensate loss of water seal in F_A. Neglect environmental conditions, such as wind speed at ground surface, temperatures difference between inside and outside of traps. Smart trap owns longer retention period (50 days) of water seal.

The retention of water seal for floor trap is also a concern. It is required to consider not only the height of water seal, but also its retention period. Surface area of water seal plays an important role here.

4. Evaporation rate of smart trap and U Trap

A direct evaluation of the theoretical mass transfer equation (Aerodynamic Equation) used to calculate evaporation from water surface.

4.1 Evaporation model

$E = (\rho r/P)(e_0 - e_z) f(u_z)$

Where E = evaporation rate (in g/cm^2 .sec)
ρ = density of air
r = ratio of the molecular weight of water to the molecular weight of air
P = ambient pressure
e_0 = vapor pressure of water at the water surface
e_z = vapor pressure of water at elevation of z
u_z = wind speed at elevation z

A simple form of the wind friction is

$f(u_z) = C_z u_z$ where C_z = drag coefficient

The equation transforms into experience formula and is for the calculation of evaporation is:

$E = - \rho * L * k * f(u_z) * (q_0 - q_z) / \ln(z/z_0)$

where E is evaporation, ρ is air density, L is the latent heat of vaporization, k is von Karman's constant, $f(u_z)$ is the friction velocity, (q_0-q_z) is the specific humidity difference between the air and near the water surface, ln is the natural log, z is the height of the dew point temperature measurement, and z_0 is a height near the water surface.

ρ can be approximated as 0.0012 g/cm^3, L is approximated by 598 cal/g, k is 0.38 and convert wind speed to cm/s (100 cm/s will be used). Assume $f(u_z)$ is to be one tenth of the wind speed (10 cm/s). Air pressure is converted to mBar and point of temperature measurement height to cm.

By experience formula, the vapor pressure in mb (e_z) for the air dew point temperature (at z) and the vapor pressure in mb (e_0) for the water temperature (at z_0, which will be close to the dew point near the water surface because the air there is almost saturated) using the following equation for both:

$e = C_0 T^0 + C_1 T^1 + C_2 T^2 + C_3 T^3 + C_4 T^4 + C_5 T^5 + C_6 T^6$

Where
$C_0 = 6.11$
$C_1 = 0.4437$
$C_2 = 0.014289$
$C_3 = 0.000265065$
$C_4 = 0.00000303124$
$C_5 = 0.000000020340809$
$C_6 = 0.00000000006136821$
and where the temperature T is in degrees C; also note that each coefficient is multiplied by as many Ts as the number in the coefficient.

The specific humilities (unitless), q_z (at z) and q_0 (at z_0) can be calculated from the following equation:

$$q = (0.622*e)/(P-0.378e)$$

Where P is atmosphere air pressure (P = 1000 mBar). Using the above information, evaporation rate can be estimated.

4.2 Setup of test rig

In Hong Kong, U trap is usually used as floor trap and bell trap is not common. A test rig had been set up to verify the evaporation rate of Smart trap and P trap. An air chamber is employed for this issue. There are 2 approaches: The first one uses model 4.1 above to evaluate the evaporation rate of Smart Trap and U Trap. It requires to measure different z_0 ,z , T_0 and T_z. The second one is to measure evaporation rate of traps (survey over 100 hours) in an air chamber which will describe later.

The air chamber possesses steel case with insulated function (inner volume: 720 x 510 x 550 height mm^3). Inner temperature and air flow can be controlled. All floor traps are installed outside the chamber, and water seal of the trap can be checked visually. Temperature inside the traps can be controlled by an external heater and can be measured.
2 traps are placed out of air chamber but their inlets are installed inside the chamber (Figure 6a to 6c).

Figure 6c

Figure 6a **Figure 6b**

Fig 6a to 6c are test rig for evaporation, U trap and smart trap are installed for testing. 6a and 6b show appearance of air chamber. Traps are placed outside and control hot temperature by a heater. 6c is wind velocity controlled by 2 fans. An anemometer (includes thermal meter) is placed in air chamber and located above the traps to measure wind velocity and temperature. The level of pan is z and z_0 which is above water level of trap water seals.

Firstly, related traps are heated to a temperature that is similar to summer in Hong Kong (say 30 ºC) and temperature inside the air chamber will be cooler (say 28 ºC). It simulates a model that floor trap is placed outside (Figure 2) the building. In the air chamber, temperature is simulated as an indoor condition. It simulates an inner condition of a toilet with a wind speed below 1m /s.

A thermal meter is to measure the temperatures at surface of water seal of traps.

4.2.1 Estimation of evaporation rate of floor traps

4.2.1.1 P trap, with size 50mm dia drain. pipe

Figure 7 - P trap is used to measure its evaporation rate

ia

Measured data:

$Z =$ 38.1 cm
$Z_0 =$ 21.1 cm (near water surface)
$Tz =$ 28ºC
$T_0 =$ 30.7 ºC
$V_{Wind} =$ 100 cm/s

Evaporation Rate is calculated by model
$E = 0.01886$ cal/cm^2/s
$= 789.27$ W/m^2

Figure 8 - Smart trap is used to measure its evaporation rate

Measured data:

$Z =$ 19.7 cm
$Z_0 =$ 1.9 cm (near water surface)
$Tz =$ 28ºC
$T1 =$ 31.9 ºC
$V_{Wind} =$ 100 cm/s

Evaporation Rate is calculated by model
$E = 0.00711$ cal/cm^2/s
$= 297.4$ W/m^2

The estimation result for evaporation rate is that Smart trap is less 2.6 times than P trap.

4.2.2 Measurement of evaporation rate of floor traps

In the second approach, when the floor traps are placed outdoor, they suffer higher wind speed at surface of inlet. Temperature at the inlet is higher than the surface of water seal.

A test was held to measure seal loss under these conditions (Figure 9a~b). The Smart and U traps were placed inside the air chamber. Temperature at surface of inlet surface is to maintain at 33^o C and surface of water seal is at 29^o C .Wind velocity at the top surface of traps is adjusted to 2.5m/s. From test record, the initial reading of water seal:

Smart and U traps started from 3.2 cm and 7cm respectively, then the test runs continuously over 100 hours under these parameters.

Figure 9a - Air Chamber **Figure 9b - Evaporation Test for U and Smart**

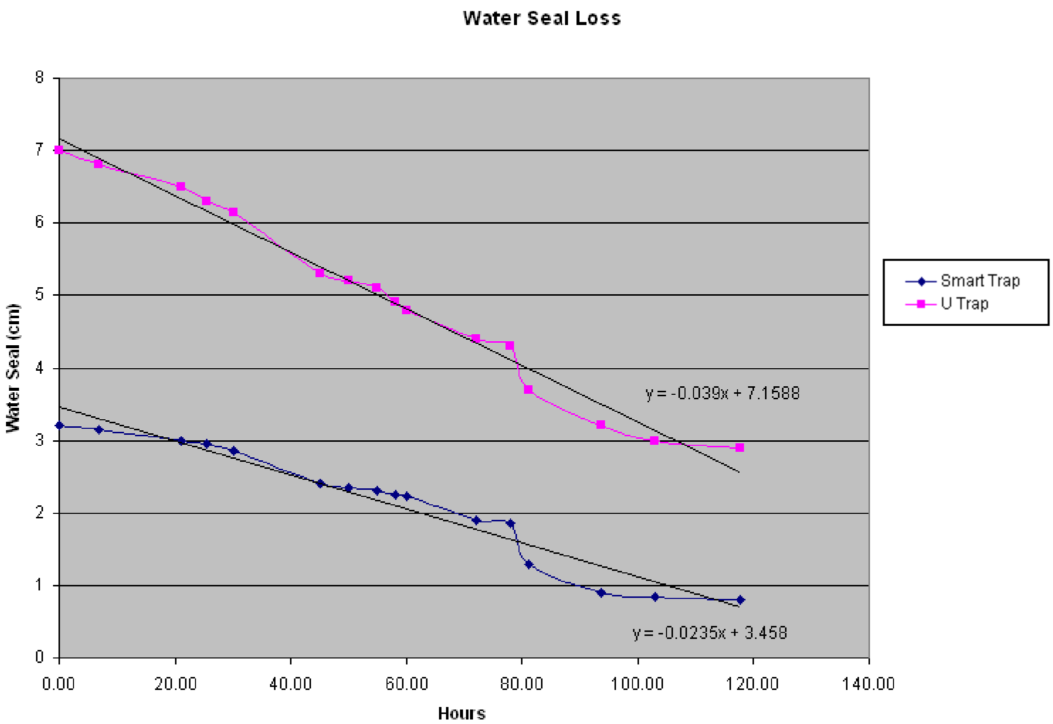

Figure 10 - test result of water seal loss

Under captioned wind speed and temperatures, for 100 hours, test result (figure 10) shows that evaporation rate (based on height of water seal) for U trap is 0.032 cm per hour (0.3 mm/hour) and 0.011 cm per hour (0.1 mm /hour). 2 regression formulas are found from the test results and used for calculation as below:

If the evaporated rate is based on loss of water volume, U trap and Smart trap shows:

Water evaporated from U trap = $\pi \times (5/2)^2 \times (0.032) = 0.62$ cc / hour
Water evaporated from Smart trap = $\pi \times (0.8 \times 6.2) \times (0.011) =0.17$ cc /hour

Evaporated rate of Smart trap is less than U trap for 3.6 times.

5. Conclusion

Good design of floor traps benefits the health of our living environment. Smart trap provides a new concept of 2 tier water seals. Two water seals are not standalone and have different sizes. Front water seal contact the outside atmosphere and suffer from various conditions (e.g. wind speed, temperature difference). The back water seal is larger than the front so that it can backup the loss in the front water seal. A new concern for water trap is water retention period apart from the height of water seal.

The new design has been proved to be applicable and it functions better in water retention.

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H1) Assessing the impact upon property-based water supply and drainage systems of rainfall events predicted by climate change scenarios

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Abstract

There is now widespread acceptance of climate change impacts and the effect they are likely to have on the built environment. In the United Kingdom, there is clear anecdotal evidence that changes in rainfall patterns have caused both severe flooding and water scarcity, and this is substantiated by evidence of current trends and by robust climate scenario predictions for the future that indicate that, generally, the UK will experience wetter winters, drier summers and more frequent extreme events. These changes will increase pressure on the water supply and drainage infrastructure, and will demand the implementation of adaptable systems underpinned by sustainable water management principles.

This paper proposes a framework for the review of water supply and drainage for a property and explains how, by viewing systems holistically, the impacts of climate change may be fully identified. This framework - to be populated in the future by algorithms descriptive of water and wastewater throughflows – challenges the fundamental precept upon which many codes are based ie, that rainwater and wastewater must be conveyed as quickly as possible away from the building. The paper presents examples that illustrate the importance of water storage and flow attenuation, and shows how, in responding to the challenges of climate change, the designer has the opportunity to implement and use to best benefit, a number of sustainable water management technologies and solutions.

Keywords

Building, property, drainage, design, climate change

1. Introduction

The aim of ensuring that all aspects of the water supply and building drainage system operate effectively whilst minimising the consumption of potable water has underpinned many of the advances witnessed within the sector across previous decades. However, as new technologies and regulatory policies have evolved, so too have the challenges faced by the design engineer. Where, in the past, a targeted reduction in water consumption, typically positioned within the broader context of achieving sustainability, has influenced design decisions and code development, the emerging challenge of accommodating predicted changes in climate has introduced an added level of complexity.

Climate change scenarios and associated weather data predictions readily illustrate the stark difference in the anticipated availability of water, with many areas in the UK, Europe and overseas expected to experience water scarcity whilst also facing a significant risk of flooding[1,2]. In many cases, this contrast is perceived as a negative attribute of climate change. However, the situation does introduce a number of opportunities that may be exploited through good design practice. For example, there is now a greater need than ever before for the integration of systems that re-use rain or waste water - a process that is already underway, as evidenced by the increasing use of greywater recycling and rainwater harvesting systems. There is also an opportunity to enhance downstream performance by ensuring that any anticipated changes in flow conditions in piped systems remove waste without introducing the propensity for surcharge or blockage, and by limiting surface run-off from a property – an aspect that, in itself, introduces a number of performance, cost and environmental benefits.

This paper will provide an overview of how the anticipated changes in climate, principally rainfall, have the potential to impact upon the performance of building and property-based water supply and drainage systems and how these impacts need not be detrimental if suitable design or adaptation strategies are adopted. It will introduce a framework for the review of system design or performance, and will illustrate how this approach is equally applicable in the assessment of water supply and drainage systems when subject to climate change impacts and in the implementation of broader sustainable water management principles. The paper will show how this perspective allows an identification of the interconnectivity of systems and how the performance of each can be affected by design changes in areas of provision perceived as relatively ‘remote’. It will also show how the time-dependency of the flow characteristics for each component underpin the performance of the overall drainage provision.

2. Climate change impacts for water supply and drainage systems

Climate change predictions for the UK show that, generally, winters are likely to become wetter and summers drier and that extreme weather events will become more common. As well as the anticipated changes in seasonal conditions, scenarios also show pronounced differences in regional rainfall predictions[1]. Thus, climate change impacts upon water supply and drainage cannot be readily represented by a simple shift in rainfall intensity figures. Instead, they demand sufficient flexibility in water management to accommodate the anticipated variability in rainfall and availability of water. Integrating this flexibility without introducing costly adaptation strategies across all components of the system thus requires a review, at the property level, of how water and drainage provision is designed and used.

Figures 1 and 2, together, present a framework that illustrates the indicative positioning of systems within the wider context of the provision of water supply and drainage for a property. Figure 1 shows the supply and use of potable water and the discharge of wastewater, whereas Figure 2 shows potential conveyance routes for rainfall. Both are based upon provision that falls within the boundary defined by the property curtilage and therefore encompass both internal and external drainage systems as well as 'small-scale' local underground drainage.

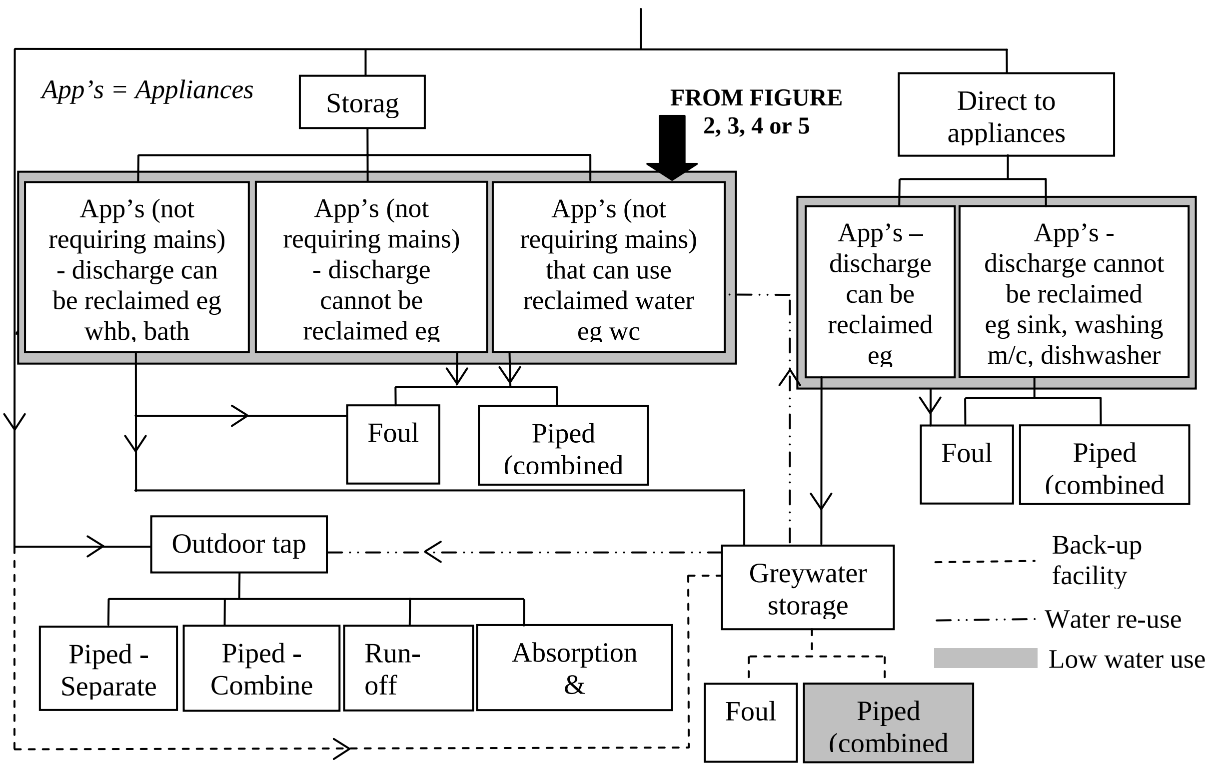

Figure 1 – Indicative supply, use and discharge of potable water

It should be noted that:

1. Neither figure encompasses every possible permutation in terms of pipework connections. Rather, the diagrams serve to illustrate the basic principles of application and positioning of systems.
2. Both figures include options for sustainability. These include, but in practice are not limited to, low water-use appliances, green roofs, and rainwater harvesting and greywater collection systems.

3. The two figures are connected as indicated by the solid arrows. This illustrates the potential for use, within the building and by suitable appliances, of harvested rainwater.

4. Importantly from a drainage perspective, the piped outflows for both figures are shown as comprising either separate or combined sewer systems (where separate networks individually accommodate either foul waste or rainwater only and are the more common of the two). Other routes for outflows are assumed to be those of surface run-off and, where appropriate, absorption by, and evaporation from, pervious surfaces. It will be appreciated that with the exception of evaporated water lost through a green roof, all outflows illustrated across the two figures are common. For example, the 'piped-combined' outflow from 'appliances whose discharge cannot be reclaimed' (as shown on the far right of Figure 1) is the same as that at the bottom of Figure 2.

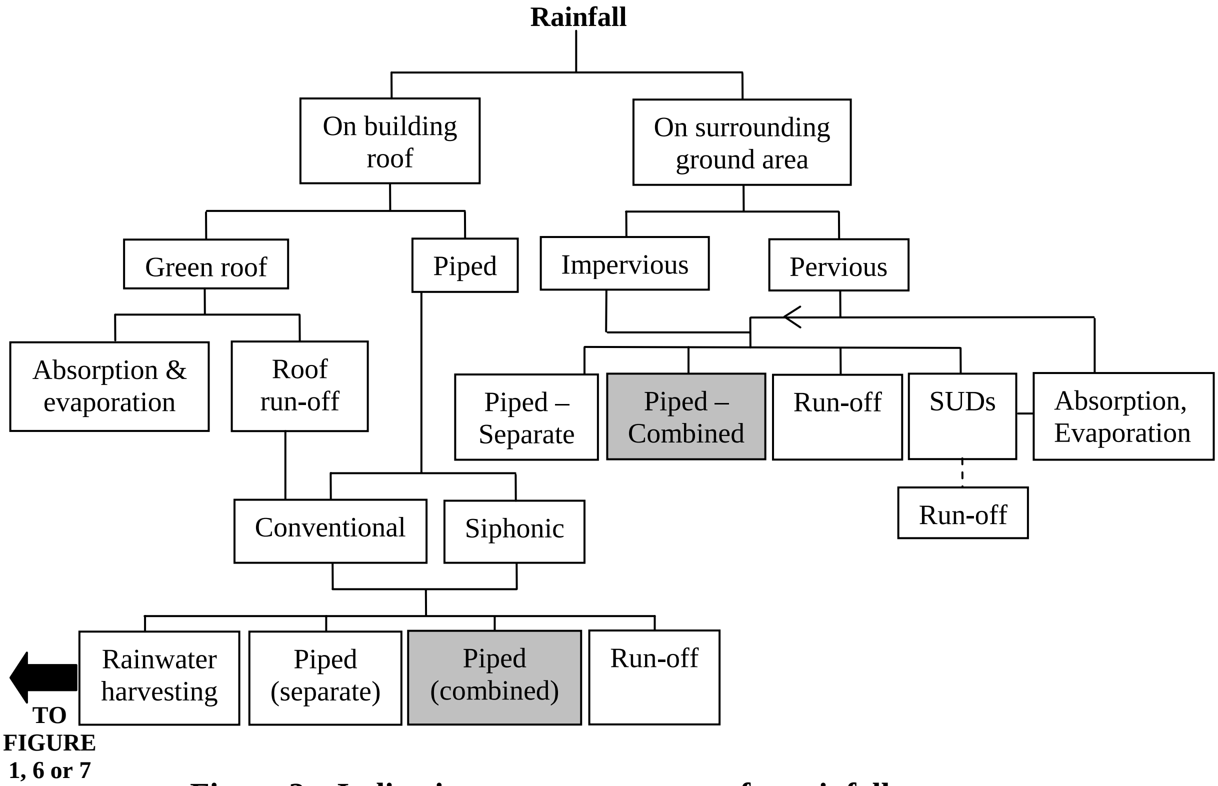

Figure 2 – Indicative conveyance routes for rainfall

It will be appreciated that for the rainwater system, Figure 2, the overall aim is one of maximising the absorption and subsequent evaporation of water within the curtilage, thereby reducing the loading upon the downstream network. This is particularly important where piped systems are combined, as the risk of pollution from overloaded sewers during storm events can exceed acceptable levels, as was the case during an outbreak of foot and mouth disease in the UK in 2007. It is also the case that run-off should be minimised as, similarly, this can introduce downstream loading and environmental protection issues. However, for the supply of potable water, Figure 1, the case is less straightforward. Here, although the aim is to reduce overall levels of water consumption, it is nonetheless important that these are not reduced to an extent that introduces the propensity for blockage within downstream sewerage. Thus, it must be ensured that reduced flows, particularly for foul discharge where this is kept separate from rainwater, ensure self-cleansing - an aspect that may rely heavily on contributory flows from a range of sanitary appliances other than the WC or on reduced diameter drains where this change is possible.

3. Using the proposed framework to assess climate change impacts

There are various ways in which this framework can be used to assess the performance of the water supply and drainage system. Figures 3, 4 and 5, with flow routes shown in bold, present an example that shows how the effect of an anticipated change in rainfall patterns can be mapped onto system design. Three assumptions underpin this example. The first is that the rainfall event is of significantly greater intensity and duration than that which might be experienced currently (and that is therefore accommodated by existing codes and design guidance). Defining system and physical characteristics, the second assumption is that the roof drainage uses either a siphonic or conventional piped system and that the local ground area surrounding the building is generally impervious. Finally, it is assumed that the downstream pipework is combined ie that it accepts flows from both the building and the rainwater network.

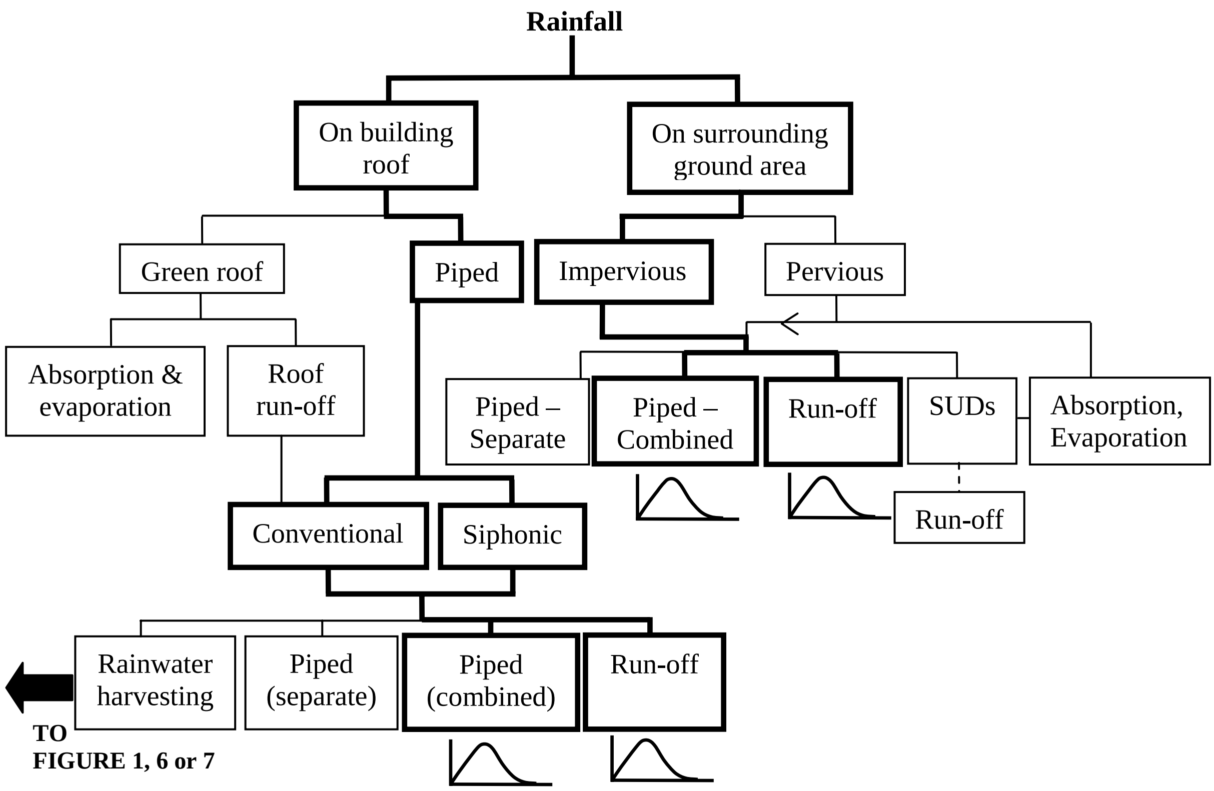

Figure 3 – Identification of the impacts of climate change upon rainwater systems where no adaptation has been integrated

It can be seen from Figure 3 that, as rain falls upon the building roof, it is conveyed to the local underground collection network via rainwater downpipes, either conventional or siphonic. Rain falling on the surrounding ground area is routed to the same receiving pipework. A qualitative assessment of the impacts of climate change show that the increase in rainfall intensity has the potential to introduce:

- temporary siphonic conditions within the conventional rainwater system, as indicated by previous research[3]. Further work may be necessary in order to establish whether or not the full-bore, sub-atmospheric conditions that characterise siphonic action introduce any detrimental effects within these, normally gravity-driven, systems.

- intermittent priming or sustained full bore flow of the siphonic rainwater system.
- overtopping of either the conventional or siphonic system where there is a lack of capacity[3].

The lack of permeability of local ground surfaces can also introduce:

- inundation of local surfaces and gulley connections (that can, in turn, result in an under-capacity of the siphonic rainwater systems[4])
- increased flow loading in the downstream pipework, increasing the risk of overspill and pollution
- increased run-off from the property, adversely affecting downstream pollutant levels and increasing flood risk

Figure 4 shows how by adapting a proportion of the surrounding ground area to allow permeability and by including a green roof (either at the design stage or, where appropriate, as retrofit), then the loading upon the downstream receiving network can be reduced, and the run-off either similarly reduced or eliminated entirely. It has been shown that the contribution of surface run-off from even moderately-sized impervious areas can have a significant bearing on downstream loading[3], thus any adaptation strategy that can alleviate this component will yield significant benefits. It is also worth noting that whereas a green roof and the inclusion of pervious area can be applied to existing as well as new building stock, the designer is likely to have less control over the type and location of the utilities provision. Thus, in this case, the receiving network type has been retaining as combined, despite a general preference for separate systems.

It will be appreciated that the integration of both a rainwater harvesting system and a SUDS (Sustainable Urban Drainage System) solution such as a small retention pond or filter strip introduces the potential to remove, completely, all piped provision, Figure 5. Whereas in the past, this type of adaptation solution was, in some quarters, perceived as rather extreme, it is now more frequently considered.

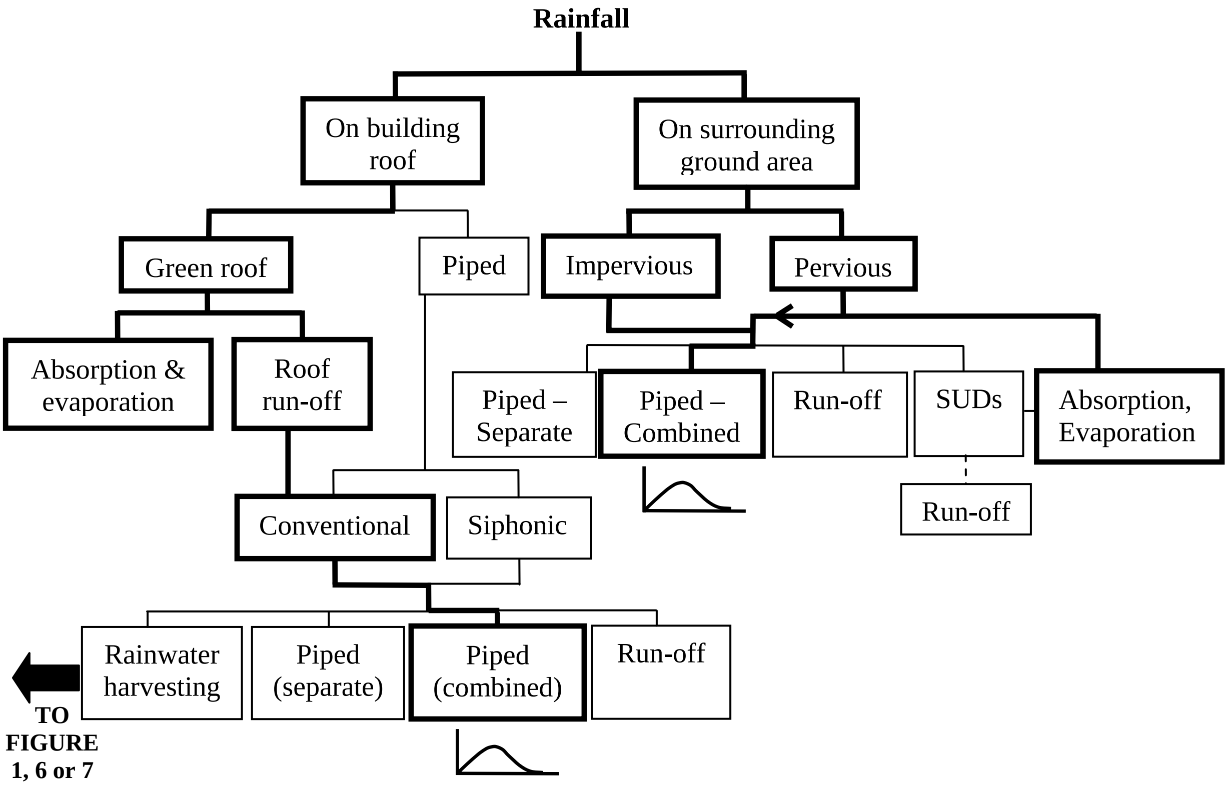

Figure 4 – Changes in flow loading once adaptation has been integrated

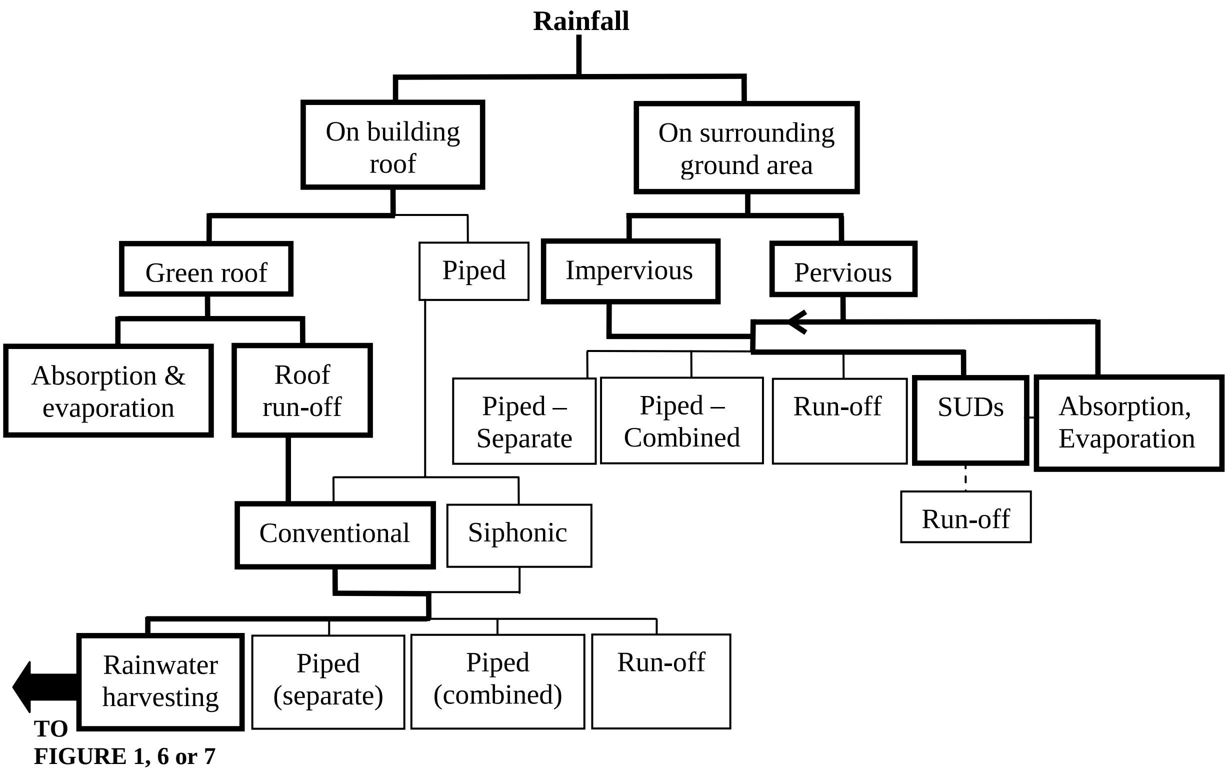

Figure 5 – Additional adaptation illustrating the potential for removal of receiving underground drainage

Figures 6 and 7 illustrate an example related to the supply and use of potable water and the discharge of wastewater. Highlighting water consumption by appliances used within the building, Figure 6 reflects the current trend in policy and guidance documents in the UK that targets an overall reduction in the per capita use of potable water for domestic purposes[5,6,7]. Assuming, in this example, that all discharge flows are ultimately routed to the foul pipework, it will be appreciated that there exists the potential for a reduction in flow loading downstream that may introduce the propensity for blockage. Thus, the frequency, volume, attenuation and general time-dependency of the discharge flows from all appliances within the building may become as important as the discharge characteristics of the WC.

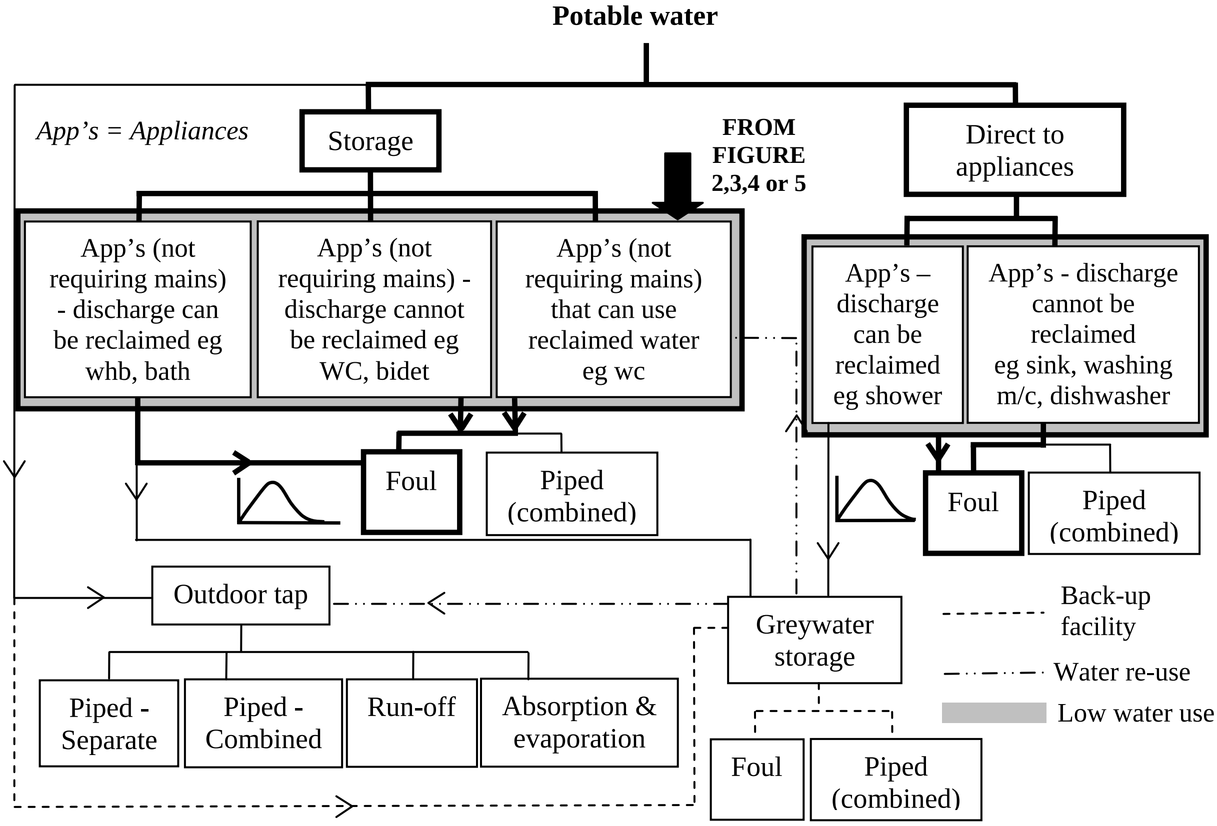

Figure 6 – The supply and use of potable water, embedding water efficiency

This example does not necessarily encompass specific climate change impacts but does embed a continued drive for water efficiency. Notwithstanding the benefits that arise from a reduction in the use of potable water, Figure 7 illustrates an alternative, and potentially more sustainable, adaptation solution. Bearing in mind that climate change impacts are likely to increase water scarcity (and that this will have a influence on the availability and cost of potable water) whilst also potentially introducing more intense rainfall events, the need to introduce flexibility within the overall provision of water and drainage can be accommodated, in part, by the inclusion of rainwater harvesting and greywater re-use systems. Figure 7 shows the positioning of these design or adaptation measures (where flow from the rainwater harvesting system is shown as a link to Figure

5) and the potential impact they introduce (although it is worth noting that a property seldom encompasses both system types).

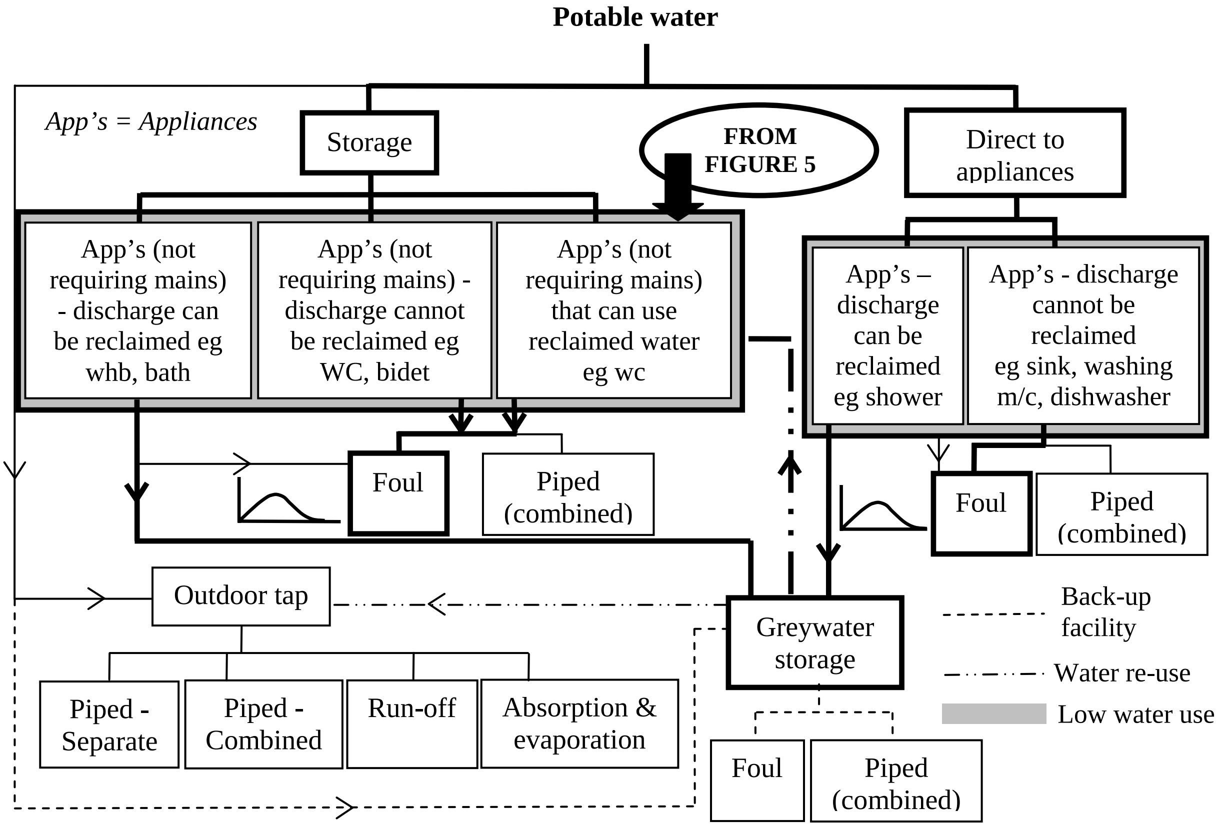

Figure 7 – Impact on water supply and drainage provision when greywater re-use and rainwater harvesting systems are implemented

Figure 7 clearly highlights the importance of the time-dependency of flows since it can be seen that:

- by reclaiming greywater from appliances such as wash-hand-basins, showers and baths, the downstream loading in the receiving foul pipework becomes notably reduced. This could be problematic if there is already a reliance upon contributory discharge flows from the range of appliances likely to be used for domestic purposes. This effect may be particularly relevant in the case of reclamation of wastewater from a bath, as this discharge is typically represented by a sustained and relatively steady flow and one that is useful in assisting the conveyance of discrete solid waste in underground piped networks.

- the use of the greywater and rainwater harvesting storage tanks introduces significant changes to the characteristic unsteady profiles of the inflows to these facilities. In the case of rainwater harvesting, the variability inherent in climate-change driven rainfall intensities, as initiated by either one rainfall event or by a cluster of events, can be entirely attenuated. Similarly, the discharge flow profiles from sanitary appliances from which wastewater can be reclaimed will be fully attenuated whilst stored. In both cases however, a transient discharge profile is re-established when the reclaimed water is used to offset potable water consumption. In most cases, the supply is to the WC – an appliance that yields a short, highly time-dependent flow output.

Thus, although the integration of systems that reclaim and re-use water and wastewater should be viewed as entirely appropriate in terms of water use reduction, their installation should be designed or adapted in such a way that takes due cognisance of the broader flow characteristics of the overall provision of water supply and drainage, as it is important that the resultant change in time-dependency that they introduce does not result in detrimental downstream flow conditions.

4. Framework Development - Quantitative

Although the framework, presented above, provides a useful visual and clearly illustrates the interconnectivity of the component parts of the water supply and drainage systems serving the property, it will be appreciated that in order to establish meaningful information for design and system adaptation purposes, this needs to be populated with quantitative performance characteristics. It is envisaged that in order to make best use of this framework, these characteristics should be based upon time-dependent flow descriptors. It is proposed that by defining both the potable water supply and the current and anticipated rainfall characteristics as flow-time (ie Q-T) profiles, and by establishing a transient-based algorithm for each component shown, the framework will facilitate an assessment of the overall performance of system provision and shift in performance when predicted climate scenarios data are applied.

It will be appreciated that determining and successfully integrating these algorithms, alongside representative climate change data, within this water management framework will take considerable time and coordinated effort. Flow characteristics exist for a number of components, for example, for a wide range of sanitary appliances. In addition, numerical techniques that facilitate the simulation of both system performance and flow attenuation are well established. Other areas, however, will require further work. In terms of climate information, existing rainfall data available for disaggregation and application within simulation techniques are currently based on four climate 'storylines' and three projected timescales (2020's, 2050's and 2080's). Late 2008 will see a significant advance in data release in that an enhanced modelling approach that produces ensemble data rather than a single result for each emissions scenario will yield information on a range of possible outcomes, each with an estimated probability of occurrence. It is therefore envisaged that, ultimately, the availability of suitable spatially and temporally disaggregated rainfall data will be able to be integrated within the framework proposed, thereby facilitating realistic predictions of performance and avoiding any over-design or over-engineering to accommodate climate change. In the meantime, difficulties in securing this data and in establishing algorithms should not deter the designer or user from undertaking a more qualitative assessment of the performance of systems when subject to climate change impacts.

5. Conclusion

This paper highlights the need for a more holistic perspective when adapting the design of water supply and drainage systems for a property to take account of the anticipated variation in rainfall intensity and in water availability arising from the impacts of climate change. It has presented an indicative framework, to be populated with transient-based algorithms representative of flow conditions within each component. A range of adaptation options, for which current technology is well-established have been discussed and their positioning within the framework identified.

Together, the framework and examples presented herein have illustrated:

1. the interconnectivity of the water supply and drainage system for a property. Figures 1 and 2 clearly show the link between the supply and use of water, the discharge of wastewater, and the conveyance of rainwater. This point highlights how the introduction or adaptation of a component part of the network, possibly perceived as remote from another, can have a significant influence on performance. In particular, a reduction in water consumption through the use of low-volume appliances or through the re-use of reclaimed water can significantly influence the downstream performance of the receiving network. Thus, ensuring that systems meet key performance criteria requires a move away from the design of component parts of the water supply and drainage provision in relative isolation.

2. how a design approach that is based upon the fundamental precept that water and wastewater must be moved, as quickly as possible, away from the building can introduce problems downstream. These problems are likely to be exacerbated by climate change impacts. Solutions for the storage and attenuation of rainwater will introduce flexibility within the system, will significantly reduce the consumption of potable water, and will hence allow best benefit from anticipated changes in rainfall patterns.

3. how important the time-dependency of the flow characteristics of the component parts of the systems is. Only by assessing the capacity for storage and attenuation introduced by each option, can an overall assessment of performance be undertaken.

4. how the ‘challenges’ presented by the anticipated change in climate instead present a key opportunity for the integration of fundamental sustainable water management principles.

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H2) The research on pipe age of Building drainage systems assessment and visualization of the design tactics for decision-making tool

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Abstract

This study focuses on renovation and maintenance of the drainage system in the existing building. By studies of construction status through observational studies and professional technician interviews, existing problems of the existing building drainage system can be realized allowing a thorough investigation into the lifecycle of pipeline system. The following items need to be discussed, (1) building drainage system plan, which can view the application of the overall system and buildings design; (2) construction site plan, a detailed plan of the environment and construction details; (3) pipe comprehensive analysis, comprising the characteristics of pvc(polyvinylchloride), abs(acrylonitrile-butadiene-styrene)and cast iron pipes; and according to analysis of impact factors on drainage system lifecycle at the design stage and during the construction, we can establish the assessment tools of building drainage system which assists to evaluate demand of the building drainage system by adopting the concept of Failure Mode Effect Analysis (FMEA). In addition, taking the advantage of computer simulation of changeable layout by using 3D-MAX, it can make three-dimensional visualization and traditional-elevation view of the visual interface with each other. Consideration of whole drainage system, appropriate decisions can be decided in correct order for the pipeline system and test through a variety of programmers which can not only suggest the variety of renovation programs but also assist the designers and owners for decision-making of building drainage system.

Keywords

life cycle; renovation; maintenance; visualization

Notation

PRND	priority renewal number of drainage	***MaxS***	maximum weighting of severity
MinS*	selected minimum weighting of components from severity	***MaxO***	maximum weighting of occurrence
MinO*	selected minimum weighting of components from occurrence	***MaxD***	maximum weighting of Detection
MinD*	selected minimum weighting of components from detection	***MaxP***	maximum weighting of pipe age
MinP*	selected pipe age		

1. Introduction

In every day life, there is a great reliance on the building drainage system to carry waste to the sewer while preventing foul air from entering the interior space. Not only does the building drainage system maintain a safe hygienic environment but it also satisfies the living quality and daily comfort. This research aims to provide a tool for the inspection and renewal of ineffective drainage systems as a result of pipe age. By using a drain evaluation and renewal simulation tool, the life span of the drainage system could be extended to coordinate with other of the building. Maintaining a healthy building is similar to maintaining a healthy body –requiring regular examination to ensure full function. Once the faults have been detected, the solution will be provided by different strategies according to the severity. Figure 1 illustrates the similarities between the health of the human body and the building drainage system. The drainage system evaluation was provided to diagnose the renewal necessity. This research attempts to simulate the renewal strategy with computer software by adopting the model of renewal factor and priority number from the previous research [1]. The renovation procedures were suggested with visualization along with the assessment. The renewal model and 3 dimensions visualization would be practical and sensible for existing building drainage systems which have already been prioritized.

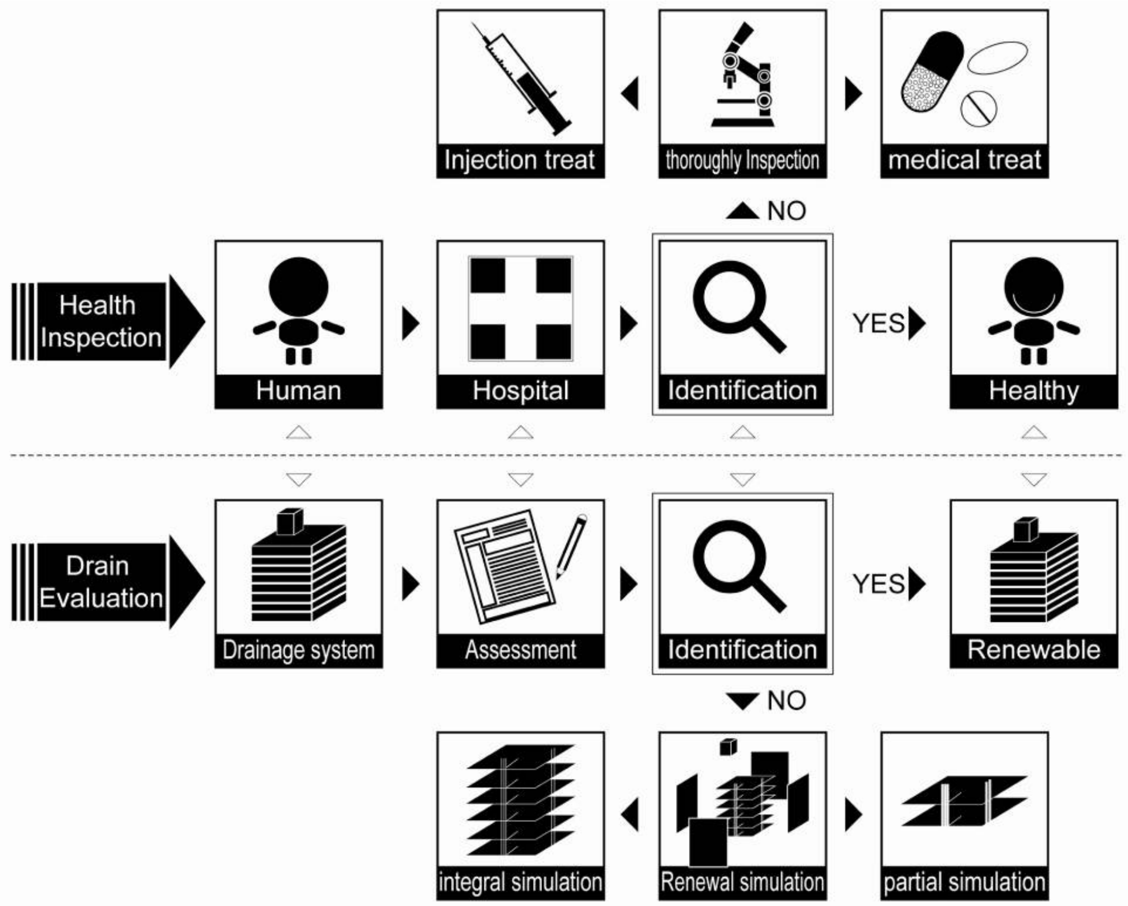


Figure 1-The diagram of observation between the health of the human body and the health of the drainage systems

2. Methodology

An observational study of the drainage system and technician interviews were undertaken to establish the construction conditions to determine the circumstances which can influence pipe age. The model was integrated the factor which may influence the pipe age from design plan, pipe material, construction quality to daily use. (Figure 2). The evaluation model would follow the concept of FMEA. The renewal priority level was proposed after the assessment. Base on the priority level, three dimensional computer simulation software would be the interface to helping the decision-making of renewal plan which could extend the pipe age.

2.1 Strategy of building drainages during life cycle

A study on the plumbing life cycle recommended that an in-use building drainage system would be examined every 15 years [2]. The life cycle of the drainage system includes production, transportation, construction, daily use, maintenance and renovation and disposal. This research focuses on the pipe age from construction to disposal. Figure 3 shows the factors which influence the drainage system during the four phases.

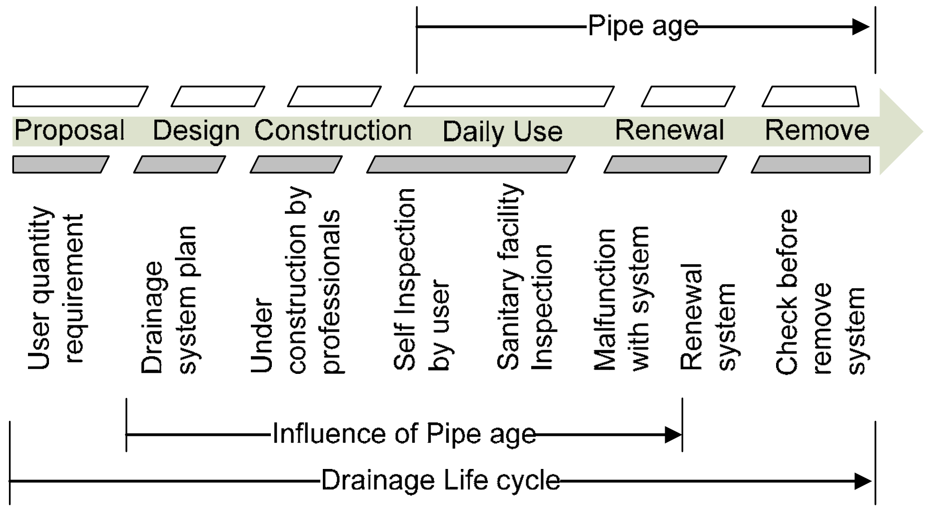


Figure 2 – Life cycle diagram of drainage system

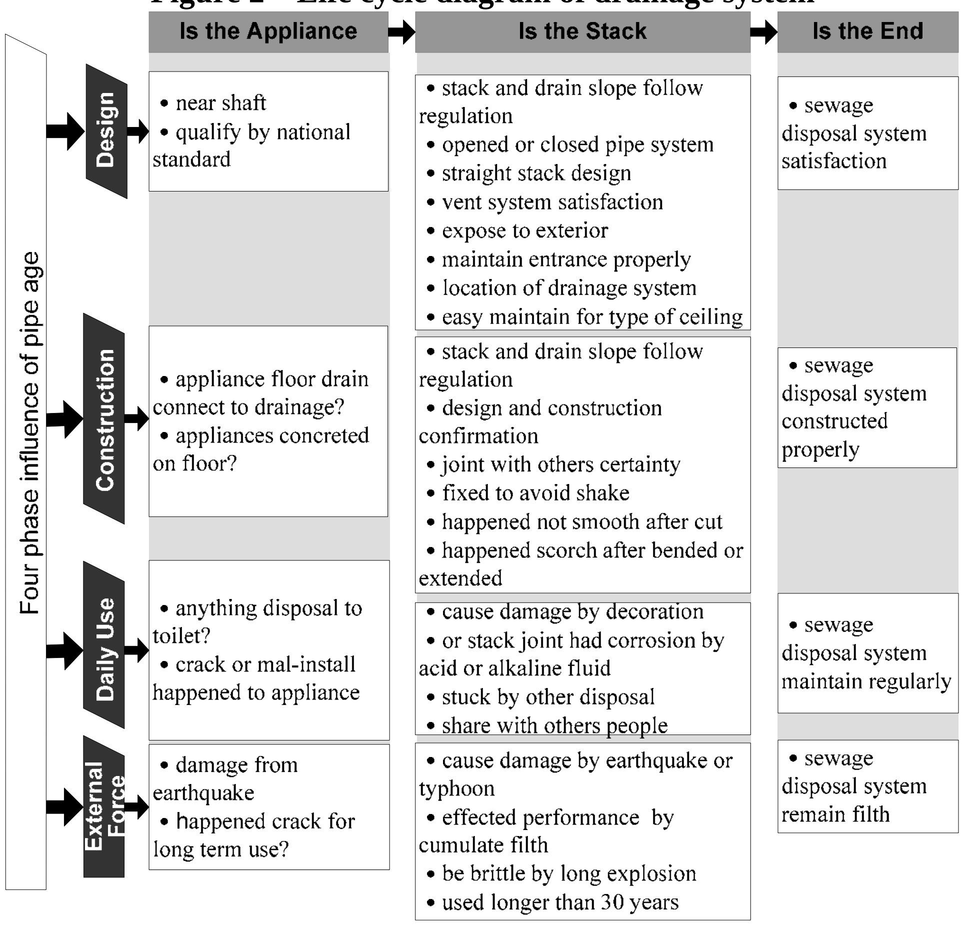


Figure 3 – Four phases of influence factor from drainage system

2.2 Failure Mode Effect Analysis, FMEA

Failure Mode Effect Analysis (FMEA) is a systematized technique which identifies and ranks the potential failure conditions in the drainage system, i.e. the probable damage, in order to prioritize remedial treatment for the system and facilities. By using the FMEA concept, problems in the drainage system can be detected. According to a systematic case study investigation in Taiwan, fundamental categories of this evaluation system for the domestic drainage system were identified. The influencing factors were determined from schematic observation and empirical experimental results performed previously [3] [4]. The weighting coefficient is determined by addressing the severity, occurrence, and detection on FMEA [5] [6]. The result will be the multiple of each factor's weighting coefficient which shows the performance ranking. This process can also identify the faults of drainage system for preventive maintenance and remedial purposes.

3. Renewal Model of pipe age

The nine influencing factors are pipe age, building height, using authority of lower floor, ceiling, vertical stack setting, building branch movement, piping material, pipe connection and Water stain. Each factor was amend using a nine level coefficient as shown in Table 1, the higher coefficient, the greater contribution influence. The weighting coefficient was transferred from qualitative description into Quantity.

Table 1 – The level of coefficient

Level	Normal				Medium				Critical →
coefficient	1	1.5	2	2.5	3	3.5	4	4.5	5

The renewal model shown as Equation 1 contains three categories, Severity, Occurrence, and Detection. Each category has same factor which will affect the operation of the drainage system. The Renewal Priority Number of Drainage (RPN-D) is the ratio of the selected products to the minimum of Severity, Occurrence, and Detection, each of which may have different weighting.

$$RPN = \frac{Min\ S^* \ x\ Min\ O^* \ x\ Min\ D^* \ x\ P^*}{Max\ S\ \ x\ Max\ O\ \ x\ Max\ D\ \ x\ P}\%\ ;\ 1 \leq RPN \leq 100 ...... \quad (1)$$

The RPN-D is between 1 to 100 which show the probability of Severity, Occurrence and Detection. According to the systematic procedure, each factor and its renewal component was appraised by professional judgment as shown in Table 2.

Table 2 – Evaluation weighting of components

components factor		RPN-D Severity	RPN-D Occurrence	RPN-D Detection
Building height	< 8F	4.5	5	5
	9 -15F	4	4	4
	16 -29F	3.5	3	3.5
	> 29F	3	3.5	3
Using authority of lower floor	user share the floor	2	2	4
	user own the floor	5	4.5	5

ceiling	entire opened	5	4.5	5
	partial opened for maintenance	3	4	3
	fixed	2	3	2
	No ceiling plywood	4	4	5
Vertical stack setting	open pipe	4	4	5
	conceal pipe	3	3	1.5
	drainage service shaft available	5	4.5	5
	drainage service shaft partial	3	4	3.5
	drainage service shaft unavailable	2	3	2
Building branch movement	stack across floor by suspension	3.5	4	4
	buried in floor	3	3.5	1.5
	raise and buried in floor slab	4.5	3.5	3.5
	Stack in two floor layers	4.5	4.5	5
Pipe material	polyvinylchloride, PVC	4	4	4
	Cast-iron	3	4	3
	acrylonitrile-butadiene-styrene, ABS	5	5	4.5
Pipe connection	Fixture	4	4	3.5
	Quick Coupling	4.5	4	3.5
	Not include above	2	1	4
Water stain	water stain underneath floor or efflorescence	1.5	3	3
	water stain underneath ceiling or efflorescence	2	3	3
	water stain with vertical stack	1.5	2	3
	water stain with branch	1.5	2	3
		Min S*	Min O*	Min D*
Pipe age	In 3 years		5	
	< 10 years		4	
	10 -20 years		3	
	20 -30years		2	
	> 30 years		1	

The priority level was given as shown in Figure 4 where the graphical interpretation of the renewal priority could provide a simplified quantification for the building management. The renewal priority level was divided into "Low", "Medium", "High" and "Very high". It was suggested that, for those buildings classified as 'Very High' level, immediate remedial improvement should be provided.

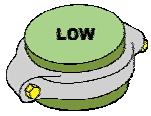
	Level 1	Level 2	Level 3	Level 4
Renewal Priority Diagram				
RPN-D	≦20 Very High	21 ~ 40 High	41 ~ 60 Medium	≧61 Low
Condition	The condition of drainage and building was good; there is no need for maintenance	Drainage system is reach its own life span, the proper maintenance was require for extend life cycle.	Drainage system was available for continuous operation with less maintenance.	The condition of drainage and building was good; no need for maintenance.

Figure 4 - Renewal priority level illustration

4. Simulation of renewal cases

4.1 Procedures of Model creating

The computer software, 3D-max, was adopted to simulate the various options available during the re-design stage. Using the computer simulation, different design options are explored making it possible to determine the most practical option in terms of pipe route, maintainability and than offering minima disruption to the original building fabric all of which can be displayed and assessed visually. The input module categories were classified as shown as Table 3 which was divided into two items, building base unit and drainage equipment. Figure 5 shows the diagram of the modeling process. The original drainage system was built at initial processing. The new three dimensional simulation was created after the model was updated to coordinate with the renewal priority level.

Table 3 – the combination category of renewal modeling framework

Building (Base Unit)	Main Structure (Structure BU)	Columns, Beams, floor slab, external wall
	Building Fabric(Non Structure BU)	Ceilings, Service shaft, Interior wall, Door, Windows, Furniture
Drain (Drainage Equipment Unit)	Drain system (Drainage Pipe DEU)	Appliances, Stacks, Vertical stack, Main drain
	Vent system (Ventilate Pipe DEU)	Stack vent, Yoke Vent, Loop Vent, Terminal vent

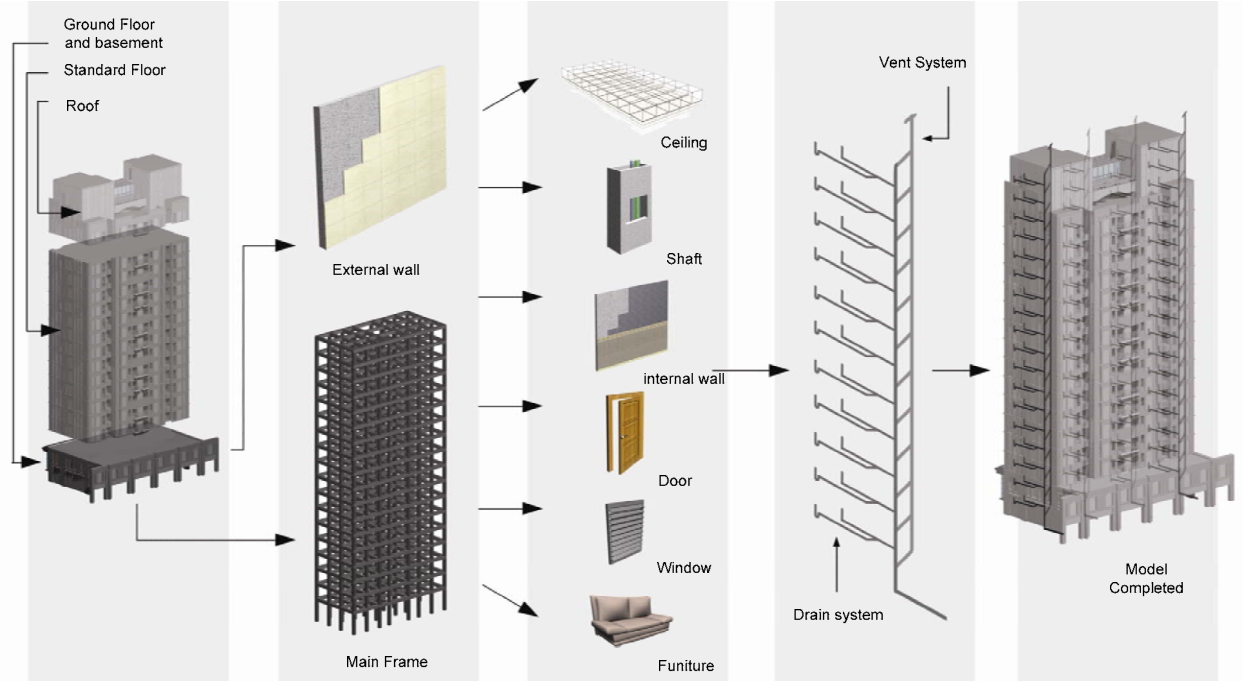


Figure 5 – The diagram of model processing

4.2 Case study - Guo-Tai Building, Taipei

The age of Guo-Tai apartment is 31 years. It has 12 floors and one basement. The drainage system has never been renewed before. There were nine service shaft and ten types of appliances. The size of maintenance hole was 20cm*15cm. The building is currently used as both commercial office space and apartment Table 4 shows the building profile and renewal priority results. Because of long term daily use, the main drain and vertical pipe were leaking and rust (Figure 6).

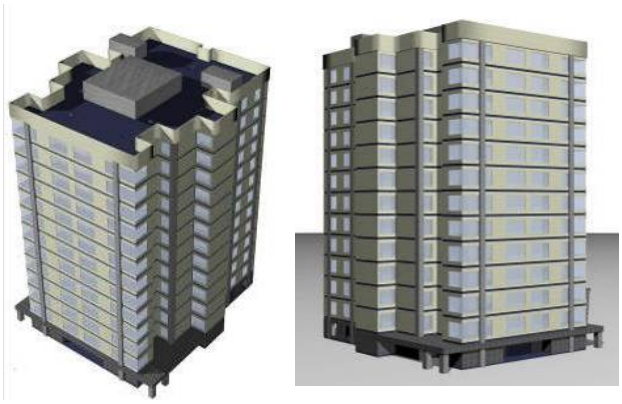
Table 4 – the initial results of Guo-Tai Apartment

Building Picture	Building Profile				
	Building age：32 years Building height：42 M Building floor：12F Ceiling：partial opened for maintenance Using authority of lower floor：user share the floor Vertical stack setting：drainage service shaft unavailable Building branch movement: stack across floor by suspension Pipe material &Pipe connection： cast-iron with Quick Coupling PRN : 0.96 □20 (Very High)				
	RPN-D				
	Severity	Occurrence	Detection	Pipe age	Amount
	1.5	2	2	1	0.96
Renewal suggestion：1.Renwal entire drainage system ; 2. Using open pipe system; 3. service shaft available					

Figure 6 – present condition of Guo-tai

After the assessment model, the Guo-Tai building was defined as “very High” (Level 1) therefore the building was chosen for case study. The plan of the building and drainage system was used to prepare for the field survey to confirm the location and system condition at present. Figure 7 shows the initial model simulation. Among the computer simulation, the practical cases were simulated on three points as below which corresponded to the renewal priority level and decision making process.

The location of the drainage system and vent system was emphasized using colors and



Simulation issue:
A. The building structure, sub-structure and drainage were established by simulation which corresponds to the present condition.
B. The appropriate strategies of renewal were proposed after discussing the relationship between drainage and sub-structure.
C. The database was created and it calculated the quantity of renewal material.

Figure 7 – initial model of Guo-Tai Apartment

groups as shown as Figure 8. The system was separated into different modules based on the different functions to attempt to conform the renewal requirement. Hence, system and structure could be used to discuss the strategy of construction and required space. Figure 8(a) shows the whole construction of a single floor plan, while Figure 8(b) shows, clearly, the location of lavatories by making the building fabric transparent. Figure 9 shows the classification of each type. Double-pipe systems were adopted for toilet sewage but the single system was adopted for sewage collect of all other appliance. Because of the pressure fluctuation caused by a discharging appliance from a higher floor, a trap seal was cost on the lower floor and the foul air spread back to interior. Consequently, the single system increase the vent stack to combined with the old vent stack. Moreover, T5 and T10 had service shaft without exit, the new opened pipe installation were suggested.

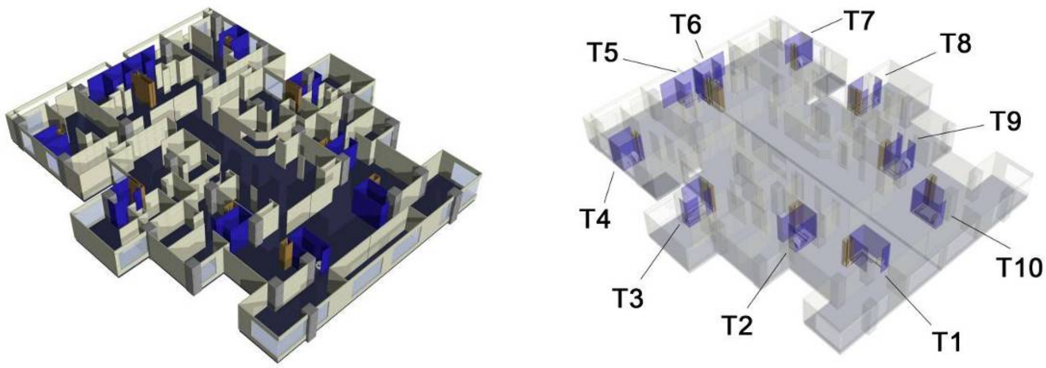


Figure 8(a) /8(b) – Perspective drawing of single floor plan

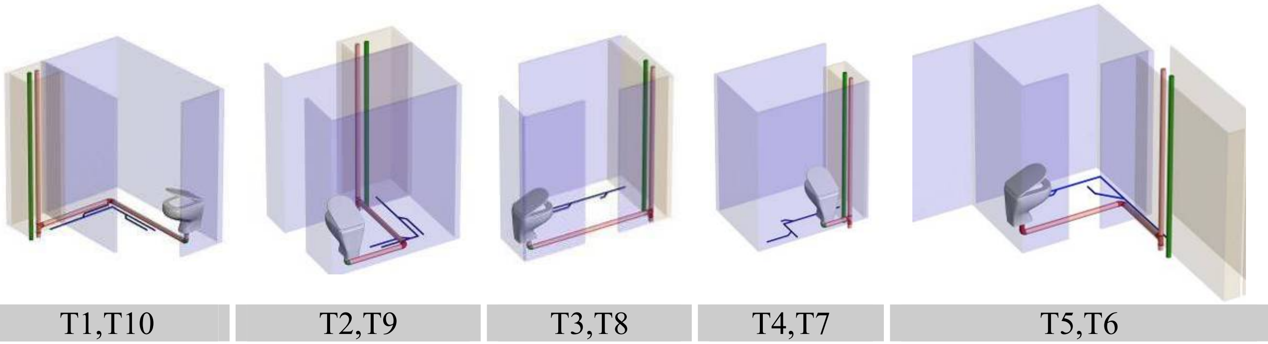


Figure 9 – lavatory type of Guo-Tai Apartment

By the way of 3D simulations, the concept of interior space and drainage system were identified. The external wall and interior wall could be hidden for clear vision of the stack drainage and service shaft location which aids preparation for renewal. Once the new drainage system was set up, the computer simulation could indicate the renewal items and structure which might be influenced by the renewal construction. Figure 10 shows the computer simulation process. Figure 10(a) shows the main structure of the building and Figure 10(b) shows the drainage system and stack making the external wall transparent. Figure 10(c) shows the proposed drainage system and appropriate construction. Figure 10(d) shows the affection area and structure during the renewal.

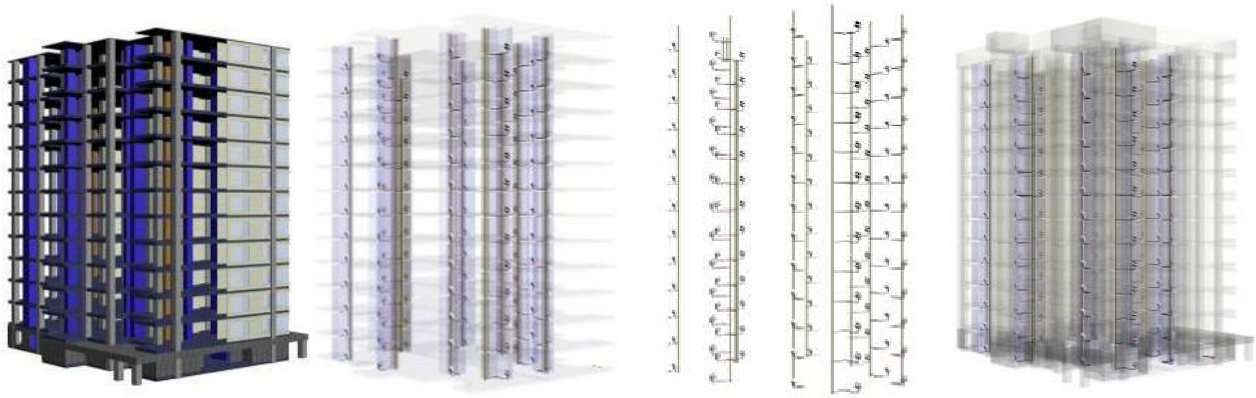


Figure 10(a) (b) (c) (d) – computer simulation process

Table 5 shows the renewal form for Guo-Tai building briefly, the form could check the renewal items.

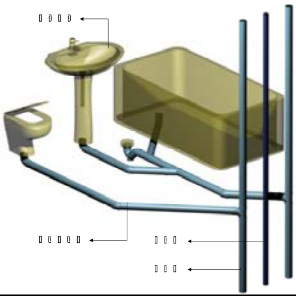
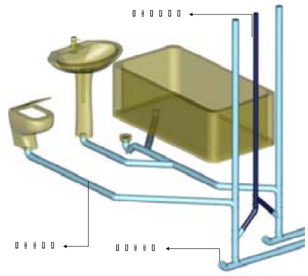
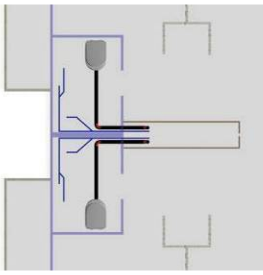
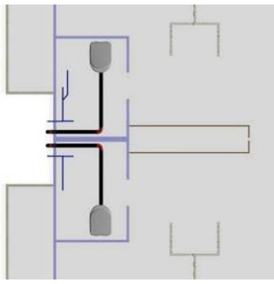
Table 5 – brief renewal form for Guo-Tai building

※Drainage system(Before)：	※Drainage system(After)：
Stack setting:■ opened pipe ■ service shaft unavailable Drain system:■ 2-pipe with other single pipe Vent system:■ Stack vent Pipe material:■ Cast-iron Connection:■ Quick couplings	Stack setting:■ opened pipe ■ service shaft available Drain: ■ 2-pipe with other single pipe Vent system:■ Stack vent、 ■York vent Pipe material:■ ABS Connection:■ Fixture

※Structure effect：■ Ceiling ■ Floor ■ Service shaft ■ Wall □ others________

※Renewal range：■ Entire system □ Partial □ Minor、□others ________

※ Drainage system renewal

Darin and vent system (Before)	Darin and vent system (After)	T5,T6 service shaft (Before)	T5,T6 service shaft (After)
			

※Material preparation (piece)

					
2”45° 960	2”90° 240	2” 120	2” 240	2” 120	2” 10
4”45° 54	4”90° 79	4” 32	4” 132	4” 120	4” 10
					
pipe 2”/320; 4”/289	trap 240	overhaul 124	5	4” to 2” 120	120

5. Conclusion

The drainage renewal model and priority level was proposed by initial research. It can help to detect the condition of the drainage system which is affected by nine factors. In order to improve the renovation efficiency, the computer simulation was given by a visual process. By using the simulation, the relation between drainage and building structure could be identified. The renewal proposal contributes appropriated decision making for designers and users. Once the renewal simulation is complete and the optimum re-design option selected, the model can be used to reassess the new system. The computer simulation could also provide the renewal strategy for accuracy on reconstruction and the quantity of material. The visualize simulation could not only assist the contractor to renew the drainage system but also help the designer to better explain the solutions for user.

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H3) Design and construction of the vacuum sewerage system

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Abstract

In our work we will present reasons for the application of special drainage techniques as the vacuum sewerage system in large scale buildings. We will explain theoretical base, components of the vacuum sewerage system and function of the vacuum sewerage system .

Keywords

Drainage for buildings/ Civil engineering / Building technology/ Computer model

1. Introduction

Vacuum sewerage, as an alternative to conventional systems, is reasonably well known, and most civil engineers are aware that there can be significant capital savings on construction costs. There are several reasons for the application of special drainage techniques. Reasons are mainly though the reason of cost reduction.

Compared to conventional sewer systems, vacuum sewer technology provides major advantages in the following circumstances:

- The topography is flat
- Groundwater table is high
- Sewer system is located near a lake, river, coastline or floodplain
- Ground has an adverse gradient
- Wastewater flows are highly variable, e.g. holiday establishments or local recreational facilities

- Difficult ground conditions, e.g. rock, running sands, peat, swamps etc.
- Refurbishment of sewer systems
- Rural area where houses and buildings are not close to each other
- Crossing rivers, streams, railwaylines, major road etc
- Groundwater protection areas

We can expect highest economy in flat areas with high ground water level and poor soil conditions. The world most famous vacuum sewer project is currently the Palm Island in Dubai.

2. History

The vacuum sewerage system exists now for nearly 150 years. Pneumatic and mechanical operating vacuum sewage collection systems were firstly introduced in the second half of the 19th century. In 1866 the Dutch engineer and former Captain in the US army, Captain Liernur (1828-1893) introduced at a Congress in the city of Haarlem, The Netherlands, his vacuum operating sewage collection system for toilet waste. He introduced the definition of the so called "black water" for toilet waste. The philosophy was based on the re-use of treated toilet waste for agriculture. In the same year (1866) the Liernur technology was registered as a patent in England and The Netherlands.

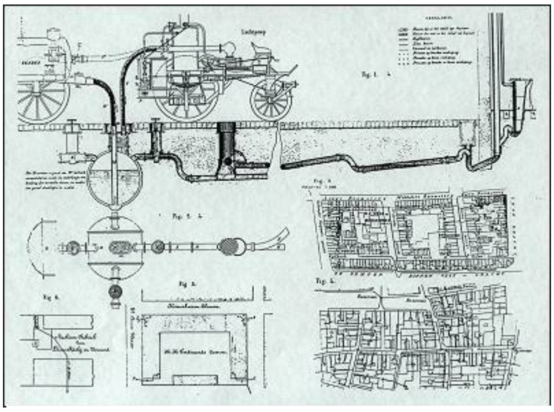

Figure 1 – Liernur/s patent

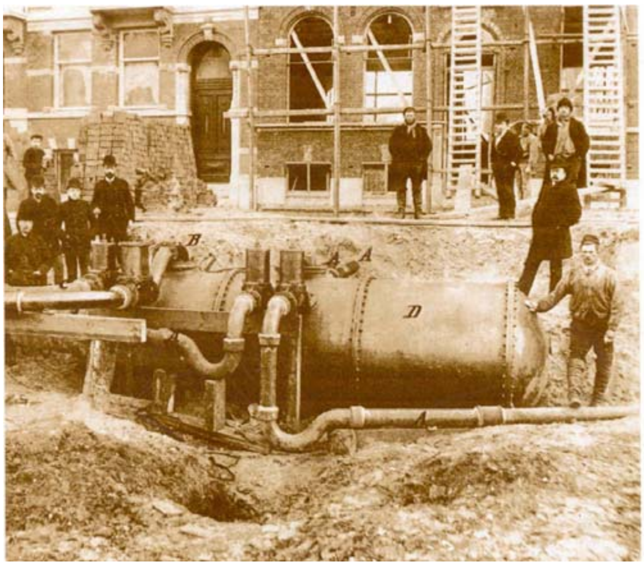

Figure 2 – First vacuum sewage system in Amsterdam in the 1873

In the year 1892 already, 500 properties with 15.000 inhabitants of the northwestern suburb of Paris, Levallois-Perret have been connected to the vacuum sewerage system.

Although the experience had been excellent the system fell into oblivion in the course of the decades.

It was not until the year 1959 the Swede Joel Liljendahl continued to develop the vacuum sewerage system and tested it in the in a residential district in the north of Stockholm. Also in Germany several communities have been installed a vacuum sewerage systems. But soon after their putting to work the system proved to be very instable. This was mainly based upon the house connections being controlled by a vacuum.

3. Principe and components of the modern vacuum sewerage system

A vacuum sewer system uses the differential pressure between atmospheric pressure and a partial vacuum maintained in the piping network and vacuum station collection vessel. This differential pressure allows a central vacuum station to collect the wastewater of several thousand individual homes, depending on terrain and the local situation. Homes are equipped with a gravity system and connected with domestic shafts.

- Domestic shaft: in which the sewage is submitted to the pipe network in measured amounts

Figure 3 – Domestic shaft and vacuum valve

- Pipe network for the transport of the sewage

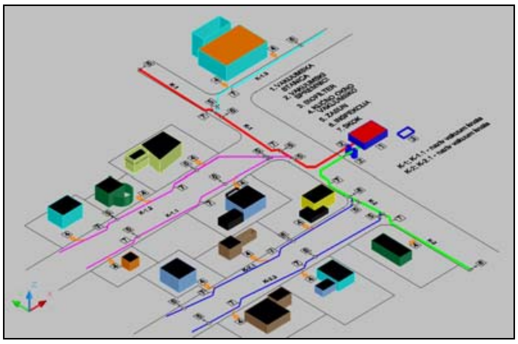

Figure 4 – Network scheme

- Pumping station in which the vacuum for the sewage conveyance is produced

Figure 5 – Pumping station in Slovenia

4. Applications

Vacuum fluid collection systems can be employed in a wide range of situations and typical applications of this versatile and environmentally attractive technology are indicated below :

- Rural community main sewerage
- Roof drainage
- Camp and caravan sites
- New housing developments
- Old towns with narrow streets
- Hospital effluent collection
- Shopping centres with difficult or confined areas
- Replacement of conventional gravity systems
- Petro-chemical industry
- Factory sewerage
- Arctic communities
- Leachate from landfills
- Spillage around industrial storage tanks
- River, lakeside and coastal communities
- Quayside re-developments
- Ship to shore sewage collection

Figure 6 – Iseci vacuum fluid collection system of Tai Wai and Tai Po in the New Territories of Hong Kong

5. Our measurements

We have made comparable test of different types of vacuum valves to compare membrane and piston technology. We have tested valves from several producers: Roediger (Roevac) – membrane type and Iseki(Redivac), Airvac, Quavac – all pistone type valves. All valves where 2” of size at different vacuum and time of open valve 10 seconds. We have measured flow through the valve in that time,

Table 1 – Flow through measured valves in litres (t = 10 sec)

	vacuum 0.6 bar	**vacuum 0.2 bar**	**vacuum 0.15 bar**
Roediger(Roevac)	**86**	**45**	**25**
Iseki (Redivac)	**80**	**41**	**22**
Airvac	**78**	**40**	**20**
Flovac	**75**	**38**	**21**
Quavac	**50**	**31**	**23**

We can see that membrane technology give us best result. Membrane technology vacuum valves are also significaly smaler. As result also domestic shalfs can be smaller.

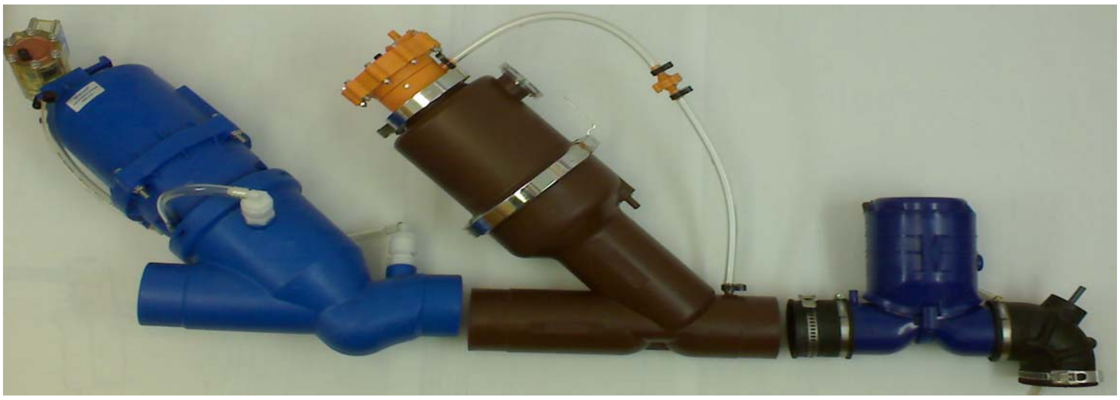

Figure 7 – Diferent types of valves

6. Dimensioning methods

Wery important question I show to properly plan vacuum sewage network. Most common planning and construction method in our area is to use tables and equations from ATW-DVWK-A 116 work sheet.

Table 2 – Example of table from ATW-116

Medium air-water-ratio upstream	Nominal width of the trunk						
	DN 65	DN 80	DN 100	DN 125	DN 150	DN 200	DN 250*
Number of inhabitants connected upstream							
2	0-110	0-350	250-600	350-900	500-1400	750-2100	(1100-3000)
4	0-65	0-200	135-340	200-500	300-800	400-1200	(600-1650)
6	0-45	0-140	95-240	140-350	200-550	300-820	(400-1150)
8	0-35	0-105	75-185	105-270	150-425	220-625	(300-850)
10	0-30	0-85	60-150	85-220	120-340	175-500	(250-700)
12	0-25	0-75	50-125	75-180	100-290	150-425	(200-600)

But some authors propose more exact numeric methods for calculation and modeling evacuation process in the pipe networks of vacuum sewerage systems.
One of possible methods is use of method of characteristics.

We can simulate the evacuation process with a model of divided parameters that assumes not only time, but location dependency as well. We assume that the gas flow in the pipe of a constant diameter is one-dimensional and non-adiabatic, there is no friction between the molecules, but the pipe is hydraulically rough, the friction coefficient of the flow is known and constant.

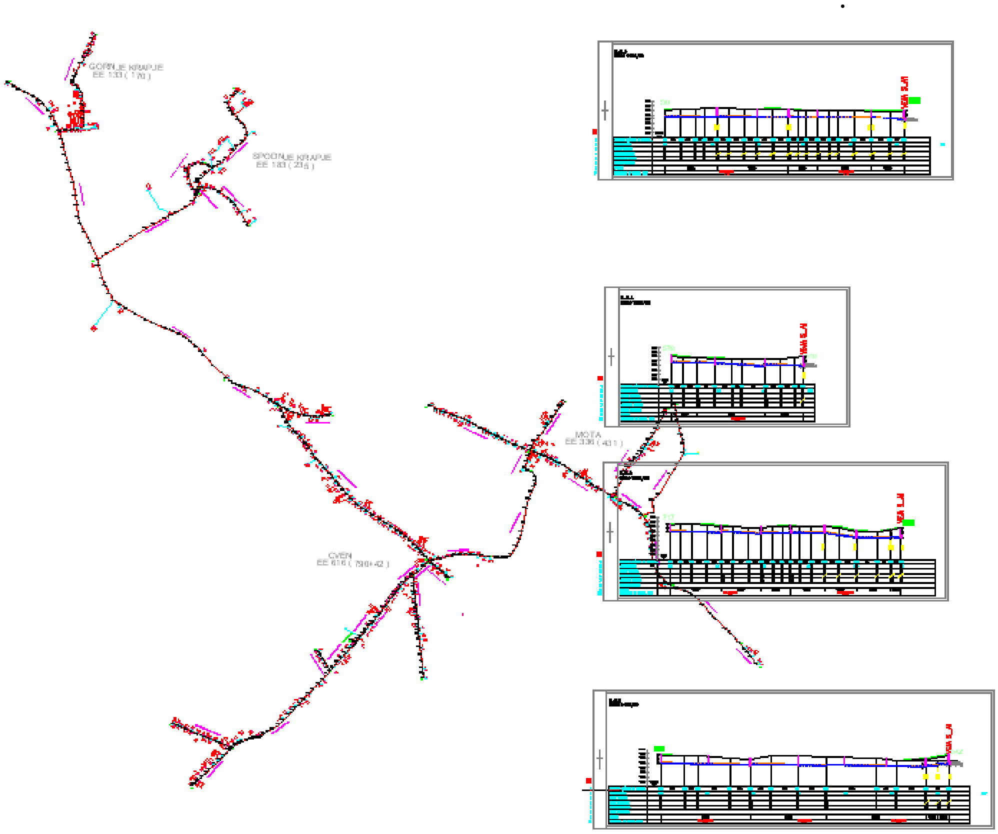

Figure 8 – Plan of vacuum sewerage network where we have tested dimensioning techniques

7. Conclusion

Our work is now oriented into development of more exact methods, tools and models for planning and dimensioning of vacuum sewerage networks.

Acknowledgments

We would like to express our gratitude to the experts of "TIBORA International" which serve as with all necessary data about their systems.

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H4) Case study: drainage and foot-and-mouth

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Abstract

Foot and mouth disease (FMD) is a severe, highly communicable viral disease of cloven footed animals. It can have devastating impacts on both livestock and national economies; the 2001 outbreak eventually cost the UK economy £8 billion. This paper examines the latest outbreak of FMD in 2007, which is thought to have originated from the drainage system of a research facility in Pirbright (Surrey, UK), and led to the infection of 8 nearby farms. The biosecurity arrangements associated with such facilities are examined, and the importance of an efficient and secure drainage system, to the overall level of biological containment, is highlighted. Information and data gathered from four comprehensive reports is used to illustrate the most probable sequence of events leading up to the outbreak. Finally, recommendations relating to the outbreak will be detailed and conclusions discussed.

Keywords

Drainage system; defects; extreme conditions; foot and mouth disease.

1. Introduction

Throughout the world, there are a number of government and privately run facilities that undertake research into various aspects of dangerous biological agents. In terms of animal-borne viruses, the potentially devastating consequences associated with FMD means that it is one of the most heavily researched of all biological agents. At each of the small number of facilities working with foot and mouth disease virus (FMDV), comprehensive biosecurity measures and procedures should be in place to prevent both inadvertent human exposure and the release of FMDV into the environment. However, such activities entail risk, and there have been 14 reported FMD outbreaks from research facilities since 1960[1].

The latest major global outbreak started in cattle at a farm in Surrey (UK) on 3rd August 2007. The initial outbreak quickly spread to infect an adjoining farm on 6th August, and is thought to have been the source for a second cluster of nearby cases between 11th and 30th September 2007 (see Figure 1). This outbreak necessitated the culling of 2160 animals (cattle, pigs, sheep, goats)[1], and resulted in a 4 month EU ban on the export of UK meat. By the time the UK was declared FMD free on 22nd February 2008, it is estimated that the total cost to the UK government and livestock industry was some £147 million[1].

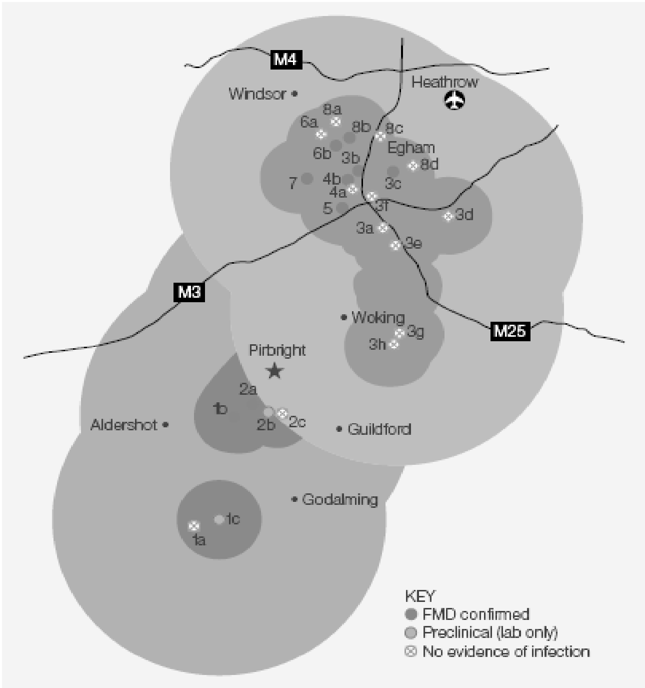


Figure 1 – FMD clusters (source: Anderson report[1])

Laboratory testing indicated that the specific FMDV strain recovered from the outbreak was essentially identical to that recovered from the 1967 outbreak[2]. As this was not known to be in circulation anywhere in the world, initial suspicion for the source of the outbreak fell on the research laboratories at Pirbright in Surrey, which are the only known locations of this strain of FMDV in the UK. These laboratories are also located close to the infected farms.

1.1 Foot and mouth disease (FMD)

FMD is a severe, highly communicable viral disease of cloven footed animals, commonly affecting livestock such as cattle, swine, sheep and goats[3]; it can also affect wild animals such as deer. The disease can cause severe pain and lameness, often leading to a decrease in productivity, and can be fatal in young and weak adult animals. Although humans rarely become infected or develop the full blown clinical disease, they can carry the virus in their throats and noses for up to three days following exposure; in addition, clothing, footwear and vehicles have been implicated in a number of previous FMD outbreaks[3].

As FMDV can be present in animal secretions, including their breath, the most common route for infection is through direct contact with infected animals. However, the virus also survives well in various media, making delayed and wind driven transmission routes a real possibility; FMDV lifespan ranges from 3 days in summer soil to 180 days in slurry[2]. Only a small infective dose is normally required (as few as 10 virus particles being sufficient to infect a cow[3]), and there is hence a rapid rate of progression.

1.2 Biosafety and biosecurity

The terms biosafety and biosecurity mean many different things to many different people and organisations. Within the context of the laboratory handling of animal pathogens, such as FMDV, these terms are defined by the WHO[4] as:

> *"Biosafety describes the containment principles, technologies and practices that are implemented to prevent the unintentional exposure to pathogens and toxins or their accidental release."*
>
> *"Biosecurity describes the protection control and accountability for valuable biological materials (including pathogens and toxins) within laboratories in order to prevent their unauthorised access, loss, theft, misuse, diversion or intentional release."*

In order to work with FMDV in the UK, an organisation requires a licence from the Department of Environment, Farming and Rural Affairs (Defra) under the *Specified Animal Pathogens Order (SAPO)*[5]. The purpose of SAPO is to prevent the introduction and spread of animal pathogens that could cause serious disease and/or significant economic loss to the British farming industry. This is achieved by careful control of biosafety and biosecurity, with SAPO specifying 4 different levels of containment; facilities handling FMDV require the highest SAPO level 4 containment level. In order to achieve secure containment, it is common to utilise a system of barriers[2].

- Primary barrier, which is closest to the biological agents and prevents direct exposure (e.g. culture vessel).
- Secondary barrier, which prevents release of 'live' pathogens to the exterior environment (e.g. walls, waste treatment system).
- Tertiary barrier, which prevents unauthorised entry to site (e.g. perimeter fencing).

2. Pirbright research facility

2.1 Overview of site

The Pirbright site is owned by the Biotechnology and Biological Sciences Research Council (BBSRC) and is the foremost facility in the UK for both research into FMDV and for production of FMD vaccine. There are essentially three different organisations based at Pirbright, each of which hold SAPO 4 licences and work with FMDV.

- Institute for Animal Health (IAH) is a publicly funded organisation that undertakes research into FMDV and its effects. IAH also undertakes diagnostic work to identify and catalogue the various different FMDV strains.

- Merial Animal Health (MAH) is part of a global, commercial pharmaceutical company. Its activities at Pirbright are related to the manufacture of vaccines for a range of animal diseases, including FMD. MAH leases their site from BBSRC.
- Stabilitech Limited (SL) is a small commercial company involved in the development of technologies to ensure effective storage of vaccines and other biological materials. SL rent laboratory space from IAH.

Although the work undertaken at Pirbright is potentially hazardous, and is certainly vital to the British nation, it is commonly accepted that the current state of facilities is not up to accepted international standards[2,3]. As a result of these concerns a £121 million redevelopment of the site was agreed in 2005, although new laboratories are not due for completion until approximately 2012[2].

2.2 Pirbright laboratory drainage and treatment

Each of the organisations at Pirbright produce FMDV to support their work; IAH and SL require only small quantities of the virus for their research activities, whilst MAH produce FMDV on an industrial scale for vaccine production purposes. Irrespective of the FMDV quantities involved, all laboratory waste undergoes chemical treatment prior to entering the main site drainage system. Although this treatment is intended to be 100% effective, it appears that live FMDV may well enter the site drainage system on occasions[3]. In fact, the MAH site director estimates that 0.01% of FMDV may still be alive after treatment, equating to ~ 1 billion infectious units in a normal production batch[2]; interestingly, the biological safety officer at IAH appears to have been unaware that such large quantities of live FMDV may be entering the site drainage system from MAH laboratories[2]. Indirect waste from each of the facilities, such as that from showers and toilets, is not treated prior to entering the site drainage system. These general procedures have been approved by Defra.

Figure 2 shows a schematic view of the main site drainage system, which exhibits the following characteristics:

- The foul drainage has been constructed in phases, and comprises of predominantly vitreous clay pipework, with some cast iron and UPVC. Older pipework tends to be 4” (100mm), whilst newer pipework tends to be 6” (150mm).
- IAH and SL waste is discharged via gravity mains, whilst MAH waste is discharged via a sump and a pump main (served by two pumps).
- All waste undergoes secondary treatment at a caustic soda plant (~50 years old). It is then held in storage tanks, until its pH is below 11, before being discharged to the main sewer where it undergoes final treatment at Hockford sewage treatment works.
- Surface water from IAH and SL areas is stored in buried open-topped tanks, with overflows to a small lagoon, and eventually discharged into the Stanford Brook. That from MAH area is discharged directly to the public sewer.

3. Outbreak

As detailed previously, the initial outbreak occurred in cattle at a farm in Surrey on 3rd August 2007, and quickly spread to an adjoining farm and a second cluster of cases. Although laboratory testing indicated that the FMDV probably originated from the Pirbright site, the minor genetic modifications that occur rapidly following release meant it was not possible to pinpoint exactly which of three facilities was responsible.

Evidence collected from a number of different investigations highlighted that the most probable sequence of events that lead to the outbreak had four stages:

- Establishment of necessary conditions.
- Release of FMDV from containment facilities.
- Transmission of FMDV from Pirbright site.
- Infection of farms.

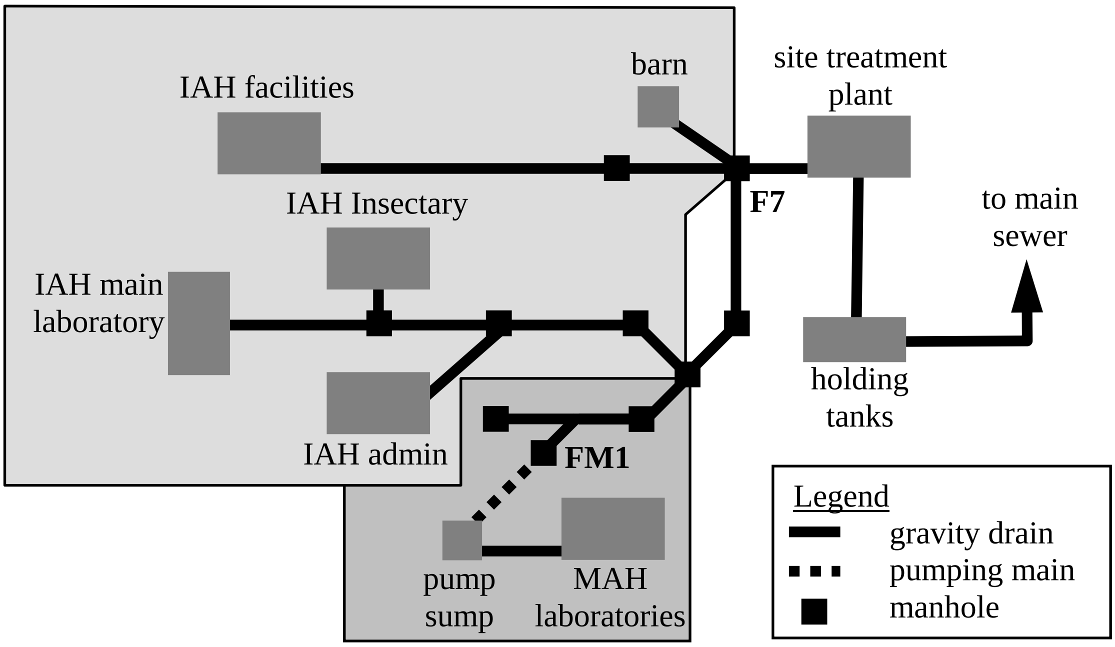


Figure 2 – Pirbright site drainage system

It should be noted that the description of the outbreak herein makes extensive use of words such as "probable" and "likely". This is because, despite extensive investigation, it has not been possible to *categorically* state how the FMD outbreak was initiated or spread; rather the description herein represents, on the balance of the evidence, the most probable or likely sequence of key events.

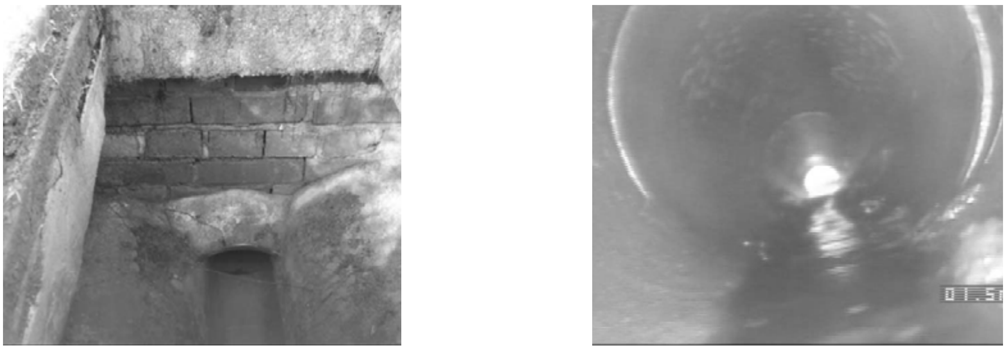
3.1 Establishment of necessary conditions

The establishment of the conditions necessary for the outbreak itself comprised of four elements, namely: weather conditions, FMDV virus production, site drainage condition and site construction activities. The prevailing weather conditions in the weeks leading up to the initial outbreak were extreme. Up to 62mm of rainfall was measured in the locality on 20th July, which resulted in localised flooding in and around the Pirbright site, with both standing water and high groundwater levels being observed until 23 July[3]. Although the site drainage system was thought to be full (though not overflowing), water was seen to enter the caustic soda treatment plant; this resulted in an agreed temporary reduction in waste discharges to the site drainage system[2].

Immediately preceding this period of extreme weather, MAH produced two significant batches of FMDV (6000l each). Waste from the cleaning of the production vessels was discharged to the site drainage system on 20th July, whilst the *theoretically dead* FMDV waste itself was discharged between 22nd - 23rd July and 25th - 26th July. Within the same time frame, both IAH and SL produced negligible quantities of FMDV.

Although the general state of the site infrastructure had long been known to be substandard, the extremely poor state of the site drainage system only truly became apparently as a result of the investigations following the FMD outbreak. In particular, inspection of the drainage system (physical surveys, CCTV surveys, documentation review) highlighted the following key defects[3]:

- General structure not well understood.
- Poorly fitting manhole covers and damaged chambers (see Figure 3a).
- Cracks and displaced joints (see Figure 3b).
- Debris accumulation and tree root ingress.
- Evidence of water ingress at pipe crowns.
- Permanent standing water in some sections.
- Dead legs associated with decommissioned facilities.
- Evidence of repeated blockage and surcharging.
- Number of recent breakdowns of final treatment plant (e.g. valve failure).
- Evidence that foul flows have entered surface water lagoon.
- Unsatisfactory maintenance/inspection procedures, including no routine testing of discharges.



a. Damaged manhole joints b. Joint misalignment and crack

Figure 3 – Examples of drainage system defects (source: HSE report[3])

As part of the site redevelopment scheme, a variety of different construction activities were being undertaken in the period preceding the initial outbreak (14th - 26th July). These included the excavation of new manholes and inspection trenches, the widening of existing site roads and the construction of new roads. Some of these works were located in close proximity to the MAH pump sump, whilst others crossed directly over drains leading from IAH laboratories. Excavated material was either left in spoil heaps on site, or transferred to an off site disposal facility.

3.2 Release of FMDV from containment facilities

Investigations concluded that there was negligible likelihood that FMDV was released from the containment facilities by either airborne or human transmission, or through solid waste disposal. In the absence of any other credible routes, it was therefore concluded that FMDV was probably released from the liquid waste system (i.e. the site drainage system). Given that only MAH discharged substantial quantities of FMDV waste to the drainage system immediately preceding the FMD outbreak (20^{th} – 26^{th} July), it is thought likely that the MAH laboratories were the source of the virus release. It should be recalled that up to ~ 1 billion infectious FMDV units may survive initial laboratory chemical treatment from a normal production batch[2], and only 10 units are required to infect a cow[3].

The drainage surveys identified that, of the many areas of concern, the section between manholes FM1 and F7 (see Figure 2) was the critical section; this portion of the system exhibited many different defects and also conveyed the greatest discharge. Within this section, manhole FM1 was highlighted to be of particular concern as it was:

- Located immediately downstream of the pump main from the MAH sump
- Connected to a short, near vertical connection to downstream pipework, hence increasing the likelihood of turbulent flow conditions and system surcharging.
- Shallow (300mm).
- Not air or water tight (poor fitting cover, evidence of tree root ingress).

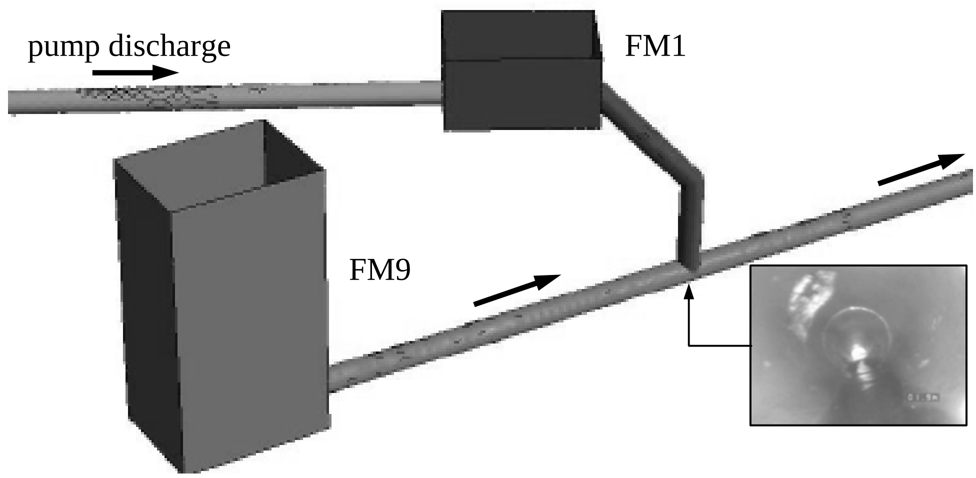


Figure 4 – CFD model and photograph of pipe configuration in vicinity of FM1 (source: HSE report[3])

CFD analysis was undertaken to determine the flow conditions in the vicinity of manhole FM1 under a variety of different pump loading conditions (see Figure 4). The results indicated that, with one of the pumps operating (6.95 l/s), FM1 was predicted to overflow only if there were a significant blockage in the downstream system; the physical surveys suggest that this could be a common occurrence. With both pumps operating (13.9 l/s), the unorthodox pipe arrangement meant that FM1 was predicted to overflow even without a system blockage. Although the results of such analysis must be treated with caution, anecdotal evidence tends to support these findings (e.g. some backup into FM1 is often observed during normal pumping operations[3]).

The CFD analysis and survey results indicate that the release mechanism from the site drainage system was most probably due to overflowing of manhole FM1 or from general pipe leakage at some point in the system (perhaps for extended period of months or years). It should be recalled that FMDV can live for up to 3 days in dry summer soil, and much longer in the type of saturated conditions that preceded the initial outbreak.

3.3 Transmission of FMDV from Pirbright site

After determining the probable cause of the FMDV release from the containment facilities, it was necessary to determine how the virus was transmitted to the locality of the infected farms. Although the whole region was affected by flooding at the time, the general topography (Pirbright is 5-10m below the elevation of the first infected farm) and natural flow lines meant that it was “practically impossible” that transmission occurred via overland flooding[2]. Investigations also concluded that it was highly unlikely that FMDV transmission was via the normal sewage system, wild animal activity or human activity (disgruntled staff, terrorists, etc). Therefore, attention turned to site construction activities.

As noted previously, there were significant groundworks during the period 14th – 26th July, which overlaps with the probable period during which FMDV was released from the drainage system (20th – 26th July). During this timeframe, approximately 1000 vehicles visited the site, some of which were 32 tonne trucks transporting excavated soil off site. These activities necessitated the trucks being in close proximity to the existing drainage system and/or in contact with soft soil near access roads. It was therefore concluded that construction activities probably led to disturbance of subsoil that had been contaminated with FMDV from the defective drainage system. As such it was concluded that construction traffic probably formed the transmission route for FMDV off the Pirbright site; it is thought that either the actual truck loads contained contaminated subsoil or the truck wheels/wheel arches picked up and transported contaminated subsoil.

3.4 Infection of farms

Although construction traffic had been highlighted as the most probable transmission route for the FMDV from the Pirbright site, none of the trucks actually had direct contact with the infected farms. However, between 20th – 25th July, six uncovered trucks left the site to take excavated subsoil to Compton landfill site. The route travelled by these trucks passed along Westwood Lane, which is adjacent to the fields of the first infected farm and is used by the farmer for access. Given the coincidental dates, it is considered most likely that contaminated subsoil from one or more of the trucks was deposited along Westwood Lane, and was then picked up by the farmer and taken into his fields, where it caused the initial FMD outbreak; an alternative theory is that contaminated subsoil fell from one of the lorries directly into the fields. It was therefore concluded that the initial farm outbreaks were caused by cross-contamination of the farmers vehicles by subsoil from construction traffic. Although no definitive explanation has been forwarded to explain the subsequent outbreaks, they were to be expected given the close proximity of the later outbreaks to the first infected farm.

4. Compliance with standards

In assessing whether the facilities at Pirbright comply with standards, it is instructive to recall the system of barriers that normally constitute suitable containment (see Section 1.2); in particular, all biological agents should be made safe before exiting the secondary barrier. As the laboratory waste treatment procedures are known not to be 100% effective, this essentially means that the site drainage system actually forms part of the secondary barrier, and should hence prevent release of biological agents to the exterior environment. This principle is confirmed by SAPO licensing authority (Defra), who have commented that drainage systems associated with SAPO licensed facilities should comply with the same containment requirements as the laboratories themselves[3]. Given these principles, it is clear that the Pirbright site drainage system does not comply with fundamental standards of containment, as is not:

- Demonstrably leak proof.
- Airtight, or negatively pressured.
- Proofed against ingress and egress of insects.
- Isolated from flooding.

Furthermore, the extensive surveys of the Pirbright site drainage system also indicate that it does not meet British Standards for workmanship for below ground drainage[6], and would be unlikely to pass standard pipe soundness testing[7]. Consideration of these issues leads to the conclusion that the existing site drainage system does not meet necessary containment standards for a biosecurity critical system. This is primarily due to poor maintenance, poor monitoring and poor record keeping over an extended period of time.

5. Recommendations and actions

The UK government accepted all of the specific recommendations made by the two main reports into the FMD outbreak[8], including the need for:

- Improvements to the site drainage system to ensure full containment (infrastructure, maintenance, monitoring, records).
  - Pending construction of a new system, existing pipework has been relined, manhole covers sealed and dead legs blocked off to ensure containment.
  - In the interim, all FMDV waste must be completely inactivated prior to discharge.
- Improved waste treatment procedures to minimise discharge of live FMDV to site drainage system.
- Improved clarity of biosecurity regulations and responsibilities.
- Improved communication between IAH and MAH biological safety officers, particularly concerning the shared site drainage system.

- Improved control and monitoring of access to site.
- Widespread circulation of the report findings to facilities involved with similar pathogens.

In addition to the above, the Callaghan review[9] recommended that responsibility for inspection and enforcement functions (concerning animal pathogens) pass to a body that is not subject to conflict of interest and has the requisite technical expertise; at present Defra is a "major customer of animal pathogens research and diagnostics at Pirbright", as well as being the regulator, licensor and inspector of such facilities.

6. Conclusions

The complexity of the events that surrounded the FMD outbreak effectively means that no one can be 100% certain of the precise cause. However, the extensive investigations that were undertaken do indicate that the most probable explanation involved 4 key stages, namely: the release of live FMDV to the site drainage system (due to ineffective waste treatment), the release of live FMDV to the Pirbright site (due to defective drainage system), the transmission of live FMDV from the Pirbright site (due to construction traffic) and the initial farm infection (due to cross-contamination of vehicles). In common with similar events, the FMD outbreak occurred due to a sequence of critical events rather than one individual cause; for example, irrespective of the effectiveness of the laboratory waste treatment system, the outbreak would probably not have occurred if the drainage system had been sound. The outbreak may therefore be viewed by some as a fluke occurrence. However, the dilapidated state of the site infrastructure, particularly the site drainage system, indicate serious systematic problems. Equally worrying is the apparent absence of regular dialogue/understanding between the main organisations regarding biosecurity; this is best epitomised by the lack of clarity concerning live FMDV discharges to the site drainage system.

Although the site redevelopment scheme should deliver improved laboratory waste treatment facilities, it is clear that there will always be the possibility of future releases of live FMDV to the site drainage system. It is therefore vital that, as recognised by all parties, the drainage system is considered an integral element of the overall containment system; as such, its design and maintenance must comply with relevant standards.

In addition to highlighting the importance of effective waste treatment and drainage infrastructure, this case study has emphasised the importance of effective communication when dealing with complex systems, particularly those involving multi-user systems. It has also highlighted the need for stringent regulatory control of sensitive national facilities. In this respect it is perhaps surprising that the maximum penalty for breaching the terms of a SAPO licence is £5000[1]. It is also surprising to learn that live FMDV was released from MAH laboratories into the Pirbright site drainage system on 19th November 2007, just 13 days after their SAPO licence had been reissued; although the leak was contained and no damage was done, IAH claim that they did not know that MAH had resumed vaccine production[1].

Acknowledgements

This report has drawn heavily on the formal investigations that followed the FMD outbreak, including:

- *Independent Review of the safety of UK facilities handling foot-and-mouth disease virus.*
- *Foot and Mouth Disease 2007: A Review and Lessons Learned.*
- *Final report on potential breaches of biosecurity at the Pirbright site 2007.*
- *A review of the Regulatory Framework for Handling Animal Pathogens.*

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Presentation of Author

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H5) Empirical study on terminal water velocity of drainage stack

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Abstract

An actual discharge of vertical drainage stack has a complex phenomenon and may consist of triple phase flow feature with incorporated solid, liquid and air. The guideline of National Plumbing Code (NPC) of US was used to set the permit flow rate as the regulation of building drainage system. Following initial work of the HASS 203 of Japan in 1970s, the method of steady flow condition was merged as the provision reference and evaluation technique. According to the importance of permit flow rate regulation, the terminal velocity in drainage stack was also seen as one of the crucial issues in building drainage studies. Couple theories and predictions were reported in previous researches. This paper would also introduce a prediction method with empirical approach by theoretical study from air pressure distribution research. A new technology with digital high speed camera was used to validate the prediction of terminal velocity in drainage stack in this paper. The theoretical study reveals the practical sense and the validation also approximately responses to the prediction results.

Keywords
terminal velocity, the fluid phenomena of the water, air-pressure, drainage stack

List of symbols

symbols	content	unit
Q_w	Water flow rate	l/s
Q_a	Air flow rate in stack vent	m^3/s
R	Diameter of stack	m
V_w	Velocity of water flowing	m/s
V_a	Velocity of airflow	m/s
V_t	Terminal velocity of water	m/s
$\xi_w \times V_w$	The water resistance in the stack.	
$\varepsilon_a \times V_a^2$	The air action force to falling water	
g	Gravity acceleration	m/s^2
Δt	time interval	sec
ΔX	Distance	m
SD	The accumulation distance of falling water	m

1. Introduction

Appliance discharges to a vertical stack of drain may be described as an unsteady or time dependent flow, and the form of the appliance discharge flow contributes to this flow condition. An actual discharge of vertical drainage stack has a complex phenomenon and may consist of triple phase flow feature with incorporated solid, liquid and air. Airflow in the drainage stack is promoted by through-flow mixing as well as the interaction of friction with the falling water and air. This mechanism causes the negative pressure on the upper floors and the positive pressure on the lower floors in the building vertical drainage system. Hunter[1)] explored the flow phenomenon of drainage stack in1940s. Afterward, Wyly[2)3)] & Dawson first issued the theory of the terminal velocity at 1960s.

The guideline of National Plumbing Code (NPC) of US was used to set the permit flow rate as the regulation of drainage system. Following initial work of the HASS 203 of Japan in 1970s, the method of steady flow condition was merged as the provision reference and evaluation technique; hence it conducted series researches of steady flow method with reference to building drainage network. According to the importance of permit flow rate regulation, the terminal velocity in drainage stack was also seen as one of the crucial issues in these series researches. Couple theories[4)5)] and predictions were reported in previous researches. However, the validation and accuracy were still criticized so far. This paper would also introduce a prediction method by theoretical study from air pressure distribution research. Meanwhile, a new technology with digital high speed camera was used to validate the prediction of terminal velocity in drainage stack in this paper.

2. Technical Reviews

The theory of the annulated flowing in drainage stack was first issued by Wyly[2] in 1960s. Afterward, some researches tried to figure out the velocity of flowing water in the stack by the experimental method and theory, however, no results were reported in that period. In 1980s, Tukagoshi[6] conducted electricity to the salt solution in Japan, and put the sensor of the electricity into the pipe which perpendicular to the pipe's section and divided into 1-25 points as observational points, when salt solution flowing into the vertical stack and pass through the sensor would evaluated the velocity and quantity of the water flowing. In 1994, Sakaue[7] in Japan continuously infused water into vertical stack for testing the velocity of the water flowing, and to return to original equation for evaluated the water flowing rate in the vertical stack. However, all these researches have not reached a clarified and validated conclusion on the terminal velocity on drainage stack.

According to the previous researches[8][9][10] on air pressure distribution, the airflow rate (Q_a) was identified as a critical parameter for a prediction model which can express the mechanism of vertical drainage flow. Therefore, the airflow performance in vertical drainage stack is the dominated issue and it needs to be solved. Hence while air flow rate is dominant in the vertical drainage stack, it plays a critical role in the subsequent operation of vertical drainage stack where the mechanism may be assumed to be a quasi-fan machine, thus the laws of fan can be introduced to link with the vertical drainage flow. The laws of fan can be expressed by the hydraulic parameters such as air density, pressure, velocity, gravity, resistance coefficient, lift, and et al. Practically, the operation energy for airflow within fan is mainly from electric power, thus potential energy of height is the dominating power for conducting the airflow in vertical drainage stack. This antithesis mechanism can be expressed as quasi-fan theory, namely the initial model of vertical drainage flow was conducted from the laws of fan machine alike.
The mechanism of flow within vertical drainage is now schematically understood. Air pressure in vertical drainage stack is caused by series interactions between downstream water and through-flow air in vertical pipe. Fig.1 illustrates the image of flow state and the modified interaction, thus it conducts the main parameters with air pressure, airflow rate, and resistance coefficients, and they are the essential factors for prediction model of air pressure distribution in vertical drainage stack.

A prediction model about the air pressure distribution, which occurred in the drainage stack by high-rise experiment tower (108m) and middle-high experiment tower (30m), was developed in Japan from 1990, then considerable progress has been made in predicting the air pressure distribution within vertical drainage stack.

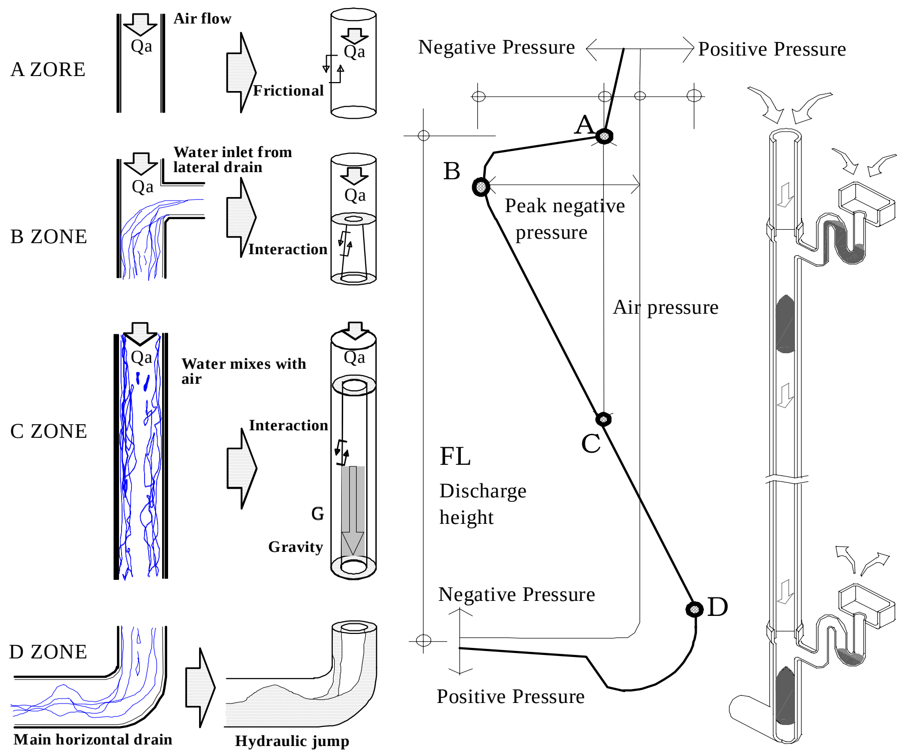


Figure 1 – Mechanism of vertical drainage feature and inverted model

According to the mechanism and feature of vertical drainage flow from the theoretical reviews, the profile of drainage stack was divided into four zones, and each zone is individually modeled due to the corresponding characteristics. Meanwhile, the air pressure distribution, which reveals the time average air pressure data with steady flow condition, does not involve the instantaneous air pressure fluctuation in vertical drainage flow

3. Theory and empirical observation

The phenomenon of drainage vertical stack can be divided by four zones (A, B, C, D) to express their individual characters which were mentioned in previous researches. According to the feature character observation, B zone is the most complex area which is the acceleration area in both water flowing and airflow in the stack. Fig. 2 shows the image of complex phenomenon that water flows into the vertical stack from the branch pipe and the interaction of water and air.

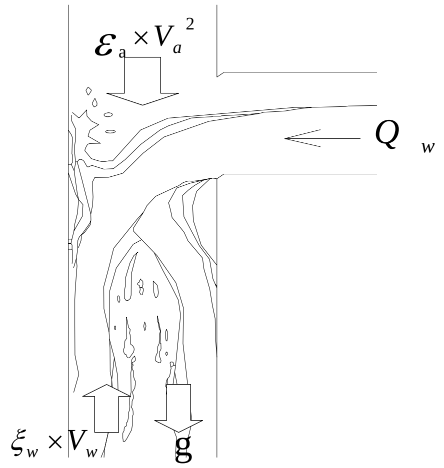


Figure 2 – The simulate diagram of the water flowing into the stage

The velocity of the flowing water in the stack is mainly dominated by the three interaction balance including gravity force (g) and friction drag of the pipe inside and the air interaction toward the falling water. As the falling water in the stack becomes the terminal velocity, that means the interaction inside the stack reaches the condition of balance and the forces actions are totally equal and neutralized. Therefore, the balance condition can be expressed as the following equation (1) which means the forces of friction drag of the pipe inside and the air interaction toward the falling water are equal to the force of gravity.

$$\mathrm{g} = \xi_w \bullet V_w + \varepsilon_a \bullet V_a^{2} \text{................(1)}$$

The velocity of the water flowing vary as speed increasing or acceleration when water flowing into the vertical stack from the sideling stack. Thus, the velocity can be expressed as equation (2) (3).

$$\frac{d\mathrm{V}_w}{dt} = g - \xi_w \times V_w + \varepsilon_a \times V_a^{2} \text{...........(2)}$$

$$V_w = \int_o^t \frac{d\mathrm{V}_w}{dt} \qquad \text{...........(3)}$$

According to the equation (2)(3), the velocity of the water Velocity in stack flowing between 0 sec and t sec can be gained from integration function of equation (4).

$$V_w(t) = \frac{\left(\mathrm{g} + \varepsilon_a \times V_a^{2}\right) \times t}{1 + \xi_w \times t} \text{...........(4)}$$

Therefore, the water falling distance from branch pipe which accumulated between 0.001 sec and t sec can also be added up by the equation (5).

$$SD = \sum_{\Delta t=0.001}^{t} \Delta t \times V_w(t) \qquad \text{..........(5)}$$

Because there are 1000 specific gravity difference between water and air, the action of the air toward water could be ignore temporary. Thus, the velocity of falling water can be expressed as equation (6).

$$V_w = \frac{g \times t}{1+\xi_w \times t} \text{ ....(6)}$$

According to the equation (6), the gravity and water resistance would be constant theoretically. The falling water will soon reach a constant velocity as time passes. Therefore, as the time is setting as infinite number the approaching constant water velocity can be seen as the terminal velocity. The function can be expressed as the following equation (7).

$$t \to \infty \Rightarrow V_t = \frac{g}{\xi_w} \text{ ....(7)}$$

The continuous flowing phenomenon of B zone is the most complex area in the drainage stack. When the water flows into the stack, the initial falling velocity is zero theoretically and the velocity is accumulated and increasing. Meanwhile, the constant air flow rate would be instantly accumulated by the flowing section extremely shrinking. Thus, the air velocity would be speedy than water velocity at this zone. According to the interaction between air and water, the falling water velocity is increasing and air velocity is decreasing. The physical phenomenon in this area causes the increasing of negative pressure. When the velocity of water and air reach to the equal point, the increasing negative pressure tendency will stop and change to decline. This critical point also expresses the maximum negative pressure point. When the water flow rate and air flow rate is constant, then the air velocity in the stack can be calculated by the equation (8).

$$V_a = \frac{Q_a}{A - A_w} = \frac{Q_a}{A - \frac{Q_w}{V_w}} = \frac{V_w \times Q_a}{A \times V_w - Q_w} \qquad \text{..........(8)}$$

According to the equation (8), the velocity equal point of water and air happens in the maximum negative pressure area. Then, the equation (8) can be substituted by the following equation (9) at this point.

$$V_a = \frac{Q_a + Q_w}{A} \text{ ....(9)}$$

Fig. 3 shows the calculation model of air and water velocity in stack and the accumulated distance of the falling water. According to this calculation model, the maximum negative pressure point can be predicted and the terminal velocity of falling water in stack can also be expressed.

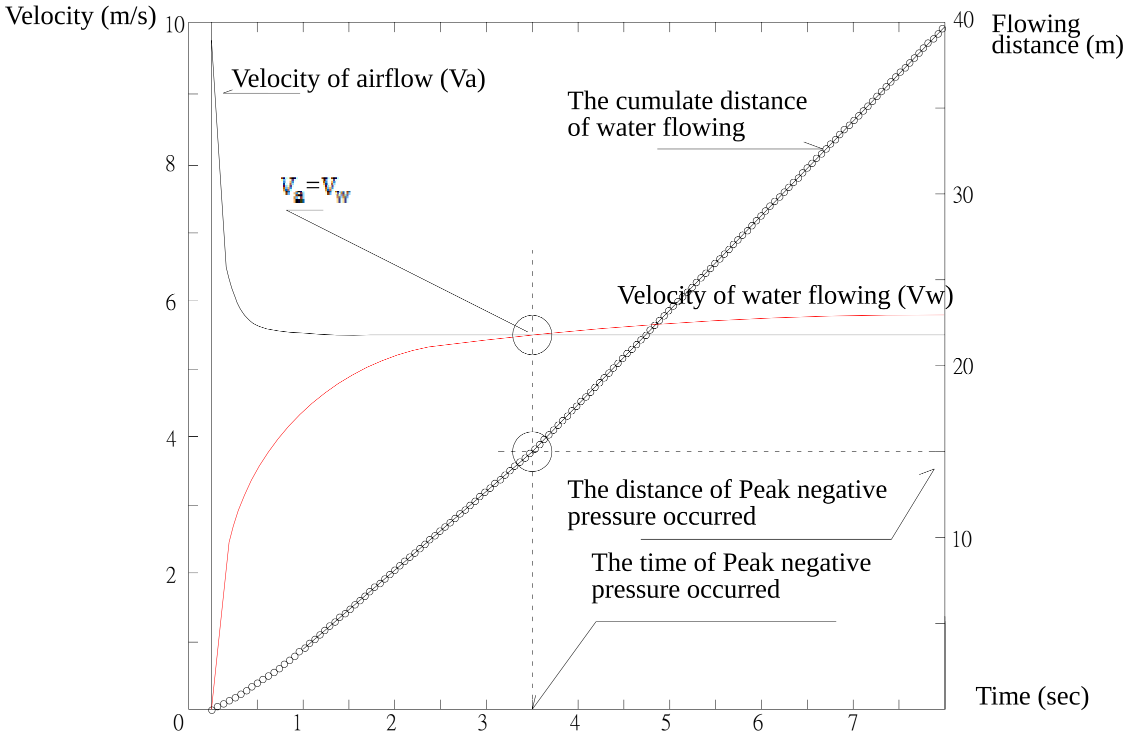


Figure 3 – The diagram of the air in the pipe and the distance of water flowing.

(Limit: the initial velocity of water flowing=0.001m/s，Q_w=2.0l/s，Q_a=40.0l/s)

Consequently, the negative pressure occurring point depends on the air flow rate in stack. Fig. 4 and 5 shows the validation of measured data and the calculation results by the above model.

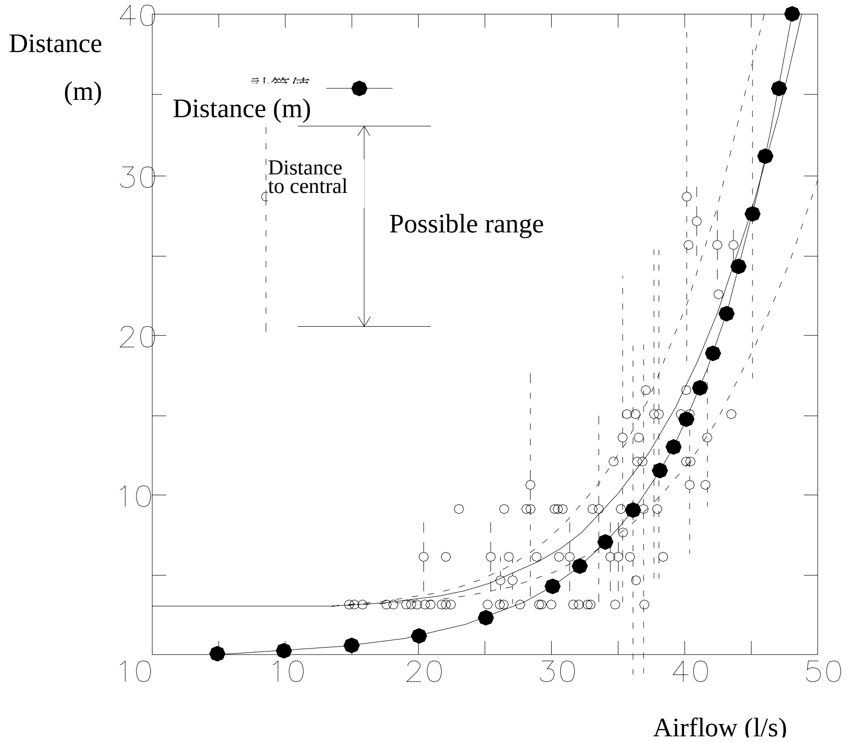


Figure 4 – The relation between the distance of peak negative pressure occurred and the quantity of the air flow. (Q_w : 2.0(l/s))

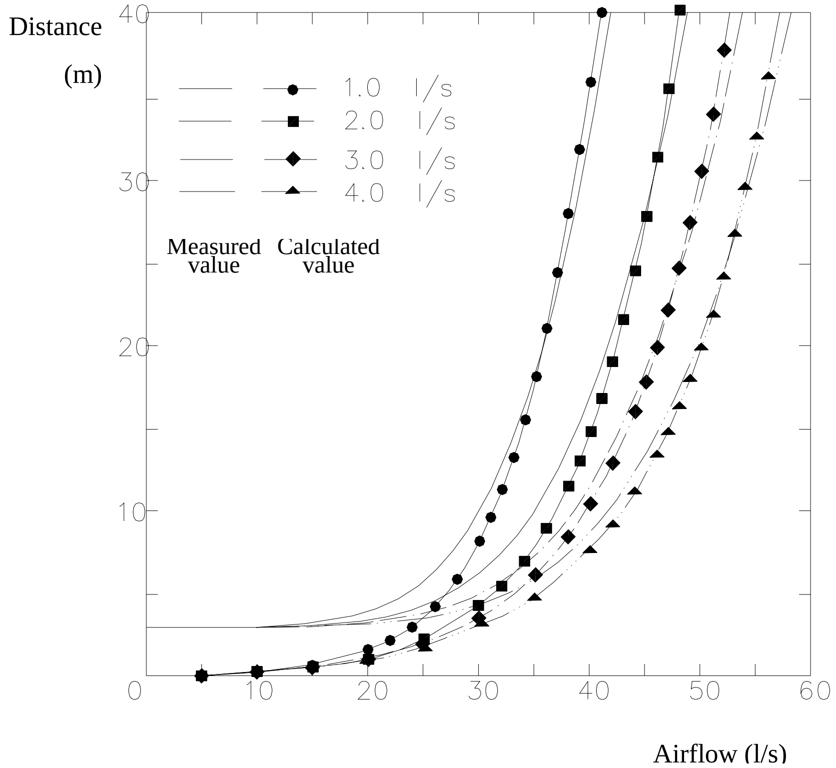


Figure 5 – The relation between the distance of Peak negative pressure occurred and the quantity of the air flow. (Q_w : 1.0, 2.0, 3.0, 4.0 (l/s))

The distance of maximum negative pressure from charge floor was surveyed in previous researches which were measured in a 100 m experiment tower in Japan. The validation is proved to be approximately matched the calculation model. Accordingly, the water resistance coefficient can be calculated by this validation process. When the distance of maximum negative pressure is catch, the time is the crucial parameter for the calculation of water resistance coefficient by equation (5). Then the air resistance coefficient also can be calculated by equation (1). The results of the calculation are shown in Table 1.

Table 1 – The resistance coefficient of water and air in stack

Water flow rate Q_w	ζ_w	ε_a
1.0 l/s	3.10	0.03454
2.0 l/s	2.20	0.01727
3.0 l/s	1.85	0.01232
4.0 l/s	1.50	0.00746

Owing to the limitation of experiment device, the measurement points are set in interval of 3 meter, thus the data can not be precisely fit to the verification result. However, the results approximately response to the theory and satisfy the validation. According to the water resistance coefficient, the terminal velocity can be predicted by equation (6) and the results are shown in Table 2.

Table 2 – The terminal velocity of water flowing in stack

Water flow rate Q_w	Previous researches		This study	Previous study
	Wyly type	Dowson type	(Cheng)	(Kurabuch)
1.0 l/s	1.60	2.06	3.161	5.48
2.0 l/s	2.11	2.06	5.353	7.90
3.0 l/s	2.48	3.20	5.297	8.79
4.0 l/s	2.79	3.60	6.533	9.30

Regarding the researches of terminal velocity, Dawson (US) used the manning equation to calculate the terminal velocity by the following equation (10).

$$V_t = 5.18 \times \left[\frac{Q_w}{2 \times R} \right]^{0.4} \quad \text{..........(10)}$$

Meanwhile, Wyly (US) reported the falling water in stack might be annual membrane flow. Thus he amended the coefficient and proposed the calculation equation for the terminal velocity as the following equation (11).

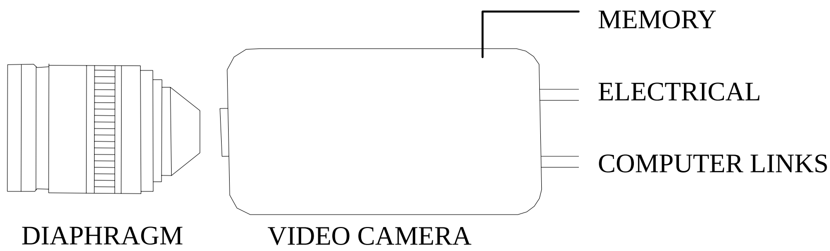
$$V_t = 4.02 \times \left[\frac{Q_w}{2 \times R} \right]^{0.4} \text{...........(11)}$$

Asano (Japan) followed the theory of annual membrane flow and proposed more precise prediction model. However, the results were similar to Wyly's calculation. In 1990s, Kurabuchi (Japan) used the theory of air pressure gradient, proposed a new approach to predict the terminal velocity. However, the prediction results were almost twice or triple of the previous researches as shown in Table 3. Meanwhile, the results were not yet be verified by experiment. Afterward, the researches of terminal velocity stopped and no reports were presented so far.

4. Validation device and the process

The theory of this paper was developed almost the same age as Kurabuch in Japan. Following the development of observation technology, this research tries to use the digital high speed camera to validate the prediction model for terminal velocity. Table 2 is the specification of this digital high speed camera which is used to observe the falling water velocity in stack. Fig. 6 is the picture of experiment in observation place which shows the circumstance and condition of the operation.

Table 3 – Specification of the digital high speed camera



Video camera	• Auto Exposure Control，Color or monochrome • 2,100 pictures per second full resolution • Software: Acquisition, Analytical playback, Measurements, Image processing and File management • 256mg RAM，for files memory
Diaphragm	• Adjustable diaphragm. • Resolution of the screen

Fig.6 the experimental device

The pictures of the transparent pipe at each floor of the experimental tower were taken by digital high speed camera. Water discharges are all from 12^{th} floor with the water flow rate of 1.0 l/s, 2.0 l/s, 3.0 l/s, 4.0 l/s, meanwhile each floor divides into 3 layers so that each floor can be taken video with three times. This research totally got 132 video data from the observation of 33 layers. The experimental device includes digital high speed camera, two lamps, notebook for recording the data and high resolution image screen. Fig. 7 and 8 show the devices of this observation. And the observation results are shown in Fig. 9~12.

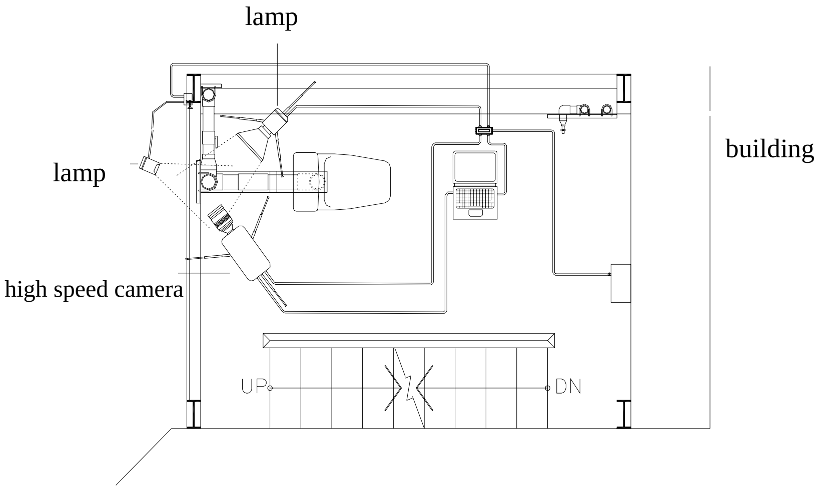


Fig.7 The plan of experimental device

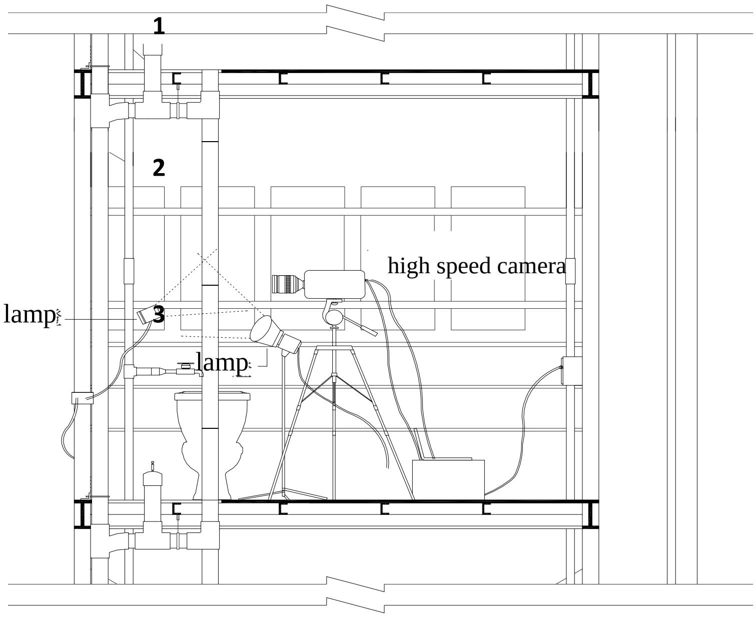


Fig.8 The elevation of experimental device

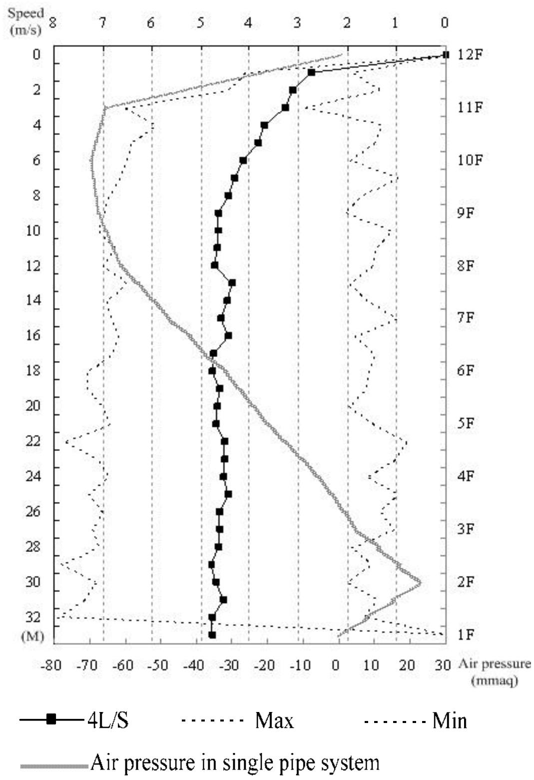


Fig. 9 Water velocity and air pressure in stack (4.0 l/s)

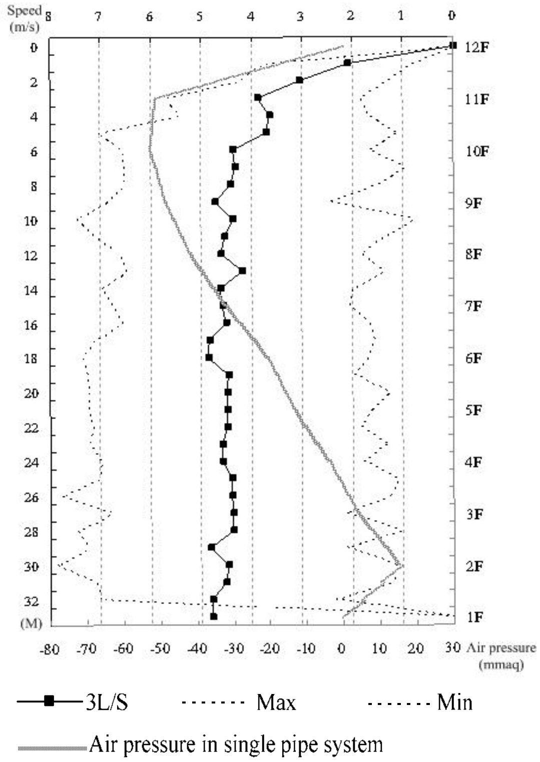


Fig. 10 Water velocity and air pressure in stack (3.0 l/s)

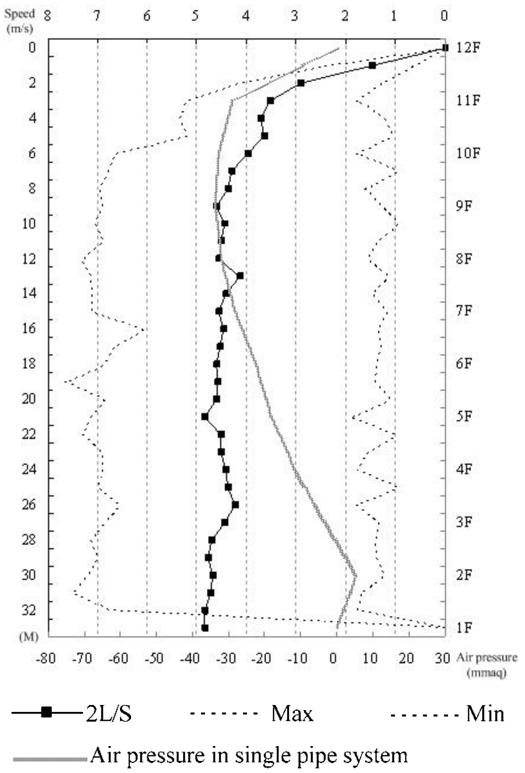


Fig. 10 Water velocity and air pressure in stack (2.0 l/s)

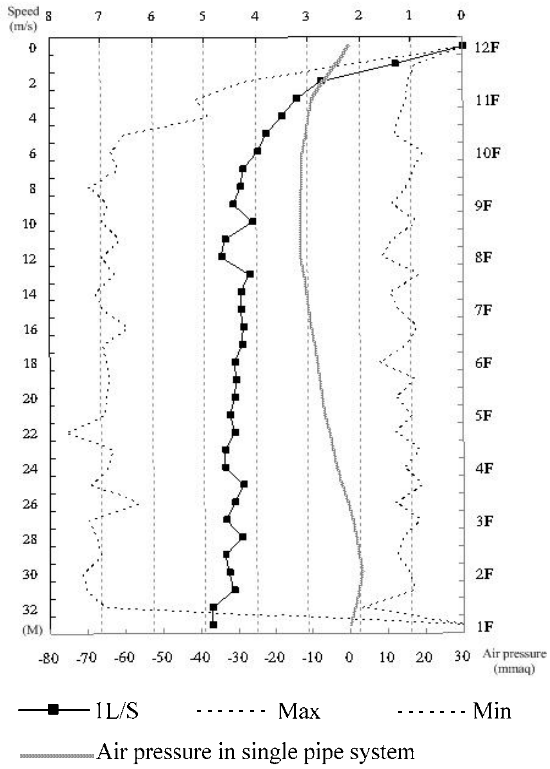


Fig. 10 Water velocity and air pressure in stack (1.0 l/s)

5. Conclusion

According to the importance of permit flow rate regulation, the terminal velocity in drainage stack was also seen as one of the crucial issues in building drainage researches. This paper introduces a prediction method with empirical approach for terminal velocity by theoretical study from air pressure distribution research. A new technology with digital high speed camera was used to validate the prediction of terminal velocity in drainage stack in this report. The theoretical study reveals the practical sense and the validation also approximately responses to the prediction results. However, the observation technology still remains some difficulties and the more precise verifications are needed to be conducted in the near future.

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7. Presentation of Author

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