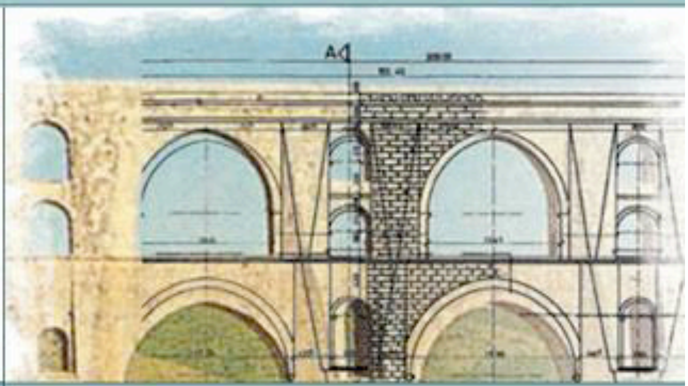
CIB W062 2003

Water Supply and Drainage for Buildings



Middle East Technical University
Department of Architecture

29th INTERNATIONAL SYMPOSIUM
SEPTEMBER 11-12 2003
Ankara TÜRKİYE

Within the general area of concern, 53 abstracts from 17 different countries were accepted for the presentation in oral and oral/poster sessions and for the publication.

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3	WATER QUALITY ANALYSIS IN THE DISTRIBUTION NETWORK – STUDY CASE, ***Romania***	Prof. Dr. Th. Mateescu Prof. Dr. C. D. Galatanu I. Toma Gh. Nechita
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CIB W62 2003
WATER SUPPLY AND DRAINAGE FOR BUILDINGS

ACROBAT READER

Proceedings of the 29th CIB W062 Symposium
11-12 September, Ankara, Turkey

Preface

Water is essential for human life. It is thus not surprising that the Commission W062 of the International Council for Research and Innovation in Building and Construction (CIB), a non profit organization, organizes nearly every year an international symposium on water supply and drainage of buildings.

At these symposia, researchers, developers, manufacturers, and building professionals find a forum for exchanging information on research projects, industrial developments, standardization, etc. In the past this meeting place was many times at the origin of industrial developments and collaborations between research institutes and industry.
By organizing this event, CIB W062 carries out the CIB objectives, i.e. to be:

- a relevant source of information concerning research and innovation worldwide in the field of building and construction;
- a reliable and effective access point to the global research community
- and a forum for achieving a meaningful exchange between the entire spectrum of building and construction interests and the research community.

The proceedings of the 29th symposium of CIB W062, organized in Ankara (Turkey) by the Middle East Technical University - Department of Architecture, on 11 and 12 September 2003, give an overview of the actual matters of concern in the field of water supply and drainage of buildings, as well in developing as in developed countries. These proceedings will certainly be a major source of interest to all those active in the related field.

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Existing and potential accessibility of private bathroom spaces in Türkiye

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Abstract

One of the most challenging issues that contemporary building design faces is to provide universal solutions that would fit the needs of people with disabilities. The reason that renders disabled population as handicapped is the fact that the built environment does not meet the requirements of this population. The way the built environment is shaped makes personal care necessary and hinders the independency to a great extent. The aim of this study is to explore the existing and potential accessibility of private bathroom spaces in Türkiye and to detect particular needs of Turkish users. A secondary aim is to explore the basic design decisions with profound effects on potential accessibility that may be helpful as a general guide for design and assessment. In this regard, an interview with 12 patients dismissed from *Turkish Armed Forces Rehabilitation Center* and a case study on 40 existing bathrooms in Ankara, Türkiye was carried out.

Keywords

Existing accessibility; potential accessibility; bathrooms in Türkiye

1 Introduction

The reason behind the persistence of accessibility issues in the agenda of design related fields is the fact that the built environment still does not totally meet the demands of the whole population. What renders some people handicapped is actually the way the built environment is designed. Designers are notorious for having a tendency to stick to the idea of ‘average person’ while considering the user requirements in a design project, so that they usually end up with designs that exploit the human beings’ quality of being adaptive.

A misconception about the accessibility is the narrow-minded approach that it is only a special aid for a small portion of the society handicapped as a result of illness or accident. However, as the lifetime expectancy is increasing and populations are getting old it is likely that everybody may experience a certain disability through his/her life. An accessible artifact, instead of a conventional design, would be beneficial for 90% of the population (Wylde, Baron-Robbins & Clark, 1994). Adoption of such an approach in architecture would provide users with buildings for lifetime.

In order to ensure that problems of accessibility are alleviated, several regulations and standards were prepared, and enforced with anti-discrimination laws all over the world (e.g. ADA, ANSI 117.1, etc.). In Turkey, the last decade witnessed two momentous steps taken forward to provide an accessible built environment. A fairly encompassing standard, titled *The Regulations for Arranging Buildings Inhabited by Disabled People*, was published in 1991 (Turkish Standards Association, 1991). The standard is enforced by *Turkish Town Development Law* (Anonymous, 1985) with an additional item passed in 1997:

> *With the aim of providing an accessible and a livable physical environment for the disabled people, all the development plans; urban, social, technical infrastructure; and buildings should comply with the related standards published by Turkish Standards Association.*
>
> (Item 48, Annex 1)

TS 9111 is significant for Türkiye since buildings that are flexible enough to be modified in order to obtain access for all are valuable in the sense that modification costs are cut and disabled people can live in environments they are familiar with (Hacıhasanoğlu & Hacıhasanoğlu, 2001). Moreover, under the guidance of TS 9111, the piecemeal modifications made arbitrarily may now be made more systematically.

2 Assessment of existing and potential accessibility in private bathroom spaces

The aim of this study is to explore the existing and potential accessibility (see sub-section 2.1) of private bathroom spaces in Türkiye and to detect particular needs of Turkish users. Another aim is to explore the basic design decisions with profound effects on potential accessibility that may be helpful as a general guide for design and assessment. In this regard, an interview with 12 patients dismissed from *Turkish Armed Forces Rehabilitation Center* and a case study on 40 existing bathrooms in Ankara was carried out.

2.1 Definition of the basic terms

Existing accessibility: The term is used to define the present conditions of a bathroom, regarding accessibility, including both the enclosure and the fixtures/equipment installed.

Potential accessibility (adaptability): The term is used to define the inherent capacity of a bathroom to be accessible with appropriate modifications regarding the type and location of fixtures to be used, without any changes in the enclosure and/or structural system.

2.2 Significance of bathroom design

The accessibility problems are best observed in relatively complex domestic systems that push users to their limits both physically and cognitively. Bathrooms, in this regard, can be considered as spaces where the interplay of building systems often leads to an incapacitating environment that calls for considerable flexibility on the users' side, even for the so-called able-bodied people (Wylde, Baron-Robbins & Clark, 1994). Furthermore, bathroom can be regarded as a 'problem area' both for people with disabilities and for designers (Raschko, 1991).

Besides the ergonomic concerns, the QoL (Quality of Life) of disabled people are greatly affected by the way a bathroom is configured. While discussing QoL many authors conclude that independency or personal control over life is regarded as a decisive factor (Hultsman, 1985; Brown, Bayer & MacFarlane, 1989; Fiddler, 1996). According to Brown (1997), "activities which involve meeting one's personal needs in a manner which is self-dependent fall within the domain of self-care and maintenance" (16). Therefore, bathroom design should be handled so that it adds to one's independency and control over life, since much of *self-care and maintenance* activities are carried out in a bathroom.

2.3 Problems specific to Turkish users

In order to elaborate on the accessibility related problems specific to Turkish users and to guide the case study that would be carried out, a structured interview with 12 patients dismissed from *Turkish Armed Forces Rehabilitation Center* was conducted. Respondents were chosen among the wheelchair-bound patients who returned to TAFRC for receiving physiotherapy or for periodical check-ups. Sampling was done according to experience levels of patients as wheelchair-bound bathroom users.

Respondents were asked questions for gathering information on:

- Home ownership
- The ranking of problem areas in their homes
- Problems faced in bathroom
    - Related with bathtub/shower
    - Related with WC
    - Related with washbasin
- Whether they made any modifications
    - Type of modifications made
    - special equipment bought
    - innovative solutions devised by the user
- Whether they were capable of carrying out tasks independently

Results indicated that only 2 of the respondents were homeowners. 8 of the interviewees responded that bathroom was the most troublesome area and 4 of them ranked kitchens as difficult-to-handle as bathrooms. 8 of the respondents reported that cleansing is the hardest task, whereas all agreed that using a WC is comparably hard. The problems reported about using a basin were usually associated with lack of shelf space. Only 4 of the respondents told that they made a modification in their bathrooms. In all the modifications bathtubs were removed. 2 of the respondents reported that they used the floor gullet for showering purposes after removing the bathtub. 10 of the respondents stated that they preferred shower instead of a bathtub; whereas 2 told that immersing the body into hot water alleviated pains associated with muscle and joint problems. None of the respondents reported purchase of special equipment. Only one of the respondents was living independently, whereas others stated that they need attendant assistance while cleansing and using the WC. Besides the formal interview, informal conversation revealed that the respondents usually associate accessibility problems with the lack of space and expensive-to-buy special equipment. . About half of the respondents complained about the washing machine taking up much space in the bathroom. As a final note, most of the subjects who do not own a home stated that they would look for a house with a spacious bathroom

Although the sample size was relatively small, interview highlighted two aspects specific to Turkish users. First of all, the problems associated with accommodating a washing machine in bathroom space is an issue totally overlooked in guidelines/standards prepared for Western users, and even in TS 9111. Another significant finding was the fact that most of the respondents reported they prefer to use shower for cleansing, which may be related both with Turkish culture and problems of using a bath tub.

2.4 Case study: An analysis of existing private bathroom spaces

2.4.1 Criteria of assessment

Accessibility is a hard to assess quality given the fact that people with disabilities show a wide variety (Raschko 1991). One design that perfectly answers the needs of one user may not be satisfactory or even may be inhibiting for another. Therefore, it is not possible to say that there is a single set of conventions that provides accessibility for all. However, there are common design principles that are helpful for the majority of user population. In this study well-established design considerations were chosen to assess the bathroom spaces for wheelchair-bound users who have considerable upper body strength.

It should be noted that assessment done in this study has limitations. First of all, the examination was restricted to planimetric configurations of the spaces with an aim obtaining results that will give feedback for new designs as well as retrofitting. Fixtures and sanitary equipment were evaluated regarding their basic dimensions, neglecting some of their qualities on their own. The findings of this study should be regarded as qualitative, considering the sampling method and the sample size.

12 criteria were selected from different sources (ANSI, 1980; TS 9111, 1991; Goldsmith, 1984; Raschko, 1991).

Table 1 – Criteria of assessment

Code	Criteria	Judgment	Source
C1	Side-hung doors should give a clear opening of 815 mm (see Fig. 1)	Measurement	TS 9111
C2	*In-opening doors to bathrooms and WCs are not recommended.*	Apparent	Goldsmith 1984, p. 181
C3	In-opening doors should provide adequate approach space regarding the sequence of door operation.	Comparison with template	Derived from ANSI 117.1
C4	An unobstructed circular space with a diameter of 1524 mm should be provided in bathrooms for maneuverability.	Comparison with template	Raschko 1991
C5	There should be minimum 1150(A) x 1050(B) mm of unobstructed area for a washbasin.	Comparison with template	Goldsmith 1984
C6	There should be minimum 1800(A) x 1200(B) and 1300(A) x 1200(B) mm of unobstructed area for a bathtub and for a shower compartment respectively.	Comparison with template	Goldsmith 1984
C7	For a convenient lateral transfer* to a WC, there should be minimum 1065 and 455 mm clearance on each side (A, B) of the fixture.	Comparison with template	ANSI 117.1
C8	For a convenient diagonal transfer to a WC, there should be minimum 455 mm clearance on each side (A, B), and 1500 mm in front (C) of the fixture.	Comparison with template	ANSI 117.1
C9	For a convenient oblique transfer to a WC, there should be minimum 950 mm clearance on one side (A or B), and 1500 mm in front (C) of the fixture.	Comparison with template	Goldsmith 1984
C10	For a convenient back transfer to a WC, there should be minimum 305 mm clearance on each side (A, B), and 1600 mm in front (C) of the fixture.	Comparison with template	Goldsmith 1984
C11	For a convenient front transfer to a WC, there should be minimum 305 mm clearance on each side (A, B), and 1900 mm in front (C) of the fixture.	Comparison with template	Goldsmith 1984
C12	For a convenient assisted transfer to a WC, there should be minimum 500 mm clearance on one side (A or B), and 2000 mm in front (C) of the fixture.	Comparison with template	Goldsmith 1984

* For more information on methods of transfer to a WC refer to Goldsmith and ANSI 117.1.

It may be argued, given the fact that there are 6 criteria about WCs, there is an overemphasis on WC compared to other fixtures. Nevertheless, WCs can be regarded as the most troublesome fixtures for wheelchair-bounds given their relatively small landing area. In addition, sequence of operation of a WC with a wheelchair demands a considerable space; therefore due attention should be paid while designing or assessing a bathroom.

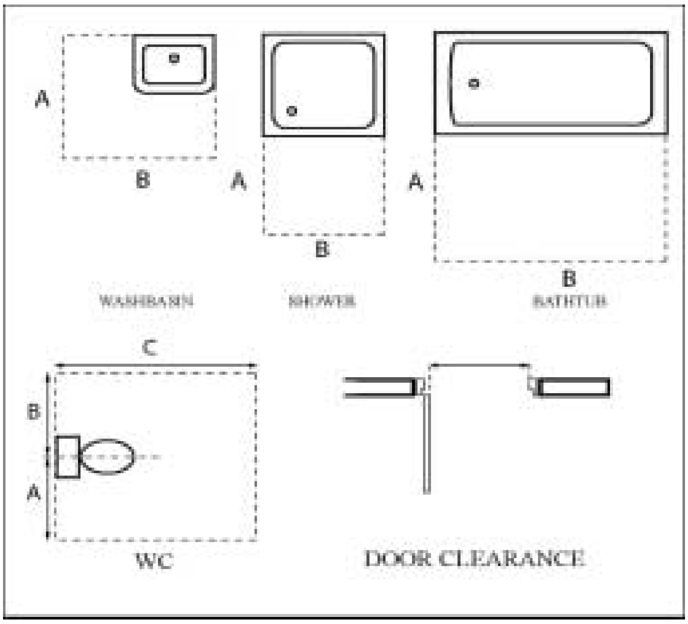

Figure 1 – Basic dimensions of fixtures

2.4.2 Sampling

40 private bathroom spaces in Ankara were selected in order to be analyzed and assessed according to accessibility criteria defined for this study (see Table 1). Accommodation of a WC, at least one basin, and a cleansing compartment were regarded as requirements to be considered as a bathroom. Sampling was done in order to cover a diversity of floor areas (see Figure 1) since accessibility of bathroom space is closely related with clear spaces for maneuverability and approach to fixtures.

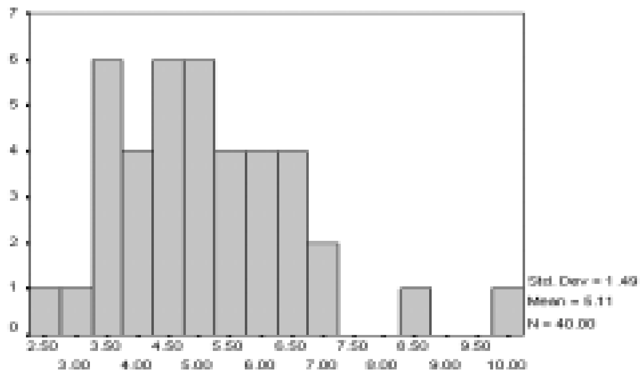

Figure 2 - Distribution of samples according to floor area

2.4.3 Method of assessment

In order to assess the samples chosen according to criteria, 1/20 scale plans were drawn. For each sample, floor areas and aspect ratios were calculated and then each was evaluated utilizing the methods of judgment given in Table 1. Since it is virtually impossible to rank the indispensability of the criteria, compliance with any of them resulted in equal scores. It should be noted that receiving a full score may not eventually mean that the sample is totally accessible. Therefore scores should be taken as indicators of relative accessibility.

In the second step, each sample was studied to find out whether it was possible to improve the bathrooms in order to obtain more convenient spaces in terms of accessibility. For the evaluation of potential accessibility, same criteria and scoring method was used.

2.4.4 Results

After the results for assessment of existing accessibility were gathered it was found that none of the samples complied with C1 and C2 (see Table 1). The highest score, that is 8 out of 12, was received by 1 of the samples (S2) (see Table 2), whereas 4 samples were not successful in meeting any of the criteria (S5, S26, S33, S35). If each criterion is examined individually, it may be concluded that washbasins (C5) in 33 of the cases were somehow properly located. On the other hand, cleansing units proved to be a problem area for 35 of the cases.

Table 2 - Summary of results for each criterion

Criterion	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
EA[1] Score	0	0	14	8	33	5	9	18	7	25	13	11
PA[2] Score	NA	NA	23	29	35	29	26	34	28	36	31	26
PA-EA	NA	NA	9	21	2	24	17	16	21	11	18	15

[1]EA: Existing accessibility; [2]PA: Potential accessibility

Table 3 - Summary of results for each case

Case	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Area	4.76	6.25	3.11	3.36	2.32	8.48	5.67	6.93	4.2	10.02
Asp. rt.	0.6	1	0.73	0.75	0.84	0.72	0.92	0.88	0.68	0.53
EA[1] Score	2	8	3	2	0	3	6	6	3	7
PA[2] Score	9	10	3	3	0	10	10	9	5	10
PA-EA	7	2	0	1	0	7	4	3	2	3
Case	**S11**	**S12**	**S13**	**S14**	**S15**	**S16**	**S17**	**S18**	**S19**	**S20**
Area	4.77	6.04	4.66	5.81	4.33	5.2	5.7	5.9	5.3	5.18
Asp. rt.	0.67	1	0.93	0.63	0.76	0.62	0.53	0.5	0.87	0.7
EA[1] Score	2	5	4	2	5	5	3	3	4	3
PA[2] Score	10	9	9	9	6	10	3	9	10	3
PA-EA	8	4	5	7	1	5	0	6	6	0
Case	**S21**	**S22**	**S23**	**S24**	**S25**	**S26**	**S27**	**S28**	**S29**	**S30**
Area	5.2	6.7	6.5	6.2	6.4	4.5	4.57	3.68	3.72	5.48
Asp. rt.	0.83	0.39	0.41	0.63	0.63	0.64	0.96	0.69	0.6	0.96
EA[1] Score	6	4	4	7	6	0	5	1	1	5
PA[2] Score	10	10	10	9	10	10	9	1	7	10
PA-EA	4	6	6	2	4	10	4	0	6	5
Case	**S31**	**S32**	**S33**	**S34**	**S35**	**S36**	**S37**	**S38**	**S39**	**S40**
Area	6.75	3.6	3.38	4.5	3.54	4.31	4.2	4.95	3.96	4.25
Asp. rt.	0.8	0.45	0.56	0.72	0.34	0.78	0.81	0.65	0.81	0.68
EA[1] Score	7	1	0	4	0	5	3	2	4	2
PA[2] Score	9	3	0	8	0	5	7	10	6	8
PA-EA	2	2	0	4	0	0	4	8	2	6

[1]EA: Existing accessibility; [2]PA: Potential accessibility

Criteria about door clearance and swing (C1, C2) were only included in the assessment of existing accessibility since replacement of the existing door set would solve the problems associated. After each sample was studied individually, a dramatic increase in accessibility was observed. A glance at the *PA-EA* scores in Table 2 will reveal that the sharpest increase was observed in accessibility of cleansing units (C6). However, it should be noted that in 21 cases replacement of the existing cleansing unit with a roll-in shower was recommended (see Table 4).

Table 4 - Nature and quantity of modifications recommended

Modification	# of cases
Fixtures were replaced with appropriate ones	25
Existing cleansing unit was replaced with a roll-in shower.	21
Washbasin was replaced with an appropriate one.	16
Fixtures were moved to appropriate locations.	32
Accessibility could not be improved without improving the dimensions of the enclosure	8

Only in 1 of the cases (C6) a glass partition enclosing WC and bathtub was eliminated. In 16 cases, desktop washbasins that did not provide room for close approach were replaced with appropriate ones.

2.5 Discussion

One of the most important implications of the study was the fact that configuration of the bathroom space is the most important factor regarding accessibility. A comparison of Figure 3 and Figure 4 illustrates that floor area was not a determining factor for accessibility in the bathrooms larger than 4.5 m². It is evident that if space is utilized well and dimensional relationships are studied, even a 4.5 m² bathroom can be considerably accessible. Although there seems to be a threshold around 4-4.5 m², there are two exceptional cases (S20, S17) worth examining (see Figure 4).

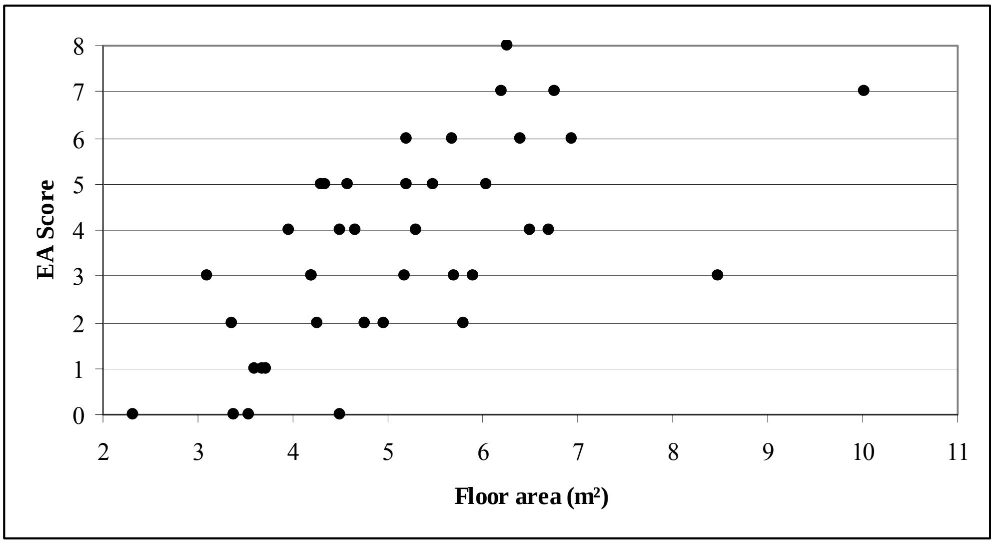

Figure 3 - EA Score-Floor area

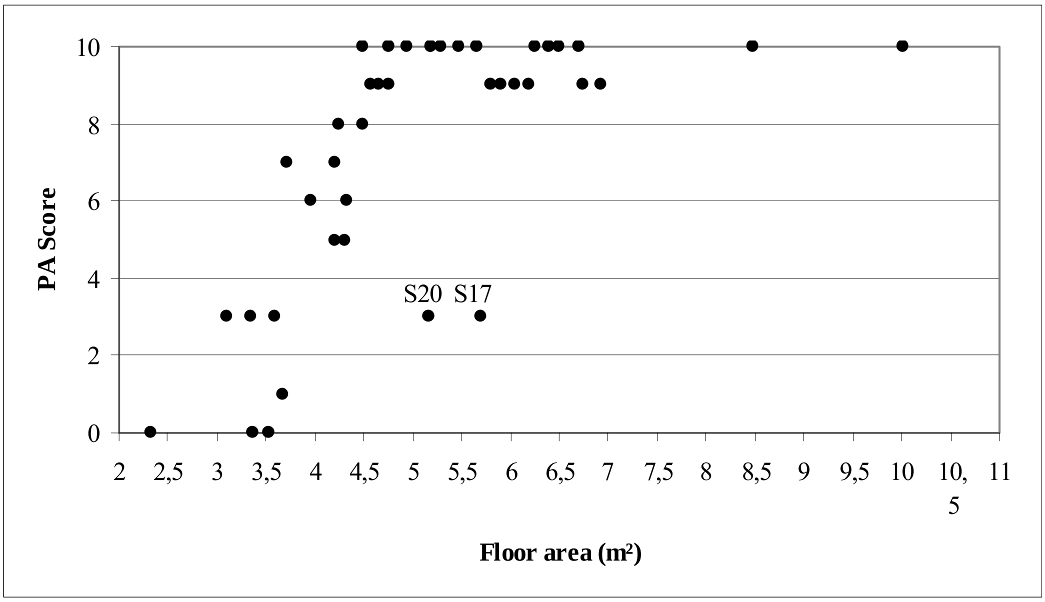

Figure 4 - PA Score-Floor area

Although both cases are beyond the threshold, PA scores are relatively low. Unlike many other bathrooms examined in this study, partitions and recesses within the enclosures inhibit maneuverability and any improvement is almost impossible (see Figure 5).

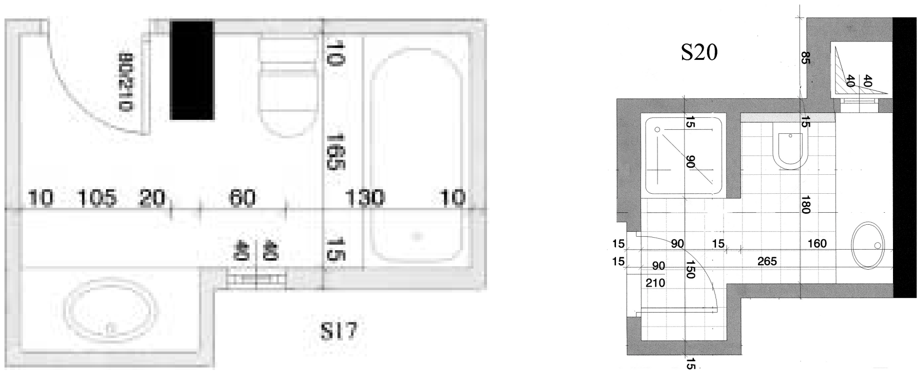

Figure 5 – Examples that show the significance of envelopment

The examples above illustrate that when the floor area is limited, envelopment efficiency (floor area/perimeter length) may be an important parameter of accessibility. A similar relationship may be observed between planimetric aspect ratio and accessibility.

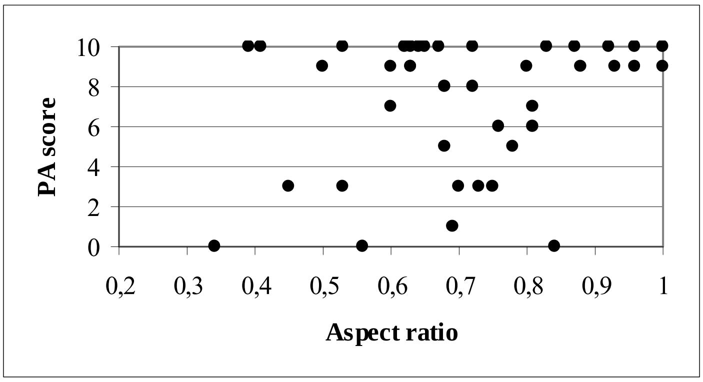

Figure 6 – PE Score – aspect ratio

Figure 6 indicates that almost square plans with a high aspect ratio (>0.85) were sucessful in satisfying at least 9 out of 10 criteria after the modifications. However, given there are many cases with a high PE score around 0.6-0.7, aspect ratio may only be a rough parameter for predicting accessibility at first glance.

Although the sample is not representative of whole Turkish bathrooms, high PA scores indicate that Turkish bathrooms have the required characteristics to provide accessibility.

The mismatches that may have effects on the suitability of guidelines and standards for Turkish users discussed before were verified in the cases. Most of the Turkish houses do not have a laundry and therefore put their washing machines in their bathrooms. In a restricted space even a washing machine can impede access to certain equipment in the bathroom. This is an issue to be considered while preparing standards and guidelines. A positive remark about Turkish bathrooms is that most of them accommodate a floor gullet that may be easily modified to a roll-in shower. A defect detected during the study which is in line with the author's personal experience is the practice of 'snap fitting' the bathtub at one side of the bathroom. This way, width of the bathtub (usually around 1700 mm) defines the width of the bathroom, which usually makes it impossible to have a clear space for 180º turn with a wheelchair (C4). Actually, one should be very critical and should take restrictions of floor area into consideration before devising a bathtub as a cleansing unit. Author's experience indicates that bathtubs in Türkiye are usually treated as shower units since streaming water is preferred over stagnant water in Turkish bathing culture. Results of the present study show that replacing a bathtub with a roll-in shower adds much to the accessibility of a bathroom, by both eliminating the difficulties in getting in and out of the bathtub and by freeing valuable space for maneuvering. It was interesting to find out that, most probably because of space restrictions, 2 of the bathrooms utilized (S28, S29) roll-in showers instead of shower compartments or bathtubs.

3 Conclusion

A major conclusion drawn is how design decisions made while designing a bathroom have serious repercussions on the adaptation process.
For instance a fixture positioned in order to have a symmetrical plan may consequently inhibit access and reinstallation may be required. That is not to say private housings should be built solely to meet the demands of disabled people, which is a thing that most of the builders are reluctant to do (Schilling, Combs & Schwab, 1982). Furthermore, as discussed before, each member of the society has quite diverse needs. However, designs should be made considering the potential accessibility of spaces, which would eventually reduce the cost of modifications as well as increasing the chances of meeting the specific demands of the users. Therefore, the question should be how to design buildings which have a potential of accessibility, rather than how to adapt existing buildings. In order to obtain much more

Since enforcement and investigation of compliance to standards seems relatively insufficient in Türkiye, a practical means of assessing potential accessibility with reference to basic parameters such as floor area, aspect ratio, and envelopment efficiency may be helpful for designers finding it difficult or even irritating to use detailed guidelines and standards. Experimental studies for the development of such a tool may be prolific.
Despite all its limitations, this study has raised more questions that it answered. The qualitative findings of this study may guide further inquires to gain insight on conditions and appropriate ways of achieving an accessible built environment in Türkiye.

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5 Presentation of the author

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Investigation And Analysis Of Stack Flows And Pressures In Indian Bamboo Soil And Waste Pipe Systems

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Abstract:

A lot has been postulated and tested with a view to improving the efficiency of water supply and Drainage for Buildings. Different types of pipes have been used in installations, with varying synoptic capabilities and qualities. The dynamic nature of science makes it possible for more investigations to be made in this area. The latest Japanese developments are in the areas of using Indian bamboos for domestic water supplies. The attendant consequences and / or prospects need to be x-rayed. This paper examines the stack flows and pressures in Bamboo soil and waste pipe systems, considering basically (a) Variation of flow parameters (b) Traverse across stack flows at different peak flow rates and angles (c) Discharge from specified distances (e) Effects of pressure offsets in different stacks. (f) Air flow rates against pressure gradients for different water flow rates in stacks of given diameters. (g) Variation of branch pressure drop factor with stack and branch flows for different diameters of stacks and branches.
The paper considers iterative procedures and computer programmes, resulting in specific computations for maximum suctions in Bamboo pipes and fittings.
In conclusion, the paper advocates for an extensive use of Bamboo in soil and waste pipe systems, with some specified modifications in the state-of-the-art technology .

keywords: Traverse, Discharge, Flow-rate, Pressure, Stack.

Introduction

The provision of Building services gulps a huge chunk of money as compared to the other components of the buildings. In public and semi-public buildings like hospitals, schools etc, the cost of providing these services could be about 50 percent of the total construction cost of the building and 20 – 30% in less complex structures (Wise,A, 1979). Building services,generally include air-conditioning, lifts or elevators, heating, sanitary, water, waste services (I HVE Guide). Water installations, handling of solid waste, drainage, ventilation and the provision of sanitary accommodation constitute the major aspects in Building service Technology. Most buildings have water, sanitary, drainage and solid waste facilities. Lavatories with spray taps and good sanitary accommodation, in offices create an excellent healthy working environment (Crisp, J and Sobolev, A 1989). Water is needed and constantly used in Buildings (Thackray J.E. et al 1978) .Normally, domestic water installations and quality are governed by some water acts and byelaws. This ensures that waste and unhealthy consumption are prevented. Following the British standards institution's reports, practice of domestic water supply and drainage, different types of pipes and fittings have been introduced. These include, among others, copper tubes, clay drain and sewer pipes; cast copper alloy pipe fittings; cast iron spigot and socket soil, waste and ventilating pipes (sand cast and spun); Asbestos-cement pipes; Drawn lead traps, steel pipes and fittings; concrete cylindrical pipes and fittings; lead and alloy pipes; centrifugally cast (spun) iron pressure pipes; polythene pipes, pitch-impregnated fibre pipes and fittings; unplasticized Pvc pipes',stainless steel tubes, carbon couplings, propylene co-polymer pressure pipes; Grey and ductile iron pipes; polypropylene waste pipes and fittings; Aluminium pipes and fittings; Galvanized mild steel pipes and fittings. (BSI).Irrespective of the type of pipe or stack, there are general functional requirements of pipes. These include;

(a) Ensuring adequate flow of waste.

There are typical flow patterns and rates in waste pipes. There is a peak flow at the beginning and a reduced rate at the end of a discharge. However, there are characteristic or optimal flow rates, expected of waste pipes, conforming to some British standards. Every pipe should, therefore, meet such flow rate requirements.

(b) Excluding smells and foul air.

Every soil or waste pipe installation should be able to exclude smells and foul air, though possession of good fittings and appliances with excellent water seal depths, considering possible loss due to pressure differences and evaporation.

(c) **Noise limitation**.

Every soil or waste pipe should be able to accommodate and limit noise as a result of turbulent discharges.

(d) **Leak proof**

The soil or waste pipes are expected to be leak proof, before and in service to avoid losses of waste and pressure.

(e) **Free-flowing**.

The pipe work should allow for a free-flow of effluents all through its service period.

(f) **Durability**

Every pipe should be durable and serviceable.

The entire network, including fittings should also be durable.

(g) **Traceability and Accessibility for maintenance.**

Pipes should be readily traceable and accessible for cleaning and general maintenance.

(h) Replaceability:

Every pipe and its network should be easily replaceable.

(i) **Testability:**

Every pipe and its network should be able to be tested, using standard techniques.

The high cost of most of these existing types of pipes, has given vent to further scientific investigations into cheaper, efficient and more durable alternatives. An example of this venture is the initiation, in 1995 of the use of Indian Bamboo pipes for domestic water supply by some Japanese scientists. This paper considers the application of Indian Bamboos as soil and waste pipes. Generally, in the design of soil and waste pipe installations, there are two major systems, one of which is usually selected and used. The most common system in the use of various branches, horizontally aligned. These are normally short, providing sanitary services for each floor but emptying into a vertically placed stack which in turn discharges the soil and waste water to the subsurface drains. (Wise A, 1979). There is also a multi-stack system which is usually employed in complex structures like hospital, public schools, blocks of flats etc irrespective of the type of pipe or stack. There are generally functional requirements of pipes (Wise A, 1979).

In contract, most hospitals, schools and public offices could be planned with a good horizontal spread, arranged in "Island" on every floor with extensive horizontal piping emptying into a vertical stack. Again, as a matter of practice, cast iron has been widely used for (i) soil stacks, (ii) major vent stack (iii) combined soil and waste stacks.

PVC pipes and fittings of low wall thickness are also widely used, but not where hot water discharges exist so that local softening does not occur. PVC pipes with a considerable wall thickness could be used without failure in hot water systems. Mild steel, pitch fibre, copper, galvanized mild steel, brass (fittings), glass are typical soil and waste pipe materials.

Conventionally, a good knowledge of the pressures, which develop in partially filled vertical pipes, is necessary in functional design of soil and waste pipe systems. Generally also, the design should be such that is open at the top, to allow escape of foul air. The network should be able to discharge the continuation of trapped air and waste, effectively, into the sewers. Mathematically, the ratio of trapped air to water flow may be as large as 100: 1 with the actual air flow between 10 and 200 l/s. The airflow and pressures depend on the drag between the water and air and on the frictional resistance of the components of the system. It is essential to determine the relationship for the estimation of the frictional force. In full pipe flow, the frictional factor, Reynolds number, diameter of pipe and roughness of pipe are united by the Colebrook-white equation for smooth turbulent and rough turbulent conditions and for the transition of the two.

$$\frac{1}{\sqrt{\lambda}} = -2\log_{10}\left[\frac{k}{3.7D} + \frac{2.51}{R_e\sqrt{\lambda}}\right] \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where λ = friction factor, k = pipe roughness
D = pipe diameter and Re = Reynold's numbers of the fluid.

Under normal conditions, for full pipe flow, $\lambda = \dfrac{8\zeta_o}{pv^2}$.

Where ζ_o = boundary shear stress
p = fluid density
v= fluid velocity

Substituting the value of λ in equation (1),

$$\sqrt{\frac{pv2}{8\zeta_o}} = -2\log_{10}\left(\frac{k}{3.7D} + \frac{2.51}{R_e}\sqrt{\frac{pv^2}{8\zeta_o}}\right) \quad \text{.......... (2)}$$

Again, equation – (1) can be applied to conditions with a free surface if the hydraulic radius R_H, defined as the ratio of cross-sectional area of flow to wetted perimeter, replaces the pipe diameter.
Therefore, for full pipe flow,

$$R_H = \frac{\pi D^2/4}{\pi D} = \frac{D}{4} \quad \text{.................. (3)}$$

Substituting Re with VD/v and D in terms of RH in equation – (2)

$$\sqrt{\frac{pV^2}{8\zeta_o}} = -2\log_{10}\left(\frac{K}{14.8R_H} + \frac{2.51V}{4VR_H}\sqrt{\frac{pV^2}{8\zeta_o}}\right) \quad \text{..........(4)}$$

Where v = kinematic viscosity of the fluid.

Considering annular flow in a vertical drainage stack, a force balance equating frictional force to gravitational force on a length of the annulus.
ΔL, of thickness, t and moving at terminal velocity V, gives

$$\pi D\zeta_o \Delta L = p\pi Dt \Delta Lg$$

ie $\zeta_o = ptg$ .... (5)

Here, the shear stress between the water and the air core ζ; is neglected since it can be shown to be small in comparison with ζ_o.

Also, by continuity $Q_w = \pi DtV$ and

$$R_H = \frac{\pi Dt}{\pi D} = t \quad \text{...................(6)}$$

Substituting for V, for ζ_o and for R_H in equation (4) and rearranging,

$$\frac{Q_w}{4\pi Dt}\sqrt{\frac{1}{2gt}} = -\log_{10}\left(\frac{K}{14.8t} + \frac{0.31375v}{t}\sqrt{\frac{1}{2gt}}\right) \quad \text{.....(7)}$$

This equation could be solved iteratively for t. Values of the annular thickness, t, could be predicted in this way.

Generally, the maximum suctions and pressures that arise in discharge stacks may be calculated, using the following simplified mathematical expression:

$$h_s = 0.974\frac{Q^2_a}{D4}\left(1.5 + \Sigma k \text{ bends} + \frac{fl}{D} + \Sigma k \text{ inlets}\right) N/m^2$$

The factor in the brackets on the right hand side represent the various pressure loss coefficients of the kinds described, whilst Q_a is the air flow and D the stack diameter. For design purposes, the computed maximum suction for any given installation is compared with the peak allowable of 375N /m^2.

Methodology

Natural lengths of Indian Bamboos were cut into short pieces in accordance with their natural inter-nodal lengths (see figures 4,5and 6).
These short lengths or pieces were well machined by coring through their internal linings making them very smooth and shaving off the rough backs.
Every piece was later threaded at both ends (i.e. internally and externally).
(see figure7) at the end of the machining exercise, the pieces were coupled end-to-end so as to create desired continuous lengths of pipes (see figure8) different diameters were used to match some standard fittings and couplings. These Bamboo stacks were then subjected to the same flow conditions as their other counterparts. These flows were then analyzed in terms of pressures and their annular thicknesses calculated for various conditions of flow. Also, a composite probe was used to traverse a stack carrying various rates of water flow (Pink B.J 1993).

Result and Analysis

In the composite probe, there was a reduction of electrical resistance across the tip of the probe, indicating the presence of water at the tip. (see Fig. 9)

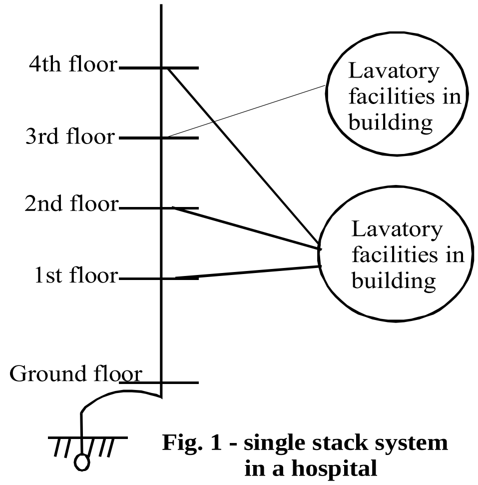


Fig. 1 - single stack system in a hospital

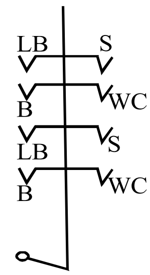


Fig. 2 - single stack system (Block of flats)

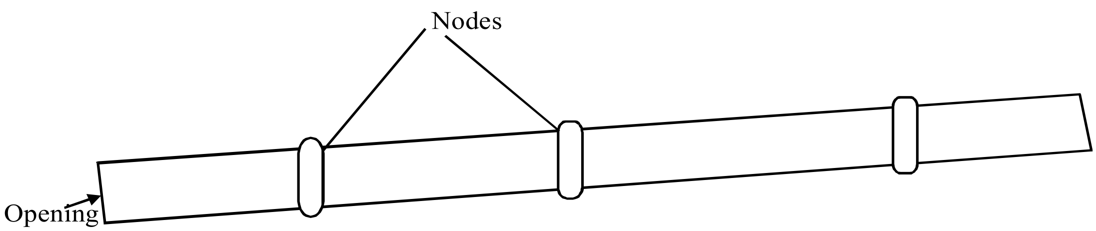


Fig. 3 - A Short Length Of Bamboo

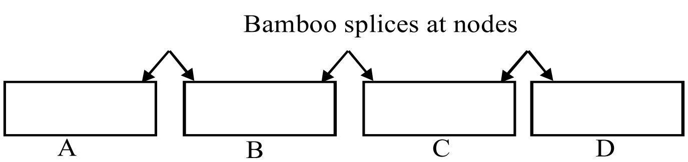


Fig. 4 - Cutting of bamboo

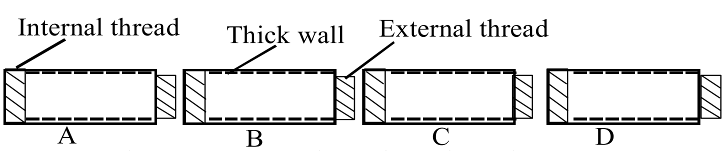


Fig. 5 Cross - Section Of Bamboo Pieces

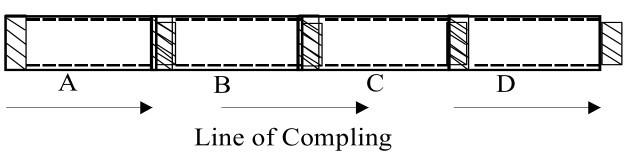


Fig. 6: Coupling of bamboo pieces

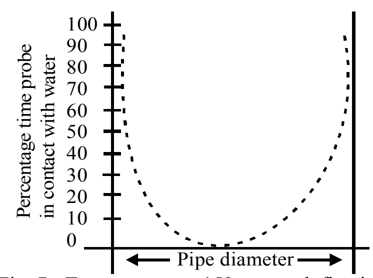
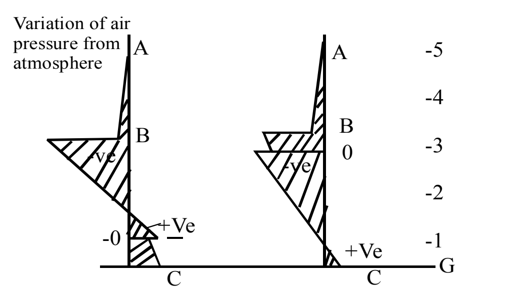


Fig. 7 - Traverse across 150mm stack flowing at 10l/s; discharge from 100m above the traverse.



(a) Low stack offset (b) High stack offset

Fig. 8 - The effect of an offset and pressure variation in a stack

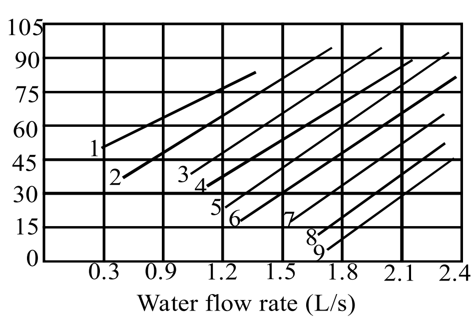


Fig. (9) - Graph of Air flow rate verses water flow rate

The variation of flow parameters with distance showed acceptable results with predictable standard, standard deviations. (see table 1).

Table 1: Variation Of Flow Parameter In Bamboo Pipes With Distance For The Appliance

	Discharge close to measuring device		Discharge into 10m of 100mm stack			Discharge into 10m 150mm stack		
	Peak flow rate L/s	Peak flow rate over 1 second duration L/s	Time of discharge for Q_w > 0.1 L/s (seconds)	Peak flow rate L/s	Peak flow rate over 1 second duration (L/s)	Time of discharge for Q_w > 0.1 (seconds)	Peak flow rate L/s	Peak flow over 1 second duration (L/s)	Time of discharge for Q_w > 0.1 L/s (second)
Low level wash down wc ‘p’ trap, 9.1 litre cistern	1.2	1.2	7	1.1	1.1	8	1.1	1.1	1.1
Wash basin ‘p’ trap 6 litres discharged	0.5	0.5	9	0.4	0.4	10	0.5	0.5	10
Sink ‘p’ trap, 11 litres discharged	0.8	0.8	12	0.7	0.7	14	0.9	0.9	13

Methods recommended by Swaffield and wakelin (1996) were adopted for most parts of this analysis. It was observed that the top of the stack maintained the atmospheric pressure, while pressure decreased down the dry part of the stack AB (where suction existed). At the point of discharge ,B, there was a marked drop in air pressure from B to C within the annular flow and at C, it was still above the atmospheric pressure. This was however subject to the resistance from the bend and drain respectively (see Fig. 10).

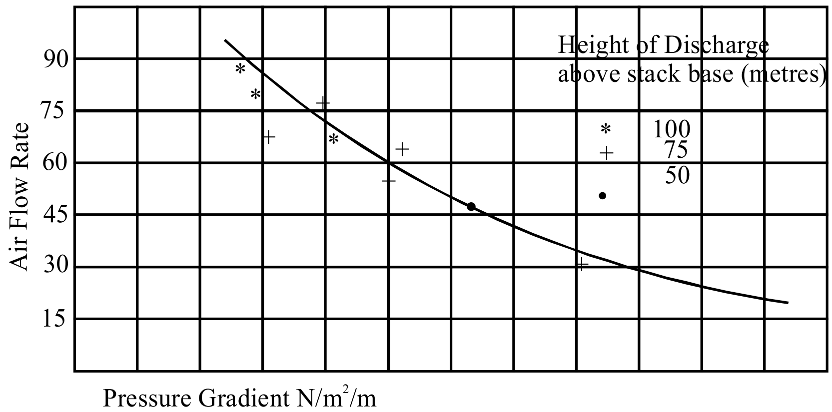


Fig. 10- Volumetric Flow Rate Of Air Versus Pressure Gradient

Considering the rates of air and water flows in these pipes, it was observed that the flows conformed to the following equation;
Q_a = f (Q_w, D, K, dp/dL), where Q_a = volumetric flow rate of air, Q_w=volumetric flow rate of water, D=stack diameter of pipe,K= pipe roughness, dp/dL=pressure gradient.

Conclusion

It is advisable to inculcate the use of machined bamboo pipes for domestic and industrial sanitary installations especially in soil and waste pipe systems.

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Water Quality Analysis In The Distribution Network – Study Case

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Abstract

To maintaining the microbiological quality (and also the odorous and taste) of the water distributed for the people consumption, it is necessary the continuing monitoring and the adoption of the methods and scenario for proper correction, in function by the necessities.
The main indicator, relevant for the global characterization of the water quality in the distribution pipes, is the "remanent chlorine".
The complexity of the biological, physicochemical and hydraulically phenomenon, impose the development of the adequate operational methods, adapted to the particularities of the analyzed water distribution system.
For the purpose of grounding of some mathematical models for the quality management of the distributed water at that are theorize the specifics qualities of the system.
The paper presents the conclusions of a case study performed in the distribution networks afferent to a urbane ensemble from Iaşi municipal town, România.

Keywords

Water quality, distribution network, remanent chlorine, specific factors for chlorine consumption, global coefficient for chlorine consumption, network's print.

1 Introduction

Drinking water, once produced (with strict respect of regulations in force), is pumped towards a network which shelters numerous factors that may cause the alteration of water's intrinsic quality. Complex phenomena and water's quality decreasing lead then to health hazards or to organoleptic alterations, directly perceived by consumers. Hence, it is for us possible to speak about a complex reactor located down streams the water plant.

These reactions are specific to the network or are correlated to the inter-actions between hydraulic conditions and the quality of water injected in the input section.

The main goal for the management of water quality in distribution systems is to keep residual chlorine concentration within prescribed limits. Romanian standards, for free residual chlorine, are listing admissible concentrations in the range of 0.25-0.50 mg.l.

Practically, the chlorine dissolved in distributed flows reacts with organic compounds present in the water and, by the other hand, with the biological film formed on the main's walls. This phenomenon is strongly influenced by the nature and the volumes of matter deposed on internal walls of mains. Hence, this matter defines the network's "print", factor which is specifically to each water system. Consumption intensity is directly proportional with the main's hydraulic radius and with water's stagnation time within networks and storage tanks.

The subject of the study is the analysis of the content diminution in time of the residual chlorine in a isolated distribution system for the establishing of the specific “stamp” which is necessary for the elaboration of the qualitative model.

2 Theoretical aspects

Chlorine consumption in reactions which occur in fluid's mass and in the vicinity of the main's walls can be expressed by a relation such as:

$$\frac{dC}{dt} = -\lambda_a C - \frac{\lambda_p}{R}(C - C_p) \qquad [1]$$

in which the first term characterizes the water consumption and the second one, the biological film.
Also, C and Cp represent the free chlorine concentrations and λ_a and λ_p are specific factors for chlorine consumption in water, and respectively within the adjacent film, whilst R is the main's hydraulic radius, equivalent with the ratio of the volume and the area implied in the consumption/kinetic reactions.

By the other hand the mass balance corresponding to residual chlorine consumption within the adjacent deposits can be defined by:

$$\lambda_p (C - C_b) = \lambda_b C_b \qquad [2]$$

in which λ_b is the chlorine consumption factor within the biological film.

After mathematical development it results:

$$C_b = C \frac{\lambda_p}{\lambda_p + \lambda_b} \qquad [3]$$

and after making the substitution in [1] it results the next relation:

$$\frac{dC}{dt} = -C\left[1 + \frac{\lambda_p \cdot \lambda_b}{\lambda_p + \lambda_b} \cdot \frac{1}{R}\right] \qquad [4]$$

It can be noticed that the term within brackets comprises exclusively factors which are determined by local conditions and therefore it can be defined as a "global coefficient for chlorine consumption" which determines the network's "print":

$$\Lambda = 1 + \frac{\lambda_p \cdot \lambda_b}{\lambda_p + \lambda_b} \cdot \frac{1}{R} \qquad [5]$$

The differential equation becomes:

$$\frac{dC}{dt} = -\Lambda C \qquad [6]$$

Or, integrated in time:

$$C = C_o \cdot e^{-\Lambda\tau} \qquad [7]$$

If this relation is implemented to concrete conditions, it is therefore possible to characterize networks in terms of residual chlorine consumption's dynamics, respectively defining the network's specific "print", needed for drafting a qualitative model.

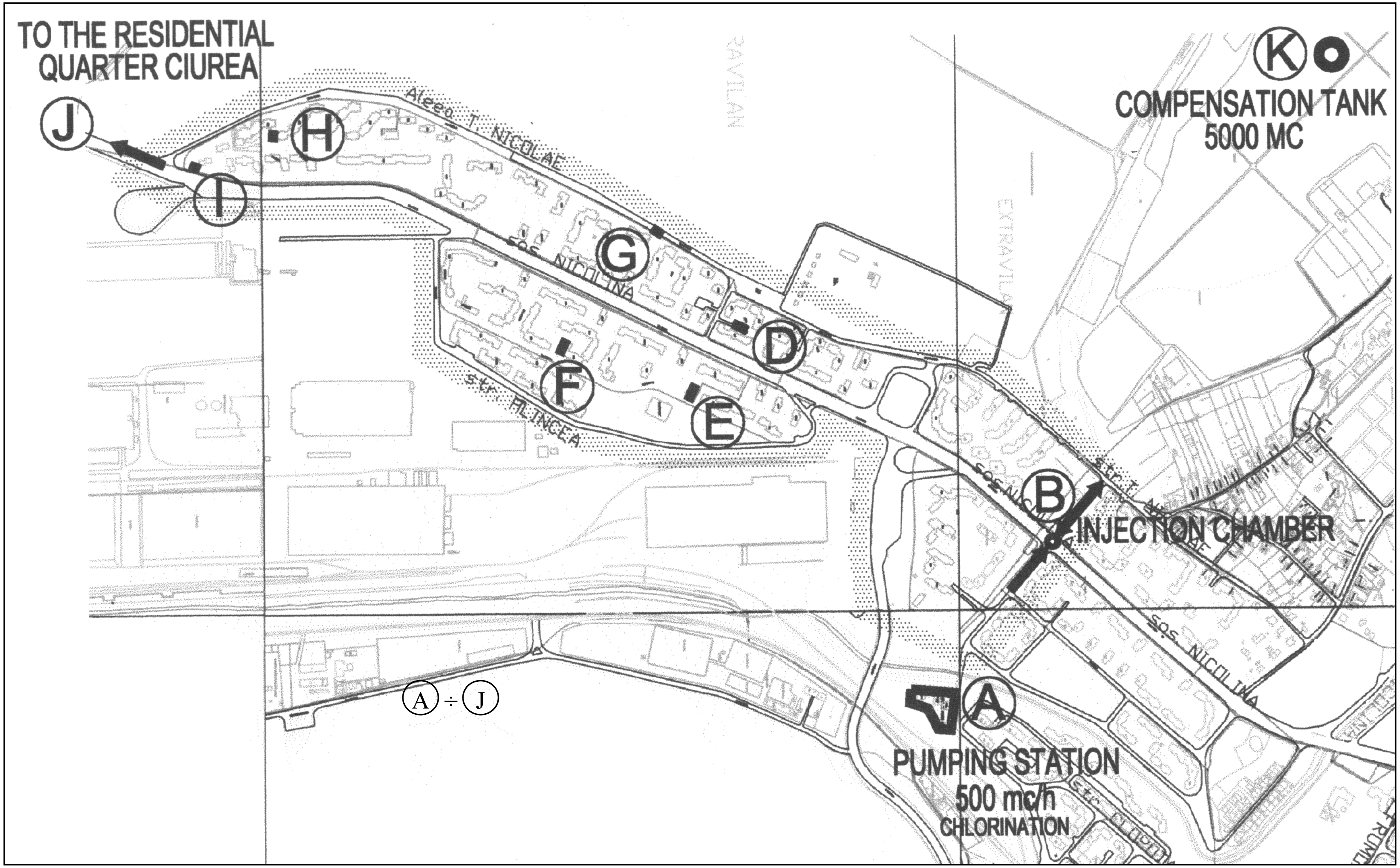
3 Description of the system

The analyzed system supplies a housing district having cca. 15.000 inhabitants dwelling in blocks of flats (ground floor + 4 to 10 storeys), build on an extension of Iasi City's urban area (figure 1).

Supply of cold and hot water is provided in a centralized manner through nine intermediary technical stations which are connected to the principal distribution main. The hourly maximal flow of 600 cubic m/h is took from the urban mains. The main network has a total length of 7,260 m with the next structure (in terms of diameters):

Dn [mm]	100	150	200	300	400	600
L [m]	1000	2500	50	150	1000+2500	60

Normal operating of this supply is carried through a pumping station able to deliver 500 cubic m/h. The compensation tank has a volume of 5000 cubic meters and is located at cca. 400 m away from the network injection device. In order to ensure consumers' sanitary protection, within this pumping station water is re-chlorinated in a manner that provides residual chlorine concentration of 0.25 to 0.50 mg/l.



TO THE RESIDENTIAL
QUARTER CIUREA
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INJECTION CHAMBER
Sos. NICOLINA
A
PUMPING STATION
500 mc/h
CHLORINATION
K
COMPENSATION TANK
5000 MC
A ÷ J
EXTRAVILAN

4 The experimental program

Currently, monitoring of water quality in supply networks is done periodically by lab tests on samples took in three relevant sections: the pumping station, the compensation tank and an extreme location of the water supply network. The main parameters which are surveyed are the residual chlorine (free and total), oxidability, pH and turbidity.

Considering the constructive and operational particularities of the studied system:

- steel mains over 20 yrs old
- direct pumping towards the network
- counter-tank laterally located
- a trend of decrease of consumptions compared to designed flows

it has been envisaged to increase the number of surveyed sections in order to accurately characterize the whole network and to add the hydraulic model with a qualitative one.
In order to establish the chlorine consumption global coefficient within the studied system, there have been carried tests (physical, chemical and microbiological) on samples drawed from 11 control sections, on a period of three days, at four hours intervals. The geometric and hydraulic features of the distribution network in implicated zone are presented in table 1.

Table 1 – The geometric and hydraulic characteristics at maxim consumption hour

<table>
<tr><th rowspan="2">Section</th><th rowspan="2">Bar</th><th rowspan="2">Length L[m]</th><th rowspan="2">Diameter D_n[mm]</th><th rowspan="2">Hydraulic raze R[m]</th><th rowspan="2">Volume V[mc]</th><th colspan="3">Maxim consumption hour</th></tr>
<tr><th>Debit Q[mc/h]</th><th>Speed v[m/s]</th><th>Time τ[min]</th></tr>
<tr><td>K-B</td><td>46-42</td><td>150</td><td>300</td><td>0,075</td><td>10,6</td><td>468</td><td>1,8</td><td>1,35</td></tr>
<tr><td>A-B</td><td>39-42</td><td>400</td><td>400</td><td>0,100</td><td>50,2</td><td>100</td><td>0,2</td><td>30,1</td></tr>
<tr><td rowspan="12">B-I</td><td rowspan="2">42-28</td><td rowspan="2">60</td><td>600</td><td>0,150</td><td>17,0</td><td>555</td><td>0,5</td><td>1,82</td></tr>
<tr><td>150</td><td>0,0375</td><td>1,06</td><td>14</td><td>0,2</td><td>4,54</td></tr>
<tr><td>28-37</td><td>140</td><td>400</td><td>0,100</td><td>17,6</td><td>420</td><td>0,9</td><td>2,45</td></tr>
<tr><td rowspan="2">37-20</td><td rowspan="2">15</td><td>400</td><td>0,100</td><td>1,88</td><td>310</td><td>0,7</td><td>0,31</td></tr>
<tr><td>150</td><td>0,0375</td><td>0,26</td><td>23</td><td>0,4</td><td>0,68</td></tr>
<tr><td rowspan="2">20-14</td><td rowspan="2">105</td><td>400</td><td>0,100</td><td>13,2</td><td>264</td><td>0,6</td><td>3,00</td></tr>
<tr><td>150</td><td>0,0375</td><td>1,85</td><td>20</td><td>0,3</td><td>5,55</td></tr>
<tr><td rowspan="2">14-11</td><td rowspan="2">57</td><td>400</td><td>0,100</td><td>7,16</td><td>200</td><td>0,4</td><td>2,15</td></tr>
<tr><td>150</td><td>0,0375</td><td>1,01</td><td>15</td><td>0,2</td><td>4,00</td></tr>
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<tr><td>150</td><td>0,0375</td><td>1,32</td><td>10</td><td>0,2</td><td>7,92</td></tr>
<tr><td>7-1</td><td>195</td><td>400</td><td>0,100</td><td>24,5</td><td>146</td><td>0,3</td><td>10,0</td></tr>
<tr><td>I-J</td><td>1-90</td><td>2500</td><td>P400</td><td>0,100</td><td>314</td><td>95</td><td>0,8</td><td>200</td></tr>
<tr><td rowspan="3">I-H</td><td>1-4</td><td>100</td><td>150</td><td>0,0375</td><td>1,76</td><td>28</td><td>0,4</td><td>3,77</td></tr>
<tr><td>4-3</td><td>25</td><td>150</td><td>0,0375</td><td>0,44</td><td>42</td><td>0,7</td><td>0,63</td></tr>
<tr><td>3-5</td><td>40</td><td>150</td><td>0,0375</td><td>0,71</td><td>42</td><td>0,7</td><td>1,01</td></tr>
<tr><td>20-E</td><td>20-21</td><td>40</td><td>200</td><td>0,050</td><td>1,26</td><td>50</td><td>0,4</td><td>1,51</td></tr>
<tr><td rowspan="2">14-G</td><td>14-13</td><td>15</td><td>150</td><td>0,0375</td><td>0,26</td><td>72</td><td>1,1</td><td>0,22</td></tr>
<tr><td>13-12</td><td>45</td><td>150</td><td>0,0375</td><td>0,78</td><td>31</td><td>0,5</td><td>1,50</td></tr>
<tr><td>11-F</td><td>11-10</td><td>60</td><td>150</td><td>0,0375</td><td>1,04</td><td>72</td><td>1,1</td><td>0,87</td></tr>
</table>

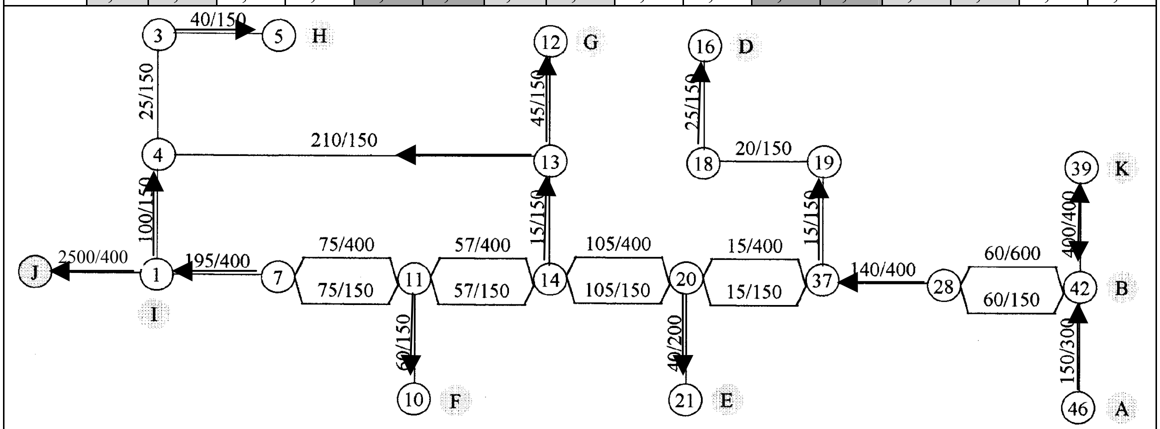
The main parameters (physical, chemical and microbiological) determined and the corresponding used methods are listed below:

- Residual chlorine (free and total)	STAS 6364
- Oxidability	STAS 3002 and SR-ISO 6060
- Turbidity (NTU)	STAS 6323
- pH	STAS 6325 and SR ISO-10503
- Escherichia Coli (no/100ml)	SR ISO 9308-1
- Enterococus (no/100ml)	STAS 3001 and SR ISO 7899

Results concerning the free residual chlorine are shown in Table 2 and in Fig. 2 and 3.

Table 2 – Evolution of free residual chlorine in control section adopted

Day	04.07					05.07						06.07				
Hour	8^{00}	12^{00}	16^{00}	20^{00}	24^{00}	4^{00}	8^{00}	12^{00}	16^{00}	20^{00}	24^{00}	4^{00}	8^{00}	12^{00}	16^{00}	20^{00}
Rez.K	0,02	0,02	0,15	0,10	0,07	0,04	0,02	0,02	0,02	0,15	0,20	0,37	0,02	0,35	0,25	0,48
SP.A	0,20	0,25	0,24	0,15	0,18	0,42	0,40	0,38	0,35	0,35	0,62	0,45	0,50	0,65	0,70	1,50
B	0,18	0,20	0,20	0,13	0,12	0,30	0,30	0,30	0,30	0,32	0,60	0,40	0,30	0,60	0,65	1,30
E ←	0,16	0,15	0,18	0,10	0,08	0,13	0,30	0,30	0,25	0,30	0,50	0,37	0,25	0,60	0,60	1,20
F ←	0,07	0,14	0,17	0,09	0,07	0,11	0,30	0,25	0,25	0,27	0,25	0,40	0,23	0,55	0,50	1,15
→G	0,02	0,02	0,02	0,04	0,04	0,04	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02
→H	0,14	0,18	0,15	0,12	0,07	0,07	0,04	0,04	0,15	0,12	0,20	0,15	0,18	0,30	0,45	0,72
I	0,20	0,20	0,18	0,12	0,10	0,15	0,15	0,20	0,20	0,28	0,22	0,48	0,25	0,10	0,55	1,25
J	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,02	0,07	0,05	0,05	0,02	0,02	0,02	0,08



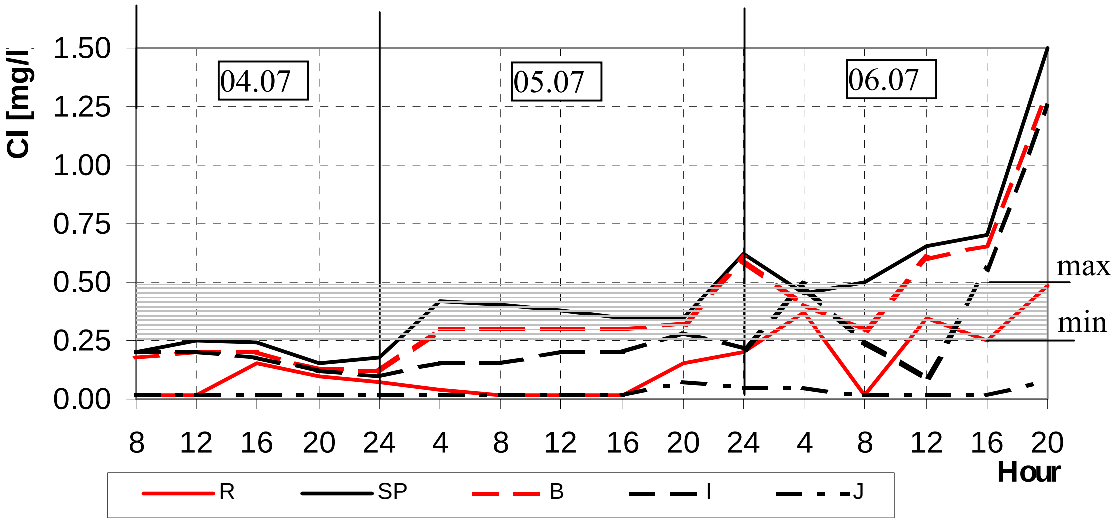


Figure 2 – Variation of residual chlorine for the main pipe

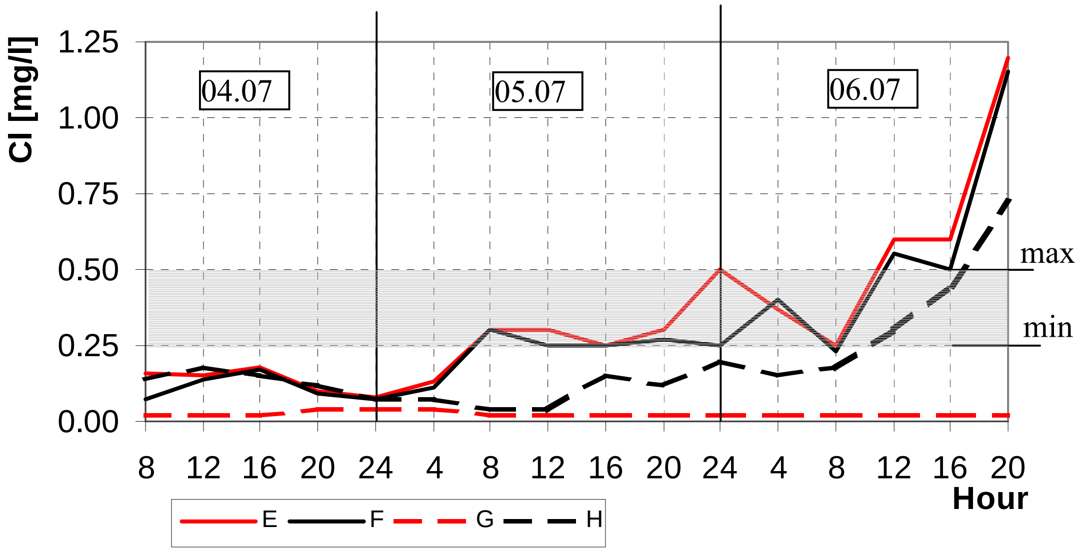


Figure 3 – Variation of residual chlorine for the secondary pipes

5 Interpretation of results

Assessment of primary data lead to some important conclusions:

- initially, the residual chlorine concentration, within the whole system, keeps below the recommended inferior limit (0.25 mg/l)
- next to the adjustment of injected chlorine dose at the pumping station, at the end of the experimental cycle, the residual chlorine concentration exceeds the recommended superior limit (0.50 mg/l)
- residual chlorine is intensely consumed in the compensation tank and within the last supplied consumer's, supplied connecting pipe with long length and diameter. Phenomenon reveals a high degree of main clogging and lower speed by refreshment.

Considering the given conditions, and after processing values which have been selected on time intervals (intervals appreciated to be characterized by minimal or null consumptions, that is between 0h00-04h00 and 08h00-12h00 – Table 2), have been subsequently calculated the average values of the consumption coefficient on main sections – Table 3.

Table 3 – Determination of consumption global coefficient

Data	Section	C_{in}	C_{fin}	ΔC C_{in} - C_{fin}	$\frac{C_{in}}{C_{fin}}$	$\ln\frac{C_{in}}{C_{fin}}$	$\Lambda = \frac{1}{T}\ln\frac{C_{in}}{C_{fin}}$
04-05.07 hour 0-4	B-I	0,17	0,15	0,02	1,133	0,125	0,0312
	B-E	0,17	0,13	0,04	1,308	0,268	0,067
	B-F	0,17	0,11	0,06	1,543	0,435	0,109
	B-G	0,17	0,04	0,13	4,250	1,447	0,362
	I-H	0,10	0,07	0,03	1,428	0,357	0,089
	I-J	0,10	0,02	0,08	5,000	1,609	0,402
05.07 hour 8-12	B-I	0,18	0,20	-	-	-	-
	B-E	0,18	0,16	0,02	1,125	0,117	0,029
	B-F	0,18	0,14	0,04	1,286	0,251	0,062
	B-G	0,18	0,02	0,16	9,000	2,197	0,549
	I-H	0,20	0,18	0,02	1,111	0,105	0,026
	I-J	0,20	0,02	0,18	10,00	2,302	0,575
05-06.07 hour 0-4	B-I	0,60	0,48	0,12	1,250	0,223	0,055
	B-E	0,60	0,37	0,23	1,622	0,483	0,120
	B-F	0,60	0,40	0,20	1,500	0,405	0,107
	B-G	0,60	0,02	0,58	30,00	3,400	0,850
	I-H	0,22	0,15	0,07	1,467	0,383	0,095
	I-J	0,22	0,05	0,17	4,400	1,482	0,370
06.07 hour 8-12	B-I	0,30	0,15	0,15	2,000	0,693	0,173
	B-E	0,30	0,30	-	-	-	-
	B-F	0,30	0,25	0,05	1,200	0,182	0,046
	B-G	0,30	0,02	0,18	15,00	2,700	0,677
	I-H	0,15	0,04	0,11	3,750	1,322	0,330
	I-J	0,15	0,02	0,13	7,500	2,015	0,503

Table 4 – Average values of consumption global coefficient Λ

Section	Diameter	Hydraulic raze	Material	Λ
B-I	400+150	0,0829	Steel	0,135
I-H	150	0,0375	Steel	0,135
I-J	400	0,100	Concrete	0,485
20-E	200	0,050	Steel	0,060
11-F	150	0,0375	Steel	0,080
14-G	150	0,0375	Steel	0,620

6 Conclusions

The performed study confirm the fact that in the distribution networks take place specific reactions determined by the interaction of the hydraulic and qualitative conditions of the injected water.

Among the potential causes of these phenomenous could be taken in consideration:
- corrosion and fatigue;
- contamination during technical interventions;
- contact with the deposited materials in the stoking tank and on the interior of the pipes;
- type and quantity of disinfectants.

The concretes results indicate inadequate circulations in the compensation tank and in the extreme zones of the network.

The determination of the global coefficient for chlorine consumption represents a necessary stage for the characterization of the network in the view of modeling for the quality management of the distributed water.

The initial investigations will be studied thoroughly in the view of the confirmation of the primary conclusions and the finality of the quality model.

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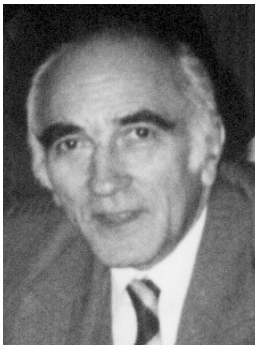
8 Presentation of Authors



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Water supply and drainage in the traditional buildings of Kayseri and its summer resorts until the 1950s

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Abstract

One of the difficulties of traditional living in Kayseri was the unavailability of running water in buildings. This was true both for the town and summer resort houses. Although the location of the city had the advantage of having great water sources, its supply was limited by the current channels and pipe network. Traditional terra-cotta pipes used since the Roman period, were not improved to spread water within the town at a desirable level. Public fountains, bath houses had water supplied, as did all of the large residences and *konaks*. Wells dug into courtyards were the other sources of water supply although well water was generally of low quality and brackish. In summer resorts water was distributed by open or closed channels to different districts and stored in private and public wells as well as large underground reservoirs. Sewage disposal was a serious problem in the city. Since it was laid out on flat land, the construction of proper sewage system was difficult. Toilets were located on the periphery of the building lot as far away from the wells as possible. A ditch dug into the garden served as cess-pit and emptied when it was full. The paper discusses water and drainage problems faced in Kayseri and its summer resorts until the 1950s, gives information about the attitudes of people towards consumption of water, and ecological balances created by careful water usage and disposal.

Keywords

Traditional Kayseri, water supply and drainage, wells, reservoirs, cess-pits.

1 Introduction

Tradition in central parts of Anatolia -Capadoccia region and surrounding towns like Kayseri, Niğde, Kırşehir, Nevşehir - has considered "water" and "building" as two separate entities. Buildings were rarely supplied with water and when they were, water sources stayed in courtyards or outside buildings. Water supply within buildings was possible but not widespread until the end of the Second World War, when cities were equipped with piped water system.

This paper examines the use of water in Kayseri until the 1950s based mainly on two extensive surveys by the first author: A survey of traditional town houses in Kayseri that started in 1986, and another one that examined summer resort houses in Kayseri that started in 1992. Both projects aimed to understand and record living conditions of people, principles of settlements, general characteristics of houses; interior and exterior space usage as well as architectural components of buildings.

Due to the scarcity of water in the region, the amount of waste water was also limited and it was either absorbed by the ground or directed to individual cess pools dug into the gardens or courtyards. A public sewage system in many of the cities was not possible until the last quarter of the 20th century. The amount of rain and snow fall was limited too; due to climatic conditions, precipitation was small (around 350-400mm in a year) and it was drained in a traditional manner: Snow cover on flat roofs was cleared by man-power, and rain water by gravity. Sloped earthen roof surfaces and gutters got rid of the water falling on roofs.

A peculiar character of these central Anatolian towns was the summer-winter differentiation in living. Native citizens lived in towns during winter months and moved to summer resorts in June where they spent three or four months. While town houses were properly built and decorated in traditional ways, summer houses in general were designed for basic human needs and had a simpler, spartan character. In these resorts interaction with nature was the fundamental principle and people lived in semi-open rooms, under trellises or shaded areas for most of the time and slept under the sky on roofs or terraces. The custom of moving to a summer house was well-established in Kayseri and prevailed for at least 500-600 years. Evliya Çelebi who visited the town in mid 16th century reports that there was a total of 103 such resorts "for enjoyment and entertainment" in and around the city (p.75). With the exception of very few families (who were poor or did not have adult males capable of arranging the families' interaction with the external world) Kayseri natives moved to summer resorts on the outskirts of Mount Erciyes, or nearby villages with vineyards and orchards. These resorts called "bağ" (meaning vineyards) were on higher elevations than the town and received cooling summer breezes. Fruit and vine trees, vegetables and flowers created a rich country atmosphere different from the one in the town where a dense urban life was prevalent (İmamoğlu, 2001).

This paper will concentrate on the city of Kayseri around the 1950s and try to examine water supply and drainage in buildings in town houses first, then will look at the situation in summer resort houses.

2 Water supply and drainage of buildings in the town of Kayseri

One of the difficulties in traditional living was the unavailability of running water in buildings. Although the location of the city had the advantage of having great water sources, its supply was limited by the current pipe network. Traditional terracota pipes, used since the Roman period were not properly improved to spread water within the town at a desirable level. One or two public fountains in each of the neighbourhoods, public and religious buildings like medreses, külliyes, mosques and churches, and of course Turkish baths had water supplied, as did all of the large residences and konaks. Even so, the supplied water stayed within the courtyards or gardens and majority of people still had to fetch their drinking water from the nearest fountain, in special water holders (called *güğüm*) and store it in large terra-cotta jars (called *küp*), or metal containers. Drinking water was brought by youngsters or servants of houses. If such an arrangement was not possible, a kind of specialized "water-men" (*saka*'s) were employed for this purpose.

Wells dug into courtyards were other sources of water supply. Since ground water level is high in the plains where the town was laid out, it was natural to utilize this water by digging wells into courtyards. Faroqhi (1987) points out that almost 40 percent of all houses documented in kadı registers - even in 1690's - possessed a private water supply, generally in the form of a well (Figure 1). Though well water was generally of low quality and brackish, it was heavily used for house cleaning, dish-washing and ablution, as well as for cleaning toilets, *tokana*s (kitchen/winter sitting room) and courtyards.

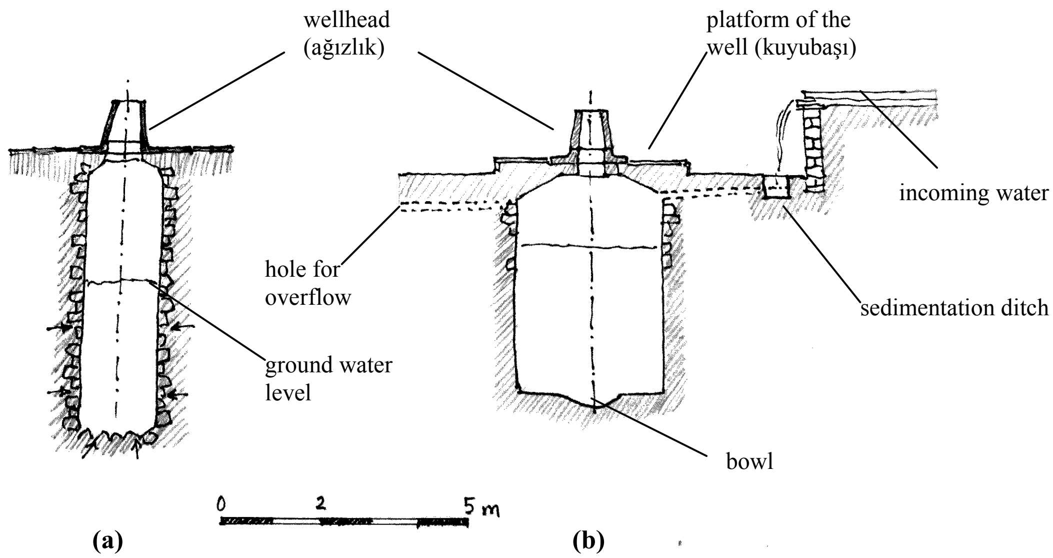

Figure 1 – a) A well in the town; b) a well in a summer resort.

Hot water was a by-product of fires in fireplaces and braziers. Buckets full of water were kept near the wood or charcoal fires in *tokana*s or exterior kitchens and heated when it was convenient. Although rooms were equipped with small washing cabins (called *gusülhane*) where one or two buckets of warm water were consumed to clean one's body - they were only occasionally used. This type of washing was not considered as proper bathing in

Kayseri and females and males paid separate visits to Turkish baths (*hamam*) in certain intervals -like every fortnight or once every three weeks- to properly clean themselves.

Since winters were cold in the town and house heating was not proper, water kept in buckets, cups and jars were usually frozen at nights. Terra-cotta jars were broken, ice blocks and pieces of broken jars were thrown away. This was also the case when piped water was first supplied to traditional houses in the old parts of the town: Since lead or steel water pipes were laid into unheated kitchens and toilets, they were exposed to cold weather and generally frozen and broken. In later stages of water distribution, these pipes were better insulated or mostly installed to heated spaces.

Since water was scarce in the town and buildings were single or double storeyed around courtyards, the amount of water consumed in buildings was limited and waste water was somehow absorbed by the ground and plants. The only wet areas in neighborhoods were those nearby street fountains and Turkish baths, near which vegetable gardens were located. Water split from fountains or discharged from *hamam*s was directed to these gardens where lettuce, cabbage, spinach and similar vegatables were grown. Such gardens also served as visual open green areas to local inhabitants who lived in a concentrated, dense urban tissue. Hence, almost each public fountain created a green open space nearby and provided fresh vegetables and open air to the inhabitants of that neighborhood.

Rain water in streets and public spaces was either directed to green areas or collected in reservoirs dug underground in the intersections of streets or public open spaces. Melted snow and rain water filled these reservoirs during spring, to be slowly absorbed by the ground in time. One may say that in general, used or discharged water did not require much special treatment and did not cause much trouble to citizens. Just like in other traditional surroundings, in Kayseri too, ecological balance was the key concept and discharged water was utilized for the benefit of plants in the surrounding gardens or fields, or discharged to the nearest water stream.

Sewage disposal was a more serious problem. Since the town was laid out on flat land, construction of a proper sewage system was difficult. Toilets were located on the periphery of the building lot, as far away from the wells as possible. A ditch dug into the garden served as a cess-pit. Depending on its size and number of users, it was used for a certain period of time. When it was full, waste was taken out, loaded on donkeys or mules and carried to vineyards, orchards or gardens nearby to be used as fertilizer.

3 Water supply and drainage of buildings in summer resorts

Summer resorts or bağ districts - south of Kayseri, on the skirts of Erciyes Mountain or in small valleys in the east were small settlements adjacent or not far from each other. Every bağ district was like a rural village made of dozens or hundreds of vineyards and orchards each including a small house in it. Size of vineyards generally varied between 3 to 20 acres and defined by a peripheral stone wall. These bağs were spread all over the slopes, ridges, valleys or located on mountain tops. Depending on the topography and locations, some of these resorts had abundance of water for people and plants while most of them lacked this opportunity. In the former case, water continuously ran from upper elevations to lower ones through a number of *bağ*s, sometimes creating swampy wet grounds and pools. In such cases, density of vegetation and evaporated water changed the climatic condition and created its own microclimate: a cool and pleasant atmosphere in dense greenery.

Spring time was the period when snow melted on Erciyes Mountain and the discharged water (in addition to the present spring water) was distributed to bağ districts by water canals according to a program. Those who lived in resorts where this kind of provision was possible, filled their neighborhood (called *niyet*) wells as well as individual wells with this water. Sizes of these wells ranged between 10 to 100 cubic meters according to their types and locations (İmamoğlu, 2002, p104). Additionally some houses were equipped with larger water reservoirs called "*mahzen*" dug into the higher portions of the ground (Figure 2). Their sizes went up to 1000-2000 cubic meters if the tufa rocks and the land was suitable. Their surfaces -like the surfaces of all wells- were covered or sealed by a special type of plaster called "*horasan*" to minimize the water lost. These reservoirs were also filled with water in spring time, and occasionally during summer, when available water was distributed to bağ districts.

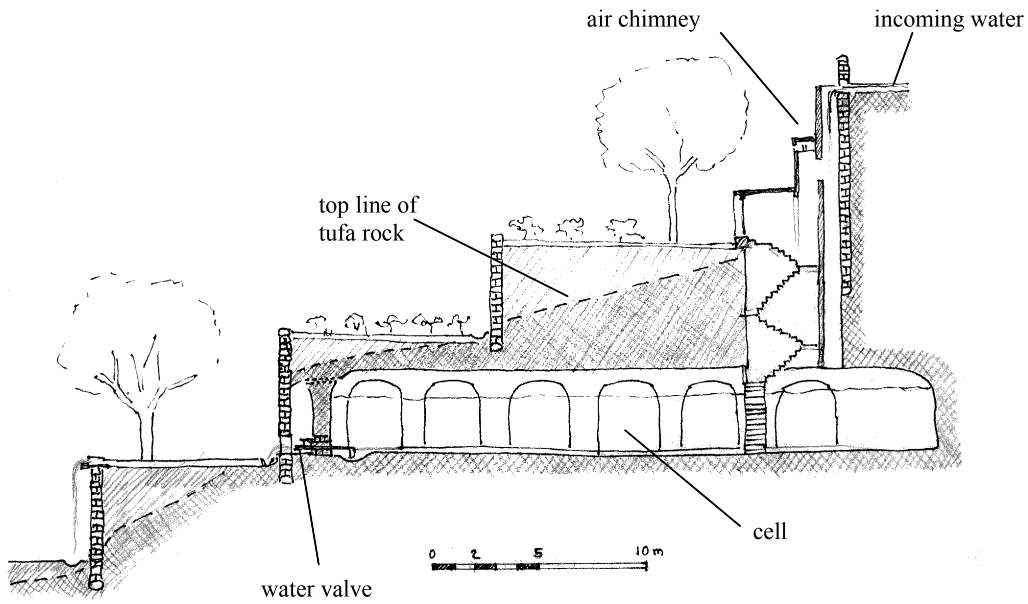

Figure 2 – A rough sketch of the 1000m^3 water reservoir (mahzen) of Osman İmamoğlu summer resort house in Talas (18th or 19th century).

In districts of higher elevations or mountains where distribution of water with the canal system was not possible, people filled or packed their wells with snow in winter time and used the melting snow for the period they lived in the house. These wells were cooler than the others and sometimes used as natural coolers to keep some of the food by hanging them down by the help of baskets. Water in this type of wells was cooler and hence more popular among *bağ*-goers. The sizes of these wells of course, were much smaller than the others.

Since drinking water was taken from wells, their cleanliness was important: Before filling wells, they were carefully washed and cleaned. They were generally filled towards spring time and usually at midnight, when water canals and closed passageways (called *avgun*) were relatively cleaner. The water was filtered by the help of a broom at the entrance hole and after it was filled, larger particles were disposed by overflowing the well through another hole at the top of the water level.

Wells had an important role in all summer resorts. Public or *niyet* wells were commonly used by neighbors surrounding the well and passer-bys; they functioned just like the public fountains in the town and enhanced public interaction around them. People passing from this area stopped and rested for a while; washed their faces, drunk some water and watered their horses or donkeys. Private wells of individuals' houses on the other hand were the focal points for family members. Since the well was generally the only water source in the house, it was strategically located in the courtyard or garden, generally in front of the summer living room (*örtme* or *köşk*) or kitchen. This area was called "*kuyubaşı*" and was a kind of focal area for the families. Children played around it, women worked or washed, prepared food, dried fruits, vegetables, entertained guests. Since water was scarce and distribution was from this area, roses, flowers, trees and vegetation that were considered more attractive or valuable by the family were planted near *kuyubaşı* and watered often.

The top of the wells were usually open to a platform which was a few steps elevated from the ground. A sculpted wellhead (stone ring; called *kuyu ağızlığı*) was located on top of the opening and generally covered with a lid to protect the water from dirt, birds and animals. One or two buckets were kept on top or near the wellhead and water was pulled or drawn from wells by these buckets and poured into various water cups or water holders. Since the water in the well was to be consumed during the whole summer, it was used carefully and economically. In certain years when summers were especially long and dry, this was not so easy and people had difficulty in managing the consumption of water. In such years they had to sacrifice from certain aspects of life, and fetch water from neighboring districts or borrow from their neighbors.

Toilets in bağs were small cubicles built on the periphery of courtyards 15-20m away from the wells. They were built out of stone but did not have a proper door or a conventional roof cover. Instead, they were roofed temporarily by dry vegetation or small sticks found in vineyards. Just like the ones in the town, a small ditch dug underneath the toilet served as a cess-pit. When it was filled, the waste was again used as fertilizer in the vineyard.

Drinking water was taken from wells in all vineyards. When a water reservoir or a *mahzen* was available, house cleaning, washing and watering plants and vegetables was possible. Pulling water from wells was not a difficult task, however having a *mahzen* was much easier. First of all, it eliminated the problem of water shortage for cleaning and washing in the house. Secondly, due to the positioning of the reservoir (which was generally located on a higher level), it was possible to create pressure difference and supply piped water to the house and garden. This way, decorative pools with water jets could be built; gardens, kitchens and bathrooms could be equipped with running water, which made everyday living much easier and pleasant.

Since vineyards were arranged in natural landscape and designed with respect to topographical conditions, rain and snow water disposal was not a big problem. Ground and plants were always in need of water and absorbed most of the precipitation. Floods on sloped areas might cause problems in spring time but streets or walkways in such districts were designed accordingly: They were paved with cobblestones sloping towards sides and had ditches on one or two sides, hence they could resist local floods. In addition, irrigation canals designed to bring water to individual bağs helped to canalize such extra ground water to vineyards or orchards. Retaining walls holding the terraces, roads or structures as well as trees, plants and natural vegetation prevented serious landslides or unwanted effects of small floods.

4 Discussion and concluding remarks

In a relatively short period of time, in about half a century, major changes occurred in central Anatolian towns including Kayseri. Old building stock was considered out of fashion mainly due to the difficulty of living and low standards of comfort. Extensive use of courtyards and open spaces in traditional urban life disappeared and people adapted to a dense living in towns, generally squeezed into apartment flats. However, a compensation for such a change is the continuing use of summer resorts by natives. The popularity and hence the number of such *bağ* houses continue to grow. However, due to the fast-growing population, the relative proportion of people moving to these houses is smaller today. Unlike in the past, *bağ*s are considered a luxury where only wealthy families can afford to live. Most of such houses are equipped with necessary facilities, but unfortunately lately built ones are larger than necessary and most resemble mansions or the apartment buildings in towns.

The lack of technical amenities, especially the lack of running water was one of the major problems in the traditional way of living both in towns and summer resorts. Women faced serious hardships in washing, house cleaning and cooking. Everybody but especially children and elderly suffered from the use of exterior toilets and lack of bathing facilities in winter time. In general, life was difficult for everyone and asked for a lot to sacrifice from males and females alike. Fetching water from public fountains or pulling from private wells, storing it in hygenic conditions caused, of course, the reduction of its consumption. The amount of water consumption per person must have been at bare minimums. One can imagine how difficult life may become without running water, especially in a muslim society where cleanliness is one of the most important assets. Additionally each muslim has to pray five times a day and in order to do that ablution (at least two or three times a day) by using water holders, or taking a bath, following sexual intercourse was required.

The economic use of water and utilization of wastes as fertilizers had probably helped to maintain the sustainability of environments both in towns and summer resorts. Every drop of water was utilized for the benefit of people and plants. Wastes and sewage were at very low levels and they did not require much special treatment. Hence, one can state that an ecological balance was widespread in Anatolia for centuries. But we cannot really figure out the price our ancestors paid for this balance and how it affected the hygenic conditions of the surroundings and quality of life at the time.

Today one rarely notices that how quality of life and comfortable living is dependent on piped water supply and drainage. In less than 100 years drastic changes have occurred in central Anatolian towns and both apartments and (most of the) summer resort houses were properly supplied with running water today. If not the summer resorts, all towns today have their sanitary systems which remove sewage by underground drains. Hardship and lack of technical facilities in traditional living has disappeared; now most of the communities have the means of enjoying facilities of a contemporary living. People have a longer and more comfortable life and of course, this was only possible through the availability of piped water and proper drainage systems. Today even the buildings with the lowest standards are much better equipped with such facilities than the palaces or *konak*s of the past. This progress has changed the attitude of people towards life and enhanced higher expectations from buildings, higher standards of sanitation, healthier and much more comfortable living conditions in their physical environments.

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6 Presentation of authors

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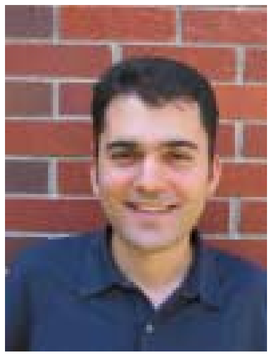

Selection of Sanitary Drainage Systems for Egyptian Villages

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Abstract

Most of the Egyptian villages are not served by sanitary drainage systems. Local unhygienic disposal methods of wastewater through soil are used, which have adverse effects on buildings condition, environment and public health. Egyptian villages have a great variance in their level of urban development and natural conditions. Using of conventional collection system and treatment of wastewater is not a suitable solution for technical and economical reasons. Economically feasible sanitary drainage systems convenient for different characteristics of villages became highly desirable. In this paper different technologies for sanitary drainage systems were clustered in three main clusters as follow; household latrines, on-site sanitation systems and off-sit sanitation systems. Several approaches have been developed to help in technology selection. A path selection scheme is suggested to reach the most suitable technology based on the main village characteristics such as potable water availability, groundwater use for drinking, type of soil, groundwater depth and urban planning.

Key words

wastewater; drainage system; Egyptian villages; on-site sanitation; rural areas.

1 Introduction

One of the most important factors of infrastructure is construction of perfect and suitable sanitary drainage systems. The presence of sanitation systems plays an essential role in improving general health and pollution prevention. The level of sanitation systems in Egypt especially in the villages still needs more effort .The sanitation

coverage percentage in the Egyptian villages is still less than 10% while the water supply coverage percentage is more than 90%.
Most villages do not have engineered sanitary drainage systems, since those systems were constructed several years ago in addition to increased population, high groundwater table, increased water consumption, village planning and change of social life conditions; therefore several problems appear as follows:

- Bad condition of buildings and public properties
- Pollution of streets and waterways
- Low level of public health and appearance of epidemic diseases
- Fetid odours

This paper discusses and suggests the technologies that can be applied in Egyptian villages, taking into consideration some of the affecting factors, which are potable water availability, ground water use for drinking, ground water depth, type of soil, village planning, project funding. Moreover, it proposes a path selection diagram to help in the selection of the most suitable sanitary drainage system for Egyptian villages.

2 Characteristics of Egyptian villages

2.1 General characteristics of Egypt

2.1.1 Geography

Generally, Egypt is divided into four regions, namely: i) the Nile valley and delta; (ii) Western desert; (iii) Eastern desert; (iv) Sinai peninsula. Since this paper deals with the properties of soil, groundwater, population and villages planning, in this paper Egypt was divided into three regions instead of four, with almost the same previous properties, which are as follows;
Area A: Nile delta
Area B: Nile valley
Area C: Western desert, eastern desert and Sinai

2.1.2 Population[1]

Egypt's population is estimated at about 65 million (2002) of which 56% is rural with annual demographic growth estimated at 2.3%. Average population density is 62/km^2, but ranges from 2/km2 over 96% of the total area, to 1,492/km2 in the Nile Valley and delta; this area is only 4% of the total area, where population density is among the highest in the world. About 55.3% of the population is localized in Cairo and Delta, 34.4% in the Nile Valley (upper Egypt) governorates, 7.4% in the Western and Eastern deserts including the northern portion of the western desert, and the rest are distributed among the remaining area of the country.

2.1.3 Soil properties

The soils of Egypt comprise the alluvial soils of the Delta and Valley, the calcareous soils along the coastal littoral of Egypt, the soils of the eastern and western deserts as well as the soils of Sinai Peninsula. The major alluvial soils were formed from the suspended solid matter of the Nile, which were deposited every year during the flood season. The flood water in the course of the recent geological period has deposited all the clay that covers the flat floor of the valley and most surface of the Delta forming the arable land of Egypt. Generally, it could be considered that the flat floor cover soils in Egypt are as follows:

- Clay, in the valley and Delta (area A and B)
- Sand, in the western and eastern desert, part of Sinai and north coastal (area C, B)
- Rock, in the mountain areas

2.1.4 Groundwater

The hydrogeological framework of Egypt comprises six aquifer systems(2):

- The Nile aquifers system, assigned on the quaternary and late tertiary, occupies the Nile flood plain region (including Cairo) and the desert fringes.
- The Nubian sandstone aquifer system, assigned to the Paleozoic – Mesozoic, occupies mainly the western desert.
- The Moghra aquifer system, assigned to the lower Miocene, occupies mainly the western edge of the Delta.
- The costal aquifer systems, assigned to the quaternary and late tertiary, occupy the northern and western coasts.
- The karstified carbonate aquifer system, assigned to the Eocene and to the upper cretaceous, outcrops in the northern part of the western desert and along the Nile system.
- The fissured and weathered hard rock aquifer system, assigned to Precambrian, outcrops in the eastern desert and the Sinai peninsula.

The main source of recharge in areas characterised by agricultural activities is the percolation from irrigation water, and the main source of recharge in urban areas are losses from water supply networks and sewerage systems.

Groundwater depth in Egypt can be approximately divided as follows:

- Shallow, in Cairo and Delta Governorates (Area A)
- Deep, in the Nile Valley Governorates (Area B)
- Very deep, in Western and Eastern Desert (Area C)

2.2 Villages

2.2.1 Drinking water and sanitation

Almost all Egyptian villages have water supply networks. The water consumption rate varies from zone to another and ranges from 60 to 150 l\c\d. The main source of potable water is the Nile and its tributaries; groundwater comes as the second source for potable water. Surface water is treated before distribution to consumers; however, groundwater, in most cases, do not need treatment. The most commonly used sanitation system is the collection of sewage in individual bottomless tanks with various dimensions. Tanks are evacuated periodically by trucks to remove sullage, and water percolates through the soil if it is permeable; in case of impermeable soil, trucks also evacuate water. Table 1 represents the percentage of buildings that have connections to public water supply and sanitation in Egypt [1].

Table 1 - Water and wastewater services in Egypt

Zone	Water supply, %		Wastewater service, %	
	Urban	Rural	Urban	Rural
Delta (Area A)	80	50	55	10
Nile valley (Area B)	70	38	25	5
Desert area (Area C)	55	40	15	3
Average	75	43	45	8

2.1.2 General planning characteristics

The planning characteristics of the Egyptian villages varies from zone to another. Generally, it could be concluded that there are three regions with homogenite planning properties as follows:

- Delta villages (Area A):
  - High population density
  - Unplanned and narrow streets width
  - Mostly more than two floor buildings
  - 60% brick buildings and 40% reinforced concrete buildings
- Valley villages (Area B):
  - Medium population density
  - Unplanned and medium to large streets width
  - Mostly one floor buildings
  - 80% brick buildings and 20% reinforced concrete buildings
- Desert villages (Area C):
  - Low population density
  - Unplanned and large streets width
  - One floor buildings
  - 90% brick buildings and 10% reinforced concrete buildings

3. Clustering of sanitation systems

The various sanitation systems that can be used for the Egyptian villages were divided into three main clusters. Each cluster was considered to have the same general attributes. Clustering was also designed to facilitate the selection process and differentiate between the different sanitation systems.

3.1 Technology selection constraints

Factors and constraints that were considered, for technologies clustering and selection process are mainly related to the general characteristics of the Egyptian villages. Table 2 represents the main factors that govern technology selection and their constraints.

Table 2 – Factors and constraints governing the selection of sanitary drainage systems

Factor	Constraints	Code	Mostly found in Egypt
Potable water availability			
	Public taps	PW01	B, C
	One tap per house	PW02	B, C
	More than one tap per house	PW03	A
Groundwater use for drinking			
	Hand or powered pumps at depth less than 100 m	PGW01	A, B
	Powered pumps with depth than 100 m	PGW02	A, B, C
Groundwater depth			
	Less than 1.5 m	GW01	A
	More than 1.5 m	GW02	B, C
Type of soil (surface layer)			
	High permeability soil (sand…etc.)	ST01	C, B
	Low permeability soil (clay, silt…etc)	ST02	A, B
Village planning			
	Houses with one floor	VP01	B, C
	Houses with more than one floor	VP02	A
	Streets width less than 6.0 m	VP03	A,B
	Streets width more than 6.0 m	VP04	C
	Low population density	VP05	C
	High population density	VP06	A, B
Project funding			
	Low funds	PF01	-
	Limited funds	PF02	-
	Open funds	PF03	-

3.2 Sanitary drainage systems clustering

Any sanitation system consists of three main steps: collection, treatment and disposal. In some of the primitive sanitary drainage systems the previous steps seem hidden but occur naturally in a simple way with the scarce interference of man. Two main factors were used for clustering the available technologies, which are the simplicity of the system and the transferring of either treated or untreated wastewater outside the village. The first cluster was classified as the simplest and the bottom limit for sanitation facilities, which is “Cluster A – House hold latrine”. Second cluster, which is “Cluster B – On-site sanitation” includes all technologies that will collect, treat and dispose wastewater within the village boundaries. Third cluster, which is “Cluster C – Off-site sanitation” includes all technologies that will transfer collected and treated or partially treated wastewater to outside the village boundaries. The following is a simplified description of the clustered sanitation technologies

	Cluster A	Cluster B	Cluster C
Collection	Defecation directly to the pit	Individual or group-user system	Group-user system
Treatment	Natural degradation inside the pit	Treatment in conventional or modified septic tanks	Partially in-situ or treatment plant outside the village
Disposal	In the site directly from the pit wall	Through soil	Outside the village

3.2.1 Cluster A – Household latrine

Household latrines consists mainly of a pit without any inside lining covered by a slab with a hole for defecation. After certain period the pit should be buried and another one should be used. The different types of household latrines that can be used are as follows;
Simple pit latrine: Consists of a slab over a pit which may be 2.0 m or more in depth. A squat hole in the slab or a seat is provided so that the excreta fall directly into the pit.
Ventilated pit latrine: Fly and odour nuisance may be substantially reduced if the pit is ventilated by a pipe extending above the latrine roof.
Pour-flush latrine: The latrine is fitted with a trap providing a water seal, which is cleared of faeces by pouring in sufficient quantities of water to wash the solid into the pit and replenish the water seal. The water seal prevents flies, mosquitoes and odours to reach the latrine from the pit.
Raised or Step Latrines: Where there is a seasonally high water table with less than 1.5m depth, a raised or step latrine may be the most appropriate option. The ground surface in the location and around the latrine is raised to a height of 1.5 m above the ground water. Any type of latrine can be raised in such cases.

3.2.2 Cluster B – On-site sanitation

On-site sanitation is the sanitary development of the household latrine. The wastewater is given an extended retention period under anaerobic conditions in septic tanks. The produced water from the septic tanks is partially treated by separating the solids and anaerobic digestion of organics. The effluent is infiltrated through the ground for further treatment and disposal.
Bottomless septic tank: An underground tank is constructed without bottom slab to receive wastewater from the users, accumulated sludge in the bottom is degraded under the anaerobic conditions. Soil under the tank may be clogged with time, but currently the usage of bio-activation products which enhance the biodegradation of solids reduces the volume of sullage and elongate the period before the soil become clogged beneath the tank.
Individual septic tank with under surface drainage: Each house has its own system, it consists of a completely sealed septic tank. The effluent from the tank infiltrates into the ground through under surface drainage system, which consists of shallow and horizontal

perforated pipes located under the ground surface by about 0.5m. This system needs relatively large area to accommodate the infiltration system and a good permeable soil.
Individual septic tank with soak pit: This system is similar to the previous system but the effluent of the septic tank is infiltrated to the ground by a soak pit, which is a constructed cylindrical pit with a diameter of 1.0-2.5 m and a depth of 2.0-5.0 m. The depth of the pit should be deep enough to reach the permeable layer of the soil.
Group septic tank with a disposal system: Wherever the streets are narrow and there is no room to construct septic tanks, shallow gravity sewers with small diameters are constructed in narrow streets to collect sewage from houses to a big septic tank in a wide area. Effluent of the tank is infiltrates into the ground as in the previous systems.

3.2.3 Cluster C – Off-site sanitation

Off-site sanitation deals with transferring the untreated or partially treated wastewater to the outside of the village. It includes the collection of raw wastewater or partially treated wastewater from septic tanks effluents to a pumping station, which in turn discharges it to a wastewater treatment plant.
Individual septic tank with truck evacuation: Each house has its own completely sealed septic tank to collect the sewage with no effluents. Water and sullage are evacuated from the tanks by trucks and sent outside the village to the nearest treatment plant. This system needs much management in the operation of the big number of trucks, which shall carry all the sewage of the village.
Group septic tank with truck evacuation: Raw wastewater is collected from houses located in narrow streets through shallow small sewers to a big septic tank in a suitable place. Trucks carry wastewater and sullage to the treatment plant as in the previous system.
Individual septic tank with small bore sewers: This system consists of a gravity sewer network with a small diameter pipes and smaller slopes than the minimum of the conventional networks. The network collects partially treated sewage from the effluent of individual septic tanks, the effluents have small concentration of suspended solids so no deposition will occur inside the pipes with small slopes. The network carries the sewage to a pump station, which discharge the sewage to the treatment plant.
Group septic tanks with small bore sewers: Shallow small sewers collect raw sewage from houses located in narrow streets to a big septic tank in a suitable place. Small bore sewers as described in the previous system collect the partially treated sewage and discharges it outside the village.

4 Selection methodology

4.1 Correlation between sanitation systems and constraints.

Table 3 represents the availability of using different technology against the proposed constraints that are always found in Egyptian villages

Table 3 - Correlation between sanitation systems and constraints

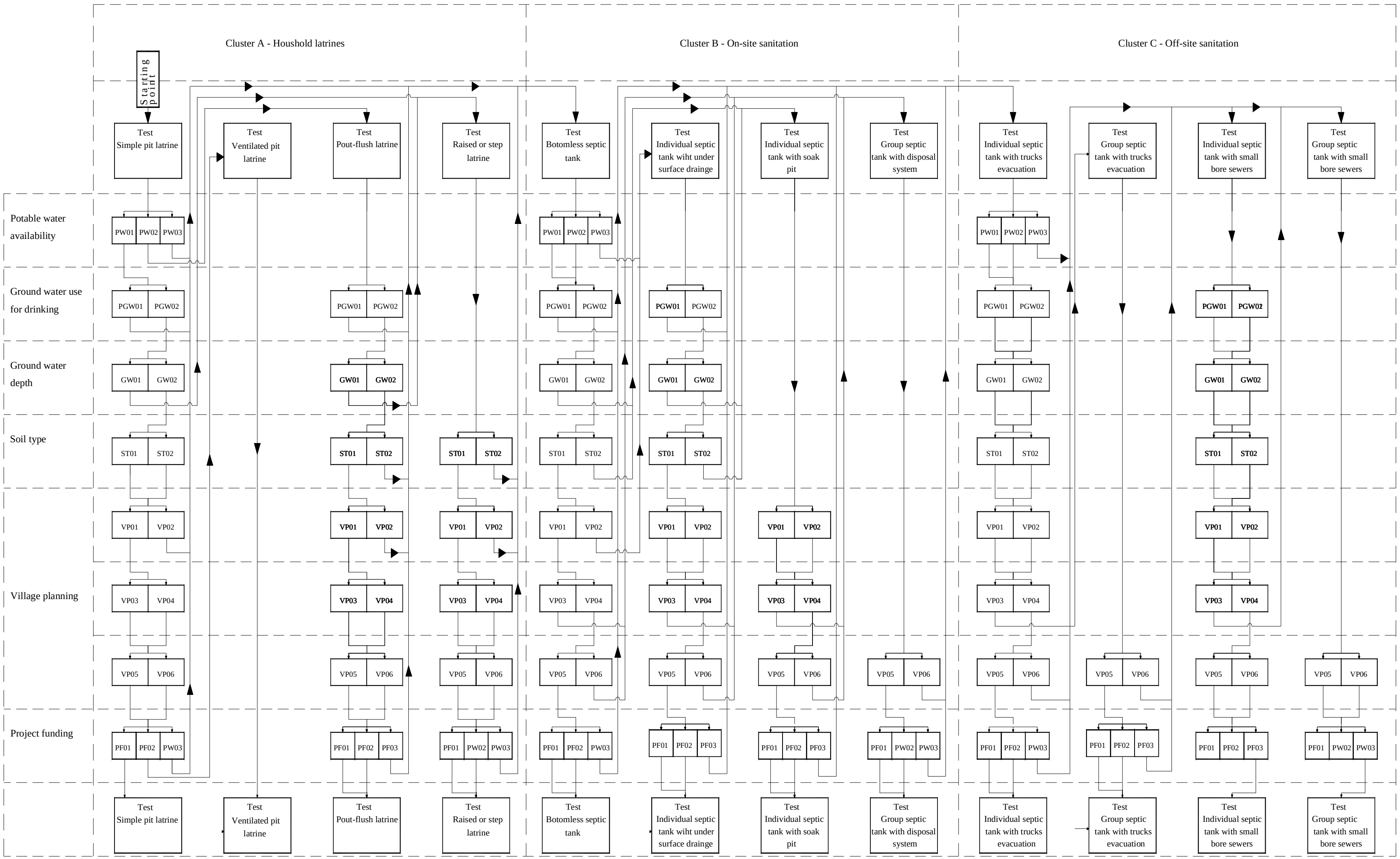
	Potable water availability			Groundwater use for d drinking		Groundwater depth		Soil type (surface layer)		Village planning						Project funding		
	PW01	PW02	PW03	PGW01	PGW01	GW01	GW02	ST01	ST02	VP01	VP02	VP03	VP04	VP05	VP06	PF01	PF02	PF03
Cluster A – Household latrines																		
Simple bit latrine	√	×	×	×	√	√	√	√	√	√	×	√	√	√	√	√	×	×
Ventilated bit latrine	√	×	×	×	√	√	√	√	√	√	×	√	√	√	√	√	√	×
Pour-flush latrine	√	√	×	×	√	√	√	√	×	√	×	√	√	√	√	√	√	×
Raised or Step Latrines	√	√	×	×	√	×	√	√	√	√	√	√	√	√	√	√	√	×
Cluster B – On-site sanitation																		
Bottom less septic tank	√	√	×	×	√	×	√	√	×	√	×	×	√	√	×	√	√	×
Individual septic tank with under surface drainage	√	√	√	×	√	×	√	√	×	√	√	×	√	√	×	√	√	√
Individual septic tank with soak pit	√	√	√	×	√	×	√	√	√	√	√	×	√	√	×	√	√	×
Group septic tank with a disposal system:	√	√	√	×	√	×	√	√	√	√	√	√	√	√	×	√	√	×
Cluster C – Off-site sanitation																		
Individual septic tank with truck evacuation	√	√	×	√	√	√	√	√	√	√	√	×	√	√	×	√	√	×
Group septic tank with truck evacuation	√	√	×	√	√	√	√	√	√	√	√	√	√	√	×	√	√	×
Individual septic tank with small bore sewers	√	√	×	√	√	√	√	√	√	√	√	×	√	√	√	×	×	√
Group septic tanks with small bore sewers	√	√	×	√	√	√	√	√	√	√	√	√	√	√	√	×	×	√

√ Technology can be used
× Technology can’t be used

4.1 System selection approach

An approach has been developed and presented to help in sanitation technology selection. A path selection scheme is designed to reach the most suitable technology based on the main village characteristics and the proposed constraints. The starting point of the path is the testing of using simple pit latrine, which is the simplest method, the flow chart carries the test for the technology through the proposed constraints step by step. If the village characteristics do not fit the requirement of the technology, the path

Table 4 - Path selection scheme for sanitary drainage systems



goes to the next technology or to the next cluster. This methodology can be incorporated into the expert system shells that can run on a P.C. The path selection method is presented in table 4.

5 Conclusions

The main factors for selecting the most suitable sanitary drainage systems are concluded in six factors, which are the groundwater depth, groundwater use for drinking, potable water availability, type of soil, village planning and project funding. The Egyptian villages can be divided into three areas; Area A (Nile delta), Area B (Nile valley) and Area C (Western desert, eastern desert and Sinai). The sanitary drainage systems that can be used in the Egyptian villages was clustered into three main clusters with subdividing into technologies as follows;
Cluster A - Household latrine (simple pit latrine, ventilated pit latrine, Pour-flush latrine and Raised or Step Latrines)
Cluster B – On-site sanitation (Bottom less septic tank, Individual septic tank with under surface drainage, Individual septic tank with soak pit and Group septic tank with a disposal system)
Cluster C – Off-site sanitation (Individual septic tank with truck evacuation, Group septic tank with truck evacuation, Individual septic tank with small bore sewers and group septic tanks with small bore sewers). A path selection scheme was designed to reach the most suitable technology based on the main village characteristics and the proposed constraints, which can be incorporated into an expert system shells that can runs on a P.C. Each village should be studied separately even some of the villages ate located within the same area. Moreover, as each village has its own characteristics, and each of such characteristics might vary within the same village; the applicable sanitary drainage system might vary from one village to another, and it might vary within the same village. Accordingly, in order to utilize the path selection scheme effectively, the characteristics of each village should be rigorously identified.

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Sustainable water management in buildings in Catalonia

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Abstract

This paper focuses on Catalan government policy on water consumption in buildings. In common with other Mediterranean countries, water is a scarce resource in Catalonia. Specific policy actions in this area are mainly implemented through the “Sustainable Planning and Building Strategy for Catalonia”. Participation of stakeholders is basic to successful implementation.

Keywords

Water, building, public administration, policy, Catalonia.

1 Introduction

1.1 Catalonia

Catalonia is a prosperous, industrialised country located in the Northeast of the Iberian Peninsula. Its surface area of 32,000 km^2 has a population of approximately 6.3 million inhabitants, leading to a population density of almost 200 inhabitants per km^2. Catalonia has more of 800 km of The Mediterranean coastline. It is also a mountainous region, almost 20% of total surface area standing at an altitude of 1,000 m above sea level or higher. Its climate in general is Mediterranean.


Figure 1 – Location of Catalonia

Catalonia enjoys a good level of political autonomy within the state of Spain. The Catalan Parliament and the Government - the Generalitat de Catalunya - have powers in a wide range of areas.

The Catalan government has powers and legislative authority in environmental matters, within the framework of EU directives and basic Spanish legislation. Through its Ministry of the Environment, the Catalan Government implements environment policy throughout the territory of Catalonia. One specific area of environment policy concerns water.

1.2 Water resources in Catalonia

1.2.1 A scarce resource

Water is a valuable resource in Catalonia since its availability is limited. Although consumption per inhabitant in Catalonia is much lower than the EU average, fresh water is, and will be increasingly, a scarce resource.

On the whole, in Catalonia availability of fresh water exceeds consumption, yet there are problems due to seasonal and location factors.

Rainfall varies widely from season to season, and even from year to year, leading to very variable levels of water availability. In general, summers are very dry and hot; however, intense rain is also frequent, especially in the autumn, which, occasionally, may cause significant damage.

Water availability is also determined by geographical location. Average annual rainfall in the Pyrenees, to the North, exceeds 1,000 mm; however, in the remainder of Catalonia the figure is much lower, lower than 700 mm in some locations, especially on the coast.

Topographically, the region can be divided into two clearly defined watersheds: the eastern basin, consisting of several internal basins - rivers arising within Catalonia, and in the west and south, the inter-regional basin of the river Ebro.

Figure 2 – Map of internal and interregional basins of Catalonia

The Water Plan for the Internal Basins of Catalonia identifies a present deficit of 13% in available water resources and predicts a deficit of 50% by the year 2012. This highlights the need to manage our water resources correctly.

The problem is further accentuated by population distribution patterns. Coastal municipalities account for 43% of the population, leading to an average population density of 1, 284 inhabitants per km^2, which doubles in summer. Furthermore, 70% of the total population live in a 20 km strip running by the coastline.

1.2.2. Water management

The Spanish state has full powers in the area of water planning. This favours management by basins rather than administrative divisions. Notwithstanding, the Government of Catalonia is responsible for the internal basins, i.e., those that lie totally within Catalonia, and has an important role in overall management and treatment of water supply.

Catalan government measures affecting the water supply are mainly exercised through the Catalan Water Agency (ACA). ACA is responsible for drawing up and reviewing plans affecting the internal Catalan basins, for water programmes and projects, for monitoring, administering and controlling water uses, and for qualitative and quantitative aspects of public water supply in general, including authorisations and concessions. ACA is also responsible for administration and census of the use of existing surface and ground waters and any dumping which could affect the quality of surface, ground and marine waters. In addition, ACA works to control water pollution and supply and treatment services.

The local administration also plays a role in that final responsibility for domestic water lies with the municipal council.

2 Sustainable Planning and Building Strategy in Catalonia

2.1 Sustainable development

The Government of Catalonia aims to reduce the environmental impacts of economic development as much as possible. This objective has led to an overall strategy for environmental improvement, in which the construction sector is one of the main areas focused on.

On 14 March, the Catalan Parliament passed Law 2/2002 on Urban Planning. One of the objectives of this law is to “develop sustainable urban planning”. The law makes provision for obligatory presentation of technical certificates. One of the required certificates concerns sustainable water use.

At local level, municipal councils are also establishing regulations on sustainable water use for urban planning and buildings.

2.2. The aims of the Strategy

The Catalan Ministry of the Environment has been working on the “Strategy for Sustainable Planning and Building in Catalonia” over the last two years. This Strategy establishes the guidelines for uniting environmental criteria applicable to the construction industry.

The main aim of this strategy is to reduce environmental impacts by improving the efficiency of resource use and waste reduction measures. This objective can be achieved by: avoiding unnecessary surface occupation, reducing water consumption to the strictly necessary levels, reducing CO_2 emissions caused by inefficient energy consumption, improving indoor environmental quality of buildings and also by integrating urban structures into the landscape.

How you can see, one of the most importants aims of the strategy is to reduce water consumption. This objective is developed within tools.

2.3. The basic axes of the Strategy

Four main structural axes have been established to achieve these aims: fostering involvement by stakeholders and the citizens, introducing environmental criteria into urban and land use planning, adapting buildings to the environment, and finally, developing appropriate certification systems. These four general axes can encompass all the actions required to boost our sustainable planning and building strategy in a coherent and integrated way.

2.3.1 Fostering involvement by stakeholders and citizens
It is important that the initiatives carried out by the Ministry of the Environment be understood. The main aim in this area is to foster a proactive attitude and progressive responsibility on the part of all agents involved. The first step was to draw up an exhaustive list of these agents. They were then contacted and informed of the strategy to promote sustainable planning and building and asked to make suggestions on what they saw as the best means for collaboration.

2.3.2 Introducing environmental criteria into urban and land use planning
Another important strategic line, especially in the mid and the long term, is to ensure that urban and regional planning include environmental criteria. Planning procedures must also take account of the environmental regulations on building.

2.3.3 Adapting buildings to the environment
A third strategic line is to ensure that public buildings can be regarded as models of sustainable building. Our aim is to extend these improvements to private buildings.

2.3.4 Developing appropriate certification systems
A fourth strategic line focuses on the development of certification systems that foster environmental improvements in the building industry. Catalonia has its own environmental certification system, which is also applied to approved water saving products, so ther is an environmental labelling and certification for water saving products in Catalonia.

3 Specific advances in water management through implementation of the Strategy

With regard to water management in buildings, implementation of the Strategy focuses on 3 basic areas:

- Improvement of the information and control system
- Development of demonstration projects
- A communication plan

3.1 Improvement of the information and control system

At present, information on water consumption in buildings is diffuse and unstructured. This does not facilitate setting of objectives, optimum decision making or monitoring and control of consumption patterns.

To overcome this problem, the Ministry of the Environment, in conjunction with the Universitat Autònoma de Barcelona and the Agbar Foundation, is developing a “Water Consumption Information System for Buildings”. (Agbar - Aigües de Barcelona - is responsible for management of most of Barcelona’s water). It is hoped that over the course of the coming year, a database will be developed establishing the basis for an information and control system for water consumption in the Metropolitan Region of Barcelona (4,5 millions of inhabitants).

This will enable us to gauge the present situation and evaluate the water saving generated by policy in statistical terms.

The Metropolitan Region of Barcelona (RMB) has been identified by the National Water Plan and by a number of other studies as an area with a serious lack of fresh water resources. It is foreseen that there will be further inputs of freshwater (from the Ebro, and perhaps the Roine). However, it is also important to find other alternatives and especially to improvement management of present water demands through water saving measures and use of non-conventional water sources, such as treated waste or rainfall water.

The water consumption by year in the RMB is nearly 500 Hm3 and the 67% of this consumption is for domestic sector. There are big differences between different kind of housing (130 l/p/d to 270 l/p/d). The 40% of this consumption are in relation with the shower and the bath. The 16% are in relation with the irrigation system of the green zones. The 15% are for the washing machine.

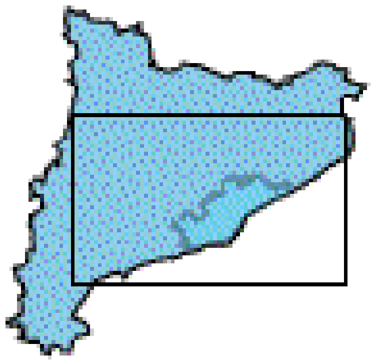

Figure 3 – Map of the Metropolitan Region of Barcelona

The objectives of the information system are as follows:

- to determine present average water consumption rates of different types of buildings and uses within the Barcelona Metropolitan Region;
- to integrate appropriate water saving measures for different types of buildings, measuring the saving generated and monitoring posterior consumption rates;
- to evaluate a compensation system to reward those achieving significant reductions in water consumption.
- To offer a tool for decision making process of the strategy

The types of building studied include the following:

- Private housing, divided into three subcategories: (1) dwellings in large-scale apartment blocks; (2) dwellings in medium-scale apartment blocks, and (3) detached or semi-detached single-family dwellings.

- Public facilities selected include: Homes for the Elderly, Secondary Schools, Sports Centres, Health Centres and Hospitals, etc.
- Public office buildings
- Hotels
- Private commercial buildings and/or premises

The methodology will involve design and development of an information system on water consumption in different types of building, which will serve for incorporation of already available information and specific questionnaires on types of buildings and sectors for which we lack information. These specific questionnaires will include the variables considered in the already existing information and will be designed to determine annual and, if possible, seasonal consumption but also other factors, such as estimates of distribution of this consumption among internal building uses, measures to obtain more information on these internal uses, and any saving measures already being implemented.

Secondly, a list of types of buildings and uses not currently following water saving programmes must be drawn up. Water saving measures must be implemented and monitored for a period of at least one year. Technical support from ACA, the Ministry of the Environment's General Directorate of Environmental Planning and other qualified organisms is desirable in this respect.

Finally, a pilot programme to reward water saving must be designed, based for example on a cost-benefit analysis of the various proposed measures (reduction in water rates/taxes, water vouchers, subventions, etc.). This pilot programme would be supervised by the water supply companies and by ACA.

A specific water law has been passed making the incorporation of water saving technology obligatory in new buildings.

3.2 Demonstration projects: Designing and building for water saving

CAT 21 is a governmental plan to optimise links between society and the Government of Catalonia (Generalitat of Catalonia). La Generalitat integrates his action around common, clear, and shared objectives. The governmental plan CAT"! is the tool that integrates multilevel desision-making and implement strategic vision in public management. Within the framework of CAT 21, a demonstration project has been approved recently: "Multi-Departmental Action Plan for the Promotion of Sustainable Construction and Use of Buildings".

This project aims to establish a model of sustainable public building for application in all departments of the Generalitat de Catalunya. Each ministry is applying sustainable criteria in its building projects. All apply water saving criteria. The aim is to establish benchmark standards for all building in Catalonia.

The various types of buildings involved in the demonstration project are:
- Offices
- Schools

- Court buildings
- Homes for the Elderly
- Residential buildings
- Water treatment plants
- Information Centre in a nature park
- Bus station
- National Library Archive
- Primary Attention Health Centre
- Hospital
- Students' residence and dining room
- Rural Agents buildings

This demonstration project will continue until 2007, gathering experience of design, construction and one year's maintenance of all these buildings. This will permit an assessment of the different innovations applied vis-à-vis traditional building practices, in economic, social and environmental terms.

The measures and systems being designed in the area of water saving are:
- Reuse of rainwater and grey water for toilet flushing
- Flow regulators and time-controlled taps to reduce consumption
- Recycling of rainwater for irrigation purposes
- Separation of rainwater and sewage
- Control of consumption and saving of supply and reused water

3.3 Encouraging water saving

We are also working to provide information and education to heighten public awareness of the need to save water. At present, we are running two campaigns: "Catalonia saves water" and "Sustainable Buildings".

The "Catalonia saves Water" campaign, which has now been in progress for a year, aims to improve efficient domestic water use and saving in Catalonia. The campaign is based on an agreement between the Catalan Water Agency and Ecologists in Action and requires total funding of 430, 000 €, paid by the Agency.

The campaign comprises five stages:
- Research to determine the present water consumption of the different types of residential building (more than 4,000) in three municipal areas with different water consumption patterns: Santa Perpetua de Mogoda (metropolitan municipality with average domestic water consumption of 126 l per person per day), three districts in Barcelona city and Torredembarra (coastal tourist centre).
- Application of the campaign with preparation of the kit and measuring system
- Evaluation of results
- Dissemination of results

The most visible results are as follows:

- A guide to water saving in residential buildings with information on saving measures (domestic appliances and water saving technologies)
- Water saving chart for management of parks and gardens
- Leaflet for schools
- Catalogue of educational resources
- Campaign poster for residents' associations, local organisations and the business sector
- Certificates for compliance with the 20 water saving and water efficiency measures in business or commercial premises
- Public information sheet
- Guide for the public
- Mobile exhibition

4. Conclusion

The sustainable planning and building strategy in Catalonia includes a range of useful measures in the drive to achieve more efficient use of water in buildings. In addition to the progressive application of water saving criteria in urban planning introduced by the new urban planning law in July 2002, which will undoubtedly have a significant effect on building , action is taking place on three main fronts.

Firstly, construction of an information system on water saving in buildings in the Metropolitan Region of Barcelona, for effective control of the reduction in water consumption due to application of available technologies.

Secondly, the CAT 21 programme projects set out to test the environmental and economic advantages of the most advanced systems and technologies.

And finally, the "Catalonia Saves Water" campaign is establishing the basis for improved public participation.

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Collecting and reusing rain water in apartment buildings in France : importance of in situ experiments and their lessons

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Abstract

Collecting and reusing rain water in buildings are increasing in France. Mostly developed during these last years in individual houses, it now also concerns buildings for collective use (schools, public services, apartment buildings, industrial buildings) where some operations have been initiated. The regulatory frame in France is incomplete on these subjects, and the lack of official documents for appreciating validity and durability of projects and realized installations acts as a brake on the expansion of these techniques.

In this context, CSTB carries out since a few years researches consisting of in situ experiments on apartment buildings equipped with rain water installation reuse for toilet flushing. The aim at the end is to contribute to the definition of prescriptions based on design, execution and exploitation/ maintenance of installations. Detailed and long term (one year) monitoring has been carried out on two experiments in apartment buildings, one of 12 flats, the other one of 39 flats. Three aspects have been analysed : water quality, system performances as well as a sociological study (understanding of the project by actors and users).

This contribution makes a synthesis of principal lessons taken from these experiments. One result is the importance of carrying out in situ experiments for defining prescriptions leading to both sanitary safety and system performances. Another result is the importance of having clear specifications for design and construction as well as a good knowledge of local conditions (weather, roof characteristics). Two major aspects have also emerged : well managed acceptance of work done on one hand, correct operating and maintenance of installations on the other hand.

Keywords

Rainwater, water reuse, filtration, water analysis, water regulations, sustainable development.

1 Introduction

Since the beginning of the first installations designed for collecting and reusing rainwater, CSTB has been interested by the scientific, technical, economical and human aspects of these experiments. If reusing rainwater for garden watering or car washing needs simple installation, reusing it for WC flushing in individual houses or block of flats requires a more complex installation realized in accordance with sanitary regulations. But the regulatory frame in France is incomplete on these subjects and the lack of official documents to appreciate the validity and durability of projects and realized installations is slowing down the expansion of these techniques. In this context, the CSTB has been carrying out for a few year researches aiming in the end to contribute to the definition of prescriptions based on design, execution and exploitation/ maintenance of installations. One of these experiments on apartment building is here analysed in terms of diagnosis looked from the angle of water quality in the installation and global efficiency due to some technical choices. Another experiment on a secondary school is presented to show the advantages of such experiments on school buildings. In order to situate these experiments, this paper presents first the state of the art today in France, in terms of regulatory frame and a revew of existing installations.

2 State of the art

2.1 The French regulatory frame

Reusing rainwater in France must respect the existing regulations on water. The first level of these regulations is the European Directive 98/83/EC dated 3 November 1998 and transcribed in the French legislation by the decree 2001-1220. Therefore, concerning the supply of water for WC cisterns, article 1 of this decree seems to consider that this water shall comply with water intended for human consumption quality. But the same decree comprises other elements that suggest the possibility of a second water conveying system inside buildings, which could be used for WC cistern supply (see article 33). The consequence of this is that the French health local authorities usually decide whether certain rainwater reuse installations in a building can be authorized or not, according to the characteristics of the project.

2.2 Inventory of existing installations

It is difficult to give an exhaustive list of installations designed for rainwater reuse, especially in individual buildings. Therefore, a research work was initiated at CSTB and focused on collective buildings in France. The first results are compiled in reference 4 from which the following inventory can be presented.

2.2.1 Map

The map below shows the localization of the compiled projects, and for each of them the state of the project (*realized* or *to be realized*) and the type of building (see legend).

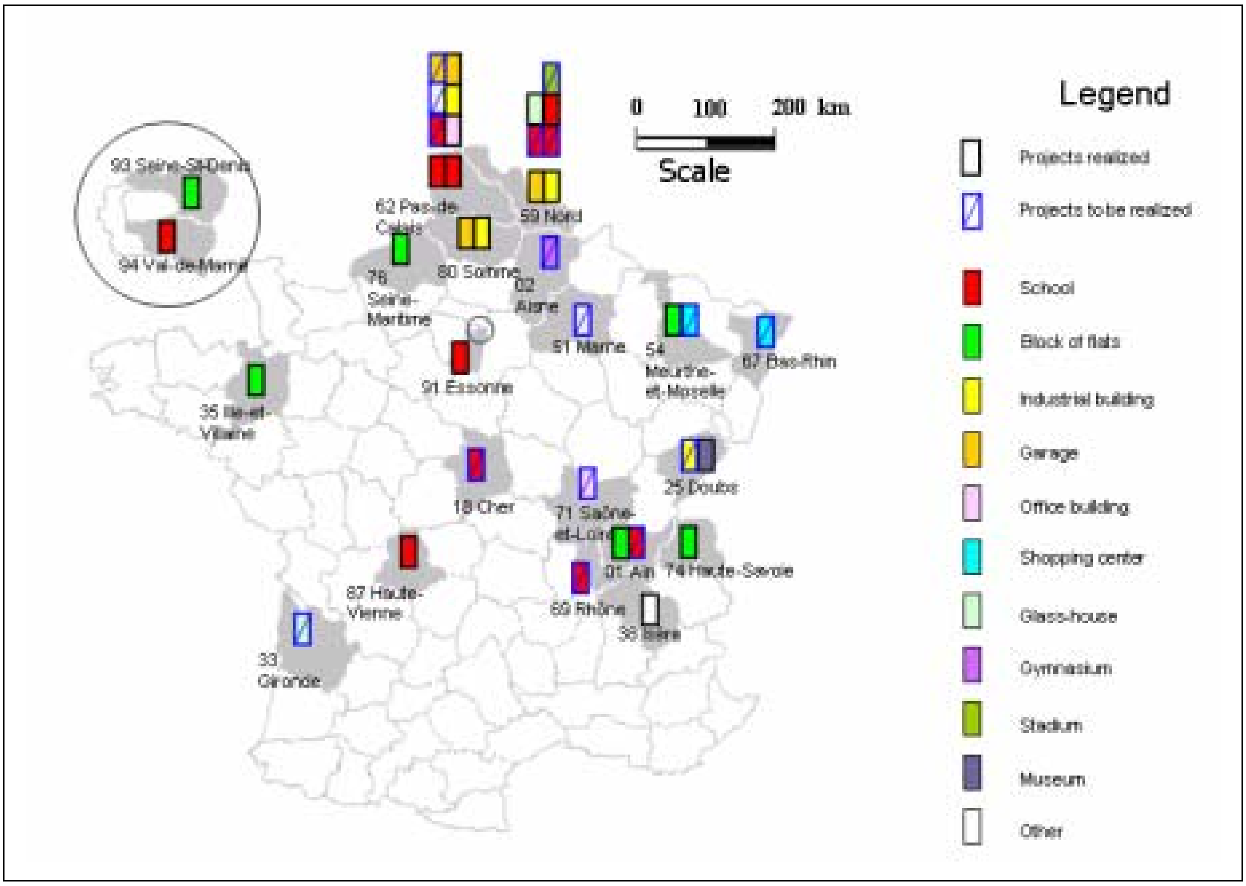

Figure 1 – Map of identified installations

38 projects have been identified: 22 are realized but are in use only for a few years, the 16 remaining are to be realized. Such data show that, in France, rainwater reuse in buildings for collective use is something quite new, with an increasing development dynamic.

As the map shows, most of the projects identified are located in the north part of France. But it is important to notice that this dynamic concerns also other parts of the country: other projects have been identified in 21 different departments (more than 20%).

20 of the 38 identified projects were initiated by a local community (region, department, or municipality). That means that local communities seem to be an essential agent to promote and spread this kind of projects.

2.2.2 Typology of the buildings

First of all, the rainwater reuse systems apply to new buildings as well as to older ones. At least 10 of the 38 projects apply to existing buildings. Two types of buildings particularly stand out.

- *Schools* (**12** projects, 6 realized), which can be subdivided into 3 categories: grade schools (depending on municipalities), junior high schools and high schools, this last category being the most important one (9 projects, 5 realized). The region « Nord-Pas-de-Calais » stands out with 4 projects (3 realized). These first realizations have aroused great interest from other regions and departments or municipalities, which are currently developing rainwater reuse projects in schools.

- *Blocks of flats* (**6** projects, all realized). The identified projects were realized a few years ago (between 1996 and 1999). It is amazing to notice that no project has been developed since then. It would be interesting to have an assessment of the 6 projects systems performance to check whether this kind of buildings is a good target or not.

2 other types of buildings also stand out.

- *Industrial buildings* (**4** projects, 3 realized). The projects listed are in the automobile industry and water jet cutting workshops.
- *Garages* (**4** projects, 3 realized). “Garage” here means a place where cars are maintained and/or repaired, whether this maintenance is a commercial activity or not.

Rainwater reuse in office buildings, shopping centers, gymnasiums and stadiums are very few in France, although these types of buildings might be interesting targets for rainwater reuse projects.

3 Study of two experiments

3.1 General

Reusing rainwater is today popular for two main reasons :

- an ecologic aspect of non wasting natural ressources,
- an economical aspect of water invoice reducing, although this aspect has to be taken in consideration with care, as far as financing the additional installation is of low profitability.

This approach is in conformance with the research theme of sustainable development and shall be analysed as a more global approach in the frame of water management on the parcel. The aim of the work started at HES department in CSTB is, in the end, to give to designers a technical guide permitting a correct achievement without risks for the user. It is, in fact, a matter of harmonisation between sanitary regulations and installation adaptations. If rainwater reuse poses no problem for garden watering or car washing, its use for WC cistern supply requires precautions, because, in this case, the piping system inside building has to be especially designed. Recommendations shall accompany this second piping system achievement, by preventing accidental pollutions of water intended for human consumption.

The work carried out was devoted to the observation of an experimental installation inside a block of flats and initial contacts with different actors. It also comprised discussions with regional councils, in order to study experimental installations in schools. A reflexion has also been carried out in order to harmonise in the future sanitary regulations with the achievement of non traditional installations.

3.1.1 Block of flats

Started in august 2001, this experimentation is supported with the help of Ministery of Buildings and a water distribution council. It is a good laboratory for pointing out requirements for realizing and following through such installations. It deals with a collective building of 39 flats. Water is collected on the building roofs, and will also be, in a next future, collected on garages roofs. Afterwards, water is stored in a double concrete tank situated in the building cellar. In case of unsufficient rain, water coming from the public mains is added via a small cistern (see figure 2). The inside part of the building is designed for a good identification of piping systems conveying rainwater towards WC cisterns, and, on request of the sanitary authorities in order not to let children drink accidentally this water, it is coloured.

Secondarily, the experiment shows, by accurate measurements of inhabitant water consumption, the the use of WC cisterns with two possible volumes is well integrated by users and is an important factor of saving.

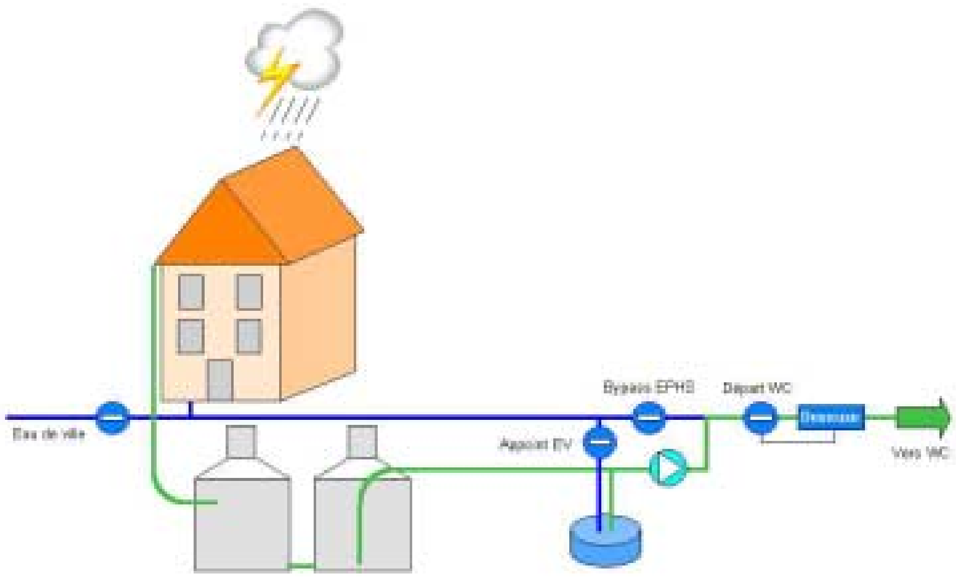

Figure 2 – Scheme of the installation

The quality of water is each month analysed at four different points : at the entry of storage tanks, inside storage tanks, after water pressurizer and at WC cistern supply. The last two points differ only by the colour, and are in dry period of the same composition as public supply water. Table 1 shows water composition in the storage tanks, at two periods of the year, one corresponding to a dry period where water quality is influenced by stagnation in contact with concrete (water 1), and the other one corresponding to a period where collected rainwater was in sufficient quantity so that stagnation in storage tanks was short (water 2). The following parameters are analysed :

- Total organic carbon (TOC) : representing pollution by organic matters (vegetal or animal decomposition). The measured values are negligible.
- Ammonia nitrogen : present in water 1 in a low quantity, possibly coming from a pollution of the public mains by agricultural products or an accidental pollution in the water retention cistern.

- Calcium : normally non present in rainwater, and introduced by the stagnation in concrete storage tanks (water 1).
- Magnesium : also normally non present in rain water, and also not contained in concrete.
- Total hardness : calculated here as the sum of calcium and magnesium concentrations.
- Alkalinity : normally poor in rainwater, with no evolution during stagnation.
- Total iron : in excess to the authorized value of 0,2 mg/L by the European Directive for water intended for human consumption. This high value is difficult to understand, because there is normally no ferrous matial in the reused rainwater installation. It can be due to an accidental pollution during maintenance process (ladder in the storage tank for example).
- Copper : the low concentration, measured here, shows that there is no dissolution in the rainwater installation pipes.
- Zinc : low value, because there is no galvanized part in the installation.
- Suspended solids : the low values shows the good quality of filtration.
- Temperature : this parameters reflects the season at which measurements are made. Even in summer (water 2), the temperature is 16 °C and shows that the storage in cellar in concrete tanks is positive, especially in consideration to bacterial growth.
- pH : rain water has a low pH (water 2) which is increased by the stagnation in concrete tanks (water 1).
- Conductivity : same comment as the comment for pH
- Dissolved oxygen : lower than the saturation value which is normally measured on tap water.
- Aerobic bacteria in 24 h at 37°C : the measurement shows a contamination in storage tanks in the stagnation period. This contamination is reduced during non stagnation periods, and situated bellow the limit given by regulation fo water intended for human consumption.
- Aerobic bacteria in 72 h at 20°C : same comment as the comment above.
- Total coliforms : here, the non stagnation periods shows an increased contamination, probably due to animal excrements either on the roof or at any place in the rainwater collection circuit.
- Faecal streptococci : the analyses do not show any streptococci at the considered period, although tey are present at other periods of the year.
- Pseudomonas aeruginosa : same comment as for aerobic bacteria.
- Yeast, mould : same comment as for aerobic bacteria.
- Salmonella : no developpement of this bacteria was found, probably due to the relatively low temperature in the storage tank.
- Legionella : same comment as for salmonella.
- Legionella pneumophilla : same comment as for salmonella.

	Water 1	Water 2	Parameters (maximum values) (European Directive or bathing waters regulations)
Physical-chemical parameters			
pH (pH units)	8,8	6,9	6,5 - 9 6 - 9 (bathing waters)
Temperature (°C)	9,7	16	25 °C
Conductivity (µS/cm)	286	115	2500
Magnesium (mg/L)	0,8	0,7	
Calcium (mg/L)	28	13	
TH (°F)	7	4	
Alkalinity (°F)	3	4	
Suspended solids (mg/L)	<0,1	<0,1	0
Dissolved oxygen (mg/L)	8,1	4,6	
Turbidity(NTU)	4,8	0,6	1
TOC (mg/L)	<0.03	<0.03	2
Iron (mg/L)	0,26	< 0,1	0,2
Zinc (mg/L)	0,05	0,05	
Copper (mg /L)	0,18	< 0,05	1
Ammonia nitrogen (NH_4) (mg/L)	0,057	0,027	0,5
Bacteriology			
Aerobic bacteria at 22°C (colonies per 100 ml)	lawn	56/mL	100/mL
Aerobic bacteria at 37°C (colonies per 100 mL)	lawn	4/mL	20/mL
Yeast/mould (colonies / 100mL)	15	0	
Pseudomona aeruginosa (colonies/100mL)	lawn	0	0/250 mL
Salmonella (colonies/100mL)	0	0	0/5 L 0/1 L (bathing waters)
Total coliform bacteria /100 mL	30	1800	0/100 mL 10 000/100 mL (bathing waters)
Faecal stroptococci (colonies/100mL)	0	0	0/100 mL
Legionella (UFC/L)	< 50	< 50	

Table 1 – Water analysis parameters

During the last year, an assessment of the experiment on this building was made. From this assessment, we learnt that the efficiency of the system was not the same as the theoretical efficiency initially calculated. This observation shows us the importance of the roof parameters such as geometry, surface, slope and nature of materials. The experiment has shown that the roof efficiency was comprised between 25 % and 30 %.This leads us to consider as being of great importance the following actions :

- monitoring of local pluviometry and regular cleaning of pluviometer, so that the potential quantity of reusable water can be correctly appreciated,
- consideration of the influence of manholes at drainpipe base, in particular the water seal which has the advantage of constituting a first clarification level, but the disadvantage of eliminating water in low precipitation period especially when evaporation or leaks are possible,
- correct design and adaptation of filters to this rainwater reuse (water seal, choice of filtering element and its positioning). Tests for checking the predicted performances shall be carried out. In particular, their "self-cleaning" characteristic has to be verified in the in situ conditions,

- correct design of piping system in order to drain towards storage a maximum of collected rainwater,
- necessity to create maintenance and regular cleaning procedures and to carry out a written registration of all operations whoever is appointed for realizing them.

Figure 3 - Manhole upstream storage cisterns

Figure 4 – Filter element

Figure 5 – Filter trap

3.1.2 School

This application is particularly interesting, as far as sanitary installations of schools are mainly destinated to flush toilets and where an adaptated and competent staff carries out supervision and maintenance, minimizing in this way the risk of misplaced additions capable of putting into contact a reused rain water with a water intended for human consumption. Furthermore, it concerns buildings having generally big roof surfaces and where sanitary equipments are grouped together in order to build blocks. All this makes that this building type leads to predict an economical efficiency of rainwater reuse greater than the efficiency estimated for housing.

One example is a grammar school in Calais (north of France), build in 1998. This grammar school is concerned by a "High Environmental Quality" process, which has the scope of assuring that the building protects environment, uses economical and renewable energies and favours well being and health. In this example, the rainwater collecting and reusing system is integrated in a global logic of rain water management all over the site. The main use of rain water is to suppy sanitary blocks of the grammar school. However, the collected water is widely used for garden watering and machinery washing. Over the overall usage, more that three quarters are destinated to WC's flushing.

Figure 6 – Storage pond for water to be reused

Figure 7 – Collecting roof for rain water

The installation consists of a chloration apparatus situated upstream of storage cisterns, a storage composed of 2 cisterns of 2 m^3 each, two pressurisers delivering a pressure level situated between 4,5 and 5.
The experiment is interesting, as far as all water needs estimated to be covered by rain water reuse are covered. In this experiment also, the risk of algae growing has been eliminated by the installation of chloration upstream storage cisterns. Another favorable element is the absence of WC cisterns (presence of pressure flush valves), eliminating all acces to collected water.

Figure 8 – Chloration system

Figure 9 – Storage tanks

4 Conclusions

Operating rainwater reuse in collective buildings shows the benefits that accompany this way of participating to sustainable development. Studying the different elements of such installations, and particularly the assessment of the experiments described in this paper, has lead to the following observations :

- to realise significant water savings, a good accurate knowledge of local pluviometry is necessary,
- a buried storage, or a storage in a cellar, is a good choice in order to have a correct water temperature so that no bacterial growth happens (we have not observed the presence of legionella in the studied installations),
- although a long stagnation period, when rain is missing, leads to a modification of collected rainwater composition, the quality of water distributed in the WC cisterns supply system is not far from having the quality of water intended for human consumption. In the most unfavourable periods, water quality is far reaching the quality criteria of bathing water,
- due to the fact that the measurement of bacterial parameters is sometimes difficult and that the results of such measurements are not easy to understand, a continuation of the water quality survey is necessary,
- the survey of the installation and its maintenance is of great importance.

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6 Author presentation

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Evaluation of the performance of wastewater disposal system according to the environmental management system adopted on an industrial building

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Abstract

Alternative wastewater disposal in industrial buildings according to Environmental Management System (ISO–14000) requirements has been presented growing importance by the need of reuse and conservation of the water, and also because the protection of the Environment. Thus this work intends to do a technical approach to evaluate the performance of the solution adopted by an Industrial Building to treat its sewer effluents.
The aim of this work is evaluate the quality of this water and verify its level of treatment, obtaining the performance rates after a year of continuous use for guarantee the preservation of groundwater and allow the water reuse. By the results analyze we will obtain the requirements to future actions and if necessary to improve the Environmental Management System implanted there.

1. Introduction

On this present study the term wastewater reuse will be considered only like water reuse because the wastewater has already been used before as drinkable one.

However as known by METCALF, EDDY, (1991), wastewater reuse is made by treated water. Following the same author reuse can be direct an indirect, drinkable water or undrinkable, planned or not planned.

The direct reuse means to course the treatment wastewater to its local use, while the indirect one needs a passage through an intermediate way for the treatment of wastewater, which in this case is the natural waterbody. The drinkable reuse is when the treatment wastewater responds to the drinkable water requirements, and can be used as drinkable water. These requirements cannot be attended at undrinkable reuse. The planned reuse has a well-planned constant monitoring system of the wastewater treatment. If occurs an accidental reuse it is known by unplanned reuse.

Another suitable classification could be micro and macro extension reuse. The reuse of micro extension will be the one related to small installations like buildings, industries, and joints ownership. However the reuse of macro extension will be related to watershed and subbasins. Generally, the micro extension reuse is management by private entities, while macro extension reuse is a public entities responsibility.

Due to the main practical objectives of reuse are:

- Water conservations of drinking-fountain
- Environmental Control

A suitable way to preserve water from drinking-fountain is reusing water for a less important uses or not uses water with more quality in cases that require less quality. Related to environmental control, the positive purpose of reuse is to decrease the wastewater volumes discharged on drinking-fountain. (FRIENDLER, 2001).

The water conservation measured by the reuse is executable mainly in function of natural demand. This demand is composed by agriculture, industries, parks and public cleaning, buildings and others possible users. For example, agriculture uses 70% of the freshwater of the world, while domestic users are responsible for 8% of this total. And industries use 22%. (MACEDO, 2001)

Based on all this possibilities we have to emphasize the growing importance of an adequate management of water reuse. Many programs are developed to constant improve reuse actions.

It is important to remember the statement of planning and management presented at EVANS et al (1989). Referring to the planning it is presented:

1. Purpose definition of reuse project
2. Obtainment of data base
3. Market evaluation
4. Grant alternatives
5. Alternative analysis
6. Preparation of report with implementation plan

For management, the purposes are:

- An implantation plan
- An institutional arrangement
- Administrative proceedings
- An operation management program

These statements can be proved by many practices in the national and international scenario. FRIEDLER (2000) presents a case study of Israel where the reuse is considered an action of local water management system. The author considers reuse water like a new water resource and emphasizes the agriculture as its main user. And also comment the importance of reuse to protect water resources associated with economic benefit.

ANGELAKIS, BANTOUX (2000) present that for north countries associated to EUREAU, the actual priority is not to increase the water supply through reuse, but to improve water resources protection. For south countries, treated wastewater is very useful to the agriculture. Those authors emphasize that reuse must be considered in reports, plans, for the sustainable use of water.

HIGGINS et al (2002) has an interesting study too. It presents the result of a research made with users and concessionaries, to evaluate their worries related to reuse and, to identify signs to improve research on this area. This work presents a technique of research that is extremely suitable to the user's characterization.

The main purpose of this study is to evaluate the performance of wastewater disposal system, on an industrial building, with objectives of reuse and groundwater protection.

2. Methodology

An electronic industry manufactory of energy distribution systems, established at northeast of Brazil, adopted a treatment system of wastewater compatible with the local needs and the purpose of water reuse according the requirements of theirs Environmental Management System applied to its Environmental Program, even the needs of conservation, reuse and rational use of water. The environmental objectives expected were to reuse water for green areas irrigation, external area wash and as main purpose avoid environmental impact on the final wastewater excedent disposal, even because it should be discharged on the nearest river.

It is important to comment that the wastewater produced by this industry used in this case study, is composed only by sewer from restrooms and industrial kitchen that serves the plant, because there is no use of water on the industrial process.

The concern from the directory of the industry was to avoid the soil contamination. After the initial environmental report, which concluded that, the soil was in perfect conditions, which means, there was no contamination. This report was made before the implantation of the industry, and the main purpose is to maintain the same perfect conditions of the soil.

Based on this scenario, were developed periodical proofs to verify the conditions of groundwater and water for reuse, not only after the treatment but also on the underground through monitoring wells inspections system.

2.1 Plant characteristics

2.1.1 Physical characteristics of the building

As said before it is an electronic plant which main physics characteristics are:

Land Area	30,570.00 m^2
Building	5,525.21 m^2
Production	3,855.66 m^2
Canteen	550,00 m^2
Office	1,119.55 m^2
Entrance Gate	150.00 m^2
Others	4,050.00 m^2
Green Area	20,844.79 m^2
Water Tank	70.00 m^3
Parking	30 cars

2.1.2 The main characteristics of building population

The main characteristics of staff are:

- Administration people 42 persons
- Productions people 600 persons (two shifts)

Considering that 70% are women we have:

- 450 Women and 192 Men

2.1.3 Wastewater treatment system

The wastewater treatment system used was a composition of septic tanks and anaerobic filters, calculated to allow obtaining water of reuse capable to be used in activities like gardens irrigation. And also the water from the end of this system that goes to the surface and the underground, could attend the requirements without causing any impact on groundwater and soil.

The following figure shows system scheme, which main elements are:

0 – Distribution

1 – Septic Tanks

2 – Anaerobic Filters

3 – Reservoir

4 – Water Exit

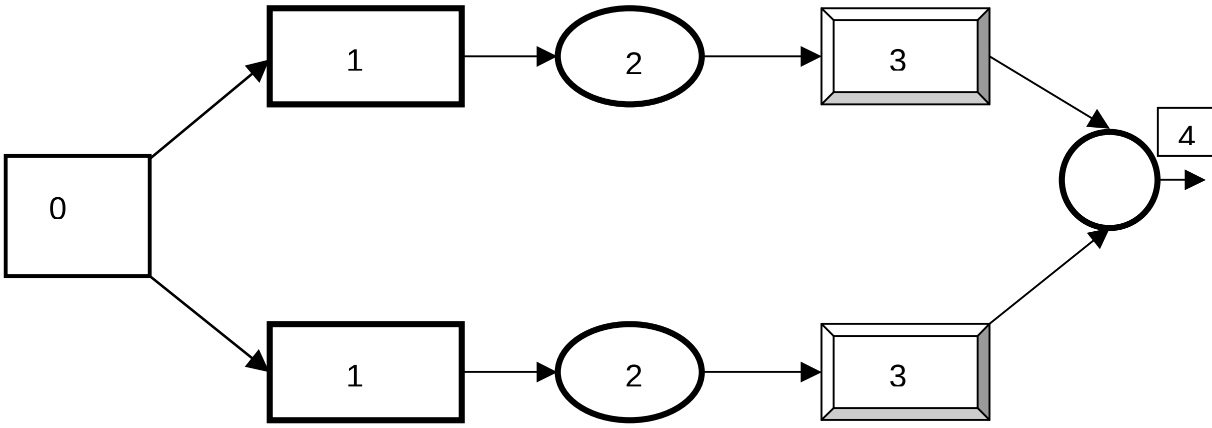

Figure 1 – Treatment system of wastewater

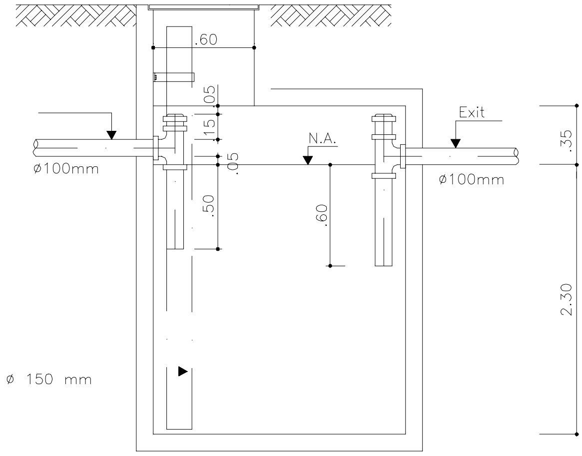

Figure 2 – Septic Tank

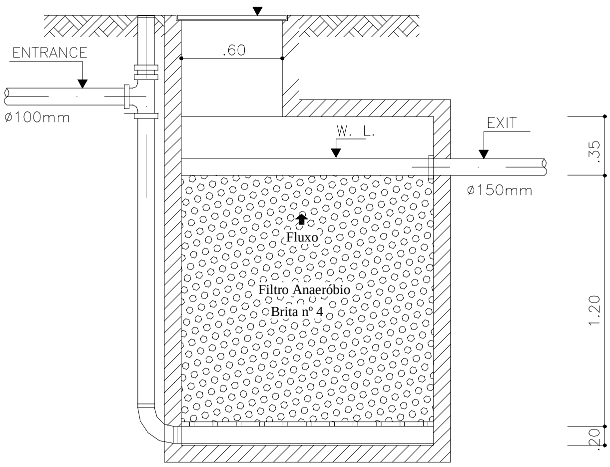

Figure 3 – Anaerobic Filter

3. Quality requirements adopted

3.1 Groundwater quality requirements

The requirements used to analyze the groundwater quality were those suggested by CETESB –Companhia de Saneamento Ambiental do Estado de São Paulo (2001) and Ministério da Saúde – Brasil (Portaria 1469/00), as well as the conceptual background used in this work. The table below shows these requirements.

The results obtained showed the quality of groundwater before the activities of the company in that site starts. After the of activities start new tests will be done to verify the quality preservation of the groundwater quality.

The groundwater was collected in three monitoring wells installed at the plant area, and the tests have been repeated each six months, to preserve the quality of the groundwater.

3.2 Treated water quality requirements

Considering that the water obtained after the treatment is assigned to reuse and final disposal we used for the groundwater where drinkable was required, because this was a condition to be maintained for area preservation.

As the treatment water exit is assigned to green areas irrigations and for pavements and sidewalks washing, requirements of EPA – Environmental Protection Agency, were adopted showing properly to the intended control.

The tests will be made each two months; the strategy of monitoring is the following:

- Collected two samples per each of three wells,
- The major values obtained in all tests will be taken as final result.

To guarantee water quality for reuse and groundwater integrity were developed procedures of collection, analysis and corrective actions. In case of the parameters values tested suffer any significant changes.

Apart from groundwater, there was no way to do the tests before treatment began. The first sample studied was taken two weeks after the beginning of operation system and then each sixty days.

4. Obtained results

4.1 Obtained results of groundwater preliminary test

The results presented next table are those obtained by the test done before the start of plant activities aiming to find out the real conditions of the groundwater at the plant area.

To proceed these tests three monitoring wells were made and will be used also during all the time to control the quality of groundwater at the plant area.

The preliminary test results showed that the local groundwater is drinkable, but contains high-level concentration of iron (Fe) fact that usually occurs in tropical areas like that.

Table 1 – Groundwater test results

Analyzed Parameters	**Preliminary Test Results (a)**	**Monitoring Test Results (b)**	**Adopted Standard Values** MS– Brasil (Portaria 1469) CETESB (2001)
pH	5.1	6.1	6.0 – 9.5
Dissolved Solids	70.6 mg/L	67.5 mg/L	1,000mg/L
Na	23 mg/L	23 mg/L	200 mg/L
Fe	1.03 mg/L	1.02 mg/L	0.3 mg/L
Al	< 1.0 mg/L	< 1.0 mg/L	1.0 mg/L
Mn	< 0.1 mg/L	< 0.1 mg/L	0.1 mg/L
Pb	< 5 µg/L	< 5 µg/L	10 µg/L
Cd	< 1 µg/L	< 1 µg/L	5 µg/L
Ni	< 0.02mg/L	< 0.02mg/L	0.05 mg/L
Cr	0.01 mg/L	0.01 mg/L	0.05 mg/L
Zn	0.01 mg/L	0.01 mg/L	5 mg/L
$N\text{-}NO_3$	< 0.3Mg N/L	< 0.3Mg N/L	10 Mg N/L
Ammonia	< 0.1 mg/L	< 0.1 mg/L	1.5 mg/L
Sulfate	< 0.7 mg/L	< 0.5 <mg/L	400 mg/L
Chloride	59.7 mg/L	56.7 mg/L	250 mg/L
Phenol	< 0.04 mg /L	< 0.04 mg /L	0.001 mg/L
Fecal coliforms	absent	absent	Absent
Total coliforms	absent	absent	Absent

As can be seen, the monitoring results after the activities began (b), no significant changes on the results were found, which means that there is no contamination of groundwater and the sewer disposal system is working in perfect conditions.

4.2 Obtained test results of treated water

The following table shows the average values obtained during 12 months monitoring of the system.

Table 2 – Reuse water test results

Parameters	Adopted Standard Values		Test Results
	EPA (Urban)	CONAMA	
Color		75	70
pH		6.0 a 9.0	6.8
Turbidity (NTU)	< 2.0	100	10
BOD (mg/L)	10	10	8
Total Coliforms (MPN / 100 ml)	0	2.10-4	Absent
Fecal Coliforms (MPN / 100 ml)		4.10-3	Absent

5. Conclusions

Resigned as seen at Table 1 presented the average values obtained during the 12 months monitoring period did not presented any significant changes of groundwater quality which means that the groundwater was preserved and anaerobic filters and tanks system were efficient due to the performance expected.

Related to reuse designated water the same occurs at Table 2 because the average values obtained at the same period are compatible with adopted parameters, except EPA turbidity, which means the water can be used for activities like green areas irrigation and external areas wash with total security.

The monitoring will continue until the values reach limits parameters or exceed them. In this case corrective actions will be promoted on the system according to the preview tasks at the original project.

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Greywater characterization in residential building to assess its potential use

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Abstract

Reducing the water demand is one of the alternatives for increasing the capacity of granting the population and optimizing the life span of the water supplying systems. However, it must be a reduction that does not imply in retroceding regarding comfort and sanitation safety conditions that have already been acquired. In this way, the responsible offices for the public water supplying are currently searching for the exploitation of new water springs, and few are searching for the implementation of operational control programs with control of water loss and leaking reduction to sustain the increasing demand. However, as the exploitation of new water springs tends to be each time more expensive and as the water loss rates in distribution pipes have already reached marks that are universally considered reasonable, the actions in search of the reduction of the consumption levels in residential buildings have become priority. According to this context, the aim of this work is to present a case study where the use of greywater and the impact on the supplying water springs are assessed, with the intention of evaluating the potentialities of the conservation activities of the water springs. To do so, the supplying system of Curitiba and the surrounding cities in Paraná, Brazil, are used as case study.

1 Introduction

The natural water source is taken as “commodity” of the 21st century. This is due to the world awareness that water is a finite source and that its availability, either qualitative and quantitative, is subjected to conditions of the urban environment. Such conditions are related to the human attitudes towards the water resources, which, inevitably, cause its degradation and consequently end up impairing the flow of domestic, industrial and agricultural consumption.

According to such conditions, countless international meetings have treated the issue of the right of drinkable water accessibility and the sustainability of the water source. One of the first conferences to approach this issue was the Mar Del Plata Conference (1977) that approached the accessibility to drinkable water regarding quantity and quality, to supply the basic human needs. In 1992, the United Nations Conference on Environment and Development in Rio de Janeiro presented the concept of

Sustainable Development, which, as essence, refers to the exploitation of resources in way of attending the current and future generations.

As the result of this Conference, the Agenda 21 emerges as an official document that instructs the actions, the aims and the means of programs implementation that are compatible to the integration of economic development to the environment protection, with the aim of reaching what the concept of Sustainable Development extols. Together with several themes, the Agenda 21 proposes in its chapter 18, actions to be developed to the sustainable use of water.

The ways to promote the sustainable use of water can happen through the conservation actions, which cover the rational use of water and/or the use of alternative sources. It is important to mention that the application of the conservation actions can revert to the water economy in the water resources of the public supplying and building systems. Regarding the cold water systems in buildings, the rational use of water covers actions of leaking control, implementation of personalized measurement systems, user awareness, among others.

It is important to mention that studies that demonstrate the dimension of physical loss in sanitation apparatus, as, for example, the research developed by De Oreo et al. (1996), *apud* OLIVEIRA (1999) on the water consumption in sanitation apparatus in Boulder, Colorado – USA. Such investigation identified that leaking represent 11,45% of the total water consumption in a residence. Other quantification of such losses was developed by the Water Company from Massachusetts (Massachusetts Water Resources Authority, 1996), *apud* OLIVEIRA (1999), in which amounts of water loss in showers, faucets and low-flow toilets were collected.

To minimize such losses and combat the waste, some countries have adopted water flow management measures. For instance, in Mexico City, 350,000 toilets were replaced by the 6-litre model, what led to a water economy capable of attending the needs of 250,000 residences. In Brazil, the Rational Water Use Program, PURA, developed by SABESP (Sanitation Company of São Paulo State), in partnership with USP (São Paulo University) and IPT (Institute of Technological Research in São Paulo), was applied in Toufic Jouliam State School, where the consumption per capita, formerly 23 liters per student, was reduced to 4,61 liters per student, thanks to actions of leaking detection and correction in water supply in buildings.

As for the use of alternative sources as way of water conservation actions, there is the utilization of rainwater and reclaimed wastewater for not noble purposes. The use of reclaimed wastewater for not drinking purposes, the aim of this work, is mentioned on Agenda 21 in its chapter 18, and also mentioned by the World Health Organization, which cites the substitution of drinking water by lower quality water, when suitable.

Specialists on environmental planning have also stated the reuse of lower quality products from human activity as one of the best alternatives to combat the pollution problem, as the reuse of lower quality products decreases the pressure on the environment, either in its role as water spring or in its role as effluents receptor. In such way, it can be understood that residual water from sanitation apparatus, except the one from the toilets, can be a lower-quality product from human activity, capable of being reused. In other words, the reuse of greywater.

According to such context, and with the objective of evaluating the potentiality of water springs conservation activities, this work aims to present a case-study where the greywater use and the results on the supplying water springs are evaluated. To do so, the supplying system of Curitiba and surrounding cities in Paraná, Brazil is used as background.

2 Considerations on the greywater

The greywater is defined as all drain water in a residence, excluding the one from the toilet (GERBA ET AL., 1995). In other words, it is the residual water that comes from the faucet, shower, washing machine or washing basin, and the sink. However, the greywater in kitchen sinks can be excluded for presenting oil, fat and grease that are difficult to be removed in a filtering process, as well as for presenting microorganisms (COBLE, 1996). The alternative uses of greywater for not drinking purposes can be:

- Irrigation;
- Toilet flush;
- External use such as car or floor washing;
- Groundwater recharge;
- others.

The use of greywater is already performed in some states in the USA. For instance, the Arizona State, which, through the Department of Environmental Quality (DEQ), controls the domestic use of greywater, approving the project and the system construction. This state, also presents a specification to the greywater use. For the superficial irrigation, the quality of the greywater must reach standards as concentration of fecal coliforms and residual chlorine (WATERCASA, 2001).

2.1 Quantitative Aspects Regarding Greywater Use

In this work, the use of greywater to promote the sustainable use of water is suggested for not noble purposes, as toilet flush and external use. Such utilization are first mentioned because the toilet flush is responsible for the biggest consumption in a residence, according to OLIVEIRA (1999). This consumption can be 41%, according to QASIM, SYED (1994) *apud* TOMAZ (2000). And for the external uses, this same author states 3.0% in floor washing and 1.0% in automobile washing. Therefore, drinkable water consumption for such uses reach 45% of the total water consumption in a residence.

Engendering a brief simulation at this point, it is indispensable to estimate initially the volume of greywater produced by the shower and faucet uses. Considering the drinkable water consumption used in the shower to be 0.10 l/s, according to NBR 5626, and that such appliance is used once on a daily basis for 10 minutes, as a result there is a 60 l/day produced volume. Considering, therefore, that the consumption of drinking water used in the lavatory is 0.10 l/s, according to NBR 5626, and taking that such appliance is used 5 times a day for 30 seconds each time, there is the 15 l/day produced volume as a result. Thus, the volume of greywater produced volume can reach 75 l/day. On the other hand, the toilet flush uses 10 to 12 l/s of drinkable water when operated, approximately. Assuming that it is used 4 times a day, the consumption is 48 liters of water. It is then noticed that if the greywater can be used instead of using the drinkable water in toilet flush, there will be the possibility of a 48 liters saving of drinkable water, and still leave 27 liters for other not noble uses.

2.2 Qualitative Aspects Regarding Greywater Use.

Considering the greywater as a effluent, special attention must be paid to its physical, chemical and microbiological qualities, to what relates to the public health issues. That's because studies on greywater have shown the presence of total and thermotolerants coliforms, which indicates the presence of pathological microorganisms. As a result, the use of greywater must be done in a planned way, in order to avoid sanitation risks.

Regarding such sanitation risks, it is important to consider that these risks are admitted to be associated to the use of contaminated water. This way, in the utilization of greywater these risks must be investigated and the usual methodology for such action consists on Beta-Poisson distribution.

In such context, it is important to quote the research presented by WATERCASA (2001), where the risk of greywater use to irrigation means is evaluated. In this study, the presence of fecal coliforms and streptococcus was verified, which showed the possibility of presence of patogenic microorganisms, such as *salmonella, shigella* and virus. Thermotolerants coliforms were detected in all analysed samples, and while analyzing the behaviour of their concentration, it was observed that such concentrations presented seasonal variations, beyond the fact that such concentrations are larger in residences with children, animals and underground tanks. It is important to mention the specific case of *Escherichia Coli*, which was detected in all researched residences. As for the protozoans, the study showed that they were not detected, although the number of samples was reduced. Table 01 shows the observations described here.

Table 01: Concentration of Fecal Coliforms in Greywater according to the building features

Building Features (Home) *	Average Values of Fecal Coliforms (MPN / 100 ml)
With Children (0-12 years old)	$4{,}99.10^3$
Without Children	$4{,}25.\ 10^3$
Underground Tanks	$1{,}82.10^4$
Superior Tanks	$6{,}43.10^2$
With Animals	$2{,}12.\ 10^3$
Without Animals	$3{,}34.\ 10^4$

* *Adapted table of data presented in WATERCASA (2001)*

This same work presents risk in fact estimated by the Beta-Poisson distribution, and it was analyzed that in buildings that use greywater for irrigation, the risks of contamination were superior than 1.10^{-4} for year of exposition. It is also interesting to note that in buildings that use the greywater from kitchen sink, the risks of contamination increased conspicuously. Homes with children also presented unexpected facts, as it was noticed that there can be additional risk according to the presence of children, mainly those younger than 6 years of age.

3 Methodology

This research was developed in the city of Curitiba, Brazil, where greywater was collected and analysed in thirty residential buildings, with the same social-economic extract, with the aim to be characterized in its physical, chemical and biological aspects. The collected greywater was only taken from shower and lavatory.

The physical-chemical parameters analysed were temperature, color, turbidity, pH, dissolved oxygen (DO), total and free chlorine, total phosphorus and biochemical oxygen demand (BOD), while the biological parameters were total and fecal coliforms. The temperature, pH, DO, total and free chlorine were measured during the collection. The others were analysed at *CEPPA*, from *Universidade Federal do Paraná* (Federal University of Paraná – UFPR). All collections and analyses followed the collections of Standard Methods, 20th, 1998.

4 Results and Discussion

4.1 Greywater Observed Characteristics Under Study

The minimum, average and maximum values found for the collection in the thirty buildings are in Table 02:

Table 02: Greywater Concentrations

Parameters	Concentrations		
	Minimum	Average	Maximum
Temperature (^oC)	21,5	24	27
Color (Hz)	9,0	52,30	300
Turbidity (NTU)	1,97	37,35	189
pH	6,7	7,2	8,5
OD (mg/L)	2,67	4,63	5,92
Free Chlorine (mg/L)	0,0	0,0	0,8
Total Chlorine (mg/L)	0,0	0,0	1,0
Total Phosphorus (mg/L)	1,72	6,24	38,49
BOD (mg/L)	16,67	96,54	286,93
Total Coli. (MPN/100 ml)	5,1	11.10^6	$1,6.10^8$
Fecal Coli. (MPN/100 ml)	2,0	1.10^6	$1,6.10^7$

These results show meaningful variations found for almost all parameters, except the temperature. For instance, there are BOD values varying approximately from 17,00 mg/L to almost 290 mg/L. Another distinction related to the variation of the values found, are the fecal coliforms that varied from 2,0 to 1,6 . 10^7 NPM/100 ml.

4.2 Comparisons of the Result Values to the Usual Values in Domestic Wastewater

Comparing the domestic wastewater to the greywater by confronting the values of some important parameters, some meaningful issues were verified, according to Table 03.

Table 03: Comparative Table between Greywater and Wastewater

Parameters	Greywater	Wastewater[1]	
		Weak	Average
Temperature (^oC)	24	--	--
Color (Hz)	52,30	--	--
Turbidity (NTU)	37,35	--	--
pH	7,2	--	--

OD (mg/L)	4,63	0,00	0,00
Free Chlorine (mg/L)	0,0	--	--
Total Chlorine(mg/L)	0,0	--	--
Total Phosphorus(mg/L)	6,24	5	10
BOD (mg/L)	96,54	100	200
Total Coli.(MPN/100 ml)	11.10^6	--	--
Fecal Coli.(MPN/100 ml)	1.10^6	--	--

1. *Average Values found Brazil*

Regarding the BOD, it is noticed that the respective average value found for greywater corresponds to the value of weak domestic wastewater. Or, in other words, the greywater presents considerable organic matter under the utilization perspective, according to what will be observed below. The average values of total and fecal coliforms detected are also considerable, when comparing to the respective values of domestic wastewater.

4.3 Comparison to Other Studies

With the aim of comparing, Table 04 presents values of greywater parameters found by researchers from several countries. As for the variation observed in the parameters, it is noticeable that the other authors also verified meaningful oscillation in the values. For the turbidity, pH, total phosphorus and BOD, it is understood in this analyses that the average values found follow reasonably those found by other authors. However, it is noticed that the total and fecal coliforms concentration found in this research is meaningfully superior, by comparing it to the concentration found in CRISTOVA-BOAL (1996) and SURENDRAM, WHEATLEY, *apud* ERICSSON et al. (2001) and JEPPERSEN et al. 1994, *apud* Draft Guidelines for the Reuse of Greywater in Western Australia, 2002.

Table 04: Comparative Table of Greywater Characterization among other authors

Parameters	Concentrations			
	Cristova-Boal et al. (1996)	Wheatley et al. (1998)	Jeppersen et al. (1994)	Santos[1] et al. (2003)
Temperature (^oC)	--	--	--	24
Color (Hz)	60 - 100	--	--	52,30
Turbidity (NTU)	60 - 240	92	22 - 200	37,35
pH	6,4 - 8,1	7,6	6,6 - 8,7	7,2
OD (mg/L)	--	--	--	4,63
Free Chlorine (mg/L)	--	--	--	0,0
Total Chlorine(mg/L)	--	--	--	0,0
Total Phophorus(mg/L)	0,11 - 1,8	--	0,6 - 27,3	6,24
BOD (mg/L)	76 - 200	--	90 - 290	96,54
Total Coli.(MPN/100 ml)	500 - $2,4.10^7$	6.10^6	--	11.10^6
Fecal Coli. (MPN/100 ml)	170 - $3,3.10^3$	600	6.10^3	1.10^6

1. According to Table 02

4.4 Evaluation of the Greywater Utilization Potentiality

In this evaluation, it was admitted some criteria for water reuse presented on the Technical Document for the Second Seminar on Water Reuse in the Mediterranean (SSWRM) and by the Environmental Protect Agency (EPA), according to the utilization intended. Table 05 presents these qualitative criteria, besides the values found in this work, with the aim of evaluating the potential of the already mentioned greywater use.

Table 05: Table for the Evaluation of Greywater Use Potentiality

Parameters	Quality Criteria		
	SSWRM (residential)	EPA (urban)	Santos[1] et al (2003)
Turbidity (NTU)	< 2,0	< 2,0	37,35
BOD (mg/L)	-	10	96,54
Total Coli.(MPN/100 ml)	0,0	0,0	11.10^6
Fecal Coli.(MPN/100 ml)	-	-	1.10^6

1 According to Table 02

Therefore, it was verified that, through the SSWRM and EPA criteria, established for turbidity, BOD and fecal coliforms, the quality of greywater found in this work is not enough for the domestic and urban uses. The turbidity, which presents negative aesthetic aspects when excessive, also indicates the presence of pathogenic microorganisms as well as presenting an average value of 2,0 NTU, extolled by both references. The average BOD found also surpasses meaningfully the limits recommended. This is a problem as 96,54mg/L BOD values indicate a reasonable organic matter availability for the microorganisms, which can proliferate in a system of greywater utilization. As for the fecal coliforms, the SSWRM and the EPA recommend their absence for the residential and urban uses, respectively. The evaluated greywater does not suit such criteria.

5 Conclusion

The quality of greywater observed in this study indicates that it presents characteristics of a weak domestic wastewater, regarding organic matter concentration. Even so, the organic matter concentration is meaningful for the greywater utilization and, therefore, it is necessary an adequate system of organic matter removal. The turbidity and total and fecal coliforms concentration were also presented meaningfully, indicating that the system of suspended solids removal and desinfection must be predicted. The adoption of the water reuse criteria presented by SSWRM and EPA must, therefore, be discussed for the possibility of being used as reference in Brazil. The costs for attending such standards are high, which make the use of the greywater not feasible.

However, if the investment on water safety in the spring water is observed, such investment may be feasible. According to SANTOS, et al (2002), in a work developed for Curitiba and surrounding cities, it was verified that if only the population growth uses greywater for not drinking purposes, especially in toilet flushes and external uses, the economy of drinking water for the year 2010 is 929 l/s and for the year 2020 the economy is 1973 l/s. It is worth to highlighten that with the economy of 929 l/s for the year 2010, it is possible to supply a population of 722.187 inhabitants.

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8 Presentation of author (s)

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WATERLESS URINAL TECHNOLOGY: CASE STUDY

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Abstract

The perception of Hydraulic Resources scarcity has caused the development of technological and cultural actions improving water use by means of reduction of water consumption, maintaining the same activities that were previously performed by man and keeping the same quality. There is no way to practice Sustainable Development if the sectors of our society do not consider the Rational Use of Water. In Civil Construction, specially for building activities, sanitary fixtures are responsible for significant water use.– Urinal is an example of hydraulic equipment that has been wasting water through the years. Based on this fact and according to world water scarcity situation, new technologies have been developed for reducing the use of water in this sanitary fixture. This study presents not only the waterless urinal technology, but also its components and its operation characteristics. It presents also labor data collected, under controlled exposition conditions, and a practical case study that shows the application of waterless urinal in two– different restrooms in a University in Brazil. This case study presents information about system performance, its limitations and factors that interfere directly in the sanitary fixture performance. In laboratory, performance was evaluated by means of durability of components that needed to be replaced due to system use frequency. The objective of this study is to present a new technology that is growing worldwide to improve Civil Construction in order to get Sustainable Development.

Keywords

Waterless Urinal, water economy, Sustainable Development.

Introduction

Civil Construction supplies built environment for men. By means of sustainable construction principles it is possible to evaluate not only the impacts of plumbing systems for human life but also its importance.

This scenery creates expectation towards new products and new technologies not only to be employed in new buildings but also to improve the performance of old buildings. New technologies are developed to ensure this demand. Professionals are entitled to evaluate different products for the same purpose but with different operations to identify which technology is more adequate to the users needs.

The objective of this study is to present a new technology – Waterless Urinal System that is growing worldwide to improve the performance of the plumbing fixtures in order to achieve a sustainable development. This case study presents information about the Waterless Urinal System's performance, the factors that interfere directly in its performance its limitations.

Waterless Urinal

According to VICKERS(1), Waterless Urinal System appeared in Switzerland in 1890 and several different types of this system have been used in Europe since 1960. Since the early 1990's this system is being commercially used in USA. Nowadays, this system is found in many countries in its individual unit, but in the United Kingdom this system can also be found in collective units. Waterless urinal system is composed by the following components:

- Vitreous china (urinal fixture): receives and conducts by means of gravity the urine to the cartridge orifice. It has an appropriate internal curve in order to avoid urine to adhere to the china surface and also to help cleaning activities;
- Housing: plastic component that constitutes the transition between the urinal fixture and the cartridge. It receives the urine from the cartridge and conducts it to drainage system;
- Cartridge: plastic component that works as the system's trap. It is installed in the housing. The cartridge has two chambers linked to each other: one that communicates with the environment and other that accesses the drainage system.
- Sealant Liquid: fluid composed by a mixture of alcohols, biocide and dye. It is less dense than water and urine to remain in suspension within the cartridge;
- Appropriate tool for changing cartridge: plastic component used to remove or to install the cartridge in the housing;
- Optional component to cartridge protection: plastic circular shape cap, installed over the cartridge that enhances sealant liquid durability and protects the plastic surface of the cartridge.

Figure 1 shows the components of the system. Urine flows through vitreous china, passing through the sealant liquid to the drainage piping.

In the first chamber of the cartridge the sealant liquid is in suspension over the urine. Urine passes through the sealant liquid. The urine inside the cartridge ends up deteriorating. The sealant liquid prevents any odors resulted from this decomposition from escaping the cartridge. With the use, the urine may carry a small quantity of sealant liquid. The cartridge works also as a seal trap.

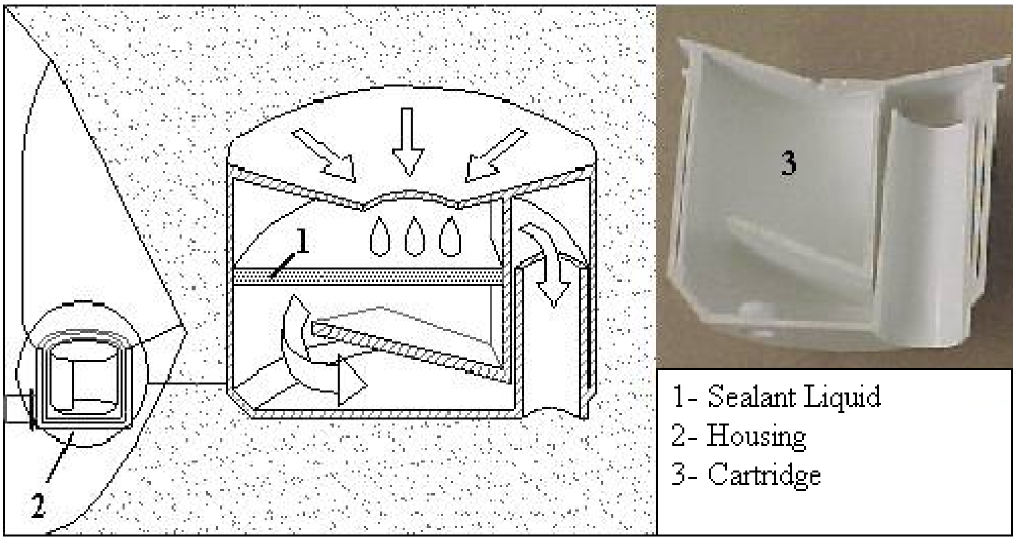

Figure 1 – Waterless Urinal System Components

The cartridge must be replaced when:

1. there is no more sealant liquid inside it; this can be noticed when odors escape from the cartridge; or
2. when urine does not easily flows through it, due to biochemical obstruction.

Waterless Urinal System requires proper cleaning procedures, their frequency depending on the number of users per day. The cleaning procedures of the urinal are:

- Remove all debris from the surface of the urinal;
- Spray urinal surface with a general cleaner purpose liquid;
- Wipe surface with a soft cloth or sponge until clean.

Some aggressive detergents should not be used because of the deterioration of the sealant liquid.

Water should not intervene in the cleaning procedures. Buckets of water should not be dumped into the urinals.

Methodology applied to evaluate Waterless Urinal Technology in Brazil

A methodology was developed in order to evaluate this technology according to Brazilian requirements. This methodology can be applied in any kind of sanitary fixture. The methodology was developed in four steps:

- Documental analysis and research;
- On site study;
- Laboratory studies and tests;
- Evaluation of results.

During the development of this methodology, many performance requirements were evaluated, which enabled to characterize Waterless Urinal System use in Brazil.

This paper will present the description and the results of the field tests.

Waterless Urinal Case Study

For the development of this study two restrooms were selected in the Civil Engineering Building - University of São Paulo. The characteristics of these restrooms are described below:

- Students' restroom: about 950 users/day;
- Professor's restroom: about 130 users/day.

Prior to the installation of the waterless urinal, the students' restroom had four collective urinals. After the intervention, five individual Waterless Urinals were installed. A horizontal branch was installed in order to collect urine from these five urinals and conduct it to an outlet. Figure 2 shows the mentioned configuration.

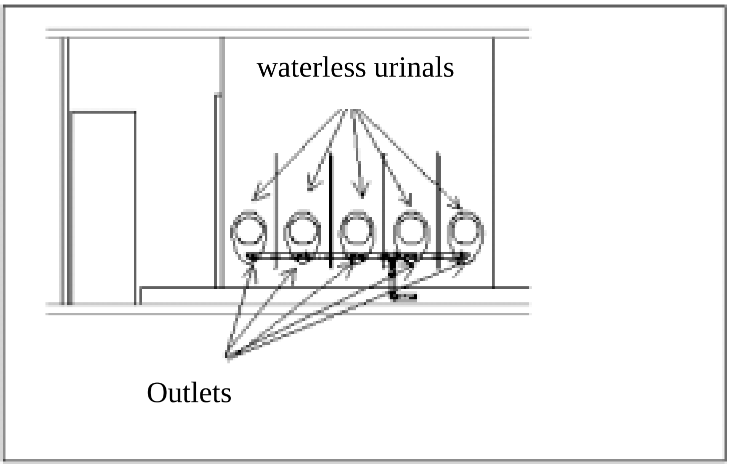

Figure 2 – Waterless Urinals installed in students restrooms

Prior to the installation of the waterless urinal, the professor's restroom had six individual urinals. Three waterless urinals replaced the old urinals. The discharge branch solution used was: vertical 50mm piping for each unit. Figure 3 shows this solution.

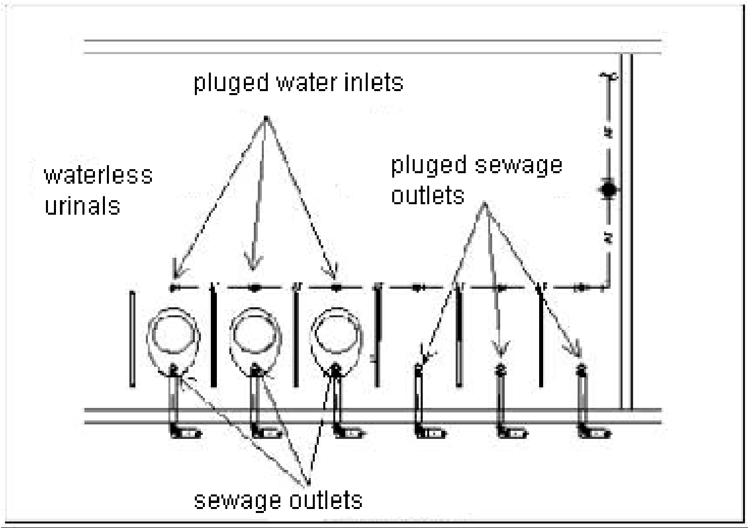

Figure 3 – Waterless Urinal in Teachers Restroom

A measurement system of urinal's uses was created in both restrooms. Metallic platforms with contact sensors were installed on the restrooms floor, in front of each urinal, according to Figure 4. The sensors were connected to a panel which registered each use.

Figure 4 – Measurement system - platforms with sensors

Results

By means of the measurement system, it was possible to quantify the lifetime of each cartridge in each individual urinal. In other words, it was possible to verify the cartridge's durability and performance.

The waterless urinal system has to have periodic maintenance, which includes the cleaning procedures and the replacement of the cartridges

Table 1 shows the summary of cartridges replacement occurred during the field study, in the student's restroom. The date of replacement of the cartridges and the number of uses in each urinal are presented below.

Date	Urinal 1	Urinal 2	Urinal 3	Urinal 4	Urinal 5
08/04/02	0	0	0	0	0
27/06/02	3471	3261	-	4089	-
27/09/02	2606	1379	-	-	-
04/11/02	-	-	8302	-	-
22/11/02	-	-	-	-	5741
06/12/02	-	-	-	5600	-
13/01/03	3116	1942	2296	341	561

Table 1 - Summary of cartridges replacement in student's restroom.

All replacements presented in Table 1 occurred due to a difficult flow through the cartridge, resulting in urine accumulation in the waterless urinal bowl. The measurement period began in April 8th, 2002 and finished in January 13th, 2003.

When the cartridges were removed, there was a formation of a big amount of a whitish paste, apparently abrasive, that adhered to the cartridge outlet and to the inside of the housing. This paste, called "biofilm", was a biochemical material which jeopardizes the performance of the system, creating the necessity of cartridge replacement.

The cartridges that were replaced on June 27th, 2002 presented a clogging due to "biofilm" on the horizontal discharge branch. The blockage removal was obtained by the means of the disposal of a big amount of water, which allowed the "biofilm" removal.

Table 2 shows the summary of cartridge replacements that occurred during the field study, in the teachers' restroom.

Date	Urinal 1	Urinal 2	Urinal 3
25/03/02	0	0	0
27/09/02	-	-	4049
04/11/02	-	3289	-
13/01/03	6644	993	1600

Table 2 –Summary of cartridge replacements in teacher's restroom

In April 2002, the cartridge of urinal two was removed in order to undergo a chemical analysis of its "biofilm". In September 27th, 2002 the cartridge of urinal 3 was replaced due to a complete obstruction by its "biofilm". During the field study, no operational and/or vandalism problems were verified in the system.

Results Evaluation

Anti-vandalism is an important characteristic of Waterless urinal. No parts can be damaged without contacting the urine.

The field study in student's restroom was significant for the system's understanding and for the measurement of some installation restrictions.

The student's restroom presented clogging of some cartridges which caused urine accumulation, due to a "biofilm" formation inside the cartridge or inside the outlet, resulting in precocious cartridge replacements if compared to the cartridge performance in other countries.

Two hypotheses were considered for the formation of this "biofilm". The first one was related to the flow of the sealant liquid and consequently the flow of the existing biocide that inhibited the proliferation of biological cultures. Such flow must have been occurred due to inadequate cleaning processes. The second one is related to urine velocity through waterless urinal and also through drainage branches of sewer system. Student's restroom had a drainage branch installed without proper declivity that prevented the urine of having the adequate velocity.

The drainage branch of the professor's restroom presented a vertical installation solution, which enabled the urine to flow adequately. Waterless urinal system showed better performance in the second type of installation, but a new case study to collect data during a longer period of time would be necessary to obtain better conclusions.

It is important to notice that the "biofilm" formation can also occur in other types of urinals, according to its characteristics of operation and water discharge. This problem is not exclusive to this system, but it can occur more intensively in this system due to its installation and operation characteristics.

The urinal of the student's restroom showed, after use, not only spots on the housing plastic borders that were attributed to inadequate cleaning procedures but also chemical deposits due to lack of adequate cleaning frequency. In the professors' restroom, where cleaning procedures occurred properly, these problems did not occur.

In order to avoid the problem of spots, the housing's rims are now manufactured in stainless steel. Another improvement is the increase of the declivity between the housing and the drainage branch, allowing a higher velocity of the flow. After these changes, the system is still being tested under the same installation conditions of the case showed in this study in order that the resultant effects can be evaluated.

This study did not evidenced problems related to significant odors inside of the restrooms.

Conclusion

The technological advances for reduction of water and energy consumption must be continuously evaluated. Waterless Urinal technology is another step towards water conservation. Although it may seem a radical solution, this field study indicated that eliminating water for urine conduction to drainage system does not affect the performance of the sanitary room.

In this case study, the application of the methodology presented a complex evaluation which considered not only the performance requirements but also the potential of economy of the system.

The professors' restroom involved in this study had plumbing installations in more favorable conditions to the application of waterless urinal. Thus, it is important to notice that the plumbing system design plays an important role in the operation of the sanitary room in order to obtain not only the correct application of the technology but the evaluation of the plumbing system as well. The study showed that parameters such as pipe slope greatly influence in the results of system performance - the declivity next to zero, as it occurred in the students' restroom gave support to the development of "biofilm". The Waterless Urinal System is still under study in Brazil so as to achieve other adjustments needed in order to reach the performance indicators that occur in other countries all over the world.

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Research of hot water supply for residential building in subtropical country

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Abstract

Countries in subtropical areas due to the short winter and high temperature in average often ignored the issues of hot water supply system. However, the hot water supply system is still identified as requisite equipment items of residential buildings in Taiwan. Our previous research presented an overview of residential water usage process, and the partial results revealed that hot water consumes a great amount of energy from this holistic process and some critical problems were seriously ignored. Following the previous researches, this paper focuses on the hot water supply system and presents results of primary observation in residential building in Taiwan to be an example in subtropical area countries. According to the investigation and comparison, we summarized several significant features of hot water supply system in Taiwan and quantitative reference parameters.

Keywords

residential building, hot water, subtropical country, energy consumption, water supply and drainage, investigation

1. Introduction

Hot water supply system belongs to the partial network of building water supply and drainage, and commonly identified as one of the most important equipment items in residential building properties. Especially, countries located in high latitude area or frigid zone always place importance on hot water supply for not only water conservation but also the energy saving. Meanwhile, owing to the multi-utility of hot water in residential building, a variety of hot water equipments and systems were conducted to applications from series of developing work.

On the other hand, the issues of hot water supply system seem to be ignored by countries in subtropical areas or torrid zone due to the short winter and high temperature in average. However, the hot water supply system is still identified as requisite equipment items of residential buildings even in subtropical countries such as Taiwan. Government and the public gradually notice the issues of hot water supply in recent years. The initial concerns were concentrated upon the topic of energy consumption, and then the problems of security were raised to the public. Therefore, considerable developing progress has been made in energy conservation, such as applying solar heater or other substitution energy on the hot water supply system within buildings. However, the essential knowledge and information of hot water supply system are insufficient nowadays.

The issues of hot water supply include not only the water demands and energy consumption, which are mentioned above, but also amenity and public security of the residents within the buildings. Our previous research presented an overview of residential water usage process [1], and provided a simple equation for analyzing energy consumption with regard to the electric power of urban water treatment systems and domestic water supply and drainage system. The partial results revealed that hot water consumed a great amount of energy from this holistic process and that some critical problems were ignored seriously. The essential knowledge and information of hot water supply system are insufficient and more relative researches need to be conducted for the countries of subtropical areas. Following the previous researches, this paper will focus on the hot water supply system and present results of primary investigation in residential building in Taiwan to be an example in subtropical countries.

2. Technical review

According to the previous records of water use from Taipei Water Department [2], each person uses 250 l water per day in which 50 l (20%) is for bathing. The details of influential factors are not considered by individual behavior in early studies. Moreover, the air temperature and water temperature are higher in subtropical area than those countries which are located in high latitude areas or frigid zone. The studies of hot water supply temperature is comparable rare previously in Taiwan, thus, this issue will also be studied in this research.

Some previous researches indicated that rapid quality-of-life improvements have increased water demand in Taiwan. This situation is very similar to the past of those developed countries such as Japan. According to the research of JSHASE [3], daily individual water utilization is 235 l and there is 51 l (22%) in bathing. Bathing temperature in Japan where is mainly located in the temperate zone is around 40.5°C. Table 1 shows the detail investigation results of many hot water utilities in Japan. [4]

Table 1 Different temperature of hot water utilization in Japan

Behaviors	Toilet	Washing-up	Washer	Hair wash	Bath	Shower	Hanging shower
Temp. (°C)	37.5	39.0	39.0	40.5	40.5	40.5	42.5

During the past 30 years in the USA [5], the water demand is also greatly increasing. Nowadays, each person uses 300 l water per day for American people in average. According to the reviews of researches, the water utilization in each American family is 847.8 l per day, hot water consists 193.3 l and cold water 654.8 l among them. As an assumption of four people in each family, the individual hot water consumption would be 48.6 l daily. The other research of Lawrence Berkeley National Laboratory indicated that energy consumption of water heating for American family is much more than that of air conditioning. There are a lot equipment companies such as E. Source in Boulder, Colo., they consider heat losing by hot water transmission and they set hot water temperature at 43.9°C (111°F). However, the suggest temperature of ASHRAE is 40.6°C (105°F) in residential building and 43.3°C (110°F) in hospital [6].

In Canada, water use volume of residential building is 340 l per person per day and it is about 52% of total water usage in 1994. Daily bathing water is 119 l per person and it is about 35% of water usage in Canada family [7]. The temperature in Canada where is located in the frigid zone must be cooler and the people might need a higher percentage of bathing water utilization. However, the previous studies about hot water supply temperature in Canada are unavailable in this research.

The investigation of this research includes mainly two phases of observation. Firstly, we arranged the questionnaires for interview to resident asking about the issues of types of heater selection, behavior of bathing and troubles in hot water supply system. The next phase is field survey for current situation regarding distance of hot water supply pipes, volume and temperature of hot water in order to calculate energy consumption of hot water.

Taiwan is located in the subtropical zone, the hot water is mostly used in bathroom and kitchen in residential building. Generally, the volume of hot water supply into kitchen is comparable small and sometimes the piping system for hot water supply system is omitted in some cases. Herein, we concentrate on the utilization of the hot water supply in the bathroom.

3. Investigation

This research focuses on the hot water supply of residential building. The questionnaire for resident's interview is developed based on previous research results [8][9] and residential building accounting database of Directorate-General of Budget, Accounting & Statistics of ROC (DGBAS) [10]. The questionnaire of this interview is mainly asking for the information of hot water supply system. The results of interviews will be analyzed by statistic method and tool to discuss current situation of hot water utilization in Taiwan.

On the other hand, the work of survey included measuring distance of the pipes from heater to faucets, volume of bathing water and temperature change from cold water to hot water. Meanwhile, we set up an evaluation method of hot water utilization for residential building including water and energy.

Investigation was performed by random sampling survey and family is seen as an survey unit. We sent out 200 questionnaires, then received 161 feedbacks, and 152 are effective. There are 77 individual houses and 75 apartments among these effective samples, which include residents of 297 males 381 females and ages from 3 to 80.

Hot water utilization is in connection with equipment installing, water use volume, and water temperature. Therefore, 3 aspects are concerned in this phase, and these include hot water equipment, behavior of using hot water, and plumbing system.

3.1 Hot water equipment

According to the results of interviews, 80% of hot water supply system adopted gas heater in residential building (Fig. 1). Gas heater is popular in Taiwan, and it is used for application not only in bathroom but also in kitchen. Practically, gas heater is seen to be convenient and clean, however gas explosions and carbon monoxide poisoning occasionally happen and sometimes raise up to the public security concerns. The results of investigation reveal that most of the gas heaters were set outdoor for the security reason and there are only 11.8% of gas heaters set indoor at present.

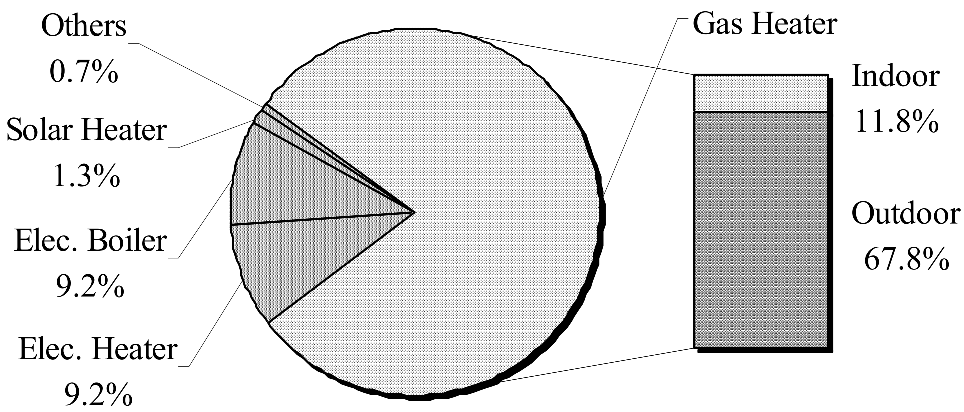


Fig.1 Types of heater and place of gas heater installation

Carbon monoxide poisoning is improved by installing sensor within gas heater, but some accidents still happen due to gas explosions. According to National Fire Agency of R.O.C., there was 2% of fire caused by gas explosions in 2001 (Fig. 2) [11]. Even the frequency of gas explosion is not very high among fire accidents, the serious gas explosions often induces terrible damage in Taiwan and causes the public attention by mass media.

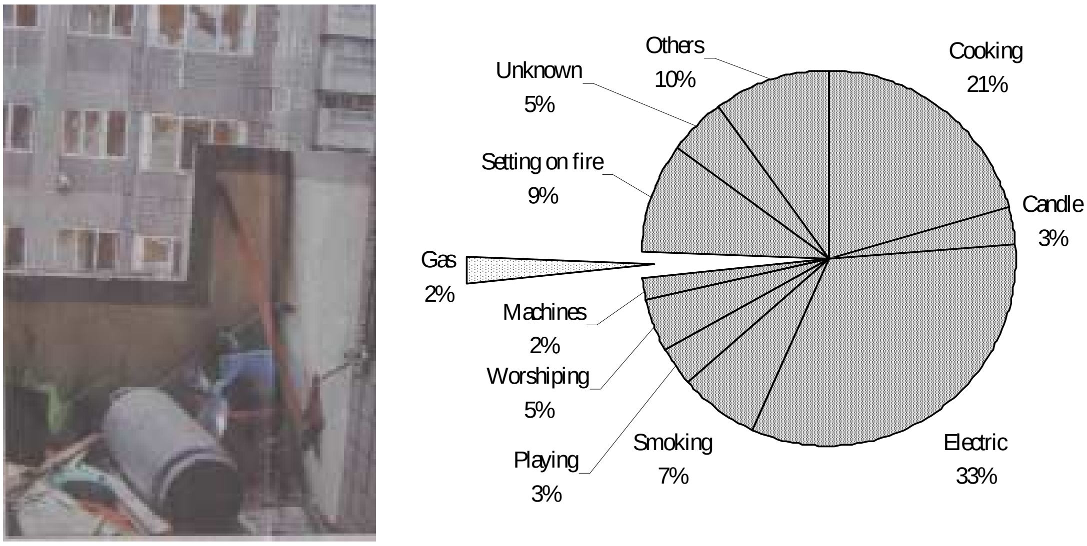


Fig. 2 Factors frequency of fire in Taiwan

Most people (82.6%) regard the safety as their premier consideration when they are choosing their heater, and 7.1% consider economic as the priority (Fig. 3). Whatever they choose, they still worry about gas loss (46.5%) and electric leakage (36.9%). Both of gas heater and electric heater have their own risk, hence it is necessary to develop a safer and less energy consumption heater. Solar heater seems to be the good option, but it is still in higher price and needs heating auxiliaries when the radiation of sunshine is insufficient.

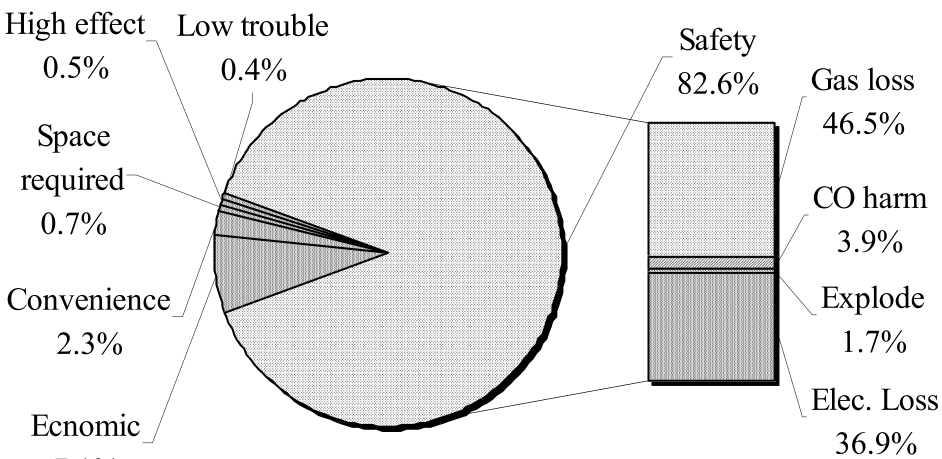
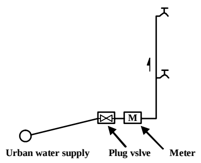
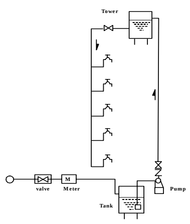
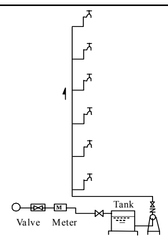


Fig. 3 Consideration for heater selected and issues of safety

Table 2 shows the main kinds of water supply system for residential buildings in Taiwan. As the direct water supply system, water is supplied by direct urban water system and is controlled by water department. Gravity water supply system which serves water downward from rooftop tower is mostly adopted in Taiwan. However, there's often lack of decompression installation and relay pumps, and some plumbing were improper set. For these reasons, residents in different floor use water of pressure. Sometimes, for example, water pressure upstairs is smaller when water downstairs is used, or water pressure in the bathroom is smaller when water in the kitchen is running on the same floor. Therefore, the heated water may get cooler when the gas heater shuts down due to unstable water pressure.

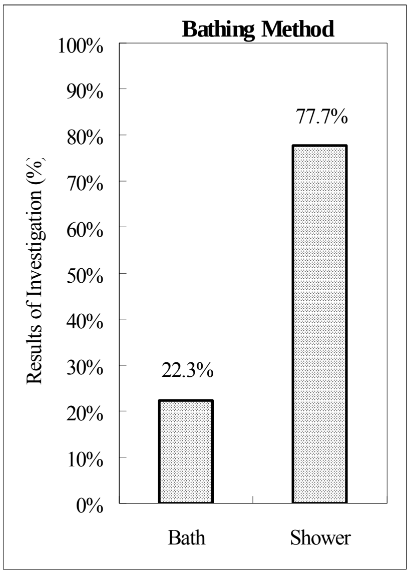
Table 2 Feature of water supply system and defect

<table>
<tr><th>Diagram</th><th>Types</th><th>Illustration</th><th>Defect</th></tr>
<tr><td>
</td><td>Direct water supply system</td><td>Water is supplied by direct urban water system and is controlled by water department.</td><td>Users at the end of the system may not be served with normal water pressure.</td></tr>
<tr><td>
</td><td>Gravity water supply system</td><td>Water supply system serves water downward from rooftop tower by gravity.</td><td>Water pressure upstairs is smaller than downstairs, causing of low water head.</td></tr>
<tr><td>
</td><td>Pressurized water supply system</td><td>Water supply system serves water upward from underground level or basement tank.</td><td>Water pressure is unstable when other faucets are used.</td></tr>
</table>

On the other hand, most twin-head faucets are changed into single faucets for convenience in recent years (current utility rate is 70.8%). Thus hot and cold water can be mixed in the one-head faucet for instant utility. However, pressure of cold water is much bigger than that of hot water that would cause extinguishments of gas heater. It is energy and water wasting and inconvenient to turn on the hot water to activate the gas heater again, and then this situation should be avoided.

3.2 Utilization behavior

Different ways to use hot water result in variable volume of water consumption. According to the results of investigation, 77.7% people take a shower, while 22.3% take a bath (Fig. 4). The influence of utilization behavior on water usage is obvious, those factors include washing hair or not, turning off water or not while using soap, and doing other work (like teeth brushing, clothing washing, etc.) or not during bathing time, all factors influence the volume of water consumed. The investigation result is shown in Fig. 5, and we detect that about 15% people consume great water quantity when bathing. This percentage would be an important reference for us to basis to evaluate energy consumption.



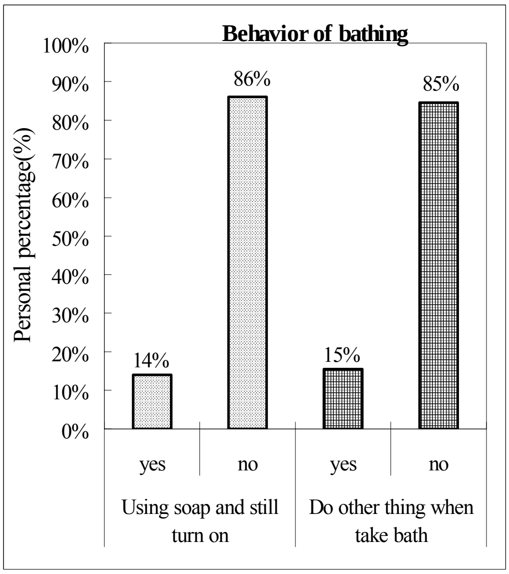


Fig. 4 Frequency of bathing method **Fig. 5 Frequency of bathing behavior**

3.3 Plumbing system

The old plumbing system of residential building in Taiwan is complicated and not concentrated (Fig. 6). Imperceptibly, that would consume water of unsuitable temperature. This study shows that the water temperature from heater is 55°C and the length of hot water pipes is 12 m. We hypothesize that all faucets indoor are 0.5 inch (1.27 cm) in caliber, and the cross section of pipes for matching these faucets is 0.0001267 m². We get equations as following:

$$Q_P = A_P \times P_L \times 1000 \; (1) \quad \text{----------------} (1)$$

From the equation (1) we calculate that the water volume with temperature of 55°C is 1.52 l, which is remained in the pipe after utilization.

Fig. 6 Hot water utilization spaces distribute among corner of plane in Taiwan.

4. Water demand

Taiwan is located in subtropical area, the hot water in residential building is mostly used in the bathroom. We focus the aspect of water demand and compare bathing water utilization with other countries. Hot water utilization differs in each country are mostly due to weather, cultures, user's utilization behavior etc. According to the previous study, individual bathing water per person in developed countries is around 40-50 l in average as shown in Table 3.

Table 3 Ratio of bathing water utilization in different countries and zones

Zone	**Subtropical**	**Temperate**		**Frigid**
Country	Taiwan	Japan	USA	Canada
Water (l / person)	40	51	49	60
Ratio (%)	16	22	23	35

Water pressure and flowing rate are also the factors on water consumption studies. Herein, we adopt the total water quantity to calculate the relation between quantity and energy consumption, thus the water pressure and flowing rate are not included in this study.

As the experiment condition, a bathtub was installed to collect bathing water, and a ruler to measure the depth of water. Then we collect bathing water in the bathtub and measure the depth of water to figure out water use volume Q_T after bathing. The water use volume includes the former cold water remained in the pipe, and that would be almost the same to hot water kept in the pipe later. The experiment device is set up as shown in Fig. 7.

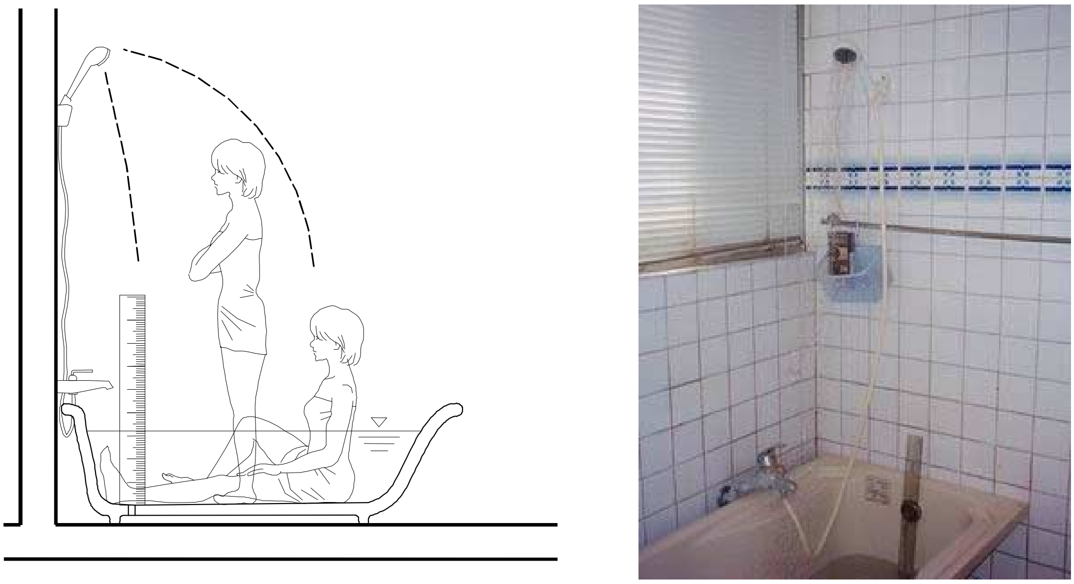


Fig.7 Surveying water depth with ruler

Volume of bathing water is greatly correlated to individual behaviors. This experiment surveys individual bathing behavior and records bathing water consumed by each sample. The results reveal that bathing water is generally wasted, due to some utilization behaviors.

We take statistic tools to check correlation between quantity of bathing water consumed and bathing behaviors. The observation types include economic and waste. The results show that both of the types are in normal distribution, and there is about 15% in wasted amounts of bathing water. The mean quantity of consumed by wasting type is 53.2 l and standard deviation is 11.4 l, namely volume of water consumed by economical type is 28.8 l and standard deviation is 9.4 l. In addition, we found that the percentage of wasting type in our behavioral survey corresponds to the results we collected from questionnaire as shown in Fig.5.

According to the results that include experiment and inspection, we infer that mean volume of bathing without wasted water is 28.8 l. We use the standard deviation to calculate maximum and minimum quantity then we get the values between 19.4 l and 38.2 l. On the other hand, we calculate the bathing water with wasted water then get the mean volume 53.2 l, maximum and minimum quantity is 41.8 l and 64.6 l respectively.

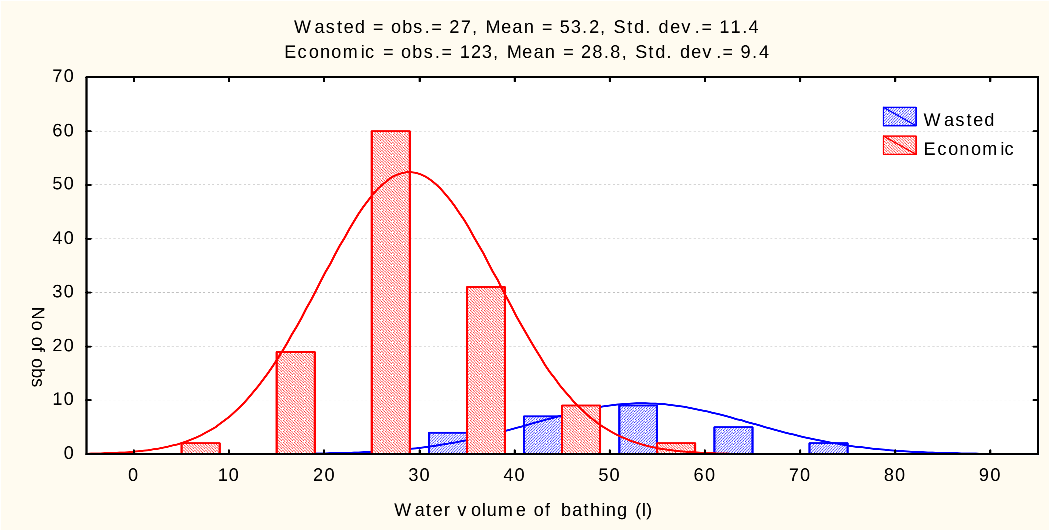


Fig. 8 Bathing water difference between behavior and quantity in Taiwan

Finally, we use the frequency of bathing behavior (Fig. 5) to be coefficients then create an equation as follow to calculated volume of bathing water:

$$Q_T = 85\% \times (Economic) + 15\% \times (Wasted)$$

$$Q_T \ \text{max.} = 42.2 \text{ l}$$
$$Q_T \ \text{mid.} = 32.5 \text{ l}$$
$$Q_T \ \text{min.} = 22.8 \text{ l}$$

We select the volume near maximum value in 40 l as hot water utilization in Taiwan. The first aspect is that the value is an integer and easy to calculate and the second one is to take higher value to ensure that most people of the wasting type may be well represented in our evaluation.

5. Temperature for amenity

Temperature is involved with safety and snug as technical review. Most countries consider heat loss due to linking distance, thus suggest bathing temperature is in 40-43°C. We carry experiments out to get the data we need with quantity survey. We install a temperature sensor on the shower faucet, and open cold water for getting T_C before bathing. Then we get temperature of bathing water T_T during shower time or bath time. The experiment is set up as shown in Fig. 9:

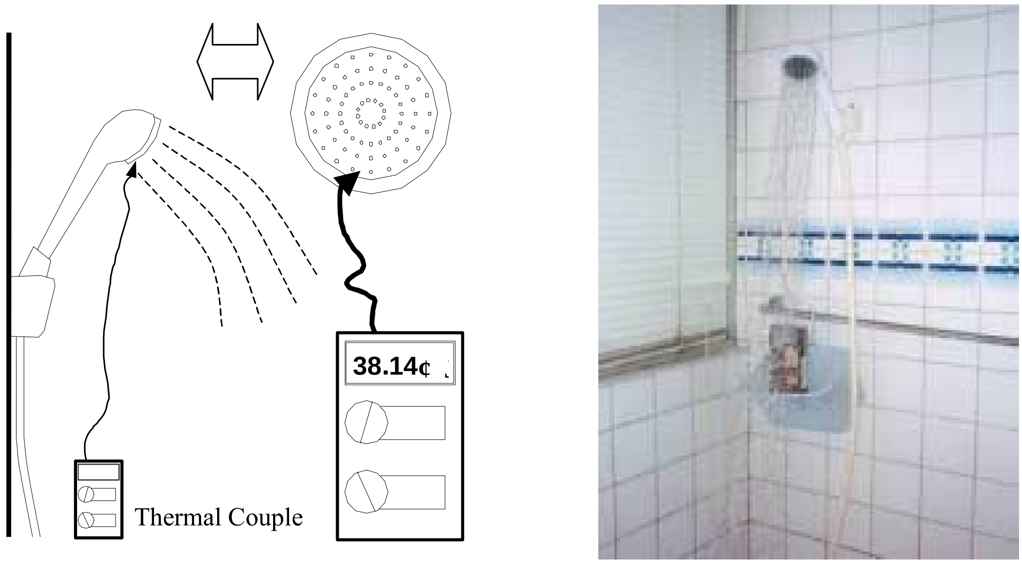


Fig.9 Temperature sensor is installed on shower outlet

This experiment was proceeded with 150 samples from March to April 2003, the mean air temperature is 25°C and mean cold water temperature is 22.5°C. According to statistic analyzing, we acquired the bathing temperature as shown in Fig. 10. The major bathing temperature is between 35 and 40°C, value P is smaller than 0.01, which means the temperature distribution is normality. Analyzing results: the mean bathing temperature is 38.4°C, median is 40°C, standard error is 4.7 1. It's harmful and uncomfortable to skin if one touches water over 50°C more than one minute. So, the bathing temperature is between 20 and 50°C, but in practice from 22 to 45°C. According to JSHASE [4], the suitable bathing temperature for Japanese is 40.5°C, and for Taiwanese who are living in the subtropical zone, the suitable bathing temperature is around 38.5°C.

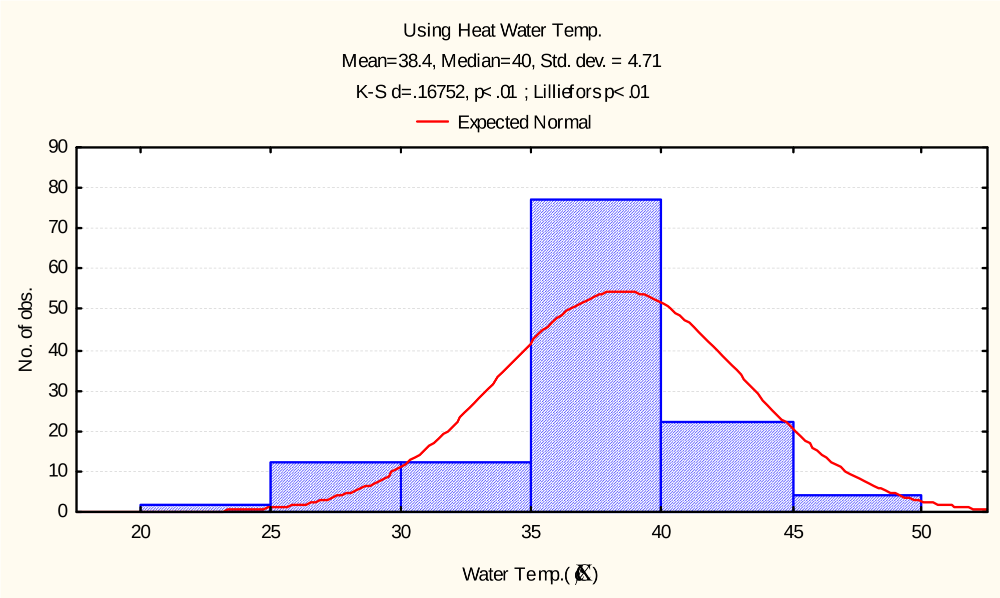


Fig. 10 Temperature of bathing water in Taiwan

6. Energy consumption

According to previous research, we adopt the equation (2) for conservative calculating energy consumption of hot water utilization:

$$E_H = Q_T \times S \times \Delta T \div 860 \text{ ------------------------- } \quad 2$$

In addition, some hot water which is remained on the linking pipes will be cooled down before next bathing time and always be released out. In long-term observation, a great amount of water and energy are wasted in this situation. Thus, equation (3) and (4) are introduced to calculate the energy consumption E_P within this part of water.

$$\Delta T = T_H - T_C \quad (°C) \text{ ----------------------------- } \quad 3$$

$$E_P = Q_P \times S \times \Delta T \ (\text{kcal}) \text{ --------------------- } \quad 4$$

Finally, we add 0.95 kWh/m^3 of pervious research result in urban water consumption to make total energy consumption evaluation in hot water utilization. Herein, we conducted a process of energy consumption calculation as shown in Fig. 11.

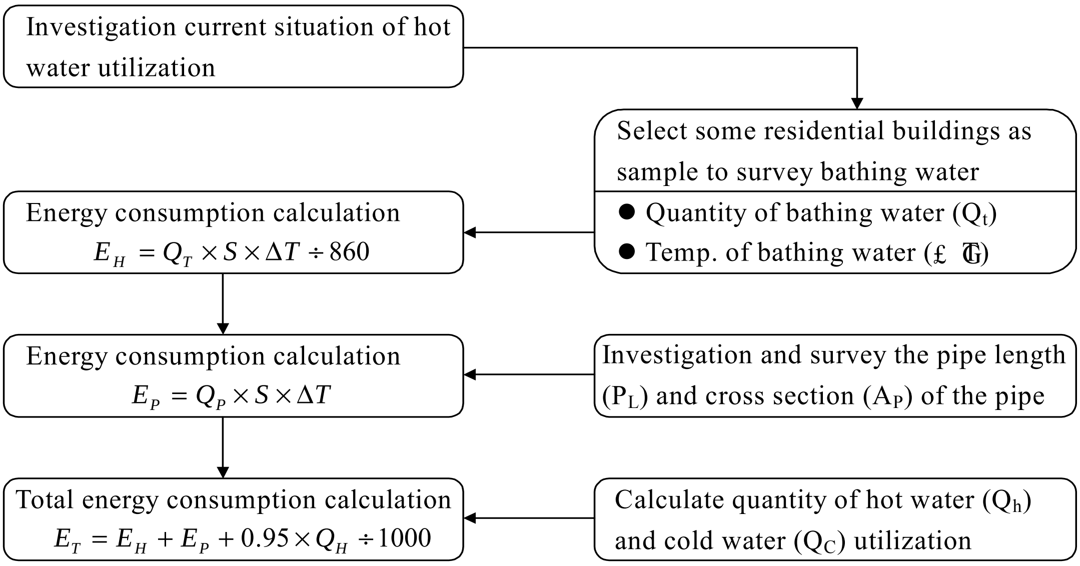


Fig.11 Process of energy consumption calculation

To get the values of Q_T (bathing water volume) and ΔT (temperature alteration) in the equation, we firstly figure out from the law of the energy conservation. The specific heat of water S is 1.0 as usual. Energy consumption of bathing water E_T is the sum value of energy consumption from heater E_h and energy consumption of cold water counteracting E_c.

$$E_T = E_h + E_c \quad \text{--} \quad 5$$

$$Q_T \times S \times T_T = Q_H \times S \times T_H + Q_C \times S \times T_C \quad \text{-----------} \quad 6$$

$$Q_H = (T_T - T_C) \times Q_T \div (T_H - T_C) \quad \text{---------------------} \quad 7$$

According to the equation (5), (6) and (7), we can figure out the equation (8), i.e. bathing water energy consumption E_H. From this equation, we measure bathing water volume Q_T, bathing water temperature T_T, cold water temperature T_C, and then get bathing water energy consumption E_H. Furthermore, we add pipe energy consumption E_P and get part of energy consumption of hot water.

$$E_H = Q_T \times S \times (T_T - T_C) \quad \text{-----------------------------} \quad (8)$$

Finally we get the result of our previous research [1], cold water per $1m^3$ equals to electric power 0.95 kWh, i.e. 817 Kcal. Therefore, the total energy consumption of hot water E_T

of each person per bathing may be determined by the following equation (9).

$$E_T = E_H + E_P + 0.95 \times Q_H \div 1000 \quad \text{------------------}（9）$$

Following the results of usage volume with 40 l and temperature with 38.5°C of bathing water, we calculate the energy consumption in Taiwan. The cold water temperature is 22.5°C and hot water temperature is 55°C that based on the result of our pervious research. We get bathing water energy consumption E_H is 0.75 kWh, pipe energy consumption E_P is 0.06 kWh, total energy consumption of hot water E_T is 0.848 kWh/person (i.e. 21.2kWh/m^3)

According to previous review in volume and temperature of hot water utilization in Japan which is located in the temperate zone, one person consumes about 1.22 kWh/person as assumed temperature 20°C for cold water. As the results, it is obvious that the energy consumption in the Japan is much more than that in Taiwan which is located in subtropical area.

7. Conclusion

This paper focuses on the hot water supply system and presents a series result of primary observation in residential building in Taiwan to be an example in subtropical countries. According to the investigation and comparison, we summarized some significant features of hot water supply system in Taiwan and quantitative reference parameters as the following statement.

(1) Individual hot water supply system with instant gas heater for each residential unit is the most popular in Taiwan, hence the amenity troubles of fluctuating temperature caused by unstable water pressure or unanticipated shut down of gas heater are frequently complained.

(2) According to a schematically observing, the average total length of hot water supply piping within residential building is around 10-12m in Taiwan, which causes inefficient water utilization and energy loss.

(3) As a primary reference the general hot water usage for personal bathing is 40.0 l with average temperature 38.5°C in Taiwan, which is relatively lower than the records of

those countries in high latitude area or frigid zone.

Furthermore, energy conservation is another critical issue in hot water supply system especially in those countries in high latitude area or frigid zone. Considerable progress has been made to find new solution for hot water energy, such as applying solar heater or co-generation system on hot water supply system in residential building. However, the essential knowledge and information of hot water supply system are still insufficient nowadays, and more relative researches need to be conducted for the countries in subtropical zone or torrid zone.

8. Nomenclature

860	: Unit transfer (1.0 kWh = 860 kcal)	Q_H	: Hot water volume □l□
A_P	: Pipe square measure (m²)	Q_P	: Pipes water volume l
E_H	: Bathing water energy consumption kWh	Q_T	: Bathing water volume l
E_P	: Pipe energy consumption (kWh)	S	: Specific heat of water = 1.0
E_T	: Total energy consumption (kWh)	T_C	: Cold water temperature (°C)
E_h	: Hot water energy consumption (kWh)	T_H	: Hot water temperature (°C)
E_c	: Cold water energy consumption (kWh)	T_T	: Total temperature (°C)
P_L	: Pipe length (m)	ΔT	: Temperature alteration (°C) $(T_H - T_C)$
Q_P	: Cold water volume □l□		

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Assessment of quality of drinking water in residential buildings

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Abstract

This work intends to present an assessment of quality of drink water in residential buildings. Initially, it is admitted that water distributed to homes is drinkable. However, it is expected that water will suffer changes in its original quality during its course in cold water system. Thus, analyses of drink water quality were made at five points of domestic water supply systems. The parameters analyzed were color, turbidity, pH, dissolved oxygen, total and fecal coliforms, free and residual chlorine. It was studied ten residential buildings, all with inferior tank, pumping systems to superior tank, superior tank and distribution system. It was observed that color, turbidity, pH, dissolved oxygen don't suffer significant modifications along domestic water supply systems. It wasn't observed coliforms, indicating that chlorine are sufficient. However, concentrations of chlorine suffered modifications at all the buildings. This fact indicates that there was considerable consumption of chlorine and, at some points, the chlorine wasn't detected. The biggest consumption of chlorine observed was in tanks.

Keywords

Cold water system; quality drink water; chlorine consumption

1 Purpose

The aim of the present research is to evaluate the behaviour of drinking water quality in residential buildings during its way along the cold water system of the buildings. This way, it will be sought to detect the existence of water contamination in such systems, as well as its possible causes.

2 Identification and characterization of the problem

Habitation Health can be regarded as the health state of a residence or any residence that contributes to the health of the residents. Such health depends on several factors as the quality of the water used, collection and disposition of the solid residues, quality of indoor air, condition of the environment comfort (temperature, acoustic), construction materials used, hygiene level of the external environment quality, the users attitudes, among others.

Regarding the water quality, the main theme of this work, it is important to comment that the drinking water is defined as the one that attends the drinking standards extolled by the recent Brazilian Guidelines of the Department of Health (Portaria 1469/MS/BR). It must present the propeieties of being clear (without colour and turbidity), inodorous and pleasant to the taste, with a reasonable temperature, neither corrosive nor crust productor, free of organisms that can cause diseases.

According to this, it is admitted that the water supplied to the habitation by the waterworks is drinkable. Therefore, the fact that the water is drinkable when it enters the building does not certify that it is drinkable when it is consumed. This can happen because there are potencial water contamination points during its way. That is to say, the water can be contaminated in the pipes, tanks and utilization points. In the utilization points (apparatus and sanitation equipments) the water served can be in touch with the drinking water. This is the case, for instance, of the toilet and the garden faucet.

The water contamination in the plumbing can happen due to the entrance of contaminated liquids to the interior of the pipe or it can be caused by the corrosion of the metal that constitutes the pipes, valves and meters. The contaminated water entrance to the interior of the pipe can happen through welding faults or through the utilization parts. It is important to mention the work by HIGGINS (1997), when the author highlightens the importance of the backsiphonage control in sanitation apparatus and hydrants. RAZOUK (1996) also highlightens a serie of factors, among them, the insufficient water flow in some parts of the distribution pipes, which can cause the spreading of pathogenic microorganisms.

Regarding the tanks, it is a fact that they are most exposed to contamination. The main causes are related to construction faults (project and execution) and the maintenance deficiency. The most common ways of contamination occur due to supplied water infiltration, through the entrance of small animals in the acces openings and overflow pipe, the lack of seasonal cleaning and consequently the organic matter accumulation on the bottom of the tank, which consumes great part of the water residual chlorine, the air pollution due to the air that is contaminated by toxic elements and suspended particles, among others. The water temperature in the tanks is also an important factor to be considered as it is known that in warm water (in superior tanks) there is the possibility of *Legionella* growth, which is pathogenic. (DAUGHERTY, 2000).

It is also important to mention that the Brazilian regulation “Instalação Predial de Água Fria – NBR 5626/1998” (Cold Water Installation in Buildings) presents a sucession of recommendations that are feasible to drinking water sanitation protection, where inquiries such as adequate material utilization, supplied water flow, and the connection between drinking and not drinking water conductor plumbing are approached.

3. Evaluation program of drinking water quality in buildings

This research is in the Evaluation Program of Drinking Water in Buildings (SANTOS, 2003), whose objective is to evaluate the behaviour of drinking water quality in Cold Water Building Systems (Sistemas Prediais de Água Fria - SPAF**)**. The intention is to detect possible alterations in the drinking water quality as well as their possible causes. This enables the stablishment of cause/effect relations which must be useful either for a continuing improvement in the project and in the execution of SPAF (Cold Water Building Systems) or for their more effective maintainance, operation and use. The stages of the program are:

1º- Compilling of Drinking Water Quality in Buildings

Such compillation is inicially the selection and the following description of the buidings. Afterwards, a physical, chemical and microbiological evaluation of the water is foreseen in order to evaluate some relevant quality parameters.

2º- Prospecting of the Relations Between Building Characteristics and Drinking Water Quality

It is intended to investigate the possible relations that effectivelly identify the means of consumption water quality alteration by analysing the characteristic data of buildings and drinking water quality parameters. Furthermore, the impact degree on each of these means on the drinking water quality will be evaluated, in a way of stablishing a hierarchy of sanitation risks resulted from them. Such hierarchy is important as it indicates a panel of priorization of actions to minimize or eliminate such risks.

3º- Review of the Performance Criteria and Requirements of the Cold Water Building Systems.

The identification of the means of drinking water quality alteration, as well as the risks associated with them, will allow the review of a series of requirements and performance criteria, related to the sanitation safety of the cold water building systems. Such requirements and criteria are found on the principle "Cold Water Building Installation" (Instalação Predial de Água Fria – NBR 5626/1998), on the codes of city public works and on Brazilian Guidelines of the Department of Health (Portaria 1469/MS/BR), among other normative referrences. They are principles that sign the project, execution, maintenance and the use of the SPAF (Cold Water Building Systems). Therefore, the review os such requirements and criteria will make it possible to confirm and improve some of them, exclude others and propose new ones.

4 Methodology

4.1 Selection and Discriptive Data Compilling of the Buildings

The first step consists on the choice of residential buildings and the consequent descriptive data compilling of them. Six buildings were chosen and a physical description was conducted through the observation of the architectural space features and the building systems, either the water supply systems (cold and hot) and the drainage systems. The number of residents was also compilled, as well as the accomplishment of measurement of water consumption despached and the assessment of the residents behaviour on the water use in consumption points.

Summing up, it is relevant to mention that all the evaluated buildings have a water supply systems with inferior and superior tanks and nine buildings are connected to the public system of water supplying and one building is connected to their own groundwater system caption. It was observed that in such system there is no desinfection system.

4.2 Data Compilling of the Drinking Water Quality in the Buildings

On this step, the physical, chemical and microbiological qualities of drinking water in its way in the water building system were assessed. Therefore, in each building the sampling points were defined and the collection and analysis of the drinking water samples were carried out. The sampling points in each studied buildings were the inferior tank entrance (Point 01), considered here as the water available by the supplier, the inner of the inferior tank (Point 02), the entrance of the superior tank (Point 03), the inner of the superior tank (Point 04), and a consumption point in an apartment (point 05). There were altogether five points.

4.3 Laboratorial Analysis of Drinking Water Quality

On this step, the physical, chemical and miscrobiological analysis of the water sample were carried out in certified laboratories. The physical standards analysed were color, temperature and turbidity. As for the chemical standards, the pH, hardness, chlorine and conductivity were analysed. As for the microbiological standards, the usual indicators microorganism (total and fecal coliforms) were analysed.

5 Results and discussion

Regarding the standard behaviour along the water way through the cold water system, it was observed that the chlorine is the only one that presents clear tendency of variation, according to Table 01 below. In other words, for the free chlorine and total chlorine it is clear the variation of its concentrations along the systems. The average variation rates among the sampling spots were:

Table 01: Concentration Averages and Free Chlorine and Total Chlorine Variation Rates in the Cold Water Systems.

Point	Free Chlorine (mg/l)	TVCL* (%)	Total Chlorine (mg/l)	TVCT** (%)
01	1,57	---	1,64	---
02	1,28	- 18	1,32	- 20
03	0,92	- 30	1,06	- 20
04	0,51	- 44	0,60	- 43
05	0,76	+ 49	0,82	+ 37

** Variation Rate of Free Chlorine   ** Variation Rate of Total Chlorine*

It is interesting to realize the decay of free chlorine between the inferior tank entrance (Point 01) and the inner of the inferior tank (Point 02), which is 18%. As for the pumping system, between Point 02 and 03, the decay of free chlorine was 30%. However, the biggest decay of the system is noticed in the inner of the superior tank, which is 44%. In the passage between the inner of the superior tank and the consumption point (Point 05), an inverse process occurs. In other words, there is an increasing of free chlorine, which is 49%. Notice that the total chlorine follows the same tendency.

As for the pH, it was presented in the drinking water conditions, as it was established by Brazilian guidelines. The color parameter was always kept really below from what was established by Brazilian Guidelines. The turbidity, in most cases, was kept below the 1,0 NTU. The microbiologic total and fecal coliforms were not detected in samplings from the buildings connected to the public system of water supplying. Therefore, in the building that is supplied by groundwater system, the indicators were detected.

6 Conclusions

Among some relevant observation, it is important to highlighten that the biggest free chlorine decay rates were detected in superior tanks, which can be related to the higher temperature of water in them, for being more exposed to the external environment, among other aspects. It is important to pay attention to this fact, as the tanks are a propitious environment for the development of pathogenes.

It was also interesting to detect that, in average, the concentration of chlorine in the water increases between the inner of the superior tank (Point 04) and the consumption part in the apartment (Point 05). This fact is attributed to the fact that the chlorine growth, probably transfered from the pipes frames, surpasses the decay rate expected. However, it is important to say that it is related to the average value, as there were situations in which the chlorine decay prevailed.

Regarding the water contamination, it is important to mention the absence of total and fecal coliforms in buildings supplied by the public system of water, with the examination that in such samples, the minimum residual chlorine detected was 0,3 mg/l. The presence of such indicators in building supplied by groundwater with no desinfection system reinforces the importance of residual chlorine maintenace.

Finally, it is relevant to highlighten that this research must be extended to a larger number of buildings, which will make it possible a bigger comprehension of the relations among the several variables envolved, as well as the causes of the deterioration of the drinking water quality in buildings.

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Losses In Drinking Water Distribution Systems: Example Of Bursa ;Turkey

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Abstract

In this study ,the ratio of the water losses is calculated for the five pilot regions in Bursa and it is fixed that the amount of the total water losses in the water supply system is % 37 in 2001.It is determined that the most important amount of the water losses in the drinking water network system is occured because of the physical losses (% 92 of the total water losses) and % 98 ratio of this value comes from the distribution system and % 2 ratio of this value comes from the service tanks and main network lines.Not physical water losses is nearly % 8 ratio and %91 of this value comes from meters and % 9 of this value comes from the illegal connections.As a result of the study, solution suggestions have been put forward to reduce the amount of the water losses.

Key Words

Not physical water losses, physical water losses, water supply, drinking water distribution systems

1.Introduction

In the world and in our country water demand is increasing together with the increasing of the population and improving of the economy.Although water demand is increasing all the world ,water resources are becoming less because of the unsuitable use and water pollution.Water is the most important element of the life but it is a very big effort and cost to supply water from the resources and to bring water to the useful form.If we want to benefit from these effort and cost very much for the purpose of presenting water to the consumers'service ,we must give big importance to the drinking water transmission and distribution systems and operating of these systems.If we can transmit and distribute the water in a healthy way ,people who are lived in the district units can use of this water very productively.

Education ,health ,defence ,industry and infrastructure are the main investments of the developing countries like Turkey.Investments of infrastructure means ,healthy drinking water supply to all the district units ,drinking water transmission ,drinking water treatment together with the distribution of drinking water within the city ,installation of wastewater and rain water networks ,construction of main collector and wastewater treatment systems and setting up to the transport ,energy and communication systems within the city and between the cities (Ulucan and Ünlü ,2001)

When we look at the subject which one is the top priority ,we can see that recently in our country like the other developing countries ,the big share of the investments are segregated to the healthy drinking water supply but infrastructure systems like treatment systems etc.have been handled second plan.(Samsunlu ,1996)

In our country ,constructions of drinking water transmission systems ,wastewater networks ,treatment systems and distribution lines reach very high costs.The big amount of costs are depend on the installation of the lines.When we select the types of installation lines ,we must be careful about the physical ,chemical ,bacterial and radioactive properties of water ,amount of water ,hydraulic properties of water like operating pressure ,velocity etc.,geologic structure of line way and underground water condition ,the potential of water pollution of the water which is evacuated ,climate of the region ,topography ,economy of the line.(Ulucan and Ünlü ,2001)

Losses in the drinking water transmission and distribution systems is the most important factor of the waste of the water resources.For this reason in our country like the other countries authorities give big importance to this matter and make a lot of studies about it.Losses of water means ,difference between the amount of water which is given to the network and the amount of water which is used by the subscriptions.In other words ,lots of water means the amount of water which isn't rewarded or the amount of water which doesn't appear in the bills.Losses of the drinking water consist of the structures of the transmission and distribution networks with the physical water leak from the lines illegal counter connections ,mistake of counter recording and uncontrolled consumptions.These losses cause a big amount of economic losses and especially physical losses are the cause of the spoiling of the quality of the drinking water.In 1970's countries like Germany and ABD is determined that the amount of the water which is losses ,is only % 20 of the total amount of the water which is supplied from resources.

(Anonymous ,1976)When we look at the our country's situation at the same times ,we can see that the amount of the water which is losses ,is nearly % 50 and more than % 50.In our country the importance of this matter is accepted but the studies to find the resources of the water losses in the city network ,the factors which are effected to the water losses and the studies to take measures for the water losses are very new.In our country is to be in need of the detailed studies about the determination of the varios factors of the water losses with the help of the experimental methods ,these factors are grouped according to the activities with the help of the statistical methods and is become widespread to all the district units of the city.The results of the studies will show us the way of improving strategies of reducing water losses actively.In this study the components of losses in the drinking water distribution system and the amount of losses water in Bursa are determined.As a results of the study ,suitable solutions have been forward to benefit from the institutions which are made with the help of the big efforts and financial resources and water resources which are presented to the people service in the maximum ratio.

2.General Look Of The Kinds Of The Water Losses

Water losses means ,the difference between the amount of the water which is produced from the resources and the amount of the water which is consumed in a legal way.The amount of the water which is produced is the total amount of the water which is supplied from the resources.In Bursa these resources contain the water which is provided from Doburca Drinking Water Treatment System ,underground water resources in Arabayatağı and Acemler and a lot of springs.Legal consumption means the amount of water which is recorded with the domestic and commercial meters. (Anonymous ,1992) Kinds of the water losses are seperated into two main groups.They are ; 1) Not physical water losses , 2) Physical water losses

2.1) Not Physical Water Losses

Not physical losses is the one of the main reason to reduce the income resources.It contains the amount of water which is used or which is consumed without recording.It is classified that illegal connection (usage without meter) and losses because of the use of the old meters.

2.2) Physical Water Losses

Water losses which is consisted of because of the losses in the network systems.These losses contains ;

- Leaks from the network ,tank and domestic connections.
- Flowing waters in vain because of the faults in the networks.
- Flowing waters in vain which is flooded from the completely full tanks.
- The amount of the water which is evacuated when the lines are out of work.
- The amount of the washing water which is used when the new network lines are started to operate

3.Losses In Drinking Water Distribution Systems Of Bursa

The Map of Bursa City is shown in Figure 1.The total ratio of losses water amount in Bursa is determined with the help of the datas of five pilot regions which represent all the network of Bursa to evaluate the amount and ratio of the losses water.

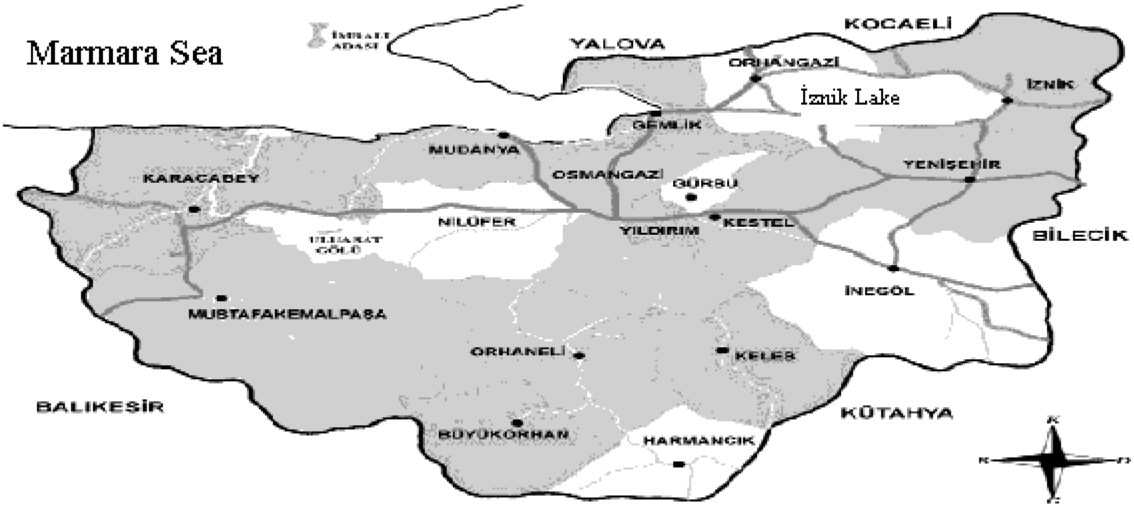

Figure 1. The Map of Bursa City

In this study ,İhsaniye ,Beşevler ,Bahçelievler ,Kükürtlü and İntizam streets are chosen for the pilot regions of all the Bursa City.After the results of the different land experiments ,legal night usage for Bursa City is ;
Legal house usage : 3.91 L / hour ,
Legal workplace usage : 5.62 L / hour (Anonymous ,1992)
İhsaniye region is given for an example of the calculation of the losses ratio in Table 1 and relatingly Table 1 calculation of the losses ratio of the other four regions are given in the Table 2.

Table 1.Amount Of Losses Water (Anonymous ,1992)

Searching area of losses water – Calculation of losses water amount
Street : İhsaniye
Min.Night Current : 9.05 L / sec
Number of subscriber : Domestic : 1569 number
Commercial /Industry : 15 number
Total : 1584 number
Subscriber appropriation : Domestic : 3.91 L / hour
Commercial /Industry : 5.61 L / hour
Flow of min. demand : 9.05 * 3600 = 32580.00 L /hour
Legal water usage :
Domestic: 1569 * 3.91 = 6134.79
Commercial /Industry : 15 * 5.61 = 84.15
Total: 6218.94 L/ hour
Total losses : *Min flow - Legal usage*
: 32580.00 - 6218.94 = 26361.06 L / sec
Rate of losses : 26361.0 / 1584 : 16.64 L /*subscriber* / hour
Daily losses : 26361.0 * 24 : 633.24 m^3 / day
Total water which is entered to the region : 1282. 30 m^3 / day
Rate of losses of İhsaniye region : 49.38 (%)

Table 2.Losses Water Calculations According To The Regions Which Are Determined (Anonymous,1992)

Searchhing area of losses water	Losses Calculations												
	Min. Night Current	Number of subscriber (number)			Flow of min. demand (L / hour)	Legal water usage (L / hour)			Total losses	Rate of losses L /subscriber/ hour	Daily losses (m^3/ day)	Total water which is entered to the region (m^3/ day)	Rate of losses of İhsaniye region (%)
		Domestic	Commercial /Industry	Total		Domestic	Commercial /Industry	Total					
İhsaniye	9,05	1569	15	1584	32580	6134,8	84,15	6218,84	26361,0	16,64	633,24	1282,30	49,38
Beşevler	5,93	951	294	1245	21348	3718,4	1649,34	5367,75	15980,2	12,84	383,53	912,00	42,05
Bahçeli evler	22,35	1637	22	1659	80460	6400,7	123,42	6524,09	73935,9	44,57	1774,46	2956,22	60,02
Çekirge Kükürtlü	18,50	4680	68	4748	66600	18298	381,48	18680,2	47919,7	10,09	1150,07	2015,50	57,06
İntizam	0,99	250	15	265	3564	977,5	84,15	1061,65	2502,35	9,44	60,06	104,90	57,25

4.Calculations Of The Not Physical Water Losses

4.1.Losses Which Occurs Because Of The İllegal Connections

After five regions of Bursa are examined to determine the amount of this kind of water losses ,authorities find out that the number of the domestic and commercial connection is 145 374.The amount of the connections equal to the % 97.5 of the number of the bildings which are located in the five regions.It is accepted that because of the new public works ,illegal connections are the half of the rest amount of the % 2.5 ratio.

4.2.Losses Which Occurs Because Of The Old Meters

After five regions of Bursa examined to determine the amount of this kind of water losses authorities find out that the amount of average faulty reading value is % 12.22 of the amount of water which is realized.

5.Calculations Of The Physical Water Losses

5.1.Water Losses In Drinking Water Treatment System ,Resources And Pump Stations

These institutions are always controlled for this reason the maintenance and repair of these institutions should be made in a very short times so they aren't taken into consideration wen losses water calculations are made.

5.2.Water Losses In Service Tank

The municipality prepares the report which is connected with the drinking water project of Bursa ,shows that the amount of water which is losses everday from the service tanks is the % 1 ratio of tanks volume.

5.3.Water Losses In The Main Network Lines

After the examinations of the lines which are used in the drinking water networks in Bursa ,the amount of the losses water is calculated with the help of these acceptances ;for cast iron lines 1100 L / km / hour and for steel lines 450 L / km / hour values of water losses are accepted for the calculations in Table 3.

Table 3.Calculations Of The Water Losses In The Main Network Lines

Total length of the main network lines		: 81958 m
These are :		
Steel line		: 70318 m
Cast iron line		: 11640 m
Calculation of water losses :		
Steel	70318 * 450 * 24 /1000	: 754,4 m^3 / day
Cast iron	11640 *1100 * 24 /1000	: 307,3 m^3 / day
Total		: 1066,7 m^3 / day
Annual Water Losses In The Main Network Lines		: 389346 m^3

5.4.Water Losses In Drinking Water Distribution System

This kind of water losses forms the biggest part of the all systems' losses.The amount of the losses in drinking water distribution system is calculated ,to subtract the amount of the losses water which are calculated from the total amount of losses water.

6.Results And Evaluations

The amount of losses water in the present drinking water network system in Bursa is determined with the help of this study.Losses water in the drinking water network system in Bursa is classified into two groups which are named physical and not physical water losses as if is shown in Figure 2 (a) and Figure 2 (b)

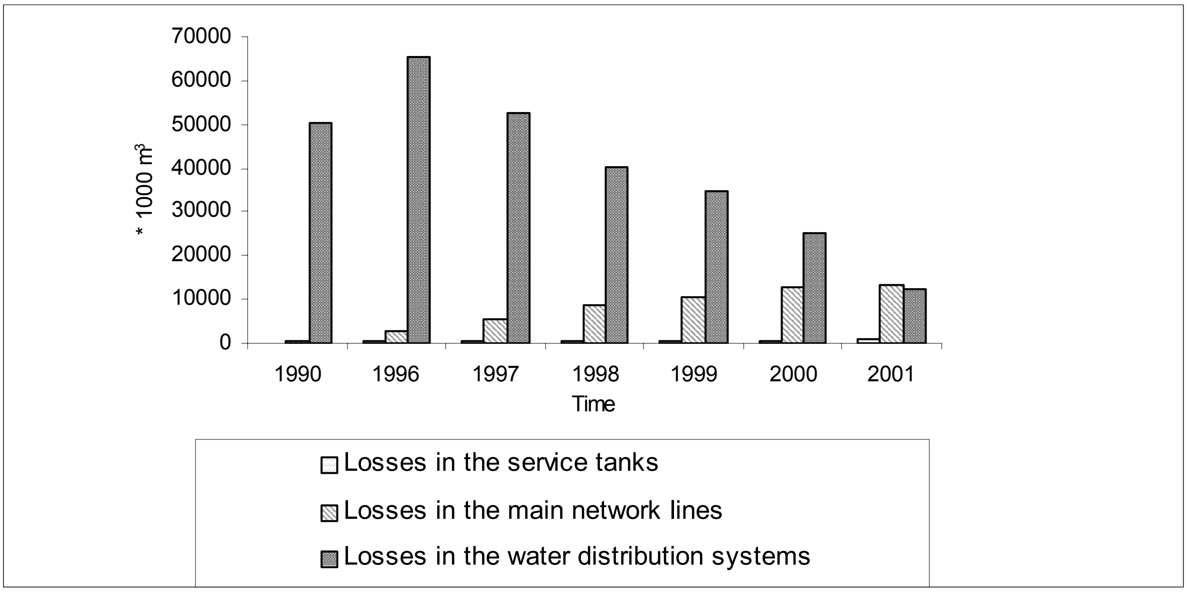

Figure 2 (a).The Amount Of The Physical Water Losses In The Drinking Water Distribution System In Bursa

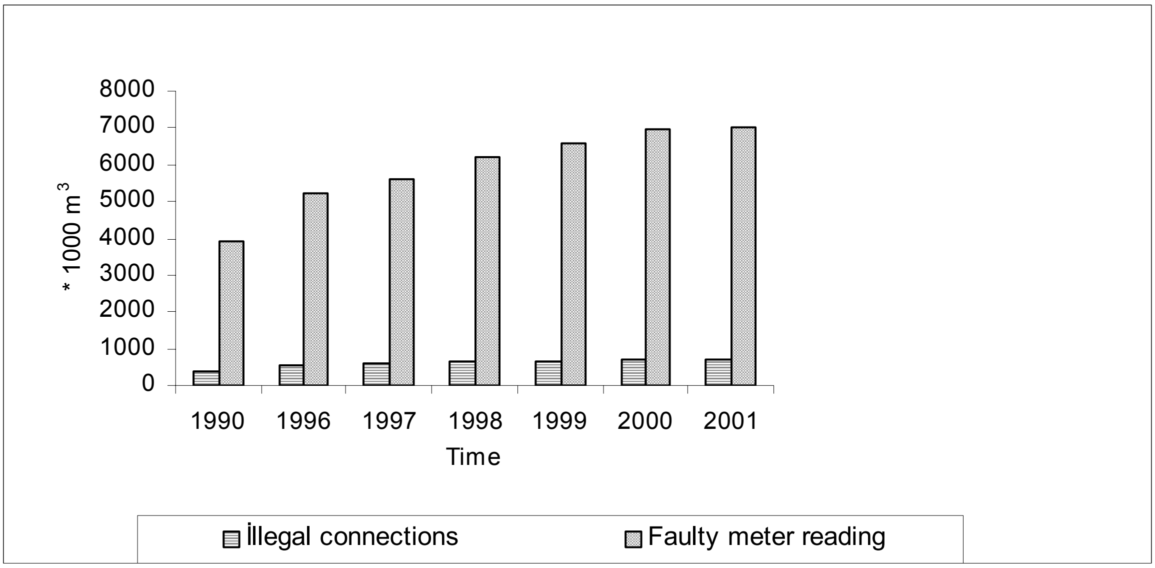

Figure 2 (b).The Amount Of The Not Physical Water Losses In The Drinking Water Distribution System In Bursa

It is calculated that physical water losses forms % 92 of the total losses.It is determined that % 98 ratio of the physical losses comes from the distribution system ,% 2 ratio of the physical losses comes from the service tanks(% 0.6) and main network lines (% 1.4) and this situation is shown in Figure 3

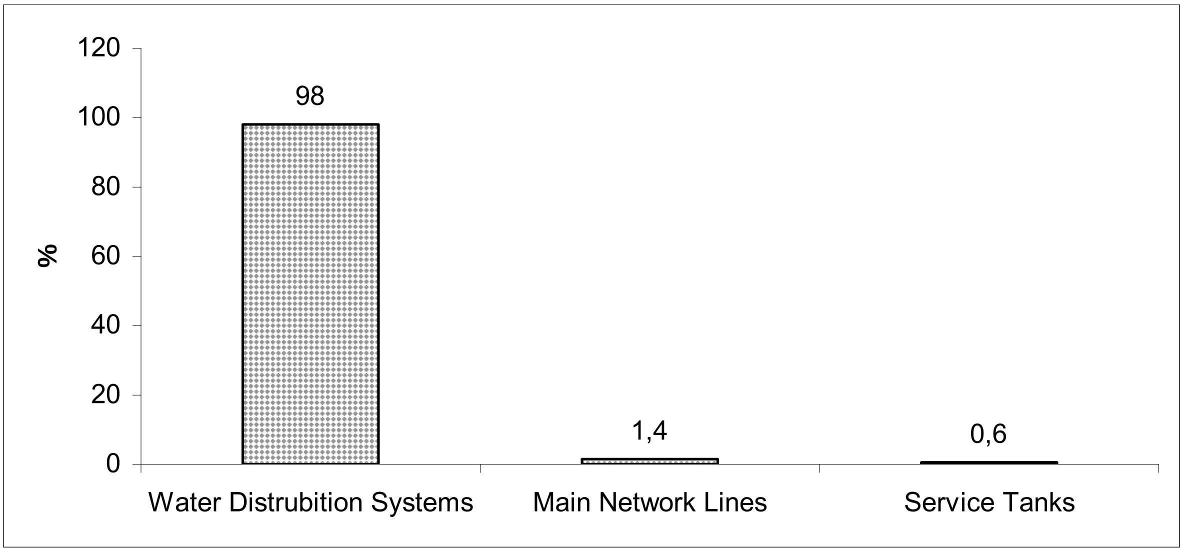

Figure 3.Physical Water Losses

Not physical water losses equals to the % 8 ratio of the total water losses.It is determined that this losses occurs because of the meters (% 91) and illegal connections (% 9)This situation is shown in Figure 4

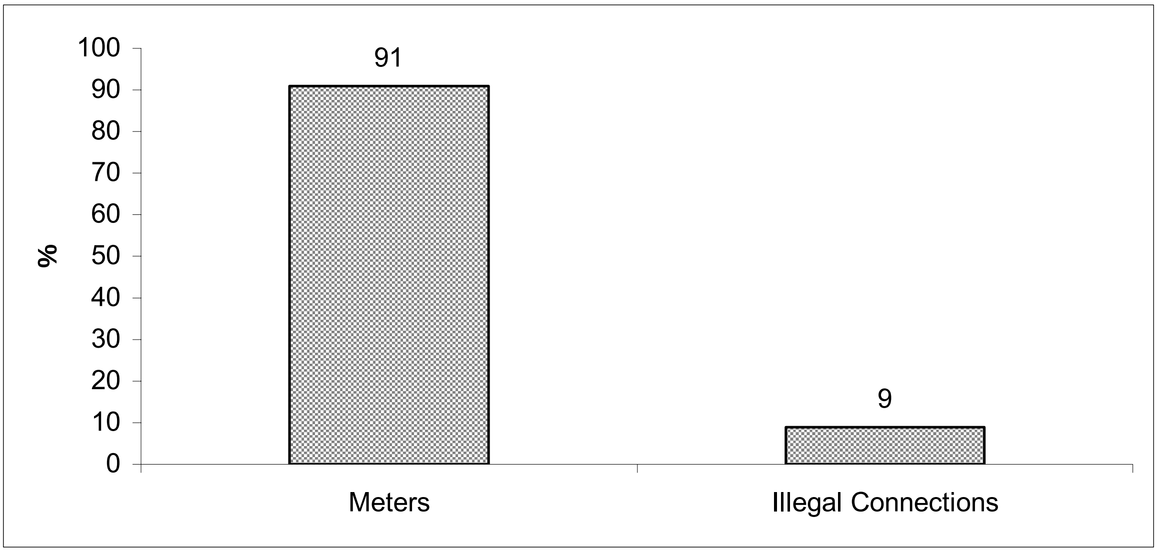

Figure 4.Not Physical Water Losses

According to the years the changes of the water production ,water consumption and water losses of Bursa City is shown in Table 4.Comparing the amount of the water which is produced with the amount of the water which is consumed is shown in Figure 5.

Table 4.Annual Water Production ,Water Consumption And Water Losses Of Bursa City(Anonymous 1992 ,Anonymous 2002)

	Report of Gast	**Anonymous Notes of BUSKİ (2002)**					
Years	1990	1996	1997	1998	1999	2000	2001
Water production(m^3 * 1000)	87531	117308	110683	107000	106760	103026	91730
Accruements of water(m^3 * 1000)	32148	42933	45987	50653	53683	56981	57554
Amount of losses water(m^3 * 1000)	55383	74375	64696	56347	53072	46045	34176
Rate of losses water (%)	63	63	58	53	50	45	37
Number of subscriber	154087	297190	310830	333870	351150	354360	363300
The Amount Of The Not Physical Water Losses Of Bursa City							
İllegal connections (m^3 * 1000)	400	535	575	630	670	710	720
Faulty meter reading (m^3 * 1000)	3930	5250	5620	6190	6560	6965	7035
Parenthetical total (m^3 * 1000)	4330	5785	6195	6820	7230	7675	7755
The Amount Of The Physical Water Losses Of Bursa City							
Water losses in the service tanks (m^3 * 1000)	130	475	510	550	580	620	780
Water losses in the main network lines(m^3 * 1000)	389	2783	5537	8642	10485	12608	13389
Water losses in drinking water distribution system (m^3 * 1000)	50534	65332	52454	40330	34777	25143	12252
Parenthetical total (m^3 * 1000)	51053	68590	58501	49522	45842	38372	26421

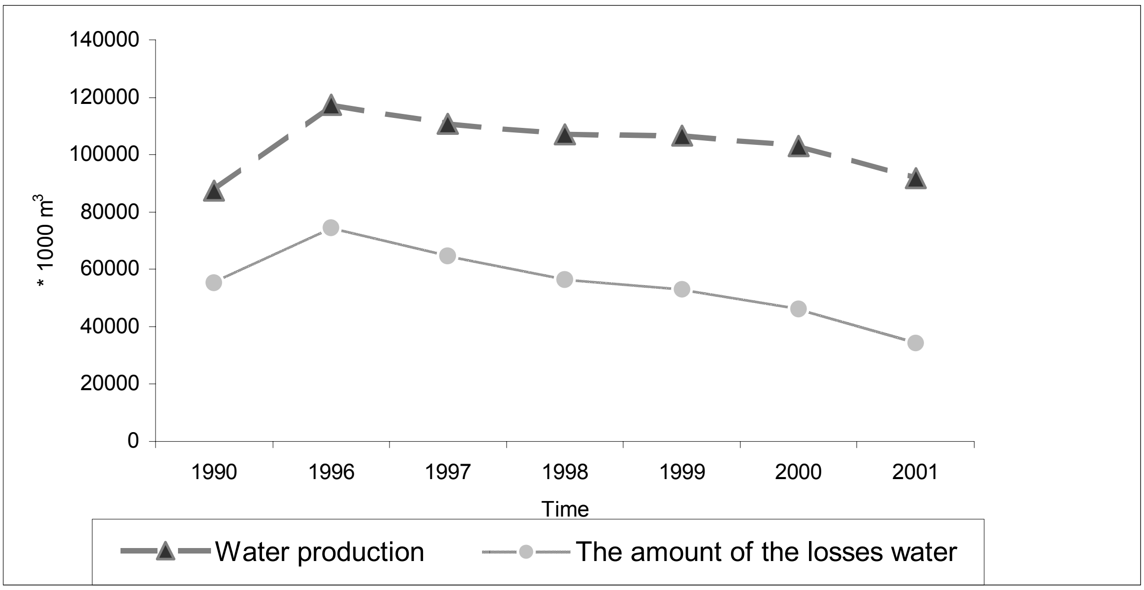

Figure 5.The Amount Of Water Which Is Produced And Which Is Consumed Of Bursa City

According to the Figure 5 ,it is seen that the difference between the amount of the water which is produced and the amount of the water which is consumed is nearly % 37 in 2001.As a result of the study ,solution suggestions have been put forward to reduce the amount of the losses water.These solution suggestions are arranged like this ;

1) Important amount of water losses is occured because of the service connections which belong to the network lines are broken owling to the rusting or lead supplements of cast iron lines are broken.Probably this situation is occured because of the speedy water which is given to the lines.At that time these lines are emptied to connect or mend.Lead material which is used to form flexible part of the service connections is the reason of the rusting ,leaking and is formed the important risk for the human health.
In the Turkish Drinking Water Regulations (TS-266) publish that the maximum lead concentration which is given permission in the drinking water is 0.05 mg / L
(Eroğlu ,1995)
The lead concentration is tried to reduce under this value with reducing the lead using operation in the distribution systems.In this context ,a lot of developing countries like England ,the connections which are used in the network are made with putting on the bronze turning ring directly to the steel or cast iron line or private bronze ladle is used.
When we unit subscriber line with the connection point we must use rustproof middle density polyethylene lines.In this way ,we put a stop to rust and we assure with using the subscriber –meter connection to reduce the probability of water losses in the middle density polyethylene line.In the drinking water network cast iron lines which have elastic ring must be prefered to instead of the lines which are made with lead connections.All the lines of the network are tried to change with the middle density polyethylene lines.
2) Old main distribution line in the old districts of Bursa City like Reyhan ,Tuzpazarı Tahtakale and Nalbantoğlu which was installed many years ago ,was supported with the parallel lines to cover the lack of water.In this way when the new lines are added ,the network gets better but as time passes connection points and additional parts of the lines damage.For this reason water losses and falling in the pressure increase.More than one feeding line systems must be cancelled and new lines which are provided to feed this regions with certain lines and network and subscriber line connections must be built with new system and new materials.
3) It is determined that the most important part of the water meter which is used in Bursa is 20 mm diameter .This water meters have theoretically 5000 L/ hour water passing capacity.This value is more than the amount of the normal house water usage.Results of the bigness and interior inertia low flows pass without turning the water meter.Water meters which are assembled to the subscribers must be suitable for the expected consumption amount to prevent this kind of losses.After the experimental studies ,it is determined that water meters which have 15 mm diameters or less than 15 mm diameters.Lighter and have a low interior inertia than the others.For this reason this kind of water meters are suitable than the others to evaluate the consumption amount.
4) When the report is collected ,it is determined that the numbers of the common fountain ,tap and toilet in Bursa is 989.The latest reports of the municipality shows that nearly all water which is used in these institutions is controlled by the water meters but the amount of water which is came back of the big amount of this water cost isn't made.For this reason the amount of water consumption of these institutions are controlled frequently and these institutions must be transfered into suitable waqf and business enterprise in a short time.
Amount of water which is used for cleaning streets and struggling fire is taken into the fire tanks directly without evaluating.Fire tanks which belong to the municipality tanks and which are used by the fire departments must be arranged with the meters in order to increase the consistency of the reports which are prepared by the municipality.

(Anonymous ,2001)
5) The most effectively and economic way of reducing the water losses is reducing the water losses is reducing the pressure of network.Especially between 02.00 and 04.00 times (the water consumption is minimum between these times) the pressure of the network is more than daytime pressure.The difference between night and daytime pressure is nearly 1,0-1,5 bar.For this reason in this context ,when the water consumption increases the pressure of the distribution system must be balanced because in this situation the amount of the water which is drawed from the network is very small and maximum static pressure is happened in the network.With the help of this method ,we try to control the pressure with the pressure reducing valve which is assembled into the regional meter system.Using the pressure reducing valves ,we try to regulate the pressure of the highest point of the distribution system.The valve of the pressure in this point must be nearly 2 bar.
6) The aim of the drinking water supply projects which are improved or which will be improved in our country ,is to reduce the water losses into the % 20-25 values which are expectable beginning from 2000
7) Total spending of the construction of the drinking water installation in Bursa which are built by DSİ and municipality is nearly 400 million $.It is determined that it will be suitable to begin to act the unit which is named “ Struggle Unit With Water Losses “ to prevent and to reduce the water losses in the drinking water installations.This unit will be decorated with the technological apparatus and equipments.

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WATER LEAKAGE AND DETECTION IN MUNICIPAL WATER DISTRIBUTION NETWORKS

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Abstract

A methodology to estimate, to determine and to locate water losses from water distribution networks is presented. Various techniques are used to reduce the losses by employing limited manpower and simple instruments. Alternatives requiring sophisticated equipments are also introduced. Related case studies from Ankara Municipal Water Distribution Network are presented.

Keywords

Water distribution networks; Water leakage; Leakage Reduction Techniques; SCADA

1 Introduction

A water distribution system should supply necessary amount of potable water at demand points, for domestic, commercial, industrial, and fire fighting purposes; the system should be capable of meeting the demands almost any time at required pressures. However, sometimes considerable water leakages from the system may cause problems related to the pressures at the consumers tap and significant water losses. Leakages might occur from the main feeder, distribution pipes, service pipes, or storage tank; the sizes of the leakages might change from small cracks to large breaks.

Excessive water losses can limit forming of further extensions of a water distribution network unless new sources are found and new transmission lines are constructed. Most important form of water losses is leakage. Leakage rates may change from very small values of 5-10% to values higher than 50%. In Turkey, leakage values are reported by the water utilities, in the big cities around 35%. The reasons of leaks are related to various factors such as the age of the network, the quality of the maintenance work, pipe material used, soil type, types of hydraulic operations, and high pressures.

2 Reduction of Water Leakages

There are various methods to reduce leakages in water distribution networks to a feasible rate (Smith et al., 2000); they are classified roughly in two groups: (1) direct methods, (2) indirect methods. Direct methods include all techniques which locate the leakage for an immediate repair. On the other hand, indirect methods comprise all the efforts to form a constant and homogeneous pressure field over the related pressure zone; indirect methods do not permit pressures above required pressures by adjusting pressure regulating valves and/or isolation valves of the network. Avoiding of excessive pressures will not allow formation of extreme leakages.

This study deals with direct methods. Application of direct methods especially in metropolitan areas is difficult because the determination of the weakest portions of the system in order to start to work is a tedious job. Most of the time, this kind of studies are conducted in areas where there is no excessive leakage. However, there are mainly two alternatives as a remedy. First possibility is to compare the supplied water and consumed water in the system. SCADA measurements and/or field measurements taken during night will indicate jerry-built networks. Second possibility is to compare the supplied water and the billings of the water utility.

If there are leaks from the system, the engineer should start his work from the weakest part. Basically, there are two kinds of leak detection methods: (i) Water Audit, (ii) Hydrostatic Testing.

In this study, Water Audit is employed. Water Audit follows the continuity principle. It can be applied to systems of various sizes such as pressure zone alone or even consumers of a bloc. If Water audit is applied to a system for the whole day, the daily demand curve of the system can be obtained. Order of the lekage can be estimated from night period of the daily demand curve. In order to conduct a water audit study, a flowmeter is required. However, the leak detection necessitates the exact location of the leak. One possible practice is listening for leaks. There are roughly two ways for water to leak from the pipe: first one is flowing out under orifice conditions, causing vibrations in the 500-800 Hz, the second one is striking the ground after escaping from the pipe, causing vibrations in the 20-250 Hz (Walski, 1985). It can be determined using different instrumentation. An acoustic leak detector as well as a more developed instrument, a correlation device is used for this purpose.

3 Case Study

3.1 Study Area

A case study has been conducted to determine the weakest pressure zone at which most of the leakage occurs; the study area is N8.1 zone of the water distribution network of the city of Ankara. N8.1 zone supplies water approximately to 25 000 people with lower incomes; this zone consists of one pumping station, one storage tank, 465 links, 373 junction nodes. SCADA (Supervisory Control and Data Acquisition System) and CIS (Customer Information System) of the water utility of Ankara (ASKI) provided the raw data for obtaining daily demand curves of various pressure zones and subzones of N8.1 pressure zone. Studies have indicated that losses around 100-200 m^3/hr occur in various pressure zones of the North line. After having determined N8.1 as one of the weakest zones (considering leakage per customer), systematic valving operations have been conducted to locate areally the weakest subzone in N8.1. Finally, a list of weak subzones was presented to the water utility to carry on studies for locating exactly the leaks using electronic leak detectors.

Succesful demonstrations had already been conducted for this purpose concerning mainly the determination of the point leaks.

3.2 SCADA

ASKI (Ankara Water Utility) / SCADA (Supervisory Control and Data Acquisition) is responsible for collecting, transmitting and storing data from various control points of the network (mainly pump stations and storage tanks) and then making decisions regarding the operations based on these data. SCADA program provides remote operation and control of pumps and control valves; 37 pump stations, 73 storage tanks and 15 further measuring stations making in total 124 stations are monitored and controlled on screens, including data in digital format.

3.3 Field Measurements

The aim of the field measurements is essentially to determine the areal locations of the water leakages of the study area (N8.1). The field program basically consisted of various valve operations at the field in order to investigate the study area as a whole (Figure 1) and in six different subzones. The purpose of the valve operations is the isolation of the related subzone in connection with the pump station (P23) and the storage tank (T53). This configuration allows acquiring the demand curve of the related zone (or the whole study area) using standard data recorded by the SCADA system employing the continuity equation.

Daily Demand Curves

Daily demand curves were derived using the continuity equation (Equation 1):

$$I - Q = dS / dt \tag{1}$$

where,

I = the average flowrate entering to the system for a period of dt, m^3/hr

Q = the average flowrate going out from the system for a period of dt, m^3/hr

dS= the storage in the tank T53 during the period dt, m^3

The inputs to the system are the flowrate supplied by the pump, P23, and the outputs from the system can be accepted as the water consumed by the consumers and leakage from the network. Three daily demand curves for the whole system are presented for illustrative purposes on Figure 2, 3, and 4.

Leakage determination at the Areal Basis

Before applying any point leak detection method (for example, acoustic leak detection), it is necessary to estimate the amount of water leaking from the defined system and to determine the weakest part of the network. The leakage can be estimated from night period of daily demand curves; the period between 0:00 and 5:00 was used for this purpose. It was believed that the night consumption at these hours would be minimum since there aren't any industrial or manufacturing facilities; therefore, the estimated value would be very close to the water leaking from that section of the network. The demand values at night hours, between 0:00 and 5:00 were averaged and leakages from the whole system and every subzone (six subzones in total) were obtained this way. Note that the continuity equation was applied to each subzone for obtaining their daily demand curves under appropriate valving operations; in other words, in order to accomplish this task related isolation valves are closed so that the rest of the network is isolated from the the subzone considered except the storage tank and the pumping station. After having evaluated the data, leakages from individual zones are estimated. The total leakage is around 60 m^3/hr (Table 1). First column of of Table 1 presents percentage of leakages and second column shows the distribution of average leakage estimated for whole N8.1 pressure zone to subzones.

According to the results, Şehit Kubilay district was indicated as the weakest portion of the N8.1 pressure zone including 25.75% of the total leakage and East of Çiğdemtepe district with 3.76% of leakage was in the best condition among other suzones. Therefore, the priority for conducting further study regarding water leakages should be given to Şehit Kubilay, then to South of Sancaktepe, West of Çiğdemtepe and North of Sancaktepe districts respectively. All these informations were transmitted to the water utility (ASKİ) for conducting further study to determine point leaks.

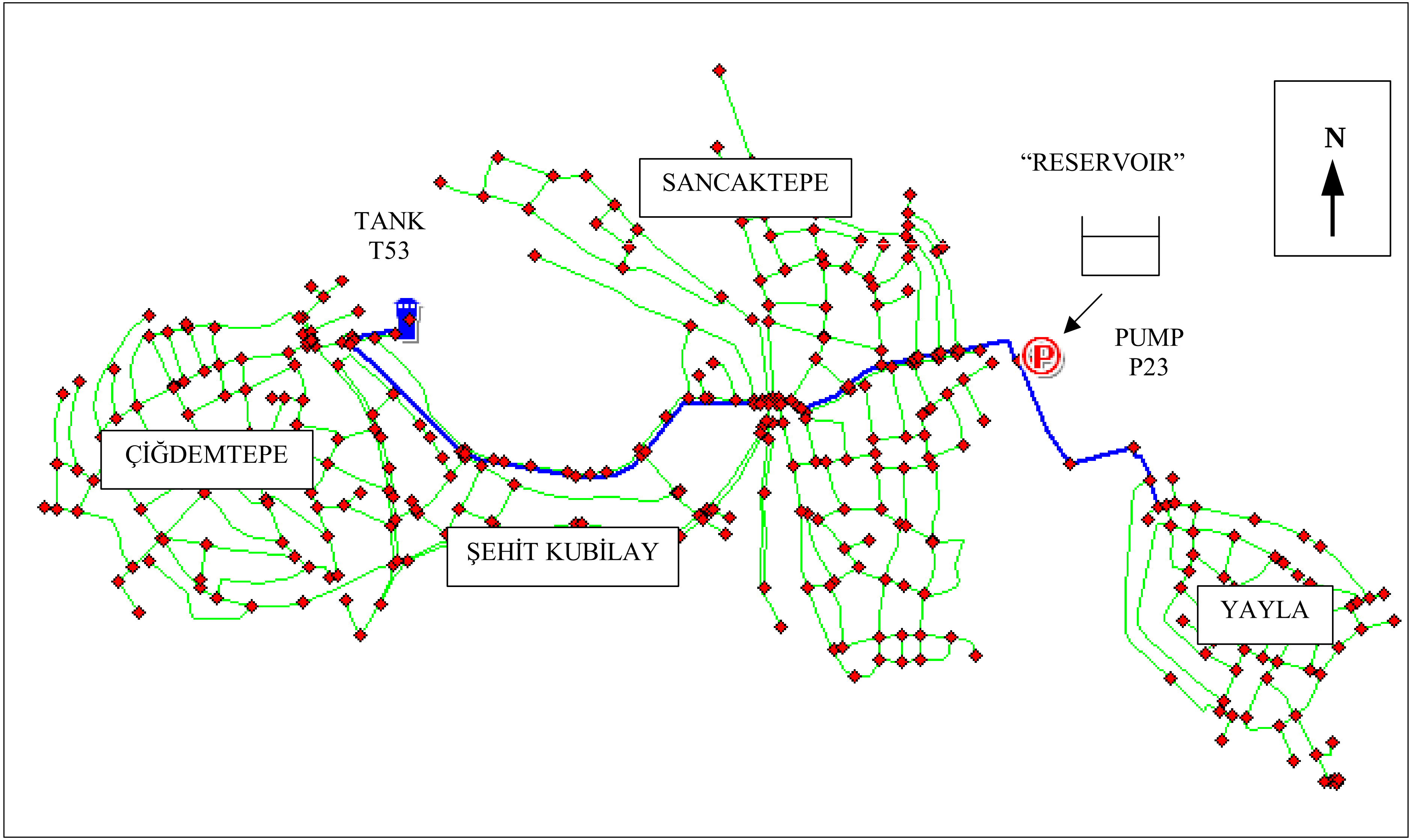

Figure 1. Water distribution network of N8.1 pressure zone

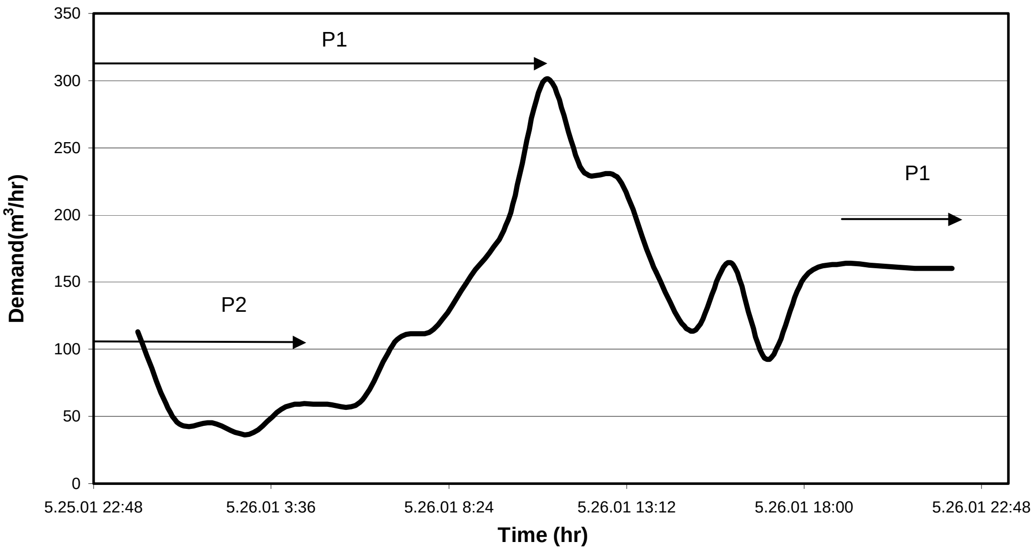

Figure 2. Daily demand curve for 26.5.2001

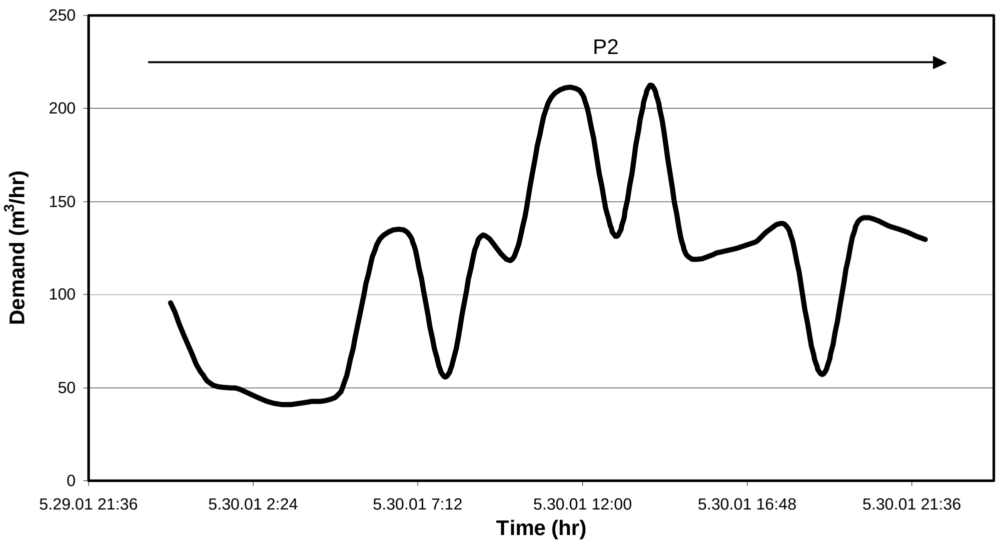

Figure 3. Daily demand curve for 30.5.2001

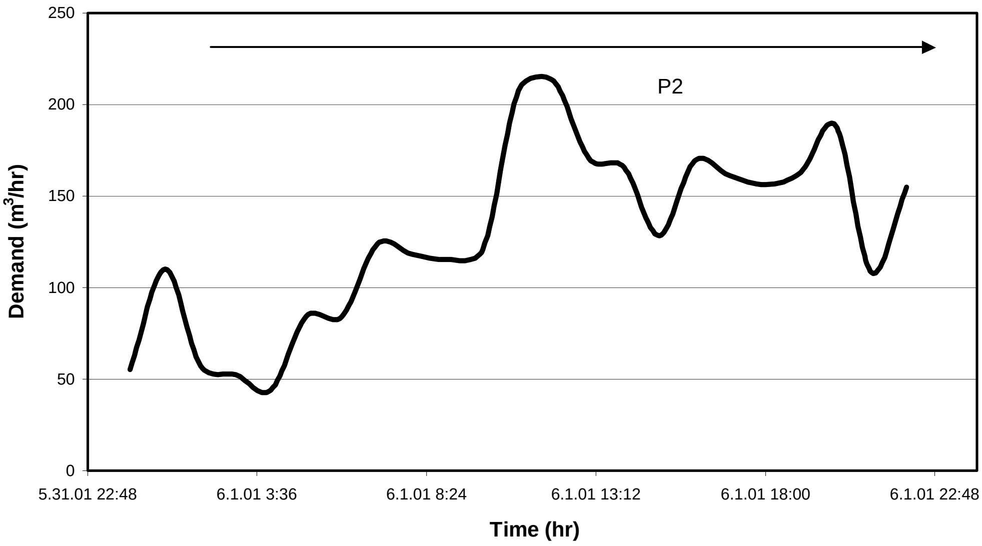

Figure 4. Daily demand curve for 01.06.2001

Table 1. Water Leakages of the Pressure Zone N8.1

ZONE	Percentage Leakage (%)	Leakage (m^3/hr)
Main-Line	5.43	3.25
Yayla	8.11	4.86
South of Sancaktepe	19.47	11.66
Şehit Kubilay	25.75	15.42
West of Çiğdemtepe	19.29	11.55
East of Çiğdemtepe	3.76	2.25
North of Sancaktepe	18.18	10.89
N8.1	100.00	60.00

4 Conclusions

This study concerns mainly the development of a methodology for the determination and locating areally the water leakages regarding distribution networks. In order to accomplish this work, a case study was conducted in the water distribution system of a Greater City, Ankara. North pressure zone was choosen for the main study area because this zone is much more under control with respect to other zones. Preliminary studies and personal communications in the water utility have indicated that N8.1 pressure zone was leaking considerably; as a result of this fact, it was decided to conduct this study in this pressure zone.

There are two basic definitions in connection with the water losses; one is unaccounted-for water, the other is water leakage. Unaccounted-for water can be estimated by comparing annual water production and annual water bills concerning water consumption; unaccounted-for water can occur due to the water leaks, the utilization of fire hydrants, flushing works, main breaks, cleaning of storage tanks, inaccurate meters, and illegal use. Water leakage, generally, forms the largest percentage among all the already mentioned items. The percentage of water losses due to leakage may vary from 5% to 50% and even larger of the total supply. Water leakage can be defined as the difference between delivered water by the water utility and consumed water by the consumers. In this study, water leakage was studied.

Water leakage involves unnecessary expenses in pumping and water treatment costs; it should be added that costs necessary for repairing broken pipes of any size should be added to this list; of course, maintaining a system regularly at an accepteable level is prefereable to apply extensive rehabilitation programs to problematic systems (Walski et al., 2001). Leakage may also cause an excessive investment for developing new sources and/or expanding the system capacity to keep pace with increasing demands. In addition to these items, the amount of water itself, may be the most important factor concerning water leakage for cities located at geographical regions which might be affected by drought periods. Generally, cities with leaking systems get informed by the drougth earlier than cities with strong sytems.

Furthermore, excessive amount of water may be a limiting factor for the development of a water distribution network; hugh amount of losses will result in low pressures throughout the network. In this case – even there is sufficient amount of water - without conducting a water leakage study, a rehabilitation program will recommend only the construction of parallel supply lines and more storage tanks, and incorporating more pumps into the system; it is obvious that these solutions will be very uneconomical.

The main point for conducting this study - among others - was to show that it is possible to determine weak pressure zones of a water distribution network of a Greater City with the available manpower, tools, and technology of the water utility. No further demand was asked to the water utility for the realization of this study. Not only the weak pressure zones but also weak subzones were determined in this study. Of course, the degree of accuracy of the results are not very high; however, the factors affecting the study were determined and ways were indicated for overcoming these difficulties.

SCADA system was very important for detecting the weak pressure zones; furthermore, it was used also for detecting the weak subzones by employing only the continuity equation.

The crews of the water utility especially teams of the Department of Operations of ASKI are formed of skillful and capable people; however, this is not sufficient for operating a water distribution system. The water utility should have a complete control of the system regarding its elements (concerning all the defined pressure zones) including the characteristics, the locations and the status of the pipes, valves, hydrants, pumps, and tanks. Especially, valves need to be mentioned/discussed much more than others, because a better performance of this study was hindered by the nonexisting or existing valves at appropriate locations; malfunctioning valves should be added to this list. If there were not big problems concerning valves, further zoning would be possible for locating the leaks more precisely.

The duty of controlling the whole infrastructure of the water distribution network should not be given only to the Operations Department; it is a task to be fulfilled also by the SCADA Department and Computer Department. Geographical Information Systems (GIS) and SCADA services should integrated together for giving services to the Department of Operations. Anyhow, a certain exploration study at an accepteable scale should be conducted to investigate the buried part of the network

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The Assessment of Surface-Water Drainage Problems in Historical Buildings by IR Thermography and Levelling survey

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Abstract

Non-destructive investigation methods have a distinct importance for historic buildings, since the building themselves remain intact. Such a study of limited extent was conducted on the 13th century caravanserai of Ağzıkarahan, located in the city of Aksaray, Türkiye, which was suffering from problems of seasonal rising damp in the lower parts of its walls. Both infrared (IR) thermography and a levelling survey were used for the purpose of determining whether or not a surface-water drainage system was incorporated into its original construction and what its existing condition was. The topographical features in the immediate periphery of the building were recorded in a map indicating overall slopes and local falls in reference to overhead roof drainage components. Damp zones in the structure and in its immediate surroundings, as well as any underground drainage path or pipeline were detected by IR thermography. Findings were then evaluated in terms of faults of surface grading and potential for taking corrective action. Results showed that rising damp problems were attributed to improper site grading resulting from inadequate and reverse falls in some areas around the building. Conditions for a satisfactory drainage are pointed out and occasional re-grading of the surrounding grounds as a preventive measure against ponding are suggested. It was concluded that the interpretation of IR thermography and levelling survey results provided a good combination for examining sub-surface and surface-water drainage systems and enhanced the accuracy and effectiveness of the survey.

Keywords

Infrared (IR) thermography; levelling survey; non-destructive methods; surface-water drainage; historical buildings; Ağzıkarahan.

1 Introduction

In order to have survived under the effects of the prevailing harsh climatic conditions over the centuries, historical buildings must originally have had quite well-designed surface-water drainage systems. However, the number of studies on these systems in terms of their characteristics, faults and compatibility with the prevailing climatic conditions is rather limited. If their original performance is in any way to continue, there is need for more extensive and comprehensive studies in this regard, preferably using non-destructive methods, in order to develop pertinent maintenance programs.

Since the surface-water and sub-surface drainage systems are out of sight, condition assessment of these systems for their improvement or rehabilitation becomes a very troublesome task. From this point of view, non-destructive investigation methods have a distinct importance for historical buildings since they allow fast and comprehensive *in-situ* evaluation of their existing conditions while the buildings themselves remain intact. Infrared (IR) thermography, in other words *thermal imaging*, is a totally non-destructive and non-invasive measurement technique, which can be highly cost-effective, for the detection of services buried within or hidden behind the structure or hidden underground, as well as for locating any anomalies, such as pipeline leaks or voids caused by erosion, by providing thermal maps of the inspected area (Grinzato, Vavilov & Kauppinen, 1998; Titman, 2001; Wirahadikusumah, Abraham, Iseley & Prasath, 1998).

A non-destructive diagnostic study of limited extent, using both IR thermography and a levelling survey, was conducted on the 13th century caravanserai of Ağzıkarahan, located in the province of Aksaray, Türkiye to determine whether or not a surface-water drainage system was incorporated into its original construction and what its existing condition was in terms of present-day maintenance requirements. Serious dampness problems arising from improper surface grading were identified in the structure (Tavukçuoğlu, 2001; Tavukçuoğlu and Caner-Saltık, 1999), and urgent interventions and routine proposals for its improvement as well as further monitoring studies were suggested.

1.1 IR Thermography measurement technique

IR thermography is commonly used for detection of building defects, such as thermal bridges, air leakage or moist spots, particularly in the context of energy conservation (Grinzato et al, 1998; Titman, 2001). In addition, based upon its ability to determine variations of emission coefficients during a cycle of suction and evaporation, IR thermography appears to be a powerful non-destructive tool for humidity detection in porous materials (Gayo, de Frutos, Palomo, & Massa, 1996; Gayo, Palomo & Garcia-Morales, 1992; Gayo-Monco & Frutos, 1998; Moropoulou, Koui & Avdelidis, 2000).

Briefly, it measures thermal radiation emitted by the material and depicts the examined area as an image in colours corresponding to a temperature scale (Moropoulou et al., 2000; Wirahadikusumah et al, 1998). Wirahadikusumah et al. (1998) explain the principle of the infrared thermography system on the basis of *the energy transfer theory*, which occurs from warmer to cooler areas. In order to provide an even flow, there must be a source of energy. The application of a hot or cold source to a specific area results in the heating up or cooling down of the exposed surface at varying rates. Final surface temperatures differ depending on the thermal resistance of the surface and sub-surface layers. Detection of deeper defects is also possible, as long as a suitable temperature gradient through deeper sub-layers which requires sufficient heating time is provided. IR images taken from surfaces exposed to direct solar radiation for longer times are expected to give thermal maps of deeper sections (Grinzato, et al., 1998). Therefore, any material anomalies or defects, such as water leaks from buried pipes, deficiencies in insulation of pipes, detachments, voids or air leaks, as well as any different materials used within a structure, will be visible in the infrared images, similar to thermal tomograms of the inspected area (Bison, Bressan, Grinzato, Marinetti & Mazzoldi, 1999; Grinzato, et al., 1998; Luong, 1998; Titman, 2001). In terms of moisture detection, the entrapped moisture in a porous material increases the thermal conductivity of the material. In other words, it decreases thermal resistance and creates a kind of thermal bridge (Grinzato et al., 1998; Langlais, Silberstein & Sandberg, 1994; Titman, 2001). Therefore, the inherent characteristics of a IR thermographic survey make it possible to locate such failures almost immediately, as cooler areas (Gayo-Monco & De Frutos, 1998; Titman, 2001). In addition, warming up of wet surfaces under solar exposure increases the evaporation rate which consequently accelerates evaporative cooling, the reason why, heating the surfaces may also enhance the visibility of moist areas in infrared images (Grinzato et al., 1998; Massari & Massari, 1993).

The accuracy of the measurements depends on whether the survey is qualitatively or quantitatively executed. The software requires that relevant parameters - ambient temperature, relative humidity, distance from target and emissivity of material – first be to improve the accuracy of measurements and for the quantitative evaluation of thermal images (Gayo et al, 1992; Titman, 2001). This is successfully achieved on site with the use of sophisticated portable thermal imagers. The second factor is the environmental conditions where the thermal imaging is performed. Sun exposure, high winds, rain, standing water on surfaces, and materials with reflecting surfaces, *etc.* are some of the factors that decrease the effectiveness of outdoor surveys (Titman, 2001). Among these, sun exposure is the most common condition during daytime surveys. The IR imager receives energy with significant enhancement from exposed surfaces due to the reflected rather than radiated solar energy, which makes measuring the actual surface temperature in the shorter wave band much more difficult (Titman, 2001). For this reason, indoor or night-time applications after sunset or just before dawn are much more preferable particularly in energy conservation surveys (Titman, 2001). Since it is not at all possible to ensure optimum environmental conditions, IR *in-situ* surveys are mostly performed qualitatively.

The heat source involved in any *in-situ* IR thermographic survey during the daytime is the sun, which warms both building surfaces and the surrounding ground to be tested, while it becomes the very building surfaces and surrounding ground itself during night-time, when they release the heat absorbed from the sun throughout the day (Wirahadikusumah et al., 1998). Colder surfaces due to evaporative cooling and relatively higher thermal conductivity are expected to indicate the presence of moisture, either trapped in the structure or sourced from subsurface leaks. On the other hand, warmer surfaces due to relatively low thermal conductivity are expected to represent subsurface voids (Grinzato et al., 1998; Langlais et al., 1994; Wirahadikusumah et al., 1998).

The effectiveness of the technique can be enhanced by integration with other non-destructive or destructive methods, such as ground-penetrating radar, levelling survey, surface temperature and moisture content measurements, and laboratory analyses (Moropoulou et al., 2000; Nappi, 1998; Titman, 2001)

2 Material: Ağzıkarahan

The other name of Ağzıkarahan is Hoca Mesud Kervansarayı (caravanserai). It is on the Aksaray-Nevşehir highway and within the boundaries of Ağzıkarahan village, which is located 15 km. to the northeast of the provincial seat of Aksaray. Records show that the monument itself was constructed between 1231 and 1239 (Esin, 1990). It consists of two parts: a square courtyard surrounded by semi-open spaces, and the fully-covered rectangular space of the serai proper (Figure 1). Located at the centre of the courtyard is a kiosk masjid. Walls are constructed with rubble stone infill faced with ashlar blocks of tuff stone, both inside and out (Altıntaş; Esin, 1990). The monument underwent restoration in 1977 by the Vakıflar Genel Müdürlüğü (General Directorate of Pious Foundations) (Altıntaş). Almost all the parapets and some of the lower parts were renewed with new-repair stone and mortar and the courtyard was partially surfaced with coarse gravel.

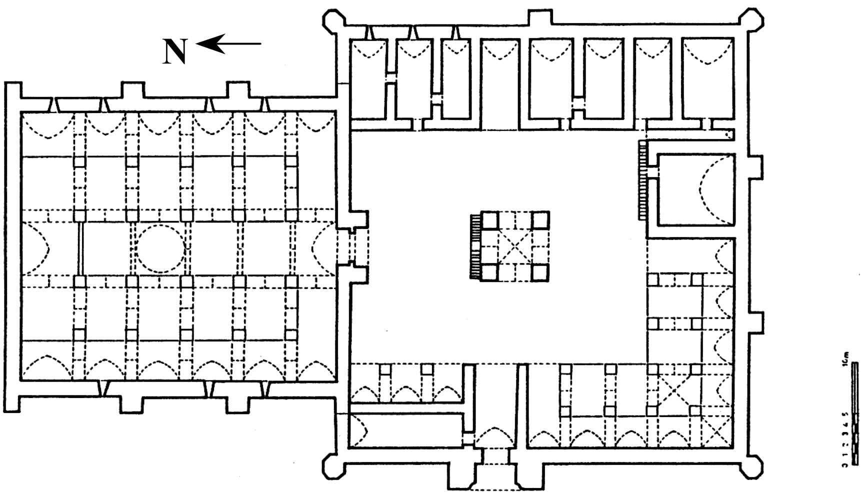


Figure 1 - Plan of Ağzıkarahan. (Source: Tükel Yavuz, 1997, p.90.)

At present, the grounds surrounding the building are in their entirety bare (unpaved), with little or no natural cover. The courtyard still retains some flagging in places. Except to the west, where there runs a paved highway some 10 m. distant, the remaining three sides of the building are encircled by ancillary facilities such as stables and coops.

3 Methods

The study consisted of IR thermography and a levelling survey of the immediate periphery of the building and of the courtyard. Spot surface temperature and humidity measurements were also taken on stone surfaces in the lower parts of the structure for supportive purposes. The investigations and all data recording were done on site.

Following an on-site visual survey to observe and record the salient features of the building and of its immediate surroundings, a planimetric survey was conducted to record topographical features in the immediate periphery of the building. Readings were then converted into a detailed map indicating overall slopes and local falls in reference to roof drainage components. This made it possible to locate problem areas with a potential risk of ponding on the map. The same survey area, together with the lower parts of the structure proper, were scanned by thermal camera to define damp zones both in and around the structure as well as to determine whether or not there exited any underground drainage path or pipeline or buried within the stone walls. Special attention was again given to the lower parts of the walls at points where a roof drainage component existed overhead. Damp zones were compared with the risky areas for ponding and warmer patches/paths were examined for their potential of harboring any underground drainage line.

The procedure of each survey phase is presented below under its respective heading.

3.1 Levelling survey

The levelling survey was designed to cover a 4 m wide strip of ground on the building periphery. This distance was deemed sufficient to determine whether or not there existed any original and/or intentional grading treatment to facilitate surface runoff away from the building proper. Where the courtyard was concerned, its entire open area was duly considered.

Topographical measurements were taken at all building corners, both internal and external, and at points immediately below the centerlines of roof drainage spouts along as well as normal to wall surfaces – the latter being at the distance noted above, except in the courtyard. All spot height readings were taken with a Wild surveyor's level and a levelling staff, and all lateral distances were taken with a surveyor's tape measure. All possible care was taken to maintain appropriate tape tension in taking these measurements. Office calculations were then made from these readings to determine directions, extents, and rates of surface falls – the last to the nearest tenth of a percentage point. A plot of spot readings and of all calculated aspects is given in Figure 2.

3.2 Infrared thermography

During the survey on site, the *AGEMA model 550 thermovision camera* was used to produce thermal maps of the grounds along the building periphery and of the courtyard. The camera was given inputs on ambient temperature, relative humidity, distance to target, and on emissivity to obtain accurate on-site measurements. Climatic data were obtained by use of a *Type 761 Lambrecht Psychrometer*. IR images were then analysed by using *IRwin 5.1* software. During the analysis, differential IR images were also produced by changing the range of the temperature scale in consideration of momentary surface conditions. Owing to the fact that the camera was available for a limited time, the survey was carried out once in May and once in September, under direct solar exposure and just after sunset.

Infrared images of the subject areas were taken in segments from the top level of roof parapets, together with their visible-light photographs, where conditions allowed. During the survey, the distance between the camera and the target area was calculated approximately from the measured plan and section drawings for each exposure. Necessary climatic measurements were taken on site at two-hour intervals. The camera position for each image was noted on a measured plan drawing and all images were given identity codes. However, some unforeseen conditions on site, such as tourist vehicles parking around the building and a herd of sheep passing by unexpectedly, partially restricted the survey, at the west and east sides of the building proper.

4 Results and discussion

The surface-water drainage system of the building was evaluated by the juxtaposition of the thermal maps with those showing ground surface falls. Results obtained, together with a discussion on such in terms of *faults of site grading, existence of a sub-surface drainage system,* and *evaluation of non-destructive methods used* is presented below under respective headings.

4.1 Faults in site grading

Surface-water discharge of the building is provided by site grading. An overall fall of 7.0% was found to run from the northeast to the southwest corner of the building. A similar fall was found to exist in the courtyard, but running at 3.8%. Within the 4-metre-wide survey strip, falls were more or less consistently away from the building walls and ranged from nil to 27% (Figure 2). However, overall site grading was found to be improper around the building due to inadequate and/or reverse falls forming ponded areas.

The present state of the site grading was found to be far from performing up to an acceptable standard for proper surface-water removal. Most falls away from the building were below 5%, which is unsatisfactory for surface drainage of unpaved areas (Rose, 1994). Almost all falls normal to the north edge of the buttresses at the east and west side of the building were observed to be nil or reverse (Figure 2). The areas with critical reverse falls were determined to be the northeast and northwest corners of the building proper, and the west corner of the third buttress–counting from the west-on the south wall (Figure 2) where seemed to be the result of some later interventions, reaching the gradients of 24% and 99% towards the wall. In a number of cases, the ground appeared to have settled into a natural grading due to erosion by rainwater discharged from the overhead spouts. For instance, a considerable section of the east wall bordering the enclosed part of the building showed no fall along its length at all and the

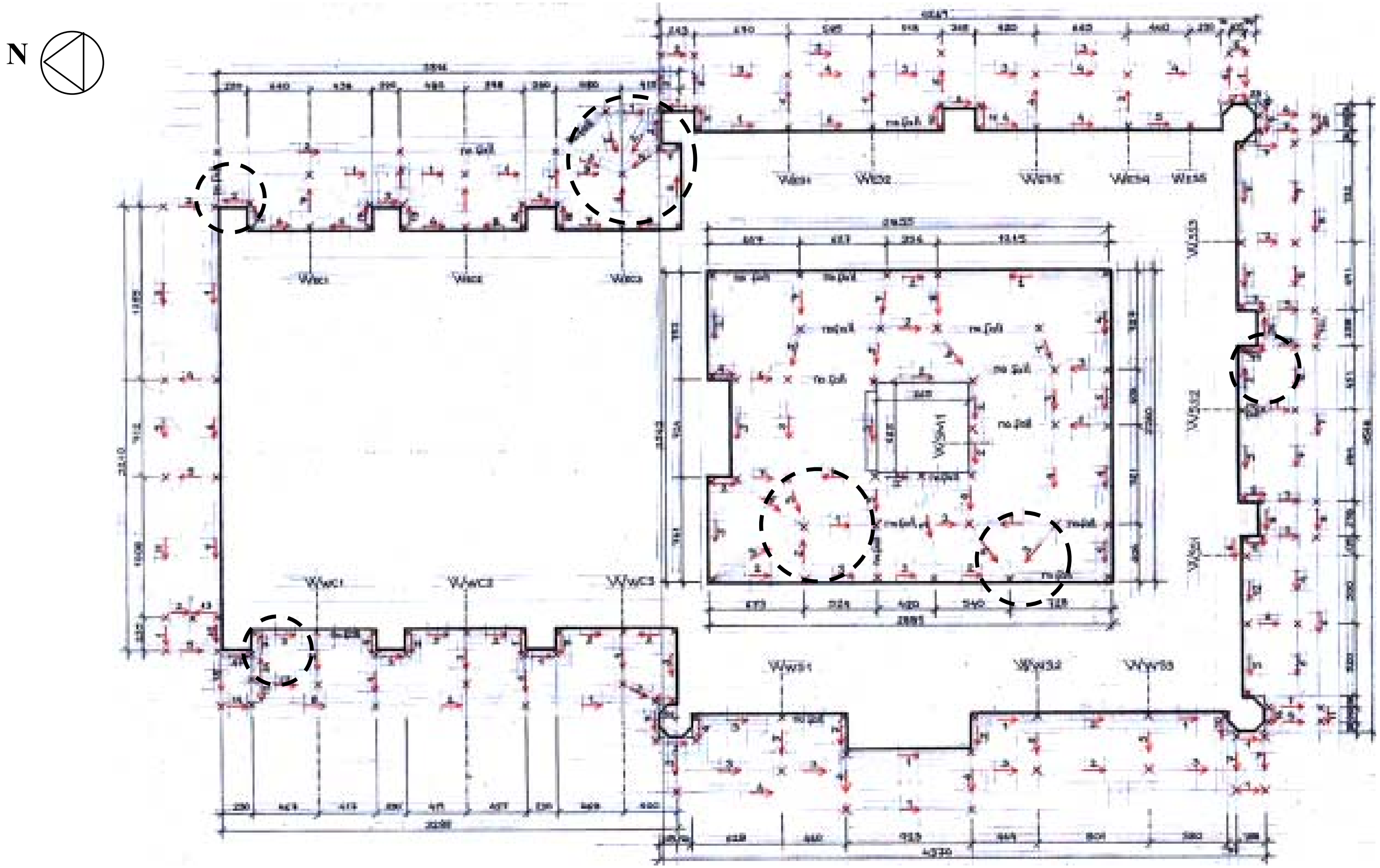


Figure 2 Map showing the slopes of immediate surroundings of the building proper and in the courtyard, scale 1/450 (slopes were given in percentages).

groundlines along walls were observed to gulley at points roughly corresponding to the centrelines of the roof drainage spouts above before distinctly falling away outwards (Figure 2). Some local depressions were also determined in the northwest and southwest areas of the courtyard and at the south corner of the east wall bordering the enclosed part of the building, to support the potential risk of long-term ponding here. The lower parts of the structure next to such problem areas were also found to be cold and damp due to the saturated soil next to the foundation (Figures 3, 4 and 5).

4.2 Existence of a sub-surface drainage system

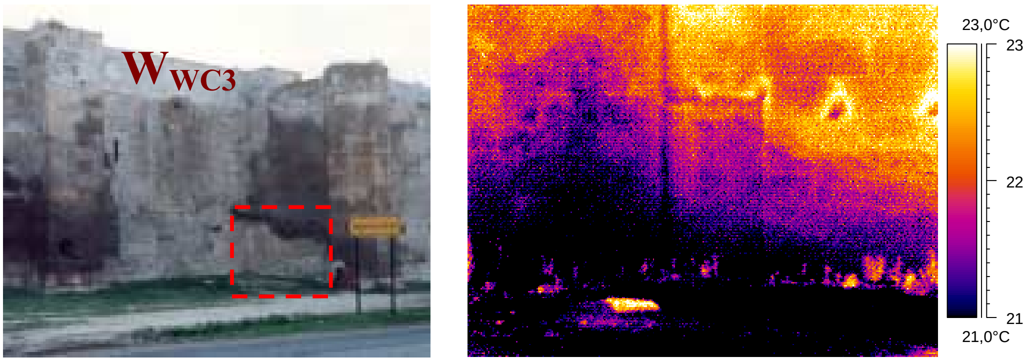
The ground surrounding Ağzıkarahan are unpaved, with little or natural cover and most parts of the courtyard are surfaced with coarse gravel with some parts are flagging, as noted earlier. The discharge coefficient of the peripheral grounds, as well as of the courtyard-calculated to lie between 0.2 to 0.5 (standard values are given as 0.5 for compacted earth surfaces; in the range of 0.4 – 0.5 for flagged pavements on sand fill; and 0.2 – 0.3 for gravelled roads)-indicated a considerably high absorption capability according to the standards set out in the literature (Isısan, 1997; Köktürk, 1994; TSE, 1988). In line with Massari an Massari (1993), it could therefore necessarily be presumed that a need for a sub-surface drainage system also became self-evident to the original builders, unless this permeability extended well below foundation levels to thus render this need redundant.

In the case where a sub-surface drainage system exists, it no longer appears to function at all in the building periphery, though it may be partially effective in the courtyard. Local depressions at the northwest and southwest corners of the courtyard were found to be warmer while they were assumed to be cold due to considerable risk of long-term ponding here (Figures 2, 6, and 7). However, the southeast corner, with zero fall, was found to be the coldest zone of the courtyard (Figures 2 and 8). This showed that, except for the southeast corner, the courtyard seemed, in general, to be well-drained.

In addition, a warm path was found to exist running from the northeast to southwest, parallel to the overall slope of the site (Figure 9) and continuing beneath the kiosk masjid (Figure 10). This supported the assumption that there existed a fountain underneath the kiosk masjid (Tükel Yavuz, 1997) and also the argument that there had originally been a water supply system transporting water from the site of Höyük located 2 km. away from the northeast of the building (Esin, 1990). The path detected in infrared images could therefore either be part of the original water supply system or of a surface-drainage system running parallel to the overall slope. The extension of the warmer path could not be detected in the infrared images; only a colder path was determined sloping down at the southwest side of the courtyard (Figure 6).

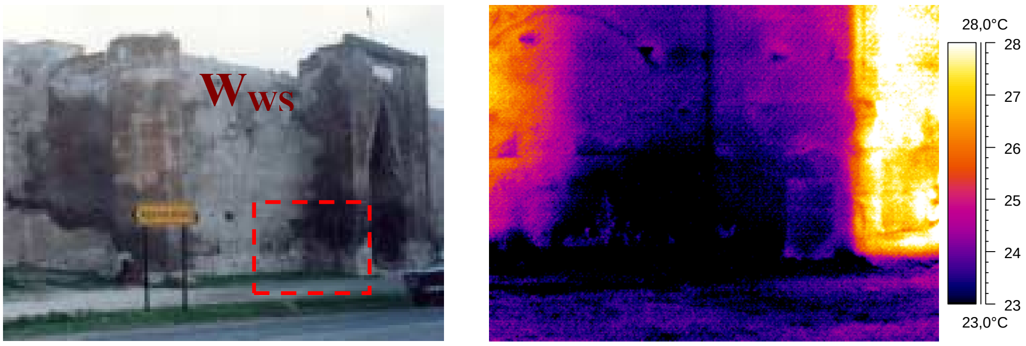
4.3 Evaluation of non-destructive methods used

Site grading is one of the major requirements of surface water removal, which can be easily and precisely measured by a levelling survey. The presence of damp areas is the sign of water accumulation or leakage, either at or below ground level, which can be immediately and accurately detected by IR thermography. The joint interpretation of their results made for a good combination in examining surface-water and sub-surface



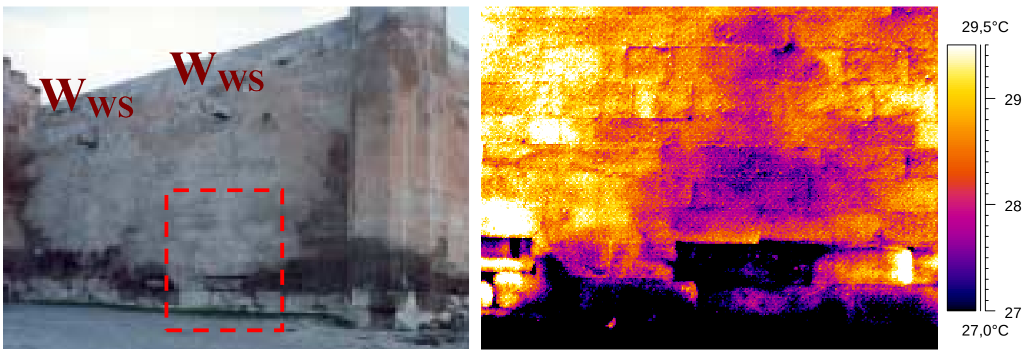
(a) (b)

Figure 3 (a) View of the west side of the building; and (b) infrared image of the selected region taken after sunset, showing the lower parts exposed to reverse fall being the coldest.



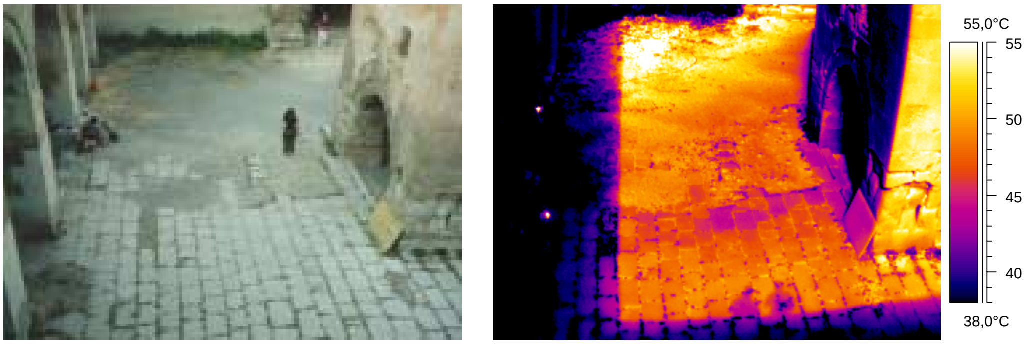
(a) (b)

Figure 4 (a) View of the west side of the building; and (b) infrared image of the selected region after sunset, showing the lower parts exposed to nil fall being the coldest.



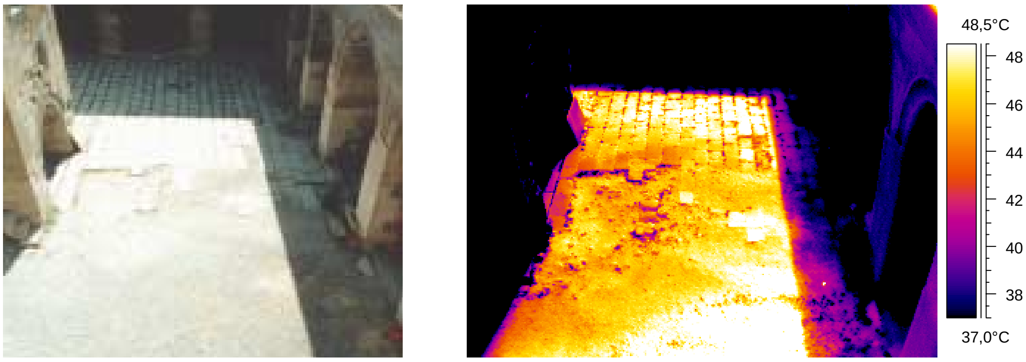
(a) (b)

Figure 5 (a) View from the west side of the building; and (b) infrared image of the selected region taken after sunset, showing that height of colder areas immediately below the waterspouts were higher and extending towards the spout.



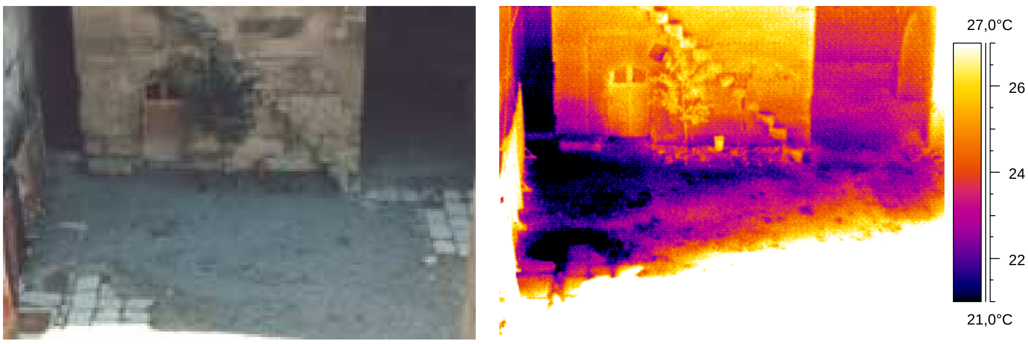
(a) **(b)**

Figure 6 (a) View of the west side of the courtyard looking towards the northwest corner; and (b) its infrared image taken in the afternoon, showing the ponded area at the northwest corner being warmer than the other parts, together with a colder path sloping down from the west of the kiosk masjid.



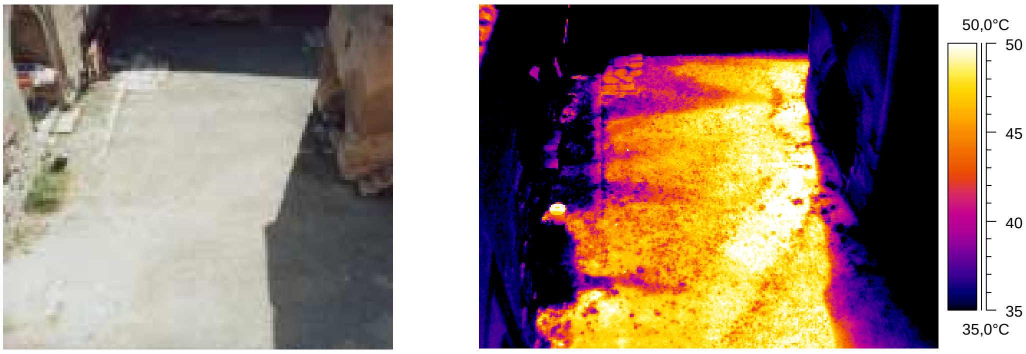
(a) **(b)**

Figure 7 (a) View of the west side of the courtyard looking towards the southwest corner; and (b) its infrared image taken in the afternoon, showing that the ponded area at the southwest corner is warm.



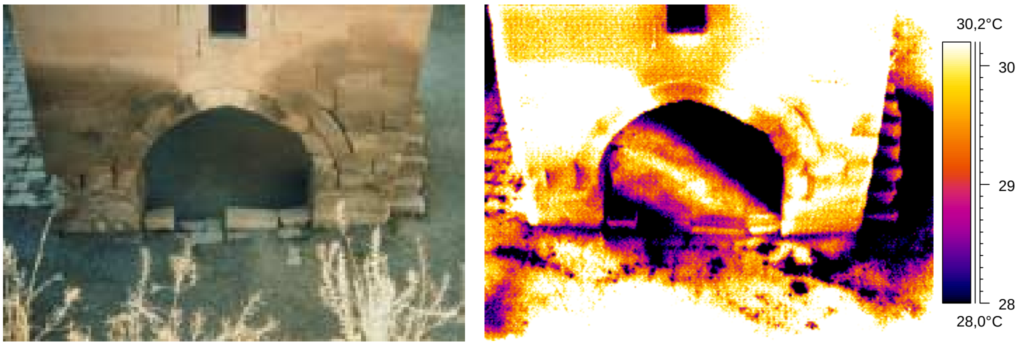
(a) **(b)**

Figure 8 (a) View of the southeast corner in the courtyard; and (b) its infrared image taken in the afternoon, showing that this is the coldest area in the courtyard.



(a) (b)

Figure 9 (a) View of the east side of the courtyard; and (b) its infrared image taken in the afternoon, showing that the warmer path extends from the northeast towards the southwest and there exist some colder patches disappearing along the direction of ground falls.



(a) (b)

Figure 10 (a) View of the lower part of the kiosk masjid taken from the east side; and (b) its infrared image taken in the afternoon, showing a warmer path passing through the bottom of it.

drainage systems. For instance, local depressions in the courtyard unexpectedly detected as extremely dry zones and the grounds with reverse falls detected as damp zones had definitely shown whether surface water was properly discharged or not. It may thus be said that use of IR thermography, along with the levelling survey enhanced therefore the accuracy and effectiveness of the study.

A preliminary survey to record the salient features of the target area beforehand by way of photographs or by mapping is essential to foresee any misleading situations. As to surface variations, in terms of material composition and type, as well as patterns of shadow and visual defects on surfaces, visible in IR images as warmer or cooler patches, may cause confusion, whether anomalies are on or behind the surfaces (Tavukçuoğlu, 2001). Such documentation also makes possible construction of differential IR images, especially for the analysis of sublayers.

IR imaging requires a periodic study on site together with surface temperature and humidity measurements. Its use for a limited time permitted only qualitative evaluation of the grounds and stone surfaces. Some anomalies appearing on the thermal maps need to be more clearly identified. For instance, colder patches detected at the east of the courtyard (Figure 9) and the colder path at the west of the courtyard sloping down towards the southwest (Figure 6) were found to disappear along the direction of ground falls. While these may be interpreted as being indicative of some failure in the surface-water drainage system, only further investigations could verify or negate this preliminary interpretation

5 Conclusion

The survival of the building in more or less intact condition over eight centuries to this date is deemed strong evidence for the presence of a proper surface-water and sub-surface drainage system, which must have functioned properly in its past for a long time.

Surface-water drainage had become disfunctional due to inadequate and reverse falls, in turn causing ponded areas in the immediate grounds of the building. It is clear that a proper site grading with a minimum of 5% falls away from the walls is necessary for satisfactory surface drainage in Ağzıkarahan. Special care at points below waterspouts must be taken to ensure that rainwater is diverted away from the building. As a preventive measure, occasional re-grading of surrounding grounds is also essential to maintain a pond-free surface drainage and for the survival of the building proper.

Most parts of the courtyard being well-drained was considered not only strong evidence for the existence of a sub-surface drainage system there, but also for the possibility that it is still functional, though such a system, if it existed all, appears no longer so for the building periphery.

Further non-destructive and non-interventionary investigations were considered necessary to determine the existence and condition of any underground elements contributing to the overall surface drainage. Such a study can be programmed by extensive use of IR imaging and by using ground-penetrating radar, which makes possible the location of not only internal voids and anomalies, but also the detection of moisture, both in the masonry and underground (Binda, Lenzi & Saisi, 1998). IR images of the grounds should be taken once more one or two days after rainfall for designation of water flow on ground surfaces and below ground level. Such a study would also make it also possible to compare dry and wet conditions of the ground for a comprehensive condition assessment of surface-water and sub-surface drainage systems.

The characteristics of the soil below the ground level should be examined by using non-destructive site survey techniques and laboratory analysis. The high absorption capability of the grounds surrounding Ağzıkarahan and rising damp zones in the lower parts of the building detected by IR images indicated that rainwater and melting snow are mostly absorbed, especially where local falls and/or flat surfaces are designated on maps. This pointed out the necessity of investigating the permeability and capillarity properties of the surrounding soils to understand how deep and rapid the penetration of water is, as well as to determine how quickly water rises again.

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Experimental Monitoring of Hot Water Supply Systems

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Abstract

The paper presents the partial research results from experimental monitoring of existing central domestic hot water production and distribution systems within residential buildings in the Czech Republic. The goal of mentioned investigation is to determine real thermal and hydraulic behaviour of these systems, evaluate the results and take appropriate conclusions for practical design. The paper is primarily aimed at the monitoring: (a) maximum flow (peak flow) of hot water delivered to the plumbing fixtures, (b) division of hot water consumption during the day. Experimental measurements in the duration of one to three weeks were realized in three residential buildings with the number of 32 to 60 flats. In spite of the wide spectrum of obtained results it is possible to state that the hourly consumption peaks are usually concentrated to evening or to morning hours but the peak flow also appears except these periods. Furthermore there was found out that the time variations of water consumption, which are expressed in the variation coefficients, are within the monitored residential buildings in practice similar and without substantial dependency on the season. Generalization to detailed conclusions is determinated by long-term measurements.

Keywords

Residential buildings, hot water, flow, consumption, measurement

1 Introduction

The current research is focused on the existing central systems of production and distribution of hot water that prevail in the Czech Republic. Within their reconstruction as well as within their designs it is necessary to carry out the technical and economical evaluation of all possible project solutions.

The appropriate technical project of all parts and components within this monitored system from domestic hot water heating equipment to the points of consumption decides on the amount of investments and operation costs. The aim of this technical

solution is to provide the system with reliable and secure functions supplying hot water within the whole day and without considerable drops in temperature during the peak loads.
For the sizing of the appropriate water distribution system whose heat losses substantionaly contribute on the total energy consumption for hot water production there are determining the properly stated of the pipe sizes which should be adequate to the real values compared to the peak flow of hot water. For the project of water heating equipment there is deciding the proper knowledge of hot water division during the day.
Relating to these reasons then for the complex system project there is the most important factor to find out the most reliable data relating to real time behaviour of water consumption within the residential buildings. In practice there are used the norm-suggested values, eventually the monthly water and energy consumptions according to the costs measurements but very often they are not sufficient.
Monitoring of domestic hot water systems (DHW systems) within its hydraulic behaviour represents a very demanding task that requires long-term measurements as the monitored quantities depend on a number of hardly noticeable factors. Within residential houses to these factors there belong e.g. flat category, number of users, their professions and age, way of spending leisure time, season and technical layout of the system [4].

2 Basic aims of system monitoring

The aim of this research project is to form the optimal model of central DHW system based on the total data evaluation that would relate to the real hydraulic and thermal behaviour of this system within residential buildings.
The concrete goal of this paper is to present experimental monitoring of hydraulic values of DHW system that include:

- measurements and analysis of hot water consumption (time behaviour of hot water consumption during day and week, determination of period of maximal consumption, determination of coefficients of water consumption variations),
- measurements and analysis of hot water flow (specification of peak flow and period of their occurrence).

The analysis of hydraulic hot water parameters follows the analysis of their thermal behaviour parameters [1,2].

3 The method of measurements and data processing

For fulfilling the above stated aims there was suggested the procedure that can be dividend in following steps:

- measurement preparation,
- measurement realisation,
- evaluation of measurement results,
- related numerical calculations.

Within the measurement preparation there was carried out the building survey within which there was chosen the place for measurements and there was decided the placement of particular sensors.
For the measurement realisation there was assembled the device set that enables the measurement of chosen quantities and their recording into the instrument or computer memory. The device set was established with these elementary components: ultrasound flowmeter, universal datalogger device, portable computer and flow, temperature and pressure sensors.
The measurement placement always was the source of hot water and there were monitored these hydraulic values:

- the flow of hot water at the heater outlet,
- consumption of hot water,
- pressure of cold water at the heater inlet.

At the same time there were carried out the temperature measurement of hot water at the heater outlet, temperature measurement of hot water circulation at the heater inlet, temperature measurement of cold water entering into the heater, temperature measurement of heat – carrying medium (supply and return), surface temperatures of insulations and the temperature of surrounding air.
For measurements of flows and pressures with expected rapid value changes there was chosen data logging interval 30 seconds, in the case of slow temperatures changes there was chosen data logging interval 120 seconds. Measurements were carried out in three residential buildings in connected intervals within one to three weeks.
Outlets of dataloggers then form wide data sets with ten thousands of numerical figures. By the means of computing technology these data were transferred into graphical outputs and there was carried out their analysis. The following numerical calculations of variation coefficients are documented by table output.

4 Results of experimental monitoring

In this chapter there are presented measured results of flows and consumptions of hot water in three chosen residential buildings. The monitored buildings differ in number of flats, water and heat consumptions (Table 1), technical layout of DHW system and quite different can be also the measurement period and its duration.

Table 1 - Hot water and energy consumptions

	Flat category			Number of persons	Hot water demand 1) m^3/person.day	Hot water consumption, energy consumption							
	2+1	3+1	4+1			2001				2002			
	Number	Number	Number			m^3/yr	m^3/person.day	GJ/yr	GJ/m^3	m^3/yr	m^3/person.day	GJ/yr	GJ/m^3
Case 1	0	16	16	113		1342	0.033	510	0.380	1341	0.033	484	0.361
Case 2	0	32	0	94	0.082	1481	0.043	332	0.224	1335	0.039	314	0.235
Case 3	12	36	12	201		2837	0.039	818	0.288	2778	0.038	821	0.296
1) Standard value, temperature 55 °C													

4.1 Building 1 (case 1)

The object of monitoring is the residential building with 8 upper floors and two separated entrances. On each floor there are always one three-roomed flat and one four-roomed flat, in the house there are totally 32 flats that are used by 113 people.

The source of hot water is the storage heater placed in separated room on the basement floor of this building. In each flat there is one mixing faucet in the kitchen and one in the bathroom that is common for the bathtub and the wash-basin as well. The faucets are mostly classical, partly levered. The hot water circulation is forced with non-interrupted operation. Heat supply is interrupted from 22:00 to 4:30 hours. The temperature of supplied water is regulated by setting up the regulating system and amounts average value 60.1 ^{o}C.

On the basis of graphical outlets of weekly measurements (Figure 1) which was carried out from 9 August to 15 August 2001 there can be stated the following:

- substantial hot water consumption begins every day including the weekend between 7:00 and 8:00,
- maximal early morning hourly consumption appears in the interval between 8:00 and 9:00 with the exception of Sunday and Friday when it is shifted by one hour,
- hourly peak consumption of hot water appears every day during evening hours between 19:00 and 23:00,
- maximum value of hourly consumption (408 litres per hour) appeared during the monitored period on Monday between 20:00 and 21:00,
- flows of hot water reach up to maximum values especially in the evening between the intervals 20:00 and 22:00, then they occur accidentally between 8:00 and 23:00,
- peak flow of 0.44 litres per second was measured on Wednesday, 15 August at 11:08:40.

Furthermore there was carried out the division of water consumption into four equal time periods: 23:00 – 5:00 (night), 5:00 – 11:00 (morning), 11:00 – 17:00 (afternoon) and 17:00 – 23:00 (evening). Results (Table 2) prove maximum consumption during the evening period and approximately the same division of consumption within the whole week.

Measured values and their time occurrence respond to the holiday period. Within the measurements there was not found substantial difference among particular days.

Table 2 – Division of hot water consumption into periods

Time period (hrs)	Water consumption, Case 1 - August 9 - 15													
	Thursday 9		Friday 10		Saturday 11		Sunday 12		Monday 13		Tuesday 14		Wednesday 15	
	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)
23 - 05	128	5.6	171	8.2	77	3.1	218	7.5	132	4.5	267	8.3	165	6.2
05 - 11	554	24.3	472	22.6	634	25.7	591	20.3	739	25.0	832	25.9	669	25.0
11 - 17	577	25.2	586	28.0	684	27.7	884	30.4	643	21.7	825	25.7	648	24.2
17 - 23	1026	44.9	861	41.2	1073	43.5	1220	41.9	1442	48.8	1285	40.0	1198	44.7
Sum	2285	100	2090	100	2468	100	2913	100	2956	100	3208	100	2679	100

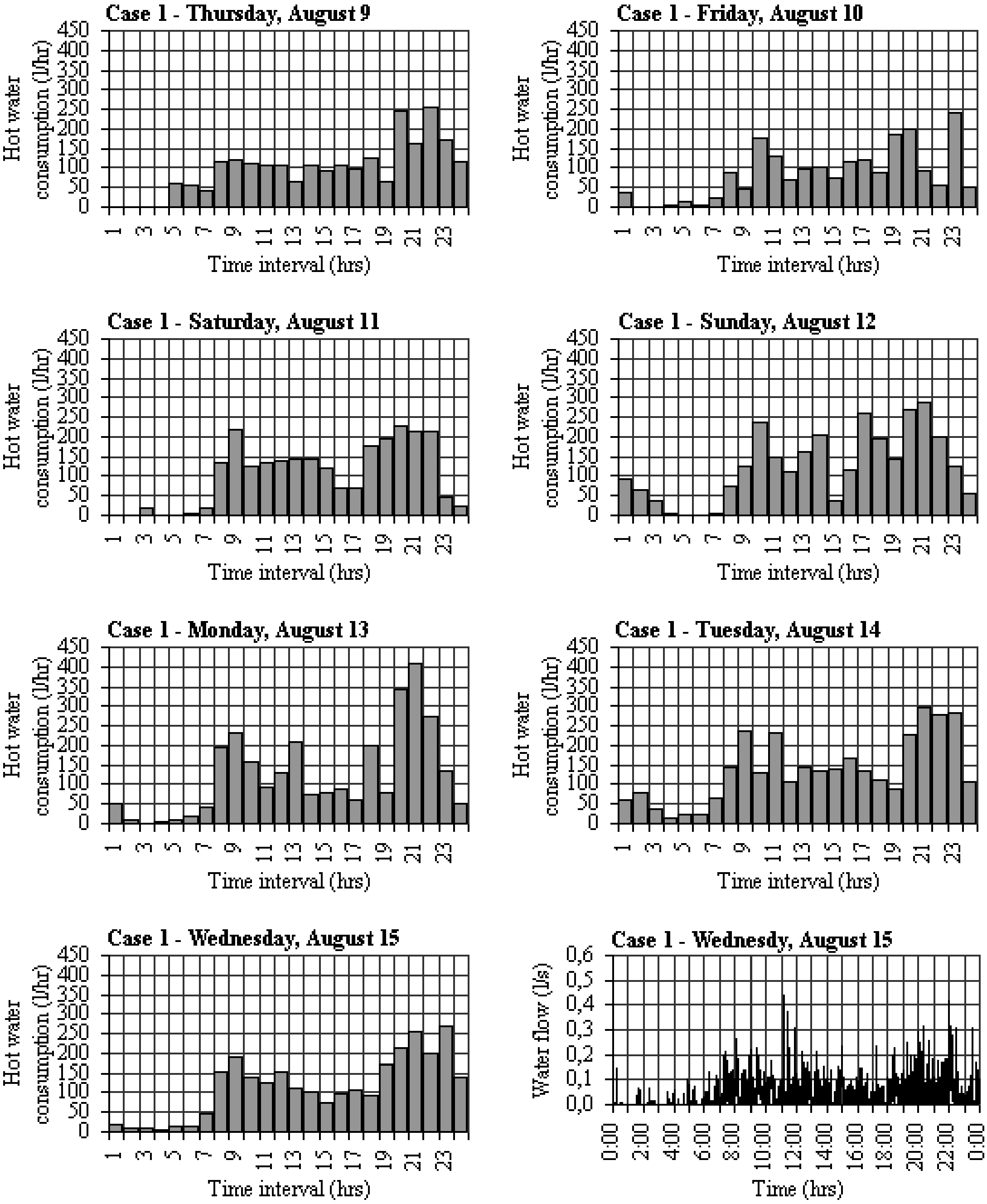

Figure 1 – Hourly consumptions, example of flow measurement

4.2 Building 2 (case 2)

The monitored object was the residential building with 8 upper floors. On each floor there were always four three-roomed flats, in the building there were totally 32 living units that were used by 94 people. The building was after complete reconstruction (carried out in August 2001) when there was made the building thermal insulation and reconstruction of building services.
The source of hot water is storage heater that is situated in the separated room on the basement floor. The hot water is supplied to particular flats to four mixing faucets – to

the kitchen (kitchen sink), to the bathroom (bathtub and wash-basin) and the toilette (wash-basin). All the faucets are single levered. The circulation of hot water is forced with non-interrupted operation. The supply of heat to heater is interrupted during 22:00 and 4:50. The temperature of supplied water is regulated by setting up the regulating system and amounts average value 50.6 ^{o}C.

Measurements were carried out from 12 June to 25 June 2003 and according to elaborated graphical evidence (Figure 2) there results that:

- substantial consumptions of hot water begins in the morning between 5:00 and 7:00 on working days, on Saturdays at 7:00 and 8:00 and on Sundays even one hour later,
- maximum hourly consumption in the morning occurs in the intervals between 6:00 and 7:00 with the exception of Saturdays and Sundays when it is put forward to later time,
- hourly peak consumption within particular days appears irregularly, but mostly within morning or evening hours,
- maximum value of hourly consumption (558 litres per hour) occurred within the monitored period on Thursday on 19 June between 6:00 and 7:00,
- maximum flow of hot water appears irregularly,
- peak water flow of 0.57 litres per second was measured on Thursday, 19 June at 6:15:30.

At the same time there was carried the distribution of water consumption into four equal periods. Results (Table 3) prove the maximum consumption in the evening period with the exception of Saturdays. The distribution of water consumption within working days differs comparing to Saturdays and Sundays.

Table 3 – Division of hot water consumption into periods

Time period (hrs)	Water consumption, Case 2 - June 12 - 25													
	Thursday 12		Friday 13		Saturday 14		Sunday 15		Monday 16		Tuesday 17		Wednesday 18	
	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)
23 - 05	307	8.9	228	7.4	264	9.7	279	7.5	184	6.5	584	14.0	562	13.1
05 - 11	1132	32.9	1084	35.2	1085	39.8	647	17.5	934	32.8	1105	26.4	1156	27.0
11 - 17	596	17.3	655	21.2	562	20.6	1131	30.6	378	13.3	799	19.1	840	19.6
17 - 23	1410	40.9	1115	36.2	813	29.8	1644	44.4	1351	47.4	1694	40.5	1729	40.3
Sum	3444	100	3080	100	2724	100	3700	100	2848	100	4182	100	4287	100
	Thursday 19		Friday 20		Saturday 21		Sunday 22		Monday 23		Tuesday 24		Wednesday 25	
	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)
23 - 05	488	10.6	359	12.8	230	5.5	452	9.4	213	5.6	232	7.1	264	7.3
05 - 11	1517	33.0	912	32.7	854	20.5	793	16.5	896	23.5	1262	38.8	1268	35.0
11 - 17	841	18.3	563	20.2	1720	41.3	1602	33.3	912	24.0	463	14.2	659	18.2
17 - 23	1754	38.1	958	34.3	1365	32.7	1961	40.8	1785	46.9	1298	39.9	1429	39.5
Sum	4600	100	2792	100	4170	100	4808	100	3806	100	3255	100	3619	100

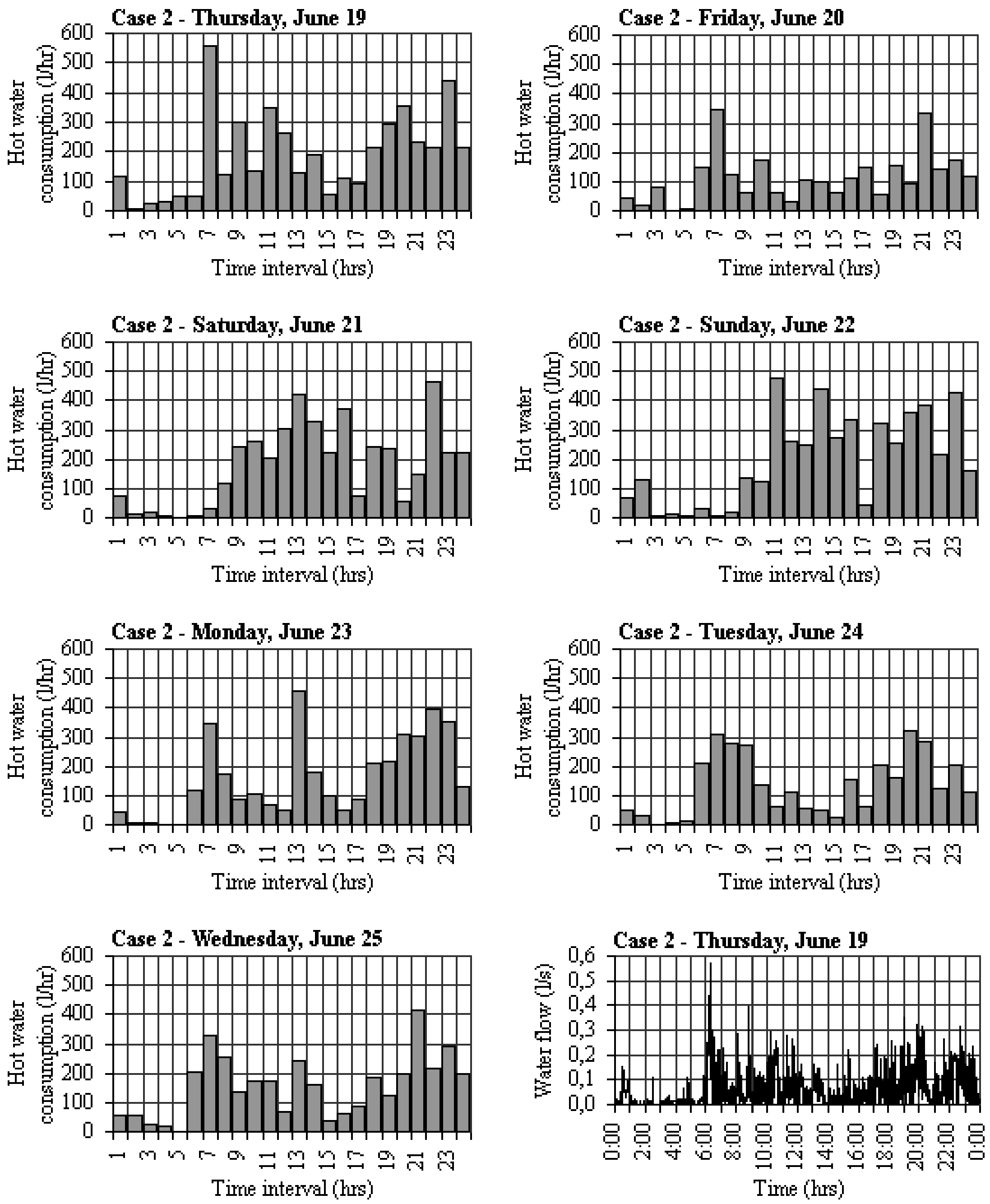

Figure 2 – Hourly consumptions, example of flow measurement

4.3 Building 3 (case 3)

The monitored object is the residential building with 12 upper floors. On each floor there are always three three-roomed flats and one two and four-roomed flats, in the building there are totally 60 living units that are used by 201 people.
The source of hot water is the instantaneous heater that is situated in a single room on the basement floor of the building. Hot water is supplied to particular flats to three mixing faucets – to the kitchen (kitchen sink) and to the bathroom (bathtub and wash-basin). The faucets are mostly classical, partially levered. The circulation of hot water is

forced with non-interrupted operation. The temperature of supplied water is given by setting up the regulating system and amounts average value 53.5 ^{o}C.
Measurements were taken from 24 December 2001 to 13 January 2002 and in accordance with working out graphical outputs (Figure 3) there results that:

- on working days there starts the consumption of hot water between 5:00 and 6:00,
- on Saturdays and Sundays and holiday days the beginning of consumption is put forward by minimally by 2 hours,
- morning and afternoon consumptions do not prove substantial peaks,
- hourly peak consumption occurs especially in evening hours mostly between 19:00 and 21:00,
- maximum value of hourly consumption (1275 litres per hour) appeared within the monitored period on Sunday 13 January between 19:00 and 20:00,
- maximum values of hot water flows occur irregularly,
- peak flow of 1.18 litres per second was measured on Thursday, 10 January at 19:33:00.

Further there was carried out the distribution of water consumption into four time periods: 23:00 to 5:00 (night), 5:00 to 11:00 (morning), 11:00 to 17:00 (afternoon) and 17:00 to 23:00 (evening). With regard to longer lasting measurements (3 weeks) including Christmas and New Years´ Holiday the division of water consumption (Table 4) into particular time periods was very variable. With the exception of some non working days the highest consumption stays within the evening period.

Table 4 – Division of hot water consumption into periods

Time period (hr)	Water consumption, Case 3 - December 24 – January 13													
	Monday 24		Tuesday 25		Wednesday 26		Thursday 27		Friday 28		Saturday 28		Sunday 29	
	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)
23 - 05	1435	11.5	580	7.0	533	6.0	819	8.9	716	7.9	576	6.5	448	5.9
05 - 11	2919	23.3	2133	25.9	2496	28.2	2081	22.7	2247	24.8	2174	24.5	1587	21.1
11 - 17	5139	41.1	2537	30.8	2566	28.9	3033	33.1	2758	30.5	2989	33.7	2522	33.5
17 - 23	3013	24.1	2991	36.3	3271	36.9	3227	35.2	3333	36.8	3142	35.4	2983	39.6
Sum	12505	100	8242	100	8865	100	9159	100	9054	100	8881	100	7540	100
	Monday 31		Tuesday 1		Wednesday 2		Thursday 3		Friday 4		Saturday 5		Sunday 6	
	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)
23 - 05	585	8.0	893	12.4	528	6.8	527	6.3	440	6.7	688	8.0	361	3.4
05 - 11	2021	27.6	1082	15.0	1498	19.3	1530	18.2	1545	23.7	1856	21.6	2148	20.4
11 - 17	3029	41.3	2403	33.3	2079	26.7	2030	24.2	2033	31.2	2731	31.8	3064	29.2
17 - 23	1698	23.2	2842	39.4	3678	47.3	4301	51.3	2495	38.3	3311	38.6	4931	46.9
Sum	7333	100	7219	100	7783	100	8388	100	6513	100	8586	100	10504	100
	Monday 7		Tuesday 8		Wednesday 9		Thursday 10		Friday 11		Saturday 12		Sunday 13	
	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)	(litres)	(%)
23 - 05	447	5.4	676	8.4	269	3.8	455	5.4	438	5.9	308	3.6	695	7.1
05 - 11	2302	27.7	1591	19.9	1555	21.7	1795	21.3	1587	21.3	1964	23.1	1523	15.6
11 - 17	1896	22.8	1772	22.1	1600	22.3	1428	16.9	2273	30.5	3590	42.2	3437	35.2
17 - 23	3670	44.1	3972	49.6	3745	52.2	4757	56.4	3147	42.3	2641	31.1	4111	42.1
Sum	8315	100	8011	100	7169	100	8436	100	7445	100	8503	100	9766	100

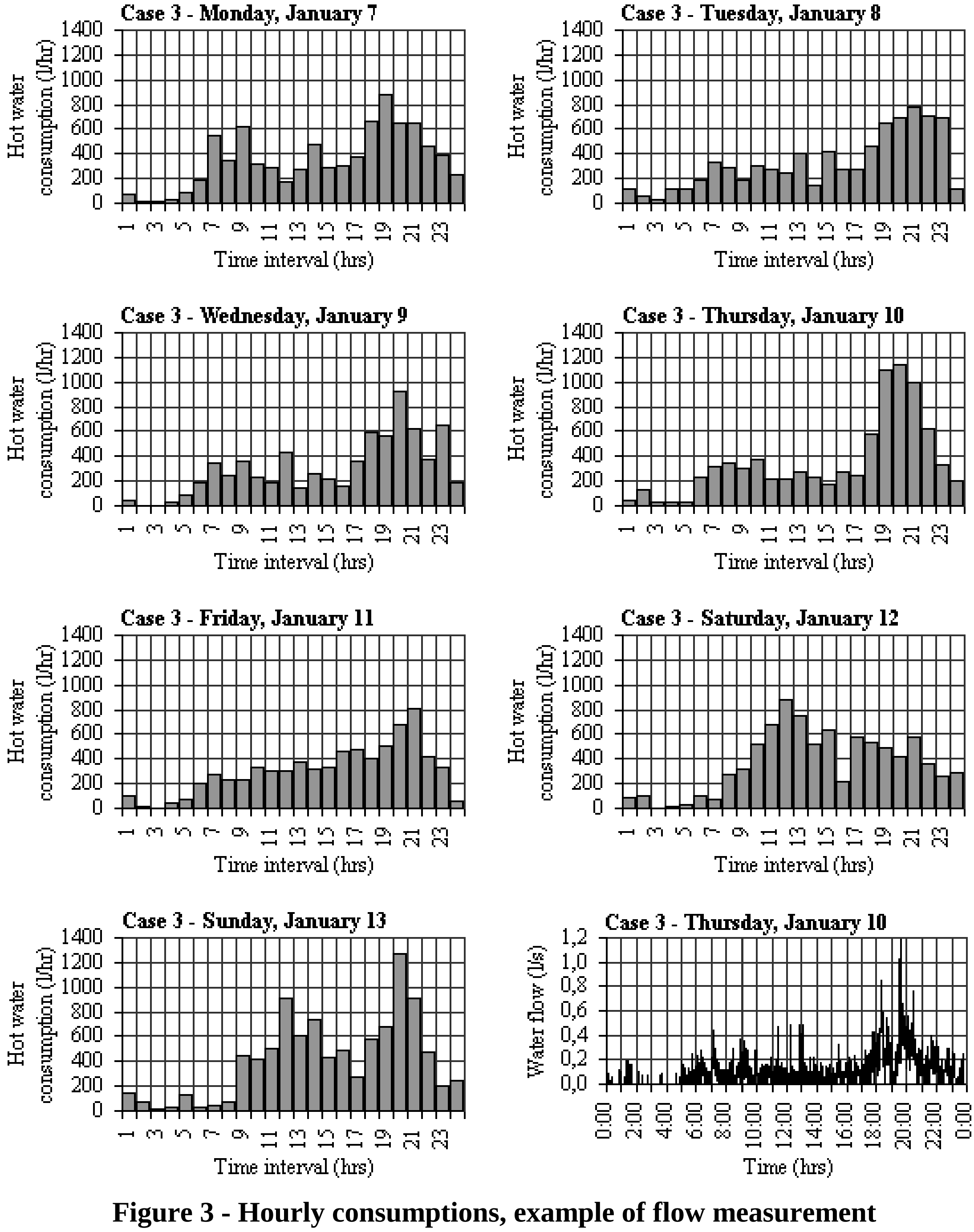

Figure 3 - Hourly consumptions, example of flow measurement

5 Coefficients of water consumption variations

Relating to acquired measured values which were taken always within the same period - one week - there were stated the coefficients of daily variations k_d, hourly variations k_h and secondly variations k_s according to the following equations:

$$k_d = \frac{Q_{dm}}{\overline{\overline{Q}}_d} \quad (-), \qquad k_h = \frac{Q_{hm}}{\overline{\overline{Q}}_h} \quad (-), \qquad k_s = \frac{Q_{sm}}{\overline{\overline{Q}}_s} \quad (-),$$

where

Q_{dm} maximum daily water consumption (litres per day),
Q_d average daily water consumption (litres per day),
Q_{hm} maximum hourly water consumption (litres per hour),
Q_h average hourly water consumption (litres per hour),
Q_{sm} maximum secondly water consumption / water flow (litres per second),
Q_s average secondly water consumption / water flow (litres per second).

Numerical calculations of stated coefficients were carried out within four chosen seasons, winter (January, building 3), spring (June, building 2), summer (August, building 1) and season of Christmas Holidays (building 3). The aim was to find out if various seasons influence the variations of water consumption in residential buildings. In accordance with the solution output (Table 5) there was not found out a substantial difference of consumption variations of hot water within monitored periods excepting values of secondly variations.

Table 5 - Coefficients of water consumption variations

	Week	Maximum hot water consumption			Average hot water consumption			Coefficients of water consumption variations		
		Litres/day	Litres/hour	Litres/sec.	Litres/day	Litres/hour	Litres/sec.	Daily variations	Hourly variations	Secondly variations
Case 1	August 9 - 15	3262	408	0.440	2667	111	0.031	1.22	3.67	14.25
Case 2	June 12 - 18	4426	454	0.520	3490	145	0.040	1.27	3.12	12.87
	June 19 - 25	4743	558	0.570	3855	161	0.045	1.23	3.47	12.77
Case 3	December 24 - 30	11866	1149	0.980	9081	378	0.105	1.31	3.04	9.32
	Dec. 31 – Jan. 6	10690	1187	0.950	8075	336	0.093	1.32	3.53	10.17
	January 7 - 13	9714	1275	1.180	8237	343	0.095	1.18	3.71	12.38

6 Conclusions

On the bases of monitoring results that were carried out within three residential buildings with the number of 32 to 60 flats there can be concluded:

- specific water consumption within the monitored houses is substantially lower than the design value stated by technical standard,
- time behaviour of hot water consumption and flow is irregular and discontinuous in accordance with the author’s assumption,
- water consumption variations cited by variation coefficients did not differ markedly comparing to particular buildings and there was not found out substantial dependency on the season,
- by the means of proved variation coefficients there can be stated assumed maximum daily, hourly and secondly consumptions for similar residential houses based on their average water consumption,
- hourly peak consumptions occur mostly in the evening, occasionally in the morning, exceptionally during the normal daily period most frequently on holiday days,

- peak flows occur also except time of hourly peak consumption,
- maximum amount of hot water is consumed during the evening period (17:00 to 23:00), the exception can be some holiday days,
- results of this study phase are important source materials for establishment of a real model within this monitored system and for determination of their designed parameters what will be the subject of the next working project phase.

Acknowledgements

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8 Presentation of Author

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Field Test of Residential Tele-care System for Senior Citizens Measuremental Study of Bathing Environment in Winter

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Abstract

Bathing is one of the riskiest home situations for health at low temperatures. A field test was conducted for a residential tele-care system, focusing on the housing environment for senior citizens and their safety during the winter.

Housing environment factors such as temperature and humidity in houses, especially when senior citizens were bathing, were measured. A comparison was made of the data for urban areas and the data for rural cold climate areas in Japan.

The results of the field test confirmed that the residential tele-care system is one of the effective measures for the safety of senior citizens.

Key Words: Information Technology, Bathing, Temperature and Humidity, Senior citizens, Residential Environment

1. Introduction

In recent years, senior citizens in Japan have come to live far from their families and relatives. As a result, there is increasing concern about the life of senior citizens on the part of senior citizens themselves and their families. This paper describes a self-supporting networking system that permits interactive communication by senior citizens, their families, their friends, the medical center, the Housing Support Center for the elderly, etc. This system is called the "tele-care system".

The tele-care system supports the care of senior citizens from a remote location through the use of video communication, a variety of information technologies and communication services, and health management systems with telecommunication capabilities. This system supports the effort to build a new community for the aging society.

This report describes a field test that was conducted for a residential tele-care system, focusing on the housing environment for senior citizens and their safety during the winter.

Housing environment factors such as temperature and humidity in houses, especially when senior citizens were bathing, were measured. Bathing is one of the riskiest home situations for health at low temperatures. A comparison was made of the data for urban areas and the data for rural cold climate areas in Japan.

2. Outdoor temperature and number of deaths in City T

Bathing, getting undressed in preparation for bathing, using hot water in the tub and using the toilet are the riskiest home situations for health at low temperatures in the wintertime, as they cause the blood pressure of senior citizens to go up and down sharply.

Between 1993 and 1997, the number of cases of death occurring in the bath that were handled by the Medical Examiner's Office in Japan in Tokyo, Osaka, and Hyogo came to 2,736. By month, 1,825 deaths (67%) occurred between November and March. The months of December and January in particular experienced a large number of accidents, 889 or 32% of the total. The average outdoor temperature is 4.7°C to 12.9°C in Tokyo, Osaka and Hyogo. According to the Tokyo Medical Examiner's Office, the cause of death in most cases is ischemic heart disease of the circulatory system or aortopathy. These causes, together with cerebro-vascular disorders, account for 80% of the deaths. For those 65 years of age or older, 25% of all sudden deaths that occur at home happen when the person is taking a bath.

Figure 1 shows the fluctuations in the average temperature in City T during a 5-year period. Figure 2 shows the cumulative total of deaths per month in City T for the 5-year period. A heating system is needed from October to the following April. Sudden deaths are primarily of persons 65 years of age or older during the months of November and December, when it starts to get very cold, and April, when it begins to grow warm. Sudden death occurs during a period of time ranging from a few hours to several days and is caused by myocardial infarct or apoplexia cerebri, etc. The figures for sudden death include persons who were slightly under 65 years of age at the time of death. Sudden death is most common from November to the following March, when the average temperature is under 5°C, and it is especially common in February, in which 60% of all sudden deaths occur.

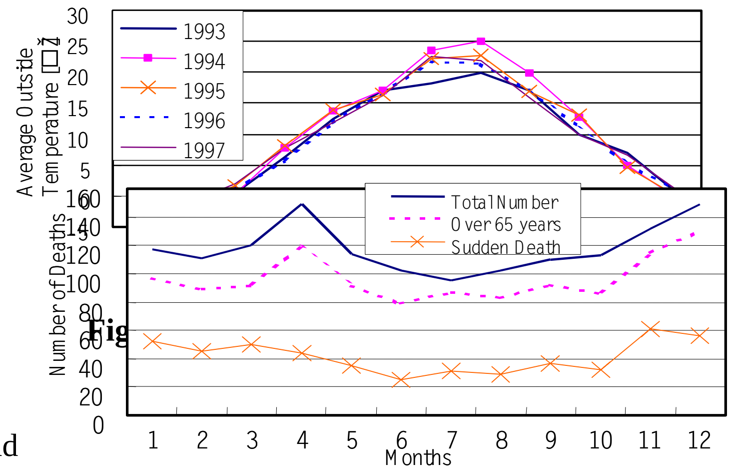


Fig.2 Cumulative Total of Deaths per Month in City T (5-year period)

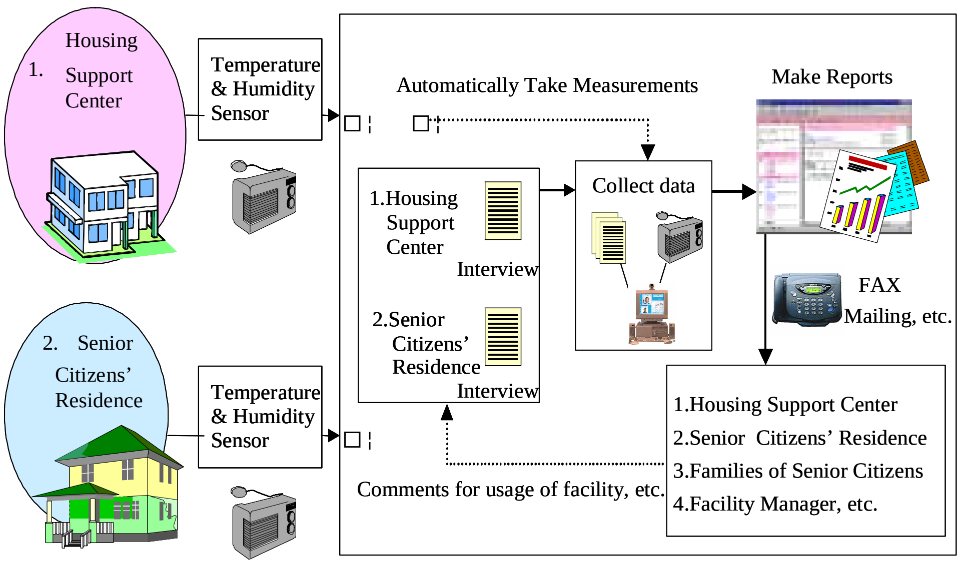


Fig.3 Overview of Tele-care System

3. Overview of the tele-care system in Tokyo

3.1 Method of Investigation

Figure 3 shows an overview of the system. Housing environment factors such as the temperature and humidity of rooms and the hot water temperature in the bath are measured at the residences of senior citizens and their Housing Support Center, where the senior citizens spend most of their time. Based on the results and interviews with the senior citizens themselves and relevant parties, problems are identified and information is provided in the form of regular reports.

Figure 4 shows the temperature and humidity at Housing Support Center Y as displayed on a personal computer monitor. This presentation was prepared by the manager of the Housing Support Center, with the aim of presenting the status inside the Center in easy-to-understand terms. Figure 5 shows an example of the regular reports that are provided to senior citizens. The activities of senior citizens are continuously considered, and those places in the housing environment in which accidents are most likely to occur are monitored, with particular focus on temperature and humidity conditions, and advice regarding equipment and facilities and the like is provided.

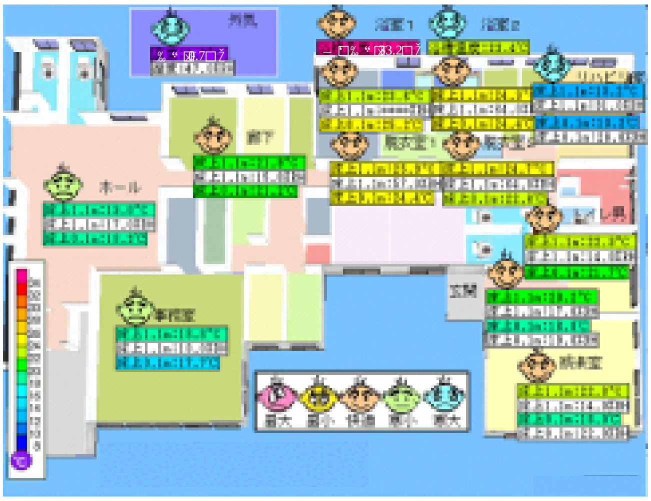
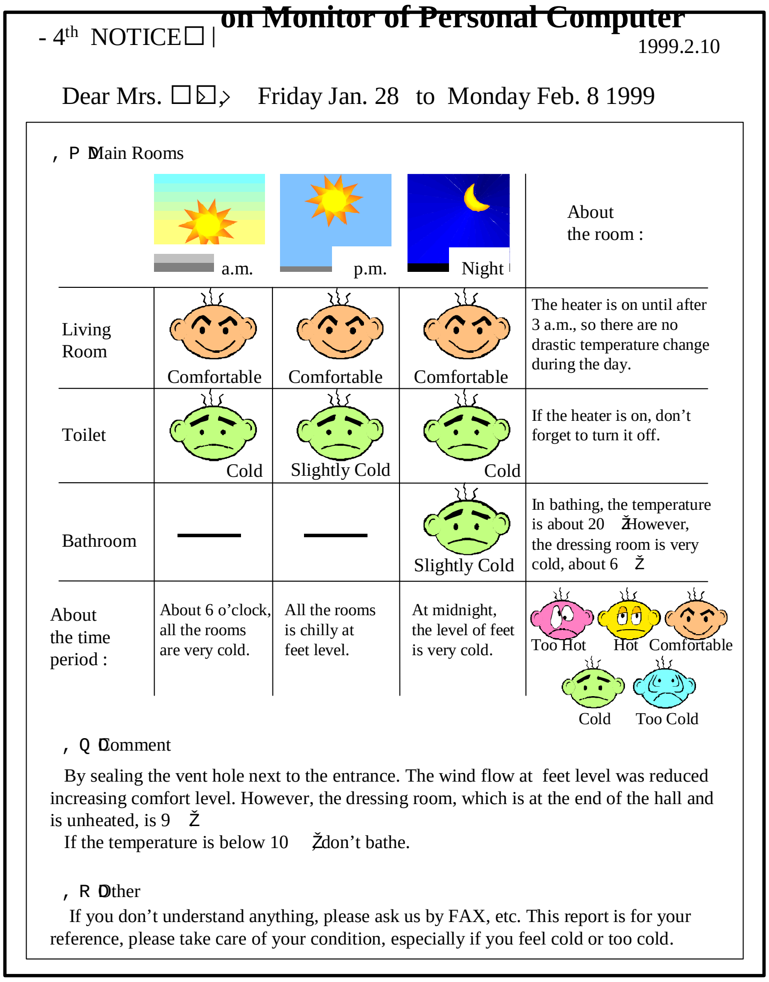


Fig.4 Temperature and Humidity Display on Monitor of Personal Computer



- 4th NOTICE□ | 1999.2.10

Dear Mrs. □□> Friday Jan. 28 to Monday Feb. 8 1999

, P Main Rooms

	a.m.	p.m.	Night	About the room :
Living Room	Comfortable	Comfortable	Comfortable	The heater is on until after 3 a.m., so there are no drastic temperature change during the day.
Toilet	Cold	Slightly Cold	Cold	If the heater is on, don't forget to turn it off.
Bathroom	—	—	Slightly Cold	In bathing, the temperature is about 20 ŽHowever, the dressing room is very cold, about 6 Ž
About the time period :	About 6 o'clock, all the rooms are very cold.	All the rooms is chilly at feet level.	At midnight, the level of feet is very cold.	Too Hot Hot Comfortable Cold Too Cold

, Q Comment

By sealing the vent hole next to the entrance. The wind flow at feet level was reduced increasing comfort level. However, the dressing room, which is at the end of the hall and is unheated, is 9 Ž

If the temperature is below 10 Ždon't bathe.

, R Other

If you don't understand anything, please ask us by FAX, etc. This report is for your reference, please take care of your condition, especially if you feel cold or too cold.

Fig.5 Routine Reports to Senior Citizens

3.2 Study Target

The target of the housing environment study was the Housing Support Center for senior citizens and the homes of the senior citizens, as shown below.

3.2.1 Housing Support Center T

Figure 6 shows floor plan and measurement points of Housing Support Center T. Lot area: 632m^2; structure: reinforced concrete; number of stories: 2; total floor space:

599m^2; opened: May 1996

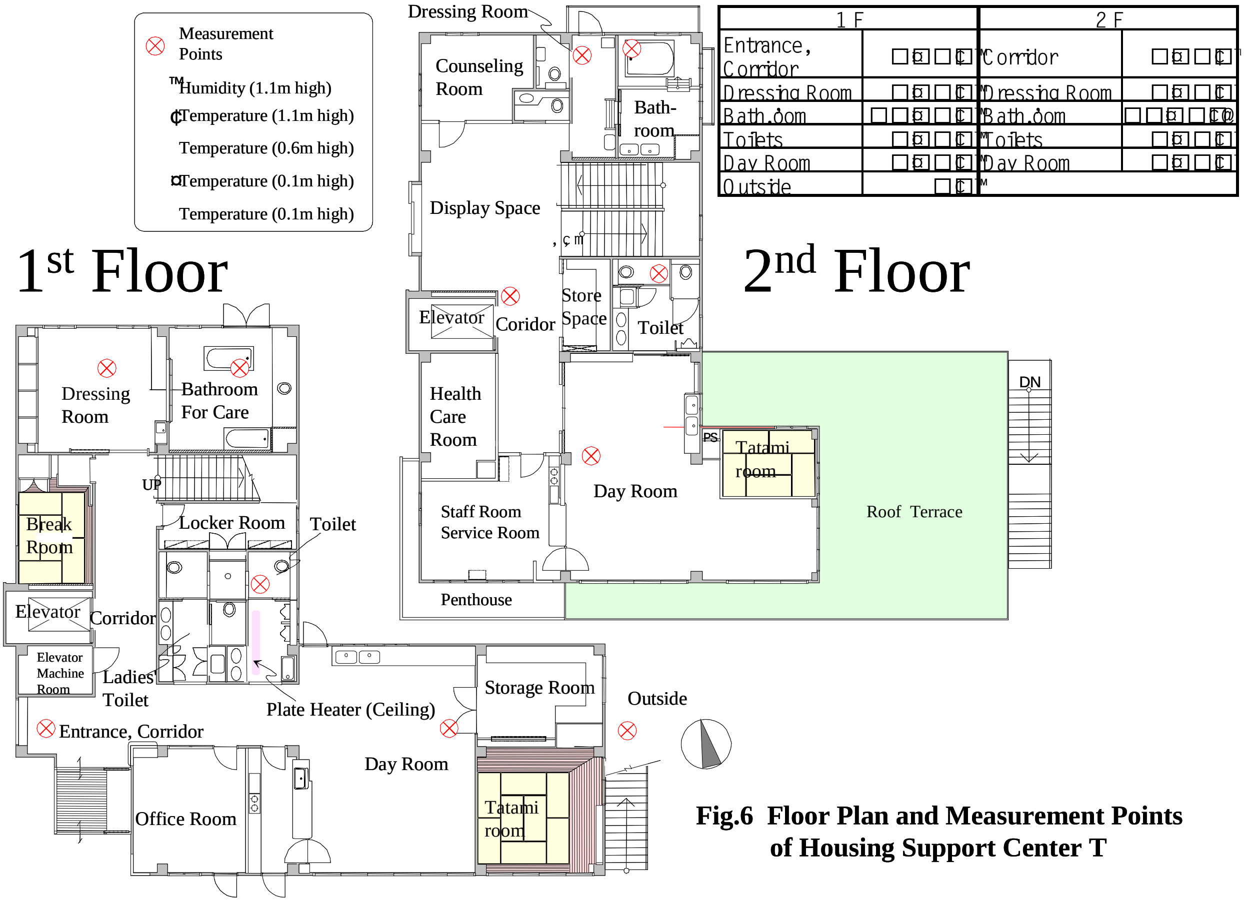


Fig.6 Floor Plan and Measurement Points of Housing Support Center T

3.2.2 Senior citizens' houses (Residence K, Residence S)

Figure 7 shows the floor plan and measurement points of Residence K. Figure 8 shows the floor plan and measurement points of Residence S.

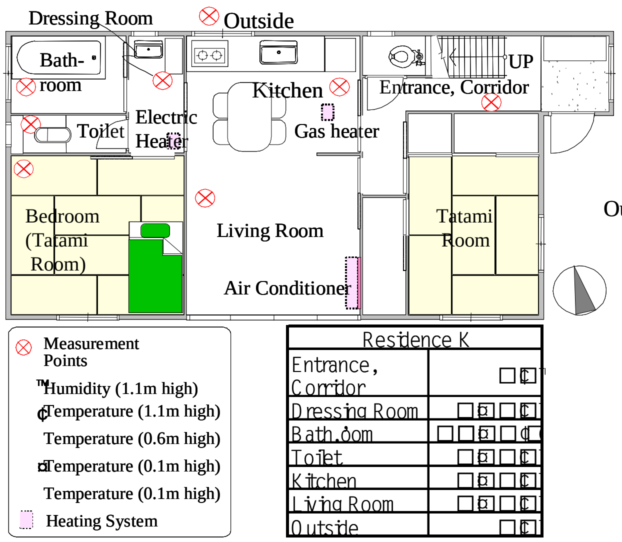


Fig.7 Floor Plan and Measurement Points of Residence K

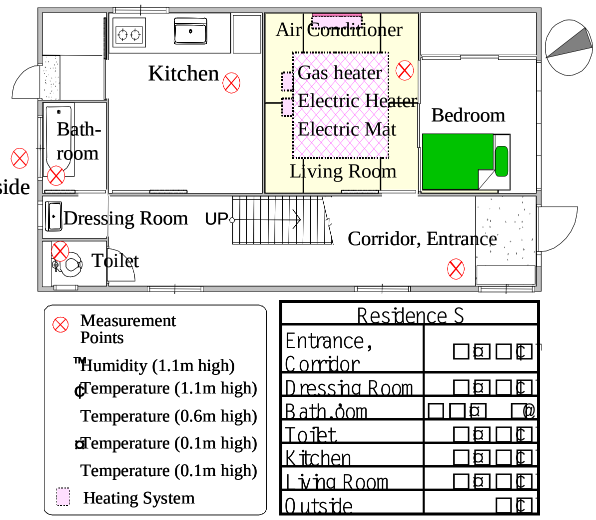


Fig.8 Floor Plan and Measurement Points of Residence S

These are 2-story wooden homes built around 40 years ago. The senior citizens and their families use the Housing Support Center. Most of their time is spent either at home or at the Housing Support Center.

3.3 Study Period

The study of the Housing Support Center and the senior citizen's homes was conducted from the end of December 1998 to the end of February 1999. Each period was about 10 days. Reports were issued at the beginning of the second period following the report period. The study of the Housing Support Center was conducted for 6 periods (6 reports) and that for the senior citizens of Residence K and Residence S was conducted for 5 periods (4 reports).

This paper cites the data for January (January 10 to 16, 1999), the beginning of the study, before any measures had been implemented, and the data for February (February 14 to 20, 1999), the end of the study, when some communication had been achieved. Each period is from Sunday to Saturday.

3.4 Comparison of Room Temperature and the Temperature of the Hot Water in the Tub during Bathing

Figure 9 shows an example of the room temperature and the temperature of the hot water in the tub during bathing at Housing Support Center T. Figure 10 shows an example of room temperature and the temperature of the hot water in the tub while senior citizens were bathing at Residence K and Residence S. The temperature of the main rooms is shown in a vertical range from 0.1m to 1.1m. The start time for bathing is the time at which the bathroom temperature increased sharply (in the case of the Housing Support Center) and the maximum temperature (at senior citizen's residences Residence K and Residence S). Reference 4) shows the bathing period in winter as 25.7 minutes; accordingly, the time for senior citizens to go from the room where they spent most of their time to the bath and undress, etc. was depicted as 25 minutes, and time required to take a bath, dress and return to the room was depicted as 40 minutes. Interviews with senior citizens revealed that they spent about 15 minutes in the bath, so as the start time for the bath, the peak temperature in the bathroom was used for senior citizen's residences, while at the Housing Support Center, the time that the temperature in the bathroom rose sharply was used as the start time for the bath.

In Residence K, people take a bath between 3 and 5 p.m., when it is relatively warm compared with the nighttime. The dressing room itself is warmed by air taken in from the adjacent heated room (the kitchen in which the senior citizens spend most of their time), or by an electric heater. Accordingly, the temperature of the dressing room and the kitchen is nearly the same. In February, the temperature in the bathroom when people are taking a bath is 16 to 17°C, as the cover of tub is removed prior to use, and the elderly people do not feel cold when they are using the bath. However, the temperature of the bathroom at a height of 0.1 m is about 13 to 14°C, so improvement is needed.

In Residence S, people take a bath after 1 o’clock in the morning, and in January the temperature in the bathroom is about 13 to 16°C at a height of 1.1m. The living room is heated, and the vertical temperature differential is considerable. The temperature of the unheated dressing room is low. However, in February, a gas-fired mechanism is used to heat the bath water, and the cover of the tub is removed while the water is being heated, so the room is warmer at 18°C (at a height of 0.1 m) to 22°C (at a height of 1.1 m).

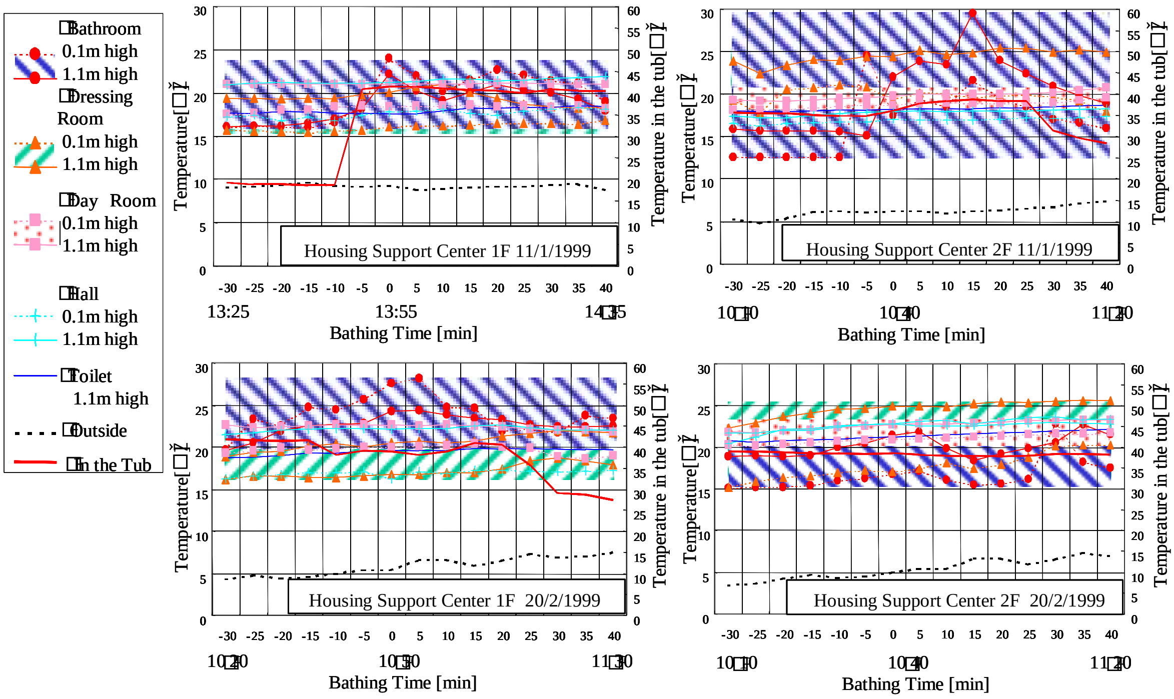


Fig.9 Example of Room Temperature and Temperature of Hot Water in the Tub (Housing Support Center T)

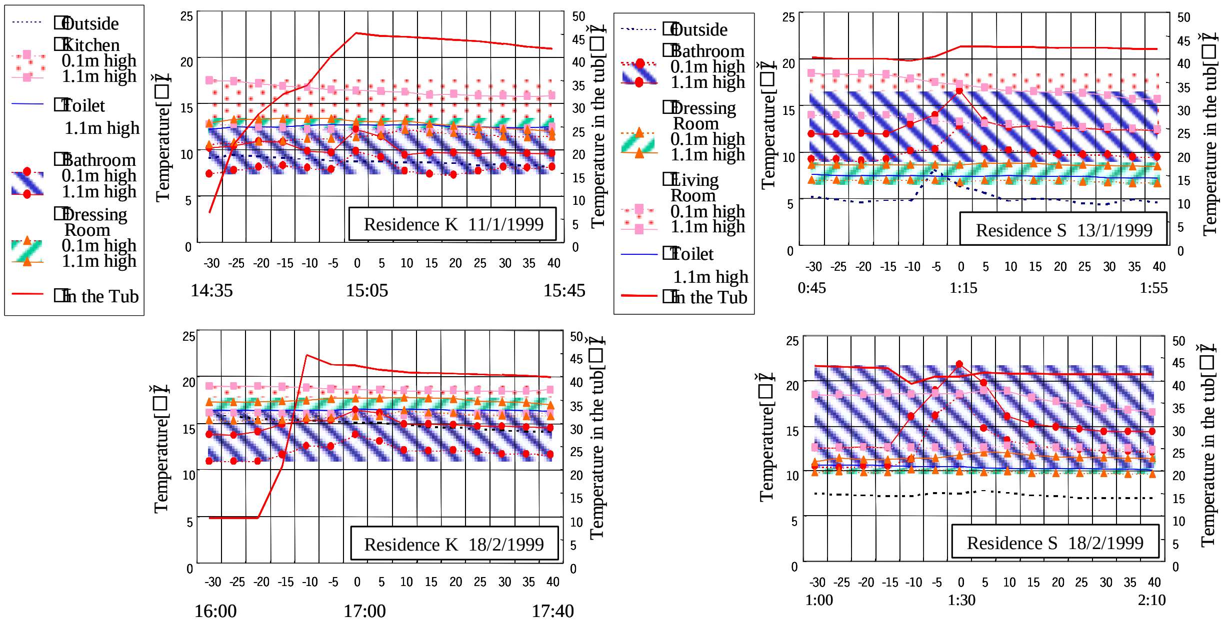


Fig.10 Example of Room Temperature and Temperature of Hot Water in the Tub (Residence K Residence S)

Moreover, some hot water is left in the tub, so the temperature in the bathroom remains relatively high.

In Residence K, the temperature of the dressing room, which is located next to the heated kitchen, is high. However, even at times when the temperature of the outside air is high, the temperature of the bathroom is low. Conversely, in Residence S, a gas-fired

mechanism is used to heat the bath water in the bathroom, and by blocking off the opening in the corridor next to the dressing room (with no partition between the two), the temperature in February can be made higher than that in January.
Nevertheless, it was not possible to arrive at suitable evaluation standards. The evaluation standards in Reference 9) for senior citizens in winter were used:

Living room/dining room (gatherings & meals) 23 ±2°C
Bath and dressing room 25 ±2°C
Corridor (movement) 22 ±2°C
Toilet 24 ±2°C (at 1.2 m above floor level)

Unless one continues to splash warm water around the bathroom, as in the case of the bath equipped with care facilities located on the first floor of the Housing Support Center, it is difficult to keep the temperature at room temperature. Due to the employment of various methods to increase the temperature, however, the temperature at foot level, though by no means adequate, has become such that the comfort of senior citizens has been increased. The difference in temperature between rooms through which senior citizens must pass on their way to and from the bath, and the vertical difference in temperature, must be reduced, in order to make the temperature as close as possible to a desirable room temperature. In addition, both the senior citizens and their families expressed the desire for improvement in the usability of water supply and drainage equipment, especially bath water supply mechanisms.

4. Relationship between room temperature and the temperature of the outside air (comparison between urban region Ward S and cold climate region City T)

4.1 Overview of the study

Housing Support Center Y, which is used by the senior citizens, is located in the center of City T. There is a considerable difference between the climate in the city center and in the surrounding areas (particularly in mountainous regions). With the aim of presenting the data on residential environments in visual terms, a visual representation was created for bathrooms, toilets, bedrooms, living rooms and so on, in which many accidents involving senior citizens occur under cold conditions in winter, as well as differences within City T and a comparison with the senior citizen's residence in Ward S, to show the difference between this facility and similar facilities. The visual representation of the data interactively shows the characteristics.

The targets of the study conducted to determine the residential environment (temperature & humidity and bath temperature) were Housing Support Center Y (social welfare facility), located in the center of City T, and four senior citizen's residences: two in Area T, located within one kilometer of this Housing Support Center, and two in Area K, in a mountainous region. In addition, a comparison study was made of Housing Support Center T in the center of metropolitan area Ward S, mentioned in the previous paragraph, and the interior residential environment of two of the senior citizens who frequent this Housing Support Center.

4.2 Study targets

The following is a summary of Housing Support Center Y in city T and the senior citizen's residences.

4.2.1 Overview of the Housing Support Center facilities

Figure 11 shows the floor plan and measurement points of Housing Support Center Y and the study locations. This facility is designed to provide the home care services needed in an aging society. It provides comprehensive health care, medical treatment and social welfare services. Here, for an outside air temperature in winter of -15°C and humidity of 68%, the target values for temperature and humidity for ordinary indoor systems are temperature 22°C and humidity 40%. The facility is heated and cooled by means of a heat pump system, while the heaters (especially the floor heaters) use a hot water heating system. The facility covers an area of 11,318 m^2, including the adjoining clinic. The health and welfare clinic section is a single-story steel-reinforced concrete building that covers an area of 2,600 m^2.

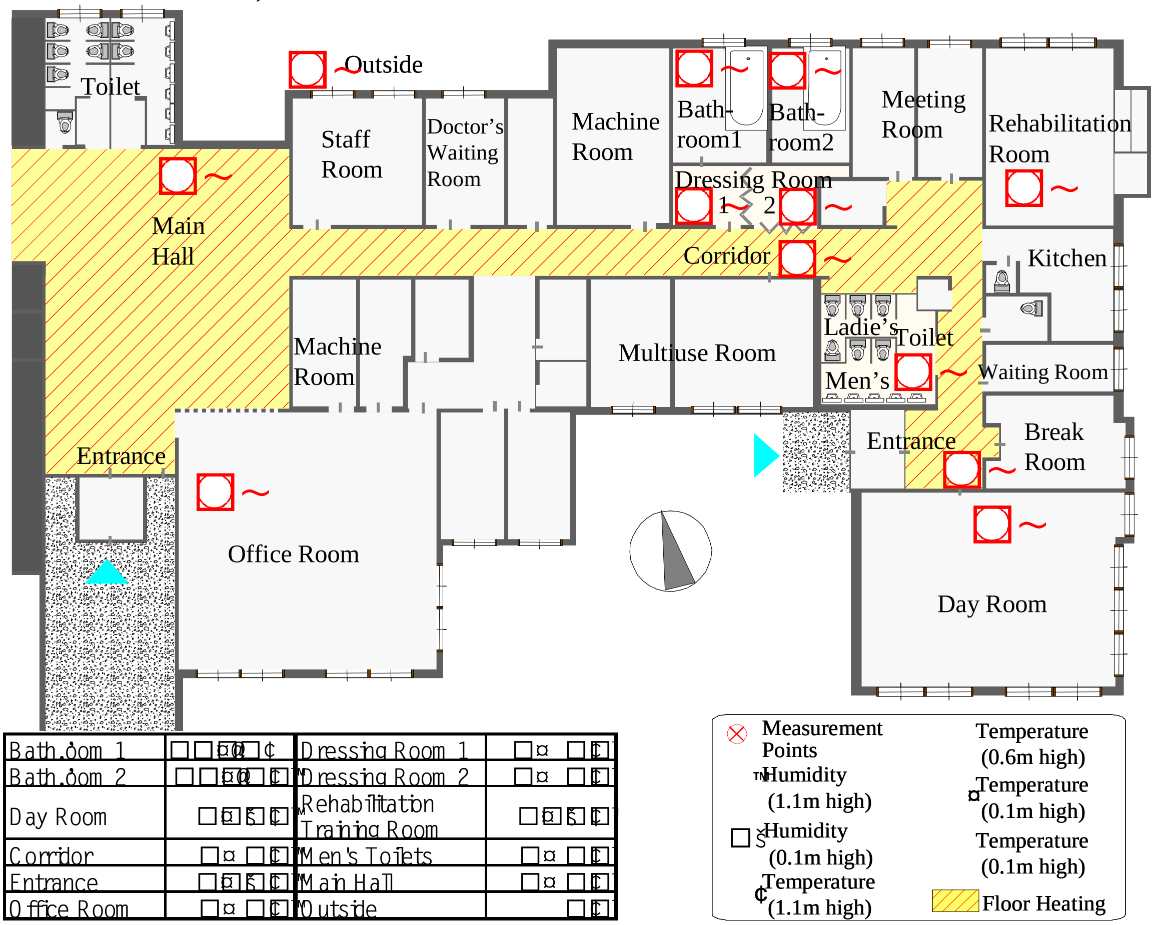


Fig.11 Floor Plan and Measurement Points of Housing Support Center Y

4.2.2 Overview of senior citizen's residences

The center of the city in which the welfare facility and Area T are located is at 273 meters elevation, while in Area K in the mountainous region, residence TT is at 428 meters elevation and Residence KA is at 374 meters elevation. There is a difference of more than 150 meters in elevation between Area K and the city center.

(1) Two senior citizen's residences in Area K (mountainous region of City T)

Figures 12 and 13 show the floor plan and temperature and humidity measurement points of the two senior citizen's residences, Residence KA (wooden house, built 20 years ago) and Residence TT (wooden house, built 35 years ago). Area K has a population density of 40/km^2, and although the population has decreased considerably, the decline in the number of households has halted although the number of families is decreasing. Many of the residents are elderly, and the youth population is very low.

(2) Two senior citizen's residences in Area T (center of City T)

Figures 14 and 15 show the floor plan and temperature and humidity measurement points of the two senior citizen's residences, Residence KT (wooden house, built 10 years ago) and Residence SK (wooden house, built 15 years ago). Area T has a population density of 492/km^2. The population is decreasing and the number of households is increasing, and the working age population is high. The rate of aging is low, but the proportion of households made up only of elderly couples or senior citizens living alone is high.

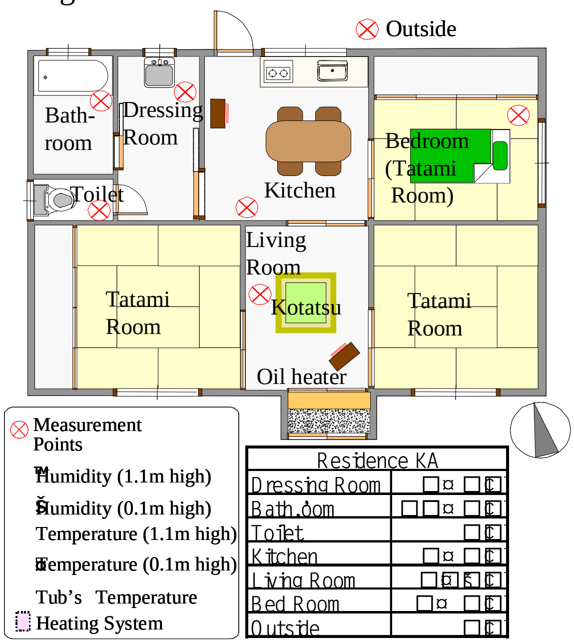


Fig.12 Floor Plan and Measurement Points of Residence KA

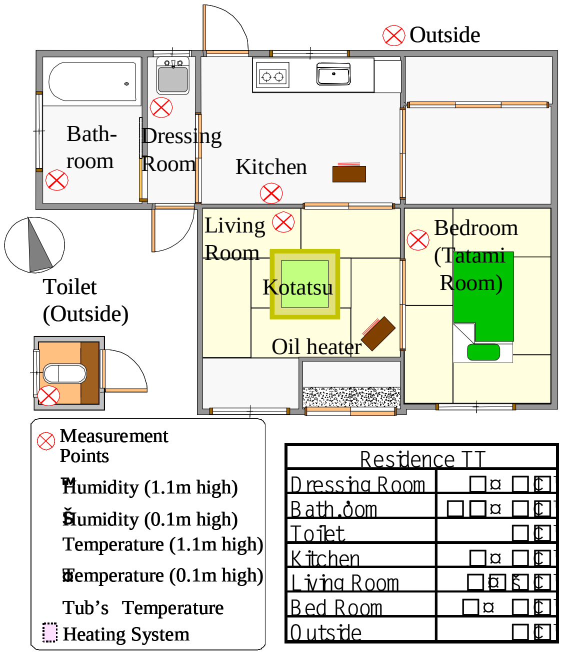


Fig.13 Floor Plan and Measurement Points of Residence TT

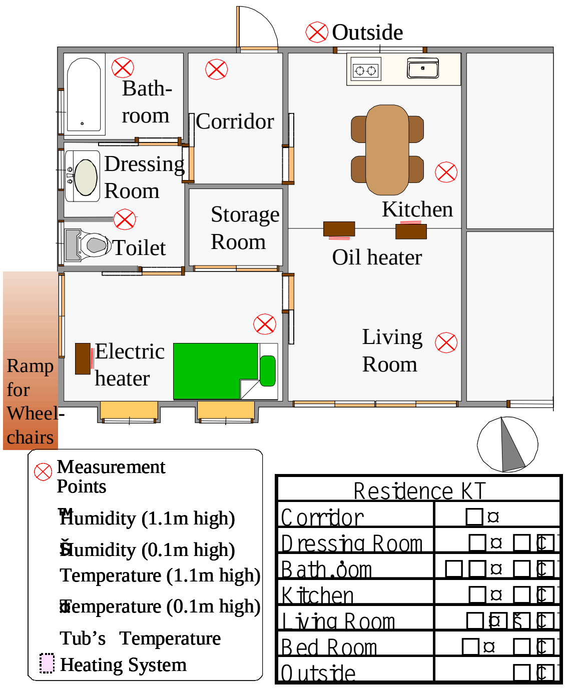


Fig.14 Floor Plan and Measurement Points of Residence KT

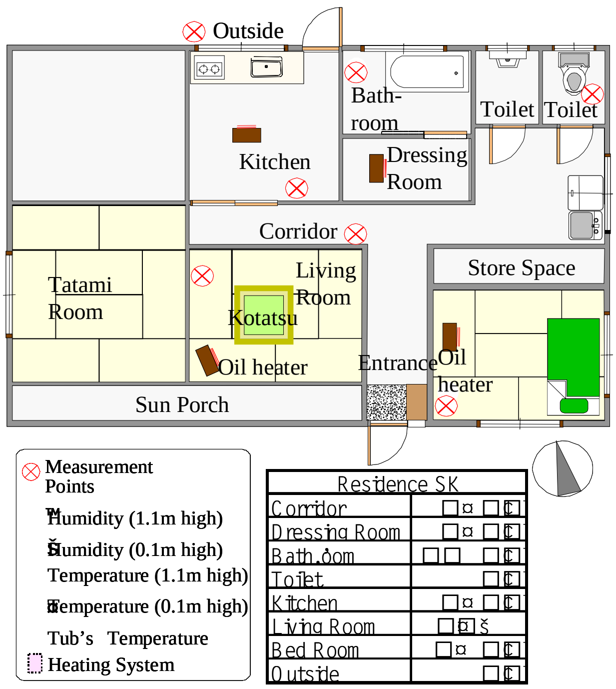


Fig.15 Floor Plan and Measurement Points of Residence SK

4.3 Period of study

In City T, a study was conducted over a period of one month in February 1999. The first part of the study was from Thursday, February 4 to Wednesday, February 10 and the targets were Housing Support Center Y and two senior citizen's residences (Residence KA and residence TT) in Area K. The second part of the study was from Thursday, February 18 through Wednesday, February 24, and the targets were the aforementioned Housing Support Center Y and two senior citizen's residences (Residence KT and Residence SK) in Area T in the city center.

The period from Sunday, January 10, 1999 through Saturday, January 16 in the study conducted in Ward S in the metropolitan center is the initial study period, during which there is assumed to be no improvements resulting from the tele-care system.

4.4 Study method

In City T, temperature and humidity sensors were installed in the living rooms, corridors, dressing rooms, bathrooms, etc. in Housing Support Center Y and in the four senior citizen's residences (Residence KA, Residence TT, Residence KT and Residence SK). During the period of data collection, interviews were conducted with the senior citizens and with Housing Support Center personnel in an effort to determine problems relating to the residential environment (temperature and humidity), and the data was studied to determine the indoor residential environment, etc. of the senior citizen's facilities.

5. Study of bath time periods

When senior citizens go to the Housing Support Center, they are provided with health care services; their blood pressure, temperature and so on are measured to determine whether they are able to take a bath or not, and so on. Most of the senior citizens who go to the Housing Support Center do not get much exercise, and they dress warmly and then add or remove clothing as the temperature dictates. The most autonomous of the service patrons (not including the disabled, those suffering from senile dementia, etc.) complained about the excessively high room temperature of the facility.

The high and low temperatures in the first half and second half of the study period differed by about 2.5°C, but the trends were the same. In bathroom 1, the temperature of the water in the bath was about 40°C both during the day and at night, and the bathtub was always uncovered, so the room temperature was virtually constant. Bathroom 2 was a bath equipped with care facilities, and the temperature of the bath water was about 40°C during use. The temperature in dressing room 1 was about 20°C even late at night and about 25°C at the times that staff and outpatients were in the facility. The day room was the room with the longest occupancy by staff and outpatients. At times of use during the day, the temperature was 22-24°C at a height of 1.1 m and 18-21°C at a height of 0.1 m from the floor. The vertical temperature differential during use is about 3-4°C. To ensure the proper room temperature, the air conditioning equipment is operated for extended periods of time. The humidity is low at 10-30%.

5.1 Senior citizen's residence for first half of study (mountainous region in Area K, City T)

5.1.1 Residence TT in Area K

The bathroom is large and difficult to heat up at bath times. Even during the day, the water droplets on the window and walls and the water in the bucket inside the room is frozen. At bath times, the senior citizens confirm that the water in the bath is the proper temperature, and then they bathe in a short period of time. The temperature during use of the dressing room and lavatory is around 0°C. In the living room, both an electric fan heater and a sunken kotatsu are used, but it is difficult to increase and maintain the temperature inside the room. The bedroom is located next to the living room, and at most the temperature is around 10°C (and only around 5°C on some days). At dawn when it is cold, the temperature drops to around -6°C. The toilet is outdoors, so the temperature in the toilet is almost exactly the same as the temperature outdoors.

5.1.2 Residence KA in Area K

The bathroom is often used when the temperature is below 5°C. In the dressing room and lavatory, the temperature during use is about the same (5°C). In the living room, a carpet has been laid on the tatami mats, and a kotatsu is used. During the day, the temperature at foot level (0.1 m above floor level) is seldom more than 10°C. At a height of 1.1 m, the temperature is high; between 2 and 7 p.m., the temperature is 17-20°C. In the bedroom, the temperature at dawn sometimes goes down to -5°C. The temperature in the toilet during the day is 5-6°C.

5.2 Senior citizen's residences in second half of study period (Area T in center of City T)

5.2.1 Residence KT in Area T

Residents take a bath between 2 and 4 p.m., when it is comparatively warm. When hot water is run into the tub, the cover of the tub is removed, so the temperature at a height of 1.1 m from the floor is 20°C or more (and about 15°C at a height of 0.1 m). Residents bathe almost every day to improve the numbness of the hands that is caused by the cold. As the residents use a wheelchair, the main method of bathing is splashing hot water on oneself. The windows in the dressing room and lavatory (with a toilet in the same space) and the bathroom are of double glass, and even when the outside temperature is -10°C, the temperature inside the room is about 5°C. The living room and kitchen constitute a single room, and the temperature when the room is occupied is about 17°C at a height at 1.1 m and 10-12°C at foot level (0.1 m).

5.2.2 Residence SK in Area T

The temperature in the bathroom is 0-10°C in accordance with the fluctuations of the temperature outside. During use, the temperature is 12-14°C. In the dressing room, an electric heater is used for warmth when the room is occupied. Since the room is small, the temperature at a height of 1.1 m is about 20°C. However, even at such times, the temperature at foot level (0.1 m above the floor) is 8-10°C.

Figure 16 shows the room temperature in senior citizen's residences for the period of time from 30 minutes prior to bathing to 40 minutes after bathing. In the dressing rooms and bathrooms in Residence TT and Residence KA in the mountainous region of City T, the temperature is very low, sometimes dropping to below freezing. Even in Ward S in City T, the temperature is seldom appropriate in rooms, and in general the rooms are cold during use.

In the unheated rooms in City T, with the exception of Residence SK, the temperature at 6 a. m. is around 0°C. In particular, the bedroom of Residence TT in Area K at a high elevation faces toward the south, and during the day the temperature rises to approximately 8°C at around 2 p.m.; however, at dawn when it is particularly cold, the temperature on some days is around -6°C (and the temperature outside is -16°C). In general, in the houses in which senior citizens live alone, both heated rooms and unheated rooms are large, and the rooms in which they dress and undress (bathrooms, dressing rooms, toilets etc.) are seldom heated.

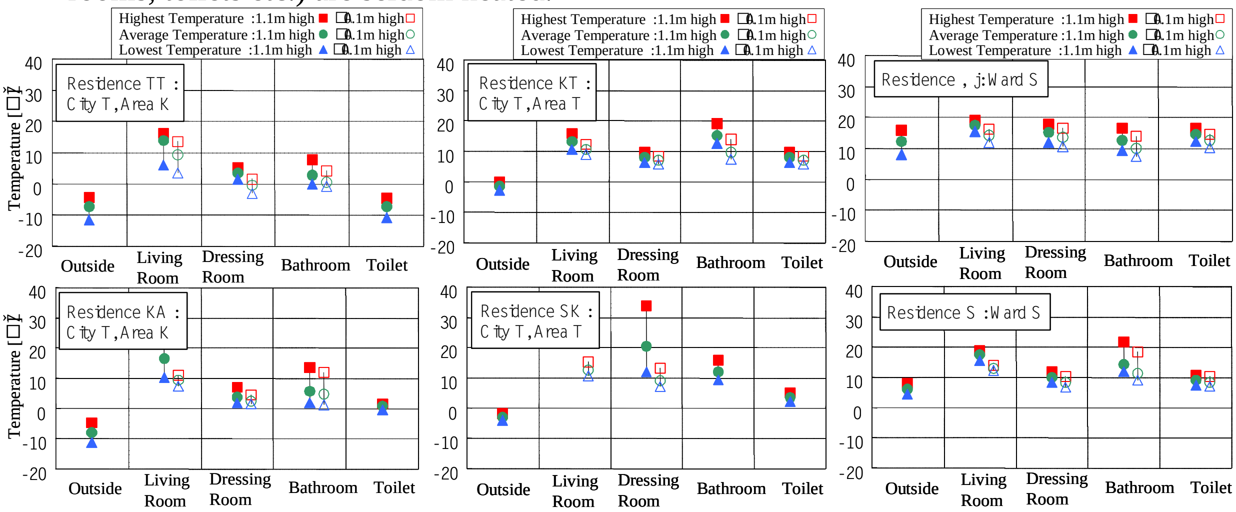


Fig.16 Indoor Temperatures 30 min. prior to and after 40 min after Bathing (Main Rooms; 1.1m high, 0.1m high)

In general, senior citizens access the toilet from the living room. Figure 17 shows the temperature differential between the inside and outside of both the living room and the toilet. In the figure, r' indicates the ratio of temperature decrease [(toilet temperature - outside air temperature) / (living room temperature - outside air temperature)], calculated with Equation (1) below.

r' = Temperature differential between toilet interior and exterior / Temperature differential between living room interior and exterior (1)

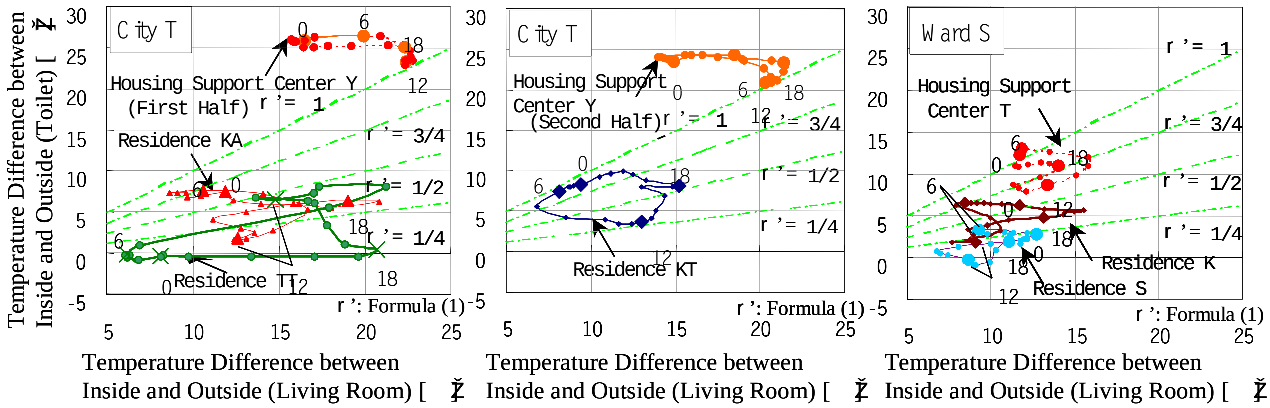


Fig.17 Temperature Difference between the Inside and Outside (Living Room, Toilet)

In Residence TT, the toilet is located outdoors, so when it is used at 6 p.m., the resident goes from an area of 21°C to an area of 0°C. Along with Residence KA, if the ratio of temperature decrease is 0-1/2, the resident often uses the toilet at times when the burden on the body is greatest.

Figure 18 shows the relationship between the temperature in the toilet and the outside temperature. In residences such as Residence KT in which the toilet has been modified to allow wheelchair access and the like, a minimum temperature of 4°C is secured before bedtime, but the temperature at dawn is low. Room temperatures in City T are low on average, and the temperature in the toilet in the early morning is around 0°C.

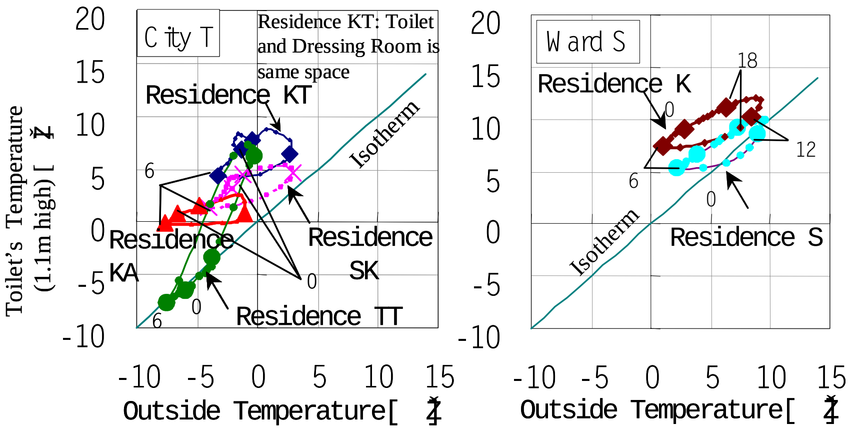


Fig.18 Relationship between Temperature in the Toilet and Outside

6. Conclusion

With the aim of gathering information on residential environments and reflecting this information in actual facilities, a comparison was made between City T in a cold climate region and Ward S in a metropolitan center, and basic reference data was gathered for basic reference materials on winter conditions, using cold climate regions and regional cities with the aging population as models. In the future, this information should be presented in visual terms to make it more accessible to senior citizens who may be unfamiliar with information technologies. An ongoing determination of the performance and use status of facilities equipped with information-gathering units is needed, particularly for conducting performance evaluations and performance commissioning of building water supply and drainage systems.

From interviews with the senior citizens and their families and the Housing Support Center personnel, the following improvements were confirmed.

(1) The senior citizens and their families were made aware of the measurements of their housing environment. As a result, they confirmed the difference between their sensation of warmth and the actual measured conditions in winter. They were also made aware of the health risks of low temperatures in the home.

(2) Regular reports on the residential environment and sharing of information among the senior citizens, their families and Housing Support Center personnel made it possible to identify the individual characteristics of the senior citizens and their homes, and to consider the safety and comfort of the residential environment from the standpoint of both the person being protected (including senior citizens, persons who are ill or are recovering from an illness and others) and the persons protecting them (families, care assistants, Housing Support Center personnel etc.).

(3) Problems with the residential environment (temperature and humidity) were identified and, based on this identification, improvements were made to the equipment use methods and the residential environment. In particular, the temperature was improved by several degrees by removing the cover of the tub when splashing warm water around the bathroom, filling the tub with hot water and heating the bath water. It was learned that, as the temperature of the bathroom decreased, latent concern

increased with regard to the water supply and drainage equipment, in terms of how the hot water supply equipment is used, the method of taking a bath and so on.

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8. Presentation of Author

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Operating roughness coefficient

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Summary

The roughness coefficient for pipes has been analyzed by many authors throughout the world. The majority of these analyses were conducted on pipes in laboratories.

In the paper we present some new aspects on the theory of roughness coefficient. Our analyses are based on the in-situ approach. All data were collected from real operating water supply pipes. The results analysis were started with the intention to simplify Colebrook's expression for the conditions prevailing in water supply pipes. The main objectives were:

- To eliminate the logarithmic term in Colebrook's formula.
- To find an explicit expression for the roughness coefficient.
- To find the functional connections between the roughness and the pipe diameter and the roughness and value of the Reynolds number, which would enable us to further simplify the formula.
- To increase the range of validity for the roughness coefficient expression in cases when Reynolds number is less than 4,000.

Colebrook's expression received the widest acceptance despite the obvious difference between conditions of water flow in laboratory and operating pipes in the water supply systems. The analysis of the roughness coefficient in the water supply system was conducted parallel to the analyses of water losses in the Slovenian water supply system over the past years.

We found the way to satisfy the above conditions, and therefore we will present a new expression for the roughness coefficient based on our analyses.

Keywords:

roughness coefficient, hydraulics, Reynolds number, turbulent flow, laminar flow, water supply systems, Colebrook's formula.

1. Introduction

Many authors throughout the world have analyzed the roughness coefficient for pipes. The majority of these analyses were conducted on pipes in laboratories. That significantly contributed to the problem because in a laboratory we cannot make the same condition as in the nature. What about the pipe ageing process? Especially in a water supply system with loops and branches we could have small flow velocities (near laminar flow). Our analysis are based on a physical model or media where the pipes are placed (in-situ approach). Therefore we named our roughness coefficient the <u>operating roughness coefficient</u>.

The analysis of the roughness coefficient in the water supply system was conducted parallel to the analysis of water losses in some towns of the Slovenian water supply system (Logatec, Grosuplje, Metlika, Ljutomer, Jesenice) and in some European cities like Munich, Essen, Basel [38].

1.1. Historical overview of roughness coefficient analysis

The first results of the roughness coefficient were reported by the de Chézy and H. Darcy. Darcy [1] was researching turbulent flow and he found out that the flow also depends on the quality of the pipe wall (respectively to coefficient **k**). Bazin [3] proceeded Darcy's research work and developed an equation which defines relations among the flow, the hydraulic grade line and the pipe diameter. Also Stanton's [4] research confirms that velocity is not a function of the pipe diameter. In 1914 Mises [5] collected all the known research data and defined the roughness coefficient as a relation between the pipe diameter and the relative roughness (mean height of roughness over pipe diameter) for round pipes with respect to the Reynolds number. Schiller [6] confirms Mises's relation between the relative roughness and Reynolds number. The greatest contribution to the roughness theory was authored by Prandtl [10], v. Kármán [12] and Nikuradse [14].

Nikuradse made a great contribution to the theory of pipe flow by differentiating between rough and smooth pipes. A rough pipe is one where the mean height of roughness is greater than the thickness of the laminar sub-layer. Nikuradse artificially roughened pipes by coating them with sand. He defined a *relative roughness* value and produced graphs of λ against Re for a range of relative roughness. Between 1936 and 1939 professor Colebrook and his student White [15], [16], [17] defined the most widely used equation for the roughness coefficient. But they did not consider the results of previous authors. Hoeck [18] was analyzing pipes for Swiss hydroelectricall power plants. It is a great pity that he analyzed only formulas given by de Chezy, Strickler, Ludin, and ignored Colebrook's equation.

Moody [19] made a useful contribution. He plotted λ against Re for commercial pipes. This figure has become known as the Moody diagram.

2. Existing expressions for roughness coefficient

Many authors study the roughness coefficient, therefore we have a lot of useful expressions. One of the first was R. V: Mises [5] in 1914. He defined the expression for round pipes in relation to relative roughness

$$\lambda = 0.00024 + \sqrt{\frac{\mathbf{R}}{\mathbf{k}} + \frac{0.3}{\sqrt{\boldsymbol{Re}}}} \qquad \textbf{(2.1)}$$

In 1932, Hopf [7] defined the empirical expression

$$\lambda = 4.10^{-2}\left(\frac{\mathbf{k}}{\mathbf{R_h}}\right)^{0.324} \qquad \mathbf{R_h} = \frac{2\mathbf{S}}{\mathbf{O}} \qquad \textbf{(2.2)}$$

$$\lambda = \lambda_0 \cdot \xi \qquad \textbf{(2.3)}$$

Eq. (2.2) was used for wall roughness, and eq. (2.3) for wall corrugation. The proportionality factor ξ for wooden pipes is between 1.5 and 2.0, and for iron cast pipes between 1.3 and 1.5.

Fluid flows are classified as laminar or turbulent. According to Reynolds [2] and Hagen – Poisseuille, the value of the Reynolds number must be less than 2000 for laminar flow, $2000 \leq Re \leq 4000$ for transition flow, and Reynolds number greater than 4000 for turbulent flow.

2.1. Laminar flow

In case of laminar flow we can calculate the roughness coefficient as

$$\lambda = \frac{64}{\boldsymbol{Re}} \qquad \textbf{(2.4)}$$

or even [22] for practical usage

$$\lambda = \frac{75}{\boldsymbol{Re}} \qquad \textbf{(2.5)}$$

2.2. Transition flow

In 1939, Reynolds [2] defined the following expression for transition flow

$$\frac{1}{\sqrt{\lambda}} = -2\,\boldsymbol{log}\left(\frac{2.513}{\boldsymbol{Re}\sqrt{\lambda}} + \frac{\mathbf{k}}{3.715\mathbf{D}}\right) \qquad \textbf{(2.6)}$$

Jeppson [23] suggests

$$\frac{1}{\sqrt{\lambda}} = 1.14 - 2.0\,\boldsymbol{log}\left(\frac{\mathbf{k}}{\mathbf{D}} + \frac{9.35}{\boldsymbol{Re}\sqrt{\lambda}}\right) \qquad \textbf{(2.7)}$$

Guido di Ricco [25] suggest the expression

$$\frac{1}{\sqrt{\lambda}} = -2\,\boldsymbol{log}\left[\left(\frac{7}{\boldsymbol{Re}}\right)^{0.9} + \frac{\mathbf{k}}{3.7\mathbf{D}}\right] \qquad \textbf{(2.8)}$$

and Nikuradse [13] expression

$$\lambda = 0.0025 \cdot \sqrt[3]{\boldsymbol{Re}} \qquad \textbf{(2.9)}$$

Moody's equation [28] with an accuracy of $\pm$ 5% is

$$\lambda = 0.0055 \left[1 + \left(2000 \frac{\mathbf{k}}{\mathbf{D}} + \frac{10^6}{\boldsymbol{Re}} \right)^{\frac{1}{3}} \right] \qquad \textbf{(2.10)}$$

2.3. Turbulent flow

2.3.1. Hydraulic smooth pipes

When the Reynolds number is less than

$$\mathrm{Re} = 27 \left(\frac{\mathrm{D}}{\mathrm{k}} \right)^{\frac{8}{7}} \qquad \textbf{(2.11)}$$

we are talking about hydraulic smooth pipes.
Feurich defines [30] hydraulic smooth pipes with expression

$$\mathrm{k} < 30 \cdot \mathrm{D} \cdot \mathrm{Re}^{-\frac{7}{8}} \qquad \textbf{(2.12)}$$

The Prandtl and v. Kármán law ([10], [12]) (sometimes also called Prandtl - Nikuradse law [14]) defines the flow in hydraulic smooth pipes, where the roughness coefficient is defined as

$$\frac{1}{\sqrt{\lambda}} = 2\,\boldsymbol{log}\left(\boldsymbol{Re}\,\sqrt{\lambda}\right) - 0.8 = 2\,\boldsymbol{log}\left(\frac{\boldsymbol{Re}\,\sqrt{\lambda}}{2.51}\right) \qquad \textbf{(2.13)}$$

In 1939 Reynolds [2] suggested the following expression for smooth pipes:

$$\frac{1}{\lambda} = 1.8\,\boldsymbol{log}\left(\frac{\boldsymbol{Re}}{7}\right) \qquad \textbf{(2.14)}$$

2.3.2. Hydraulic rough pipes

Feurich [30] defines hydraulic rough pipes when the mean height of the laminar sub-layer is less than 4 **k**. The Prandtl and v. Kármán law ([10], [12]) also defines the flow in rough pipes with expression

$$\frac{1}{\sqrt{\lambda}} = 2.0\,\boldsymbol{log}\left(\frac{3.71}{\frac{\mathbf{k}}{\mathbf{D}}}\right) = 1.14 - 2.0\,\boldsymbol{log}\left(\frac{\mathbf{k}}{\mathbf{D}}\right) \qquad \textbf{(2.15)}$$

Prandtl [11] suggests

$$\frac{1}{\sqrt{\lambda}} = 1.74 + 2.0\,\boldsymbol{log}\left(\frac{\mathbf{D}}{2\mathbf{k}}\right) \qquad \textbf{(2.16)}$$

2.4. Roughness coefficient for water supply pipes

In addition to Colebrook's equation [15], [16], [17] we can use some other equations for water supply system, e.g. Ševelev [32]

$$\lambda = \frac{1}{\mathbf{D}^{0.9}}\left(1.5 \cdot 10^{-6} + \frac{\nu}{\mathbf{v}}\right)^{0.3} \qquad \textbf{(2.17)}$$

Wood [33] suggests the following equation

$$\lambda = \mathbf{a} + \frac{\mathbf{b}}{\boldsymbol{Re}^{c}} \qquad \textbf{(2.18)}$$

where the coefficients **a**, **b** and **c** are defined as

$$a = 0.094\left(\frac{k}{D}\right)^{0.225} + 0.53\left(\frac{k}{D}\right)$$

$$b = 88\left(\frac{k}{D}\right)^{0.44} \qquad \textbf{(2.19)}$$

$$c = 1.62\left(\frac{k}{D}\right)^{0.134}$$

Šerek [34] combined Blasius [31] and v. Kármán [12] equation into the expression:

$$\lambda = \left[\frac{1}{\left(2\,\boldsymbol{log}\,\frac{k}{D} - 1.13874\right)^{8}} + \frac{0.01}{\boldsymbol{Re}}\right]^{0.25} \qquad \textbf{(2.20)}$$

2.4.1. Equation for energy losses

Energy losses in water pipes system are calculated by the Darcy-Weisbach [1], [35] expression

$$h = \lambda \frac{L}{D} \cdot \frac{\mathbf{v}^2}{2\mathbf{g}} \qquad \textbf{(2.21)}$$

The Hazen-Williams [36] equation for energy losses is

$$\mathbf{h} = \frac{10.7 \cdot \mathbf{L}}{\mathbf{C_{HW}}^{1.852} \cdot \mathbf{D}^{4.87}}\mathbf{Q}^{1.852} \qquad \textbf{(2.22)}$$

Manning defined energy losses as

$$\mathbf{h} = \frac{10.29 \cdot \mathbf{n}_G^2 \cdot \mathbf{L} \cdot \mathbf{Q}^2}{\mathbf{D}^{5.333}} \qquad \textbf{(2.23)}$$

3. Analyses of results and the proposed new expression for the roughness coefficient

The analysis of results was started with the intention to simplify Colebrook's expression for the conditions prevailing in water supply pipes. The main objectives were:

1. To eliminate the logarithmic term in Colebrook's formula
2. To find an explicit expression for the roughness coefficient
3. To find the functional connections between the roughness and the pipe diameter and the roughness and the value of Reynolds' number, which would enable us to further simplify the formula
4. To increase the range of validity for the roughness coefficient expression in cases when Reynolds' number is less than 4,000.

In connection with the first objective we could only confirm that the logarithmic law distribution is also valid for water supply pipes. Our results confirm the logarithmic function, which was also defined by Prandtl, v. Kármán and Nikuradse.

We wanted to define the mathematical relation between the coefficients **k**, **D** and **Re,** like was done for sewage systems [37]. The coefficient **k** depends on the material of pipe, but from measurements we see changing of coefficient **k** in the same material.

We can rewrite Colebrook's formula [15] in this form:

$$\frac{1}{\lambda} = -2\,\boldsymbol{log}\left[\mathbf{f}\boldsymbol{(Re)} + \mathbf{f}\left(\frac{\mathbf{k}}{\mathbf{D}}\right)\right] \qquad \textbf{(3.1)}$$

Because of the undefined relation for the part of the relative roughness

$$\frac{1}{\lambda} = -2\,\boldsymbol{log}\left[\mathbf{f}\boldsymbol{(Re)} + \frac{\mathbf{k}}{3.715\cdot\mathbf{D}}\right] \qquad \textbf{(3.2)}$$

We must define first term in eq. (3.2), which is a function of Reynolds number with usage of least square method. The Analysis shows that we must redefine the first term if we want to use eq. (3.2) on the entire range of Reynolds numbers ($0 \le Re \le 10^8$). The modified eq. (3.2) will be:

$$\frac{1}{\lambda} = -2\,\boldsymbol{log}\left|\frac{\mathbf{a}^*}{\boldsymbol{Re}^{\mathbf{b}^*}} + \frac{\mathbf{k}}{3.715\cdot\mathbf{D}}\right| \qquad \textbf{(3.3)}$$

Where the coefficients a* and b* are functions of the Reynolds number and the relative roughness

$$\mathbf{a}^* = \mathbf{f}\left(\boldsymbol{Re,}\,\frac{\mathbf{k}}{\mathbf{D}}\right) \text{ and } \mathbf{b}^* = \mathbf{f}\left(\boldsymbol{Re,}\,\frac{\mathbf{k}}{\mathbf{D}}\right) \qquad \textbf{(3.4)}$$

Finally, the new expression for the roughness coefficient is

$$\lambda = \frac{0.25}{\left[\boldsymbol{log}\left|\frac{8.494}{\boldsymbol{Re}^{0.936}} + \frac{\mathbf{k}}{3.715\cdot\mathbf{D}}\right|\right]^2} \qquad \textbf{(3.5)}$$

for Reynolds number between 500 and 10^8. For Reynolds number less than 500 we suggest

$$\lambda = \frac{65}{\boldsymbol{Re}} \tag{3.6}$$

Table 1 shows the measured results and **Figure 1** presents them graphically. **Figure 2** shows the diagram of eq. (3.5).

$\frac{k}{D} = 3 \cdot 10^{-4}$

Re	λ_{EP}
345	0,192
369	0,179
524	0,124
520	0,122
535	0,120
542	0,118
554	0,152
573	0,111
607	0,103
633	0,102
647	0,101
669	0,095
691	0,092
706	0,091
715	0,088
730	0,088
771	0,082
824	0,079
831	0,078
900	0,074
931	0,071
951	0,070
967	0,075
971	0,069
983	0,064
1,016	0,064
1,025	0,063
1,038	0,065
1,073	0,063
1,110	0,063
1,312	0,059
1,995	0,050
3,481	0,040
10,827	0,034
10,873	0,021
14,601	0,021
19,869	0,020
20,120	0,027
30,199	0,025
37,701	0,025
40,483	0,040
49,493	0,019
59,007	0,023
90,440	0,023
100,419	0,021

$\frac{k}{D} = 1 \cdot 10^{-2}$

Re	λ_{EP}
197	0,330
201	0,328
212	0,307
216	0,310
231	0,280
237	0,277
260	0,220
263	0,218
269	0,240
390	0,170
401	0,187
451	0,140
461	0,140
483	0,130
501	0,138
509	0,117
512	0,120
572	0,110
573	0,109
613	0,110
625	0,109
664	0,094
682	0,100
697	0,100
703	0,100
796	0,083
800	0,079
821	0,083
850	0,079
875	0,076
878	0,079
916	0,076
918	0,073
1,024	0,070
1,129	0,066
1,139	0,069
1,278	0,064
1,392	0,063
1,412	0,063
1,427	0,063
1,621	0,061
1,638	0,060
1,987	0,057
2,981	0,053
3,045	0,053
3,244	0,051
3,353	0,051
3,600	0,0492
3,661	0,0489
4,019	0,0490
4,065	0,0491
4,531	0,0481
4,570	0,0484
4,997	0,0472
5,032	0,0471
5,975	0,0468
8,043	0,0442
10,041	0,0431
19,457	0,0405
59,753	0,0386
99,582	0,0386
120,226	0,0383
266,351	0,0374
499,090	0,0369
641,612	0,3789
730,527	0,0372

$\frac{k}{D} = 1 \cdot 10^{-3}$

Re	λ_{EP}
227	0,2938
283	0,2284
327	0,2043
304	0,1860
401	0,1748
425	0,1584
444	0,1495
483	0,1259
518	0,1255
529	0,1228
537	0,1220
546	0,1191
561	0,1161
565	0,1240
577	0,1126
580	0,1070
592	0,1043
603	0,1043
615	0,0977
634	0,1024
655	0,1010
672	0,0960
691	0,0925
701	0,0916
712	0,0899
724	0,0898
733	0,0837
744	0,0881
777	0,0907
789	0,0822
817	0,0795
843	0,0784
892	0,0741
921	0,0719
945	0,0703
968	0,0690
992	0,0641
1,011	0,0663
1,012	0,0678
1,025	0,0654
1,057	0,0632
1,099	0,0605
1,167	0,0622
1,302	0,05997
1,513	0,0568
1,608	0,0585
1,789	0,0547
1,821	0,0564
2,012	0,0505
2,080	0,0547
2,697	0,0468
3,229	0,0450
4,029	0,0411
4,949	0,0418
5,404	0,0379
6,443	0,0348
10,603	0,0316
14,760	0,0293
16,665	0,0272
25,013	0,0253
26,972	0,0247
46,286	0,0239
52,261	0,0201
66,624	0,0206
150,094	0,0183
236,889	0,0165

Table 1: Calculated roughness coefficient from measurement

We can conclude that our objectives were not completely satisfied. The logarithmic law distribution in Colebrook's equation stays unchanged and the real data confirm that.

We can confirm the second finding for water supply systems that our roughness coefficient can be defined in explicit form and with enough accuracy. But mathematical relationship between **k**, **D** and **Re** remains unsolved.

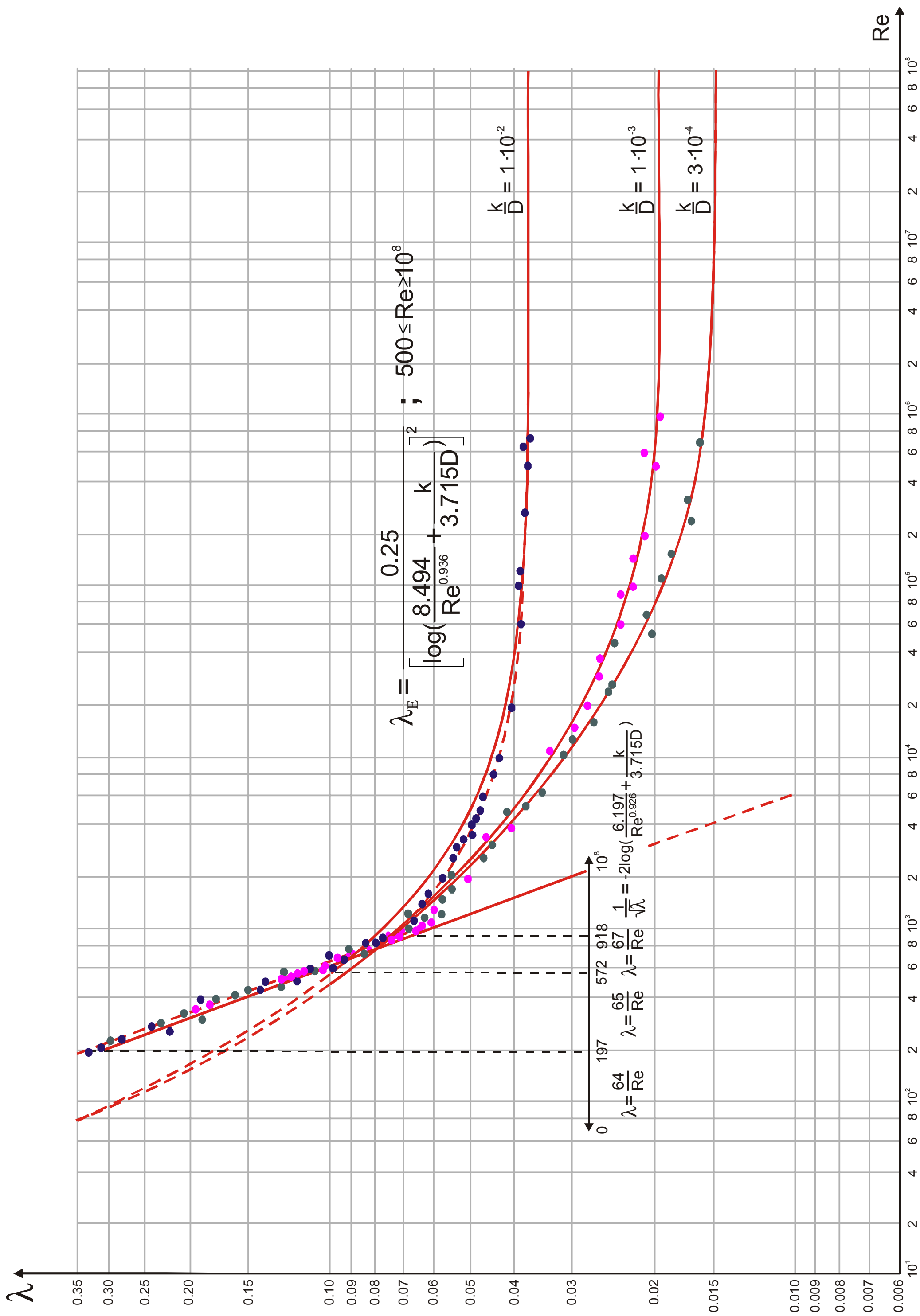

Figure 1: Measured curves of the operating roughness coefficient

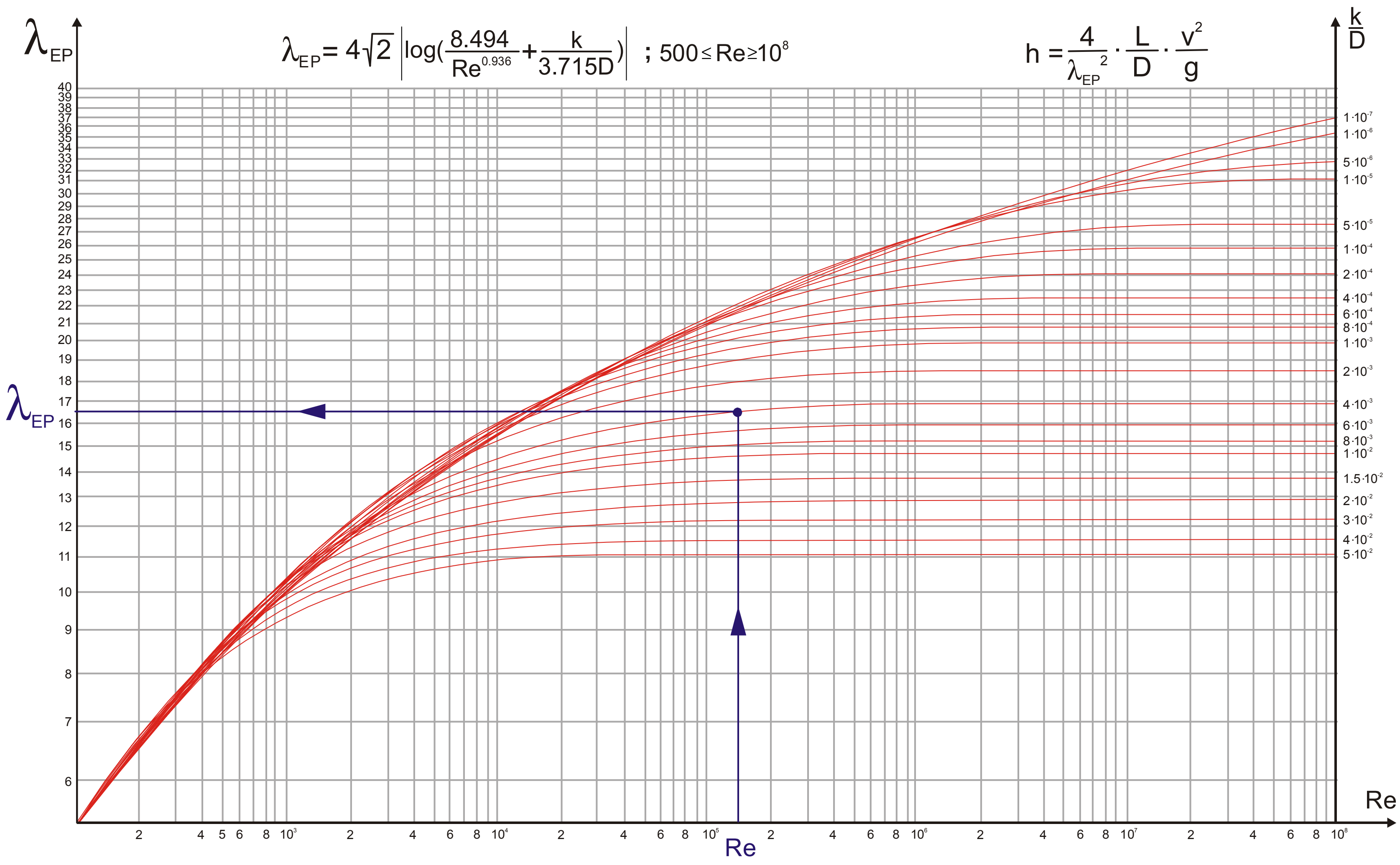

Figure 2: Diagram of the operating roughness coefficient (from eq. (3.5))

4. Conclusions

The different characteristic expressions were compared among them selves. On the ground of the analysis it was found that very few expressions for roughness coefficients of water supply pipes were proposed. Colebrook's expression received the widest acceptance in our conditions despite of the obvious difference between conditions of water flow in pipes for which the formula was derived and errors in the Colebrook’s and Nikuradse’s formula because different characteristic expressions were compared among themselves.

The analysis shows that the roughness coefficient can be given explicitly for the needs of a water supply system with enough accuracy.

We try to define a functional relationship between the roughness, pipe diameter and Re, but we fail. We can also establish that the roughness does not follow the formulas given in the literature about it increase in time (ageing process).

5. List of used symbols

Symbol	Definition	Units
Re	Reynolds number	-
λ	Roughness coefficient	-
λ_{EP}	Operating roughness coefficient	-
k	Roughness height	mm
R	Radius	m
D	Diameter	m
R_h	Hydraulic radius	m
S	Area	m^2
O	Perimeter	m
V	Flow velocity	m/s
ν	Kinematic viscosity	m^2/s
Q	Flow discharge	m^3/s
L	Length	m
H	Head	m
n_G	Manning’s roughness coefficient	-
n_{CW}	Hazen-Williams roughness coefficient	-

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Development of the Calculating Method for the Loads of Water Consumption in the Office Buildings

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Abstract

In resent years, the performance of sanitary fixtures has changed to more convenient and more comfortable by the progress of technology and the view point of energy saving. Under these conditions, it is supposed that the characteristic of office worker's fixture usage has changed in comparison with before.

We have advanced the development of calculating method for cold and hot water consumption based on the fixture usage in the time series through a day. This method is adaptable to office buildings by setting up the calculating model. Therefore, we carried out the questionnaire investigation about office worker's fixture usage. Also, we measured cold and hot water consumptions and frequency of sanitary fixtures usage in toilets and hot water service rooms in an office building. The measurement was carried out at four seasons over a year and all data were recorded in every one-minute by using flow meters, pulse recorders and some sensors. After that, we analyzed daily and hourly frequency of sanitary fixtures usage and daily, hourly and instantaneous loads of water consumption in each fixture. From the results, we clarified the latest tendency of office worker's sanitary fixture usage in toilets and hot water service rooms. We calculate daily, hourly and instantaneous loads of water consumption by using the calculating method applied the Monte Carlo Simulation technique.

This paper shows the results of measurement and simulation as for the loads of water consumption. By comparing the results of measurement and simulation, we confirm the simulation technique to apply the calculating method for office buildings.

Keywords

Water Consumption, Monte Carlo Simulation, Fixture Usage, Office Buildings

1. Introduction

Several researchers have analyzed about the loads of water consumption in the various kinds of buildings in Japan. However, the conditions of water usage are changing with the progress of technology. Therefore, it is important to investigate the actual conditions of water demands for the design of building services. Also, the calculating method of water consumption needs to adapt the various conditions that may occur by the development of water using fixtures.

Now, we have advanced the development of calculating method for cold and hot water consumption based on the fixture usage. The method applies to the Monte Carlo Simulation technique. The idea of calculating method was described by S. Murakawa in the paper presented at the CIB/W62 Symposium held in Iasi, Rumania, 2002[1]. In another paper presented at the CIB/W62 Symposium held in Ankara, Turkey, 2003[2], we propose the calculating method of cold and hot water consumption loads in apartment houses.

This paper deals with the same method to calculate the water consumption in office buildings. First, we show the results of the measurement that carried out in toilets and hot water service rooms. Based on the results of analyzing the measurement data, we set up the calculating model for office buildings. Finally, we estimate daily, hourly and instantaneous loads of water consumption by using the calculating method and compare the results of measurement and simulation.

2. Outline of the investigation

2.1 Outline of the office building

The investigation was carried out for an office building located in Hiroshima City, Japan. The outline of the building is shown in Table 1. The building has 14 stories on the ground and one story under the ground. We selected a tenant which occupied the 9th - the 13th floor as the objects for the investigation.

Table 1 - Outline of the office building

Office building	IN building
Completion date	November,1989
Structure	Steel encased reinforced concrete
Scale	14 stories, 1 basement, 1 penthouse
Lot area	1,470.05‡ u
Building area	840.86‡ u
Total floor area	13,071.49‡ u
Typical floor area	840.86‡ u
Cold water supply system	Booster pump system
Hot water supply system	Central and individual system
Cold water supply equipment	Receiving tank 72.5m^3, 1 tank Control tank 4.5m^3, 1 tank Water supply pump
Hot water supply equipment	Air source heat pump chiller Hot water storage tank 800L, 1 tank Electric water heater 20L

Table 2 shows the number of office workers in winter and summer, 2002. The 10th, 12th and 13th floors have a main working room. The 11th floor has an information desk, a dicker room, a meeting room, a changing room, etc. The 9th floor is shared with some tenants, and the investigation tenant has one working room in this floor.

As for the water supply system, cold water is supplied by booster pump system from receiving tank. And hot water is supplied with the temperature about 30 from the hot water storage tank served by the heat recovery heat pump system. In the hot water service room, hot water is reheated by the individual electric water heater.

Table 2 - Number of the office workers

	Floor	13th	12th	11th	10th	9th	Total
Male [person]	winter	36	41	0	32	1	110
	summer	36	46	2	29	4	117
Female [person]	winter	9	12	5	4	1	31
	summer	11	10	5	4	2	32

2.2 Outline of the questionnaire investigation

We carried out the questionnaire investigation for office workers to grasp the state of office worker's presence and fixture usages. The office workers who working at the 9th - the 13th floor replied for three days (Tuesday, Wednesday, Thursday) in winter and summer for each. The workers checked off the state of presence and fixture usage every 30 minutes from 7 to 24 o'clock in a sheet prepared to each one.

2.3 Outline of the measurement

We selected the 10th, 12th, 13th floor's male toilets and hot water service rooms as the subject of investigation, because there are many male office workers in these floors. We also selected the 11th - the 13th floor's female toilets as the subject of investigation. The 11th floor has a changing room for female, so it was supposed that the toilet is used according to the change of clothes etc.

As for the measurement of the frequency in each fixture usage, we set up photoelectric sensors and proximity sensors in each fixture and toilet doorway. The sensors respond to the user of fixtures and toilets. The period of the measurement is 5 days of weekday in each season, but in summer, the measurement is carried out for 10 days of weekday. In this paper, we show the results about the data measured from 12th to 14th March, 2002 as the winter measurement and from 3rd to 5th September, 2002 as the summer measurement. These measurement periods are same to the questionnaire investigation periods.

Besides, we measured cold and hot water consumption by setting up water meters to cold and hot water supply pipelines. At the water supply line of the male toilets, cold water is used with water closets, urinals and hot water service rooms, and hot water is used with basins and hot water service rooms. At the female toilets, cold water is used with water closets, and hot water is used with basins. However, at the 12th and 13th floor's female toilets, one of two basins is installed with a single-lever mixed faucet, so a little cold water is used in the basins. Figure 1 shows cold and hot water supply pipelines and locations of the meters and the sensors. Table 3 shows the items of measurement in each floor. We started the measurement from the middle of January 2002. The measurement was carried out continuously about 4 weeks in each season; winter, spring, summer and autumn. The volumes of cold and hot water consumption, the water temperature supplied, and the frequency of fixture usage were recorded by one minute interval.

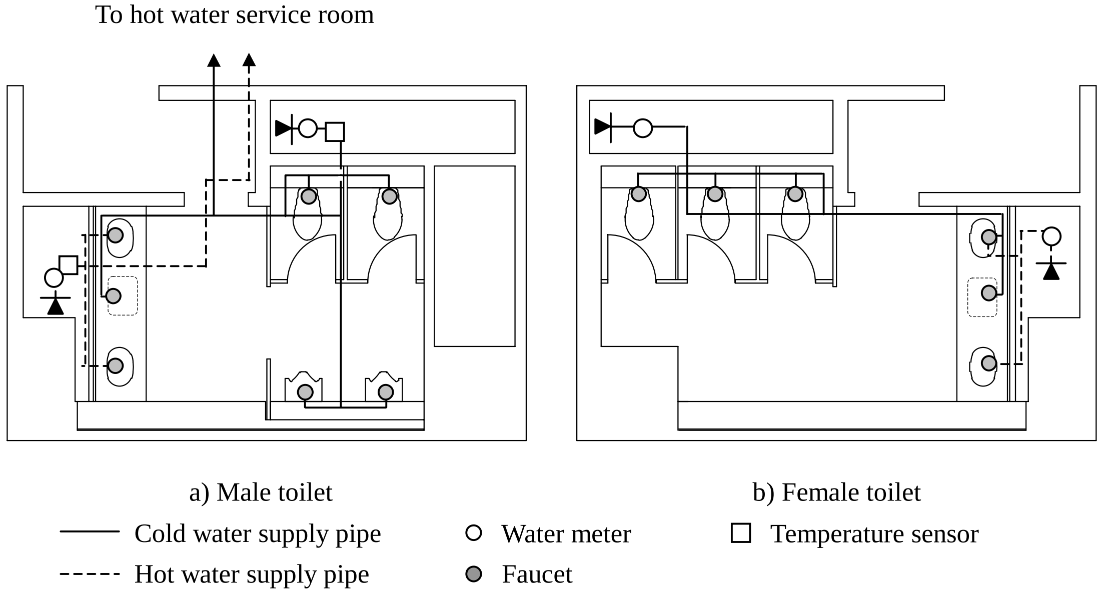


Figure 1 - Ground plan of the toilets

Table 3 - Measurement items

Measurement item	Floor
Cold water consumption in the male toilet and hot water service room Hot water consumption in the male toilet and hot water service room Frequency of fixture usage in the male toilet (Water closet, Urinal, Basin, Doorway)	10th, 12th, 13th
Cold water consumption in the female toilet Hot water consumption in the female toilet Frequency of fixture usage in the female toilet (Water closet, Basin, Doorway)	11th, 12th, 13th
Cold water supply temperature in the male toilet and hot water service room Hot water supply temperature in the male toilet and hot water service room	10th

3. Results of the questionnaire and measurement

3.1 The state of office worker’s presence

Figure 2 shows the hourly ratio of the number of presented workers to the number of all office workers. On the time-zone of 8:00a.m. - 6:00p.m., the male’s ratios are changing between 70% to 90%. In case of female, the ratios are about 90% to 100% except the time-zone of noon - 1:00p.m. The fluctuation has not so big difference between winter and summer. Some of the workers are coming to office from 7:00a.m., and numbers of the workers are coming on the peak time-zone of 8:00a.m. - 9:00a.m. included the start of working hour (8:30a.m.). Thereafter, the ratios show some fluctuation through the working hours; 8:30a.m. - 5:15p.m. because of some workers have gone outside work. On the time-zone of noon - 1:00p.m., the ratio is a little low because of some workers have gone out for lunch. Table 4 shows the average ratio of the number of presented workers to the number of all office workers on the time-zone of 8:00a.m. - 6:00p.m..

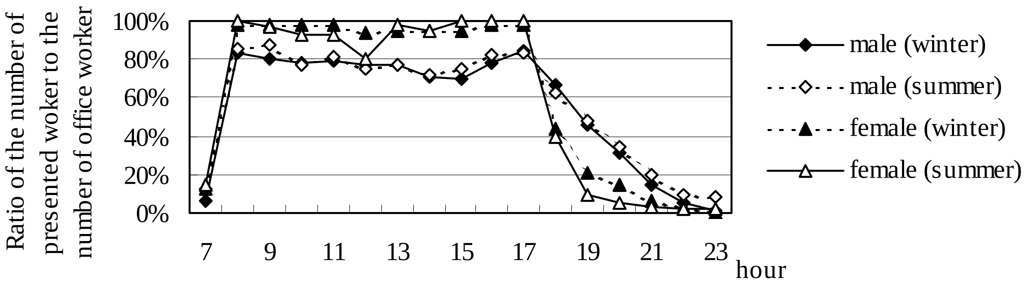


Figure 2 - State of office worker's presence

Table 4 - Presence ratio of office workers (average of 8 o'clock to 18 o'clock)

	winter	summer	total
Male [%]	77.8	79.6	78.7
Female [%]	96.9	95.5	96.2

3.2 The state of fixture usage

Figure 3 shows the hourly average ratios of the frequency in each fixture usage based on the results of questionnaire and measurement. We show the values as the average results for three days, the term carried out the questionnaire, investigated in every story. Because the fluctuation tendencies have no difference between winter and summer in every fixture, we show the results of summer as an example. The ratio of frequency is calculated as the value of hourly frequency to the value of daily total frequency. The frequency of fixture usage that measured at the female's toilet of the 11th floor lacked for a period of questionnaire investigation, so we analyzed the data of period from 31st July to 1st August instead. We compared the both period's data of the 12th, 13th floors and confirmed that the both period's data has same fluctuation tendency of fixture usage.

For the male's water closet, the ratio reaches the peak on the time-zone of 8:00a.m. - 9:00a.m.. For the female's water closet, the ratio maintains about 10% on the time-zone of 8:00a.m. - 6:00p.m.. The fluctuations of ratio at the male's urinal and female's water closet have relations with the state of worker's presence. According to the results of questionnaire, the usage of male's and female's basin just corresponded with the usage of urinal and water closet, respectively. According to the results of measurement, the ratio of fixture usage is larger then the questionnaire's ratio on the time-zone of noon - 1:00p.m. The office workers checked the fixture usage at 30 minutes interval on a questionnaire sheet, but we measured the frequency of fixture usage by one minute interval. Specifically, if a worker used basin two times in one time usage of toilet, he or she wrote as one time even though the measurement sensor responded as two times. This tendency appears to female's usage especially, because the female worker uses basin for making up and making appearance as several times in one time usage of toilet. In hot water service room, both male and female workers frequently use on time-zones of 8:00a.m. - 9:00a.m., noon - 1:00a.m. and 5:00p.m. - 6:00p.m.. We suppose that hot water service room is used by office workers for washing a cup, making a coffee or brushing teeth on the time-zones of after coming to the office, lunch break and before getting away from work.

Table 5 shows the frequency of each fixture usage per 10 hours and per person presented at the office. As compared with the results in the previous studies, the values are larger than the past results [3]. We suppose that the frequency of fixture usage is influenced by the progress of comfort in office building's toilet installed high quality sanitary fixtures.

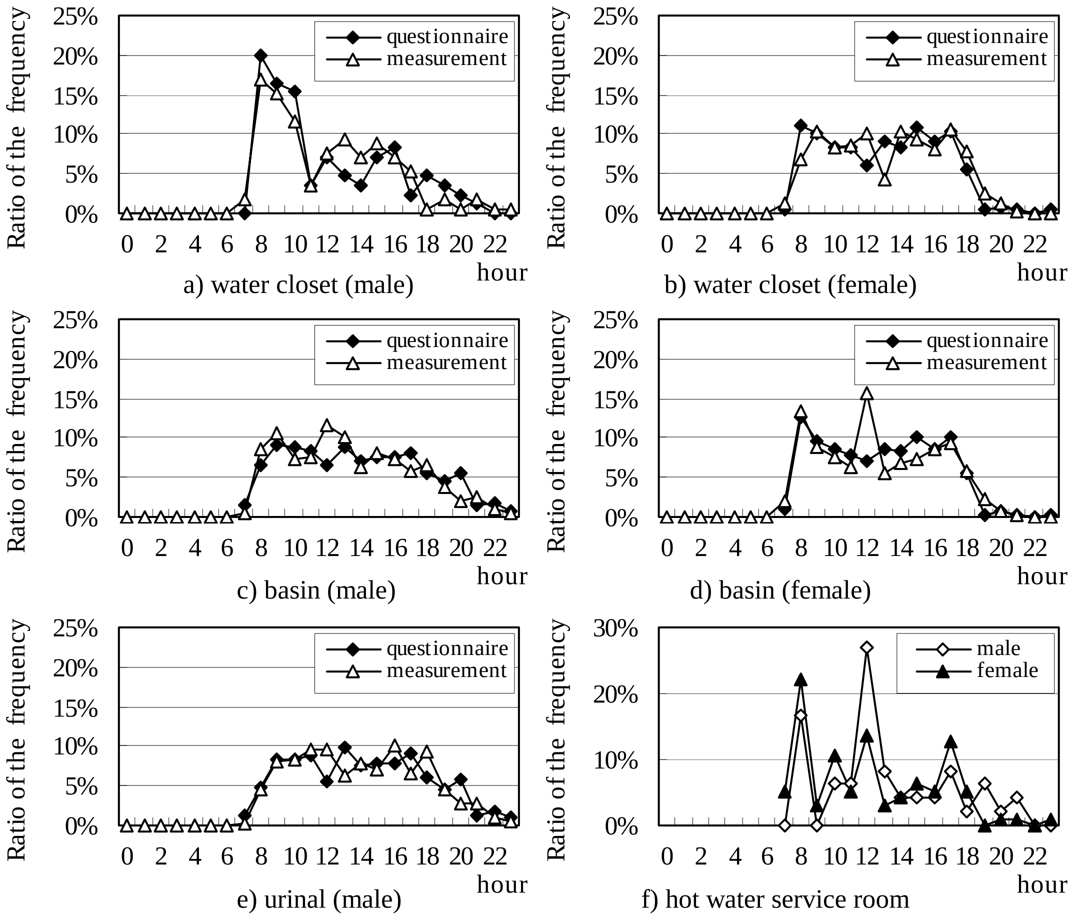


Figure 3 - Fluctuation of hourly frequency in each fixture usage

Table 5 - Frequency of each fixture usage per 10 hours and per person

		winter		summer	
		questionnaire	measurement	questionnaire	measurement
Male	Water closet	0.56	0.52	0.54	0.60
	Urinal	3.01	2.82	2.91	2.41
	Basin	3.47	—	3.27	3.12
	Hot water service room	0.21	—	0.30	—
Female	Water closet	4.27	3.89	3.82	3.61
	Basin	4.61	—	4.07	5.46
	Hot water service room	1.20	—	1.36	—

Unit : [frequency/10h/person]

Table 6 shows the ratio of water usage at basin and hot water service room. The ratios of basin are calculated at the case of usage only for basin without usage of water closet. Both male and female use water at a high ratio. As for the total value, female's value is lower than male's value because female uses basin for making up without using water. In hot water service room, a total value of female is higher than male's value.

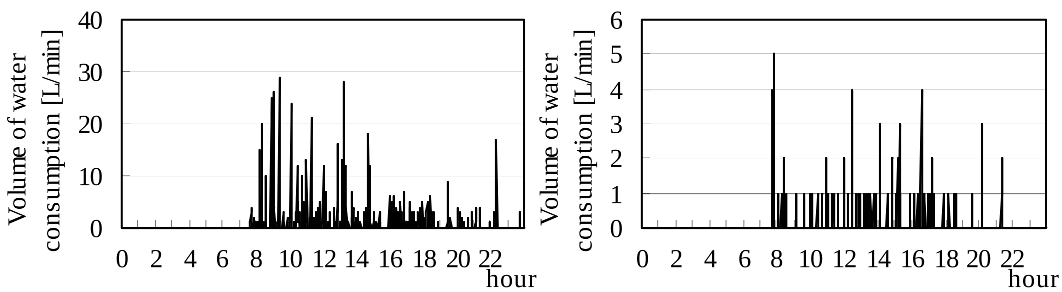
Table 6 - Ratio of water usage

	Male			Female		
	winter	summer	total	winter	summer	total
Basin [%]	100.0	93.8	97.7	90.0	94.7	91.8
Hot water service room [%]	86.0	93.8	90.1	98.1	91.6	95.0

3.3 Water consumption in the toilet

We recorded the signal of pulse by one minute interval as the water consumption (1L per pulse) in each supply pipe line. Figure 4 shows cold and hot water consumption recorded by one minute interval as an example of male toilet at the 13th floor, February 22,2002.

Table 7 shows cold and hot water consumption per day and per person. On this analysis, we excepted the values out of range from average plus or minus three multiplied standard deviation. As for the total of each floor's consumption, the values in winter are the largest among 4 seasons. As for the male's water consumption, the total values of each floor are 21.1 - 26.6 [L/day/person]. The average values in each floor are almost same in each season. However, as for the female's water consumption, the total values of each floor are 60.3 - 73.9 [L/day/person]. The average values of the 11th floor are 96.3 - 123.1 [L/day/person]. The 11th floor's values are larger than other floor's values in each season. Because the 11th floor has a changing room, other floor's female workers use the 11th floor's toilet when they use the changing room.



a) Cold water consumption　　b) Hot water consumption

Figure 4 - Cold and hot water consumption measured by one minute interval (Example of male toilet at the 13th floor, February 22,2002)

Table 7 - Daly water consumption in each floor

			Cold water consumption			Hot water consumption			Total water consumption		
			Average	Standard deviation	Maximum	Average	Standard deviation	Maximum	Average	Standard deviation	Maximum
Male	10F	winter	24.8	2.3	30.8	3.5	0.7	5.0	28.3	2.6	34.6
		spring	24.4	3.1	30.8	4.1	1.0	6.1	28.6	3.4	36.7
		summer	24.1	2.6	29.9	3.4	0.5	4.5	27.6	2.7	33.6
		autumn	20.2	2.3	25.4	3.1	0.7	4.6	23.3	2.6	28.3
	12F	winter	21.8	2.5	26.3	1.6	0.3	2.3	23.5	2.6	27.8
		spring	18.8	2.2	23.5	1.4	0.2	1.7	20.2	2.3	24.9
		summer	17.3	1.8	21.6	1.4	0.2	1.8	18.8	1.8	23.1
		autumn	16.5	1.6	19.7	1.3	0.2	1.7	17.8	1.7	21.0
	13F	winter	26.1	2.4	31.9	3.3	0.4	3.9	29.4	2.5	35.4
		spring	27.5	3.2	33.5	2.5	0.4	3.1	30.0	3.3	36.2
		summer	26.3	2.7	32.1	2.0	0.4	2.9	28.3	3.0	34.3
		autumn	25.8	2.9	31.5	1.6	0.2	2.2	27.3	2.9	33.1
	Total	winter	23.9	1.3	26.5	2.7	0.3	3.3	26.6	1.5	29.8
		spring	21.7	1.6	24.6	2.4	0.3	2.8	24.1	1.7	27.1
		summer	20.9	1.6	24.3	2.0	0.2	2.5	22.9	1.7	26.4
		autumn	19.4	1.4	21.8	1.7	0.2	2.3	21.1	1.5	23.8
Female	11F	winter	112.9	15.3	148.6	10.2	1.7	13.6	123.1	16.0	161.6
		spring	90.0	14.9	112.2	7.0	1.2	9.0	97.0	15.7	119.8
		summer	86.8	16.4	122.2	9.5	2.3	14.8	96.3	17.2	131.8
		autumn	96.3	13.2	117.4	17.4	3.4	25.0	113.7	12.4	137.8
	12F	winter	65.5	22.1	143.3	4.9	1.4	7.9	70.4	22.4	148.8
		spring	71.3	11.3	101.6	5.7	1.2	8.2	77.0	12.0	108.5
		summer	69.1	12.7	97.7	4.4	1.2	7.3	73.6	13.4	105.0
		autumn	58.4	9.5	81.1	3.9	0.9	5.8	62.3	10.0	85.5
	13F	winter	85.2	14.1	112.8	7.1	1.3	9.9	92.4	14.5	120.4
		spring	58.9	8.6	73.4	5.6	0.7	7.0	64.3	9.0	79.2
		summer	69.6	9.0	90.2	3.8	1.2	7.2	73.4	9.4	94.5
		autumn	63.5	11.0	88.5	3.7	1.1	5.7	67.2	11.5	93.1
	Total	winter	68.3	9.7	102.2	5.6	0.7	7.3	73.9	9.8	108.8
		spring	56.5	5.4	66.1	4.8	0.5	5.5	61.1	5.6	70.8
		summer	59.1	5.5	70.2	4.2	0.6	5.2	63.3	5.6	74.7
		autumn	55.2	4.4	63.6	5.2	0.6	6.8	60.3	4.6	69.2

Unit : [L/day/person]

4. Simulation of water consumption in office buildings

4.1 Calculating model of office buildings

We set up the calculating model in each water usage of fixtures installed in toilets and hot water service rooms. Table 8 shows the calculating model of office buildings in winter and summer. And figure 5 shows the average frequency of fixture usage per hour as a percentage to the total frequency for 10 hours. Each value is set up based on the results of investigation in an office building and the model of railway station's toilet [4]. We set up the operation times of a flashing valve for water closet to change the value according to ratio of the measurement operation times. As for the hot water usage, we suppose that the cold water is heated up by individual heater at the basin and hot water service room. So, we calculate the volume of total water consumption that is summed up cold and hot water. By inputting the other conditions such as the number of workers and the ratio of number of male and female, we can calculate the volume of the water consumption in each fixture.

As for the calculating method, the same technique presented in another paper about the apartment houses at this CIB-W62 Symposium is applied. We generate the random numbers by using the personal computer. And the occurrence of time interval in each fixture usage is calculated based on the frequency of fixture usage simulated by the random numbers. Similarly, duration time, flow rate and operation times are determined. We calculate the loads of water consumption in every one second by using the personal computer.

4.2 The results of calculation

The simulation is carried out for every hour from 8:00a.m. to 6:00p.m.. The number of simulation trials for one hour is set up one hundred times. The calculating conditions are set up from the results of measurement. Therefore, the number of office workers and the average ratio of presence workers are decided as the total value of the three floors where we carried out the measurement. The numbers of office worker are as follows: male and female in summer are 111 and 26 persons, and in winter are 109 and 26 persons, respectively. In the building investigated, the cleaning of fixtures is carried out on the time-zone of 8:00a.m. - 10:00a.m. and 1:00p.m. - 2:00p.m.. So, we set up the frequency of fixture usage on the time-zone to add the number of frequency of cleaning of fixtures.

Table 8 - Calculating model as an example of office buildings

		Male				Female		
		Water closet	Urinal	Basin	Hot water service room	Water closet	Basin	Hot water service room
Frequency of fixture usage [frequency/10h/person]	winter	0.52	2.82	3.32	0.18	3.89	5.4	1.18
	summer	0.6	2.41	2.93	0.28	3.61	5.17	1.25
Arrival interval's distribution		Exp.						
Number of fixtures		unlimited						
Duration time per frequency [sec]		5.5	7	7	16	5.5	17	16
(Distribution)		Erl.4	Erl.8	Exp.	Hyp.3	Erl.6	Exp.	Hyp.3
Flow rate [L/min]		120	30	5	10	120	5	10
(Distribution)		Erl.6	Erl.10	Exp.	Erl.15	Erl.6	Exp.	Erl.15

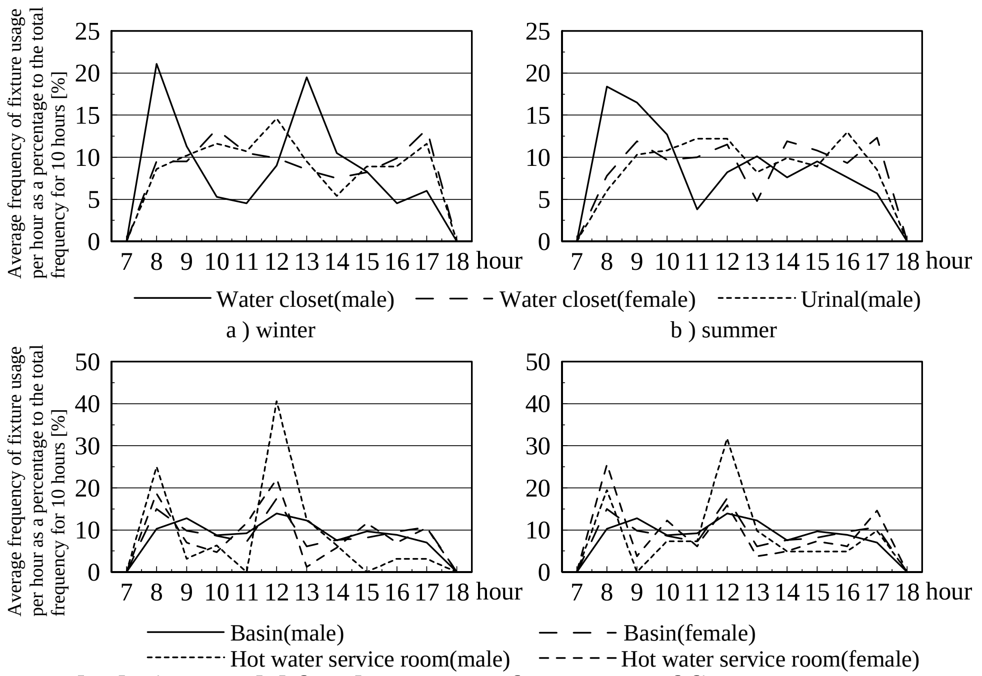


Figure 5 - Calculating model for the average frequency of fixture usage as an example of office buildings

Figure 6 shows the results of the simulation as an example of one case among one hundred trials in summer. The volume of water consumption in each fixture and the total of them are shown by one-minute interval. The values of water consumption per minute are calculated as the total values for 60 seconds. As for the instantaneous maximum flow rate, we have proposed to apply the values of one-minute interval on the apartment houses in the CIB-W62 Symposium, 2002[1].

Table 9 shows the moving average values of instantaneous maximum flow rate in each time interval as the total water consumption in the office building. As for the results of calculating values in each interval, the moving average values of instantaneous maximum flow rates decrease as the interval time becomes long. However, the instantaneous maximum flow rates of 60 seconds interval are almost same with the values of failure factor 1% or 2% of 5 seconds interval. Therefore, it is possible to apply the values of 60 seconds interval as for the instantaneous maximum flow rate in office buildings also. Figure 7 shows the instantaneous flow rates calculated by the simulation and the values of measurement in each failure factor. Compared with the simulation results, the measurement values show the tendency to have a little lower values within the small percent of failure factor.

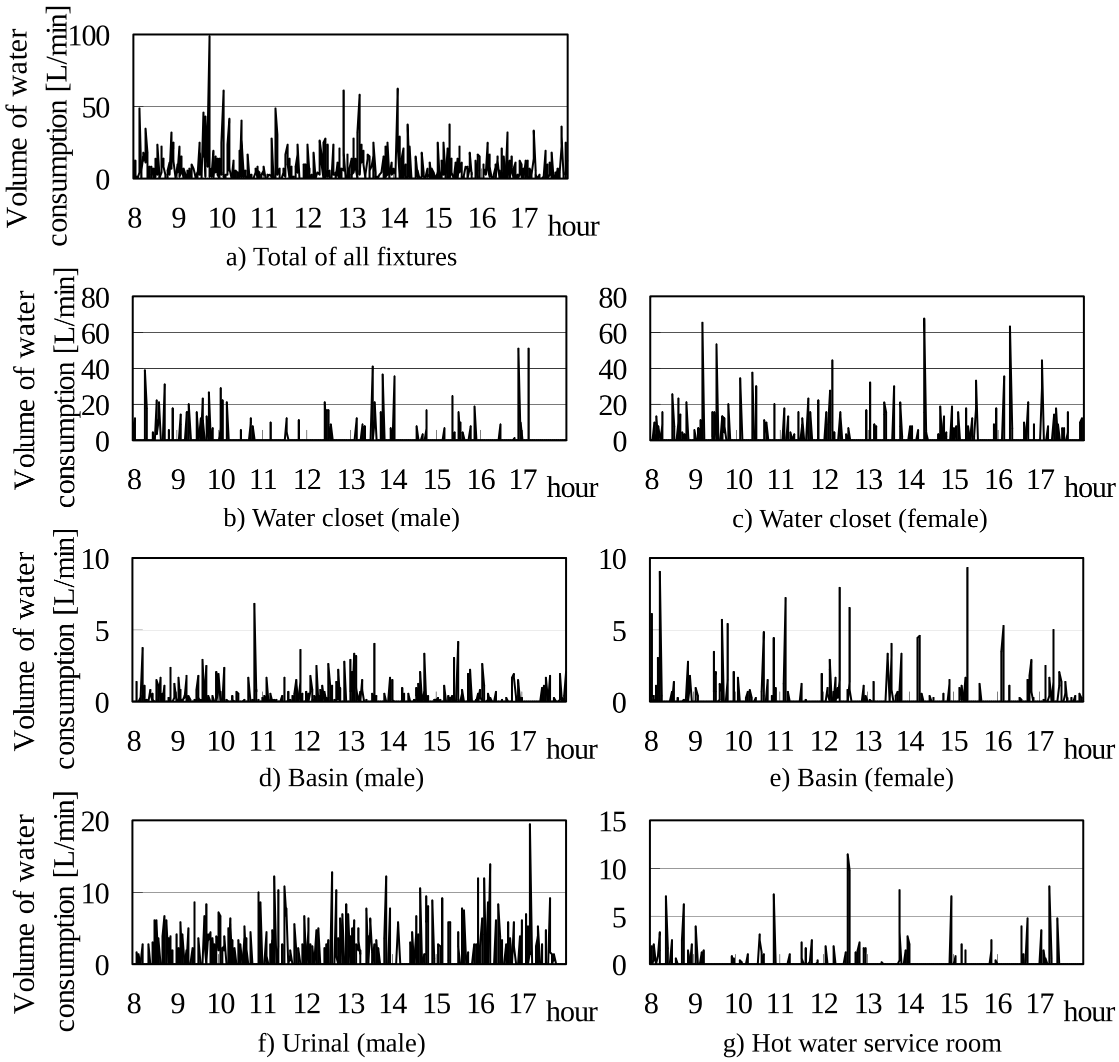


Figure 6 - The results of the simulation as an example of one case

Table 9 - Instantaneous maximum flow rates in each time interval

		Average [L/sec]	Maximum [L/sec]	Failure factor 0.1%	0.2%	1.0%	2.0%	5.0%	10.0%	25.0%	50.0%
Winter	1sec	0.56	8.59	5.24	4.73	3.64	3.15	2.47	1.84	0.59	0.19
	5sec	0.42	7.96	4.64	4.17	3.13	2.66	1.94	1.26	0.46	0.16
	10sec	0.33	6.91	3.96	3.56	2.58	2.12	1.46	0.93	0.36	0.13
	60sec	0.15	3.21	1.53	1.35	0.95	0.77	0.55	0.40	0.20	0.08
Summer	1sec	0.56	8.02	5.24	4.72	3.65	3.14	2.47	1.83	0.59	0.19
	5sec	0.42	7.66	4.58	4.17	3.10	2.62	1.93	1.26	0.45	0.15
	10sec	0.33	6.89	3.99	3.57	2.54	2.09	1.46	0.94	0.36	0.13
	60sec	0.15	3.07	1.51	1.32	0.92	0.75	0.54	0.39	0.20	0.08

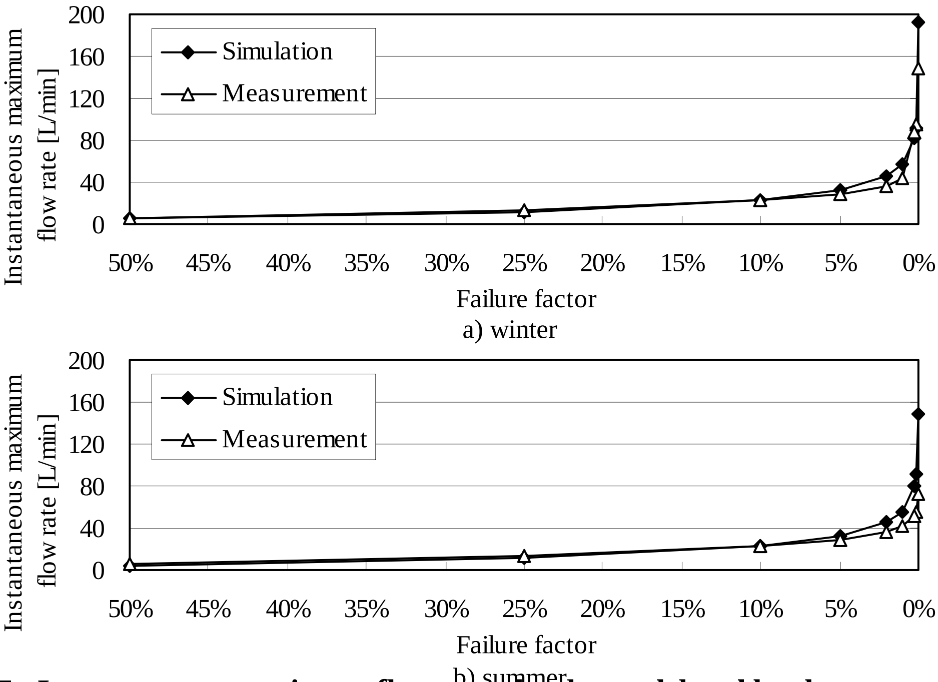


Figure 7 - Instantaneous maximum flow rates by the model and by the measurement

Figure 8 shows the hourly volume of water consumptions calculated in each fixture by the simulation. The measurement values of hourly total water consumption are shown in this figure too. The simulation values of total water consumption are almost equal to the measurement values in each time-zone. The hourly peak values occur on the time-zone of 8:00a.m. - 9:00a.m. and 1:00p.m. - 2:00p.m. in winter and summer. Both peak time-zones are influenced of the male's water closet usage on which water consumption occupies 30% of the total consumption in each peak time-zone. However, the cleaning of fixtures is also carried out in the time-zones. Therefore, some of water consumptions in the peak time-zones are used for cleaning of fixtures. The ratio of female’s water closet usage occupies 30% - 40% of the total water consumption in each time-zone. And water consumptions in hot water service room are a few ratios as 5% - 10% of the total water consumption in each time-zone.

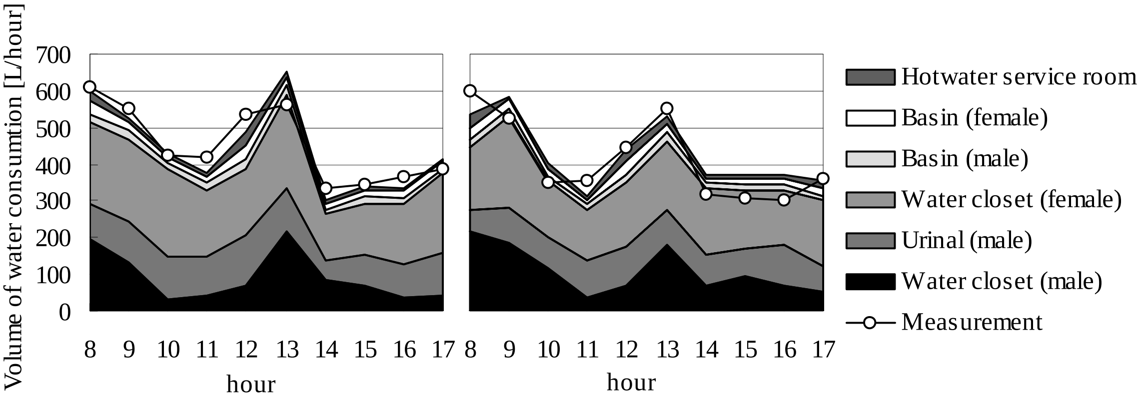


Figure 8 - Hourly consumption of water in each fixture usage

5 Conclusions

In this paper, we studied about the calculating method for the loads of water consumption in office building.

First, the measurement of water consumption and the frequency of fixture usage were carried out in toilets and hot water service rooms to clarify the actual conditions of water usage in office building. Next, the calculating model of water usage in each fixture was set up based on the values of measurement and the results of previous studies. We calculated the loads of water consumption by every one second. And we confirmed that it is possible to apply the values of 60 seconds interval as for the instantaneous loads. Finally, the loads of water consumption were calculated from 8:00a.m. to 6:00p.m. by using the calculating method applied the Monte Carlo Simulation technique. The hourly values of simulation were almost equal to the values of measurement. And the simulation values of failure factor 1% or more large percent were almost same to the instantaneous loads of the measurement value. We confirmed the simulation values were almost same with the measurement values. Therefore, the calculating method proposed by us is useful to estimate of water consumption in office buildings.

Acknowledgements

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Main author presentation

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SIMULATION OF HOT-WATER CONSUMPTION OF APARTMENT HOUSE BY MONTE CARLO METHOD

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Abstract
On deciding apparatus capacity of hot water supply system, it is very important to evaluate the actual hot water consumption. Especially in apartment house, the fluctuation of consumption is stabilized as houses' number increases, so it is difficult to evaluate the actual fluctuation. This paper describes the daily and time fluctuation in hot water consumption. At first, we analyze the data of actual consumption of selected 22 houses of high-rise apartment in Tokyo. Consumption was measured in each faucet. Through the analysis, we sum up the differences between each house,which is necessary to simulate. Finally, we executed computer simulation based on Monte Carlo method for hot-water consumption and evaluate the output behavior as a case study.

Keywords
Hot water, Consumption, Saving energy, Apartment house, Survey, Simulation

1. Introduction
These days, saving energy is most important topic for every field, including industrial, commercial, and private one. In COP3(The 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change), which was held in Kyoto Japan on December 1999, participant announced "Kyoto Protocol", in which, Japan has to reduce CO2 emission by 6 % from 1990 level in 2008 to 2012. Japanese government is now serious to achieve this goal, even in private field.

To accomplish saving energy and improvement of living condition at the same time, introduction of "Co-generation" system to ordinary houses is under examination. Co-generation system is a total energy solution to produce the heat and electricity simultaneously for higher efficiency up to 80%, compared with 40 % of most-advanced power plant. Usually, Co-generation is composed of Gas engine and power generator or "Fuel-cell", Heat storage tank, controller. Emitted heat from gas-engine or fuel-cell can be used for hot water and heating. Co-generation is one of most promising step to reduce energy consumption and CO2 emission, but it is so sensitive to heat and electricity consumption that we have to grasp the actual heat and electricity demand with much higher accuracy before the introduction. Especially, hot water is the largest heat demand in houses, so much more accurate evaluation method is needed urgently.

In this paper, we tried to establish the more flexible and accurate evaluation method of hot water consumption in house, especially of apartment. First, we analyze the surveyed data of hot and cold water consumption in actual houses and sum up the real state of usage. Then, through the establishing of primitive model of hot water consumption, we prospect the possibility of evaluation method more suitable for actual usage.

2. Analysis of actual cold and hot water usage

In this chapter, we explain the detail of reference data adopted, and overview the consumption of each houses.

2.1 Detail of surveyed data

To access the actual usage of hot water consumption in houses, we analyze the surveyed data on 22 houses of high-rise apartment in Tokyo. Detail is shown in Table 1.

Table 1 Details of surveyed data

Building Type	High-rise apartment house, Tokyo
Hot water supply system	Central water heating system(Supply Temperature 60deg.)
Period of observation	Winter:January.11.1993-January.31(21days) Summer:July.1.1993-July.31.1993(31days)
House number	22Houses (Single:7, Couple:5, Family:10) There were trouble on data in some houses
Object of survey	Flow rate of hot and cold water on each faucet (Kitchen, Bathroom, Lavatory, Laundry, Toilet) Temperature of hot and cold water
Interval of measurement	Flow rate: 1Sec, Temperature: 1 hour

2.2 Average Consumption

At first, we compare the average consumption of each house. In Figure 1, daily average total volume of hot and cold water is shown ("S" for Single, "C" for Couple, "F" for Family). Volume ranges is approximately 200-400L/day for Single, 200-700L/day for Couple, 400-1100 for Family. Ranges are rather close to previously known ones. In comparison of each faucet, volume of "Kitchen" and "Bathroom" are largest.

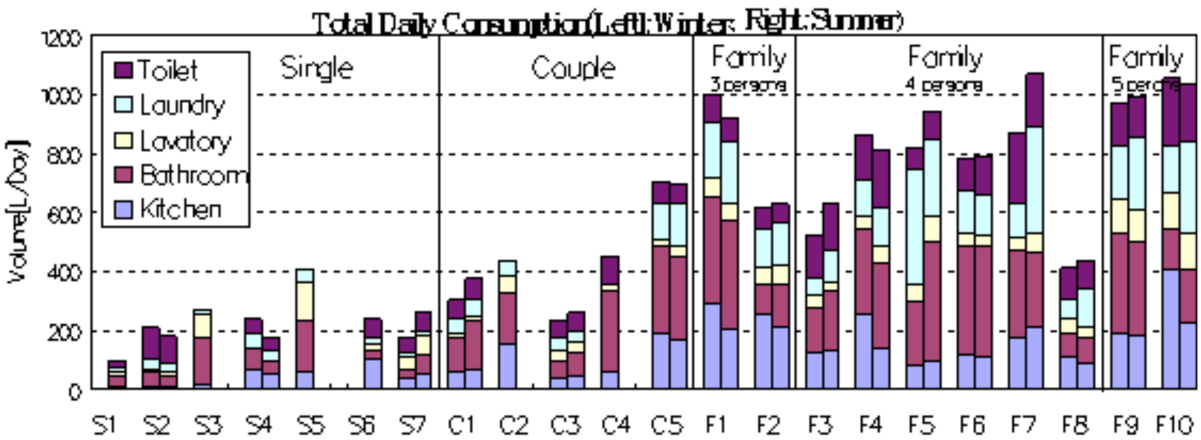

Figure 1 Average daily consumption of hot and cold water

2.3 Definition of "Mixed hot water"

To facilitate the analysis, we introduce the definition of "Action" and "Mixed hot water". As shown in Figure 2, Continuous consumption of hot and cold water in faucet is integrated to 1 "Action". If hot water is included, it is classified as "Mixed hot water".

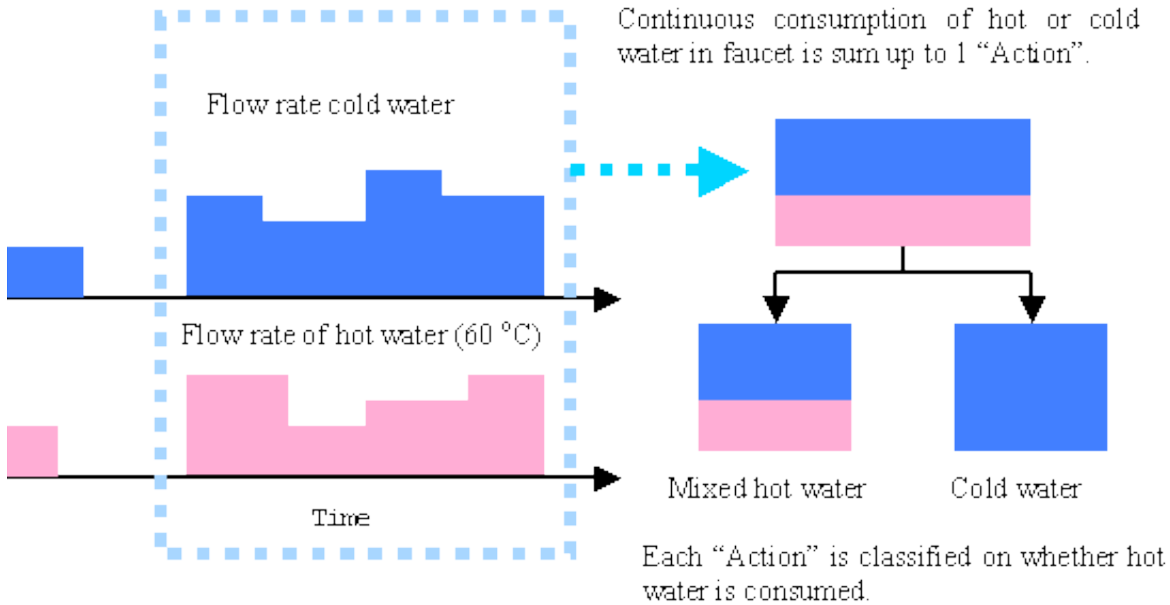

Figure 2 "Action" of "Mixed hot water" and "Cold water"

Each feature of "Action of Mixed hot water" is expressed in equation(1) to (5)

Total Volume:
$$V_{total} = \sum_{t=0}^{T_{total}} F_{cold}(t)\Delta t + \sum_{t=0}^{T_{total}} F_{hot}(t)\Delta t \qquad (1)$$

Heat of Cold Water
$$H_{cold} = c\rho \sum_{t=0}^{T_{total}} [F_{cold}(t) + F_{hot}(t)] T_{cold}(t)\Delta t \qquad (2)$$

Heat Load
$$H_{load} = c\rho \sum_{t=0}^{T_{total}} F_{hot}(t)[T_{hot}(t) - T_{cold}(t)]\Delta t \qquad (3)$$

Total Heat
$$H_{total} = H_{load} + H_{cold} = c\rho \left[\sum_{t=0}^{T_{total}} F_{cold}(t) T_{cold}(t) + \sum_{t=0}^{T_{total}} F_{hot}(t) T_{hot}(t) \right] \Delta t \qquad (4)$$

Average Temperature
$$T_{average} = H_{total} / (V_{total} c\rho) \qquad (5)$$

In these equation, *Fcold(t)*:cold water flow rate[L/sec], *Fhot(t)*:hot water flow rate[L/sec], $T_{cold}(t)$:cold water temperature[°C], $T_{hot}(t)$:hot water temperature[°C], *t*:passed time from the opening of faucet[sec], Δt :Time interval of measurement[sec], *c* :Specific heat of water[kJ/(kg K)], ρ :density of water[kg/L].

Average daily consumption of "Mixed hot water" in each house is shown in Figure 3.

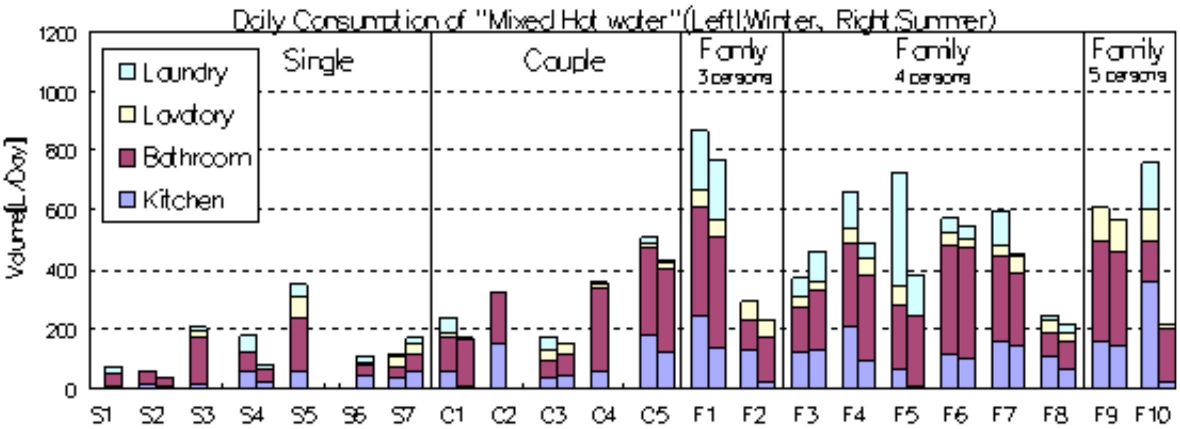

Figure 3 Average daily consumption of "Mixed hot water"

2.4 Fluctuation of Daily Consumption

To evaluate the hot water consumption, especially in design process of heat storage capacity, daily fluctuation is very important. Energy efficiency of heat storage can be improved by setting the capacity smaller, but shortage of hot water would happen more frequently. Relation of average and variance of "Mixed hot water" daily consumption in each house is shown in Figure 4. Average and Coefficient of Variance(Standard Variance/Average) is shown in Figure 5. There is a tendency that the fewer member family produces the smaller consumption, but on the other hand, the wider fluctuation. This may indicates Single's or Couple's lifestyle is more irregular, and consumption is largely affected by one or two person's presence or absence.

Winter **Summer**

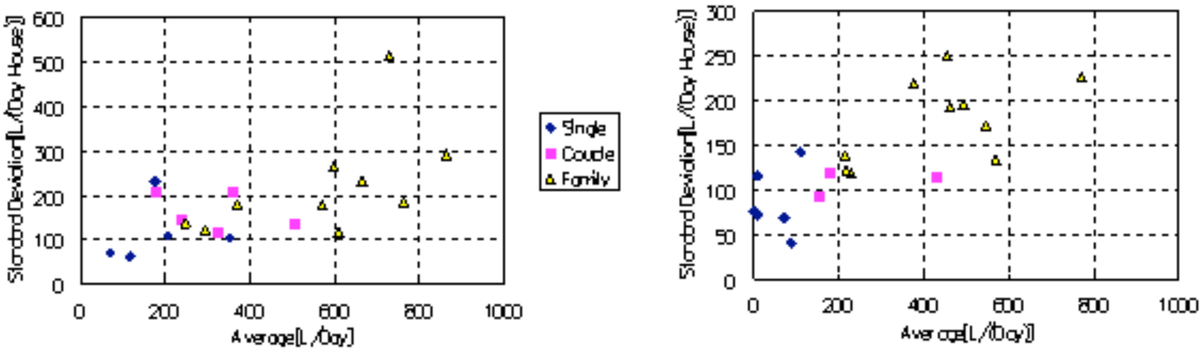

Figure 4 Average and standard variance of daily "mixed hot water" consumption

Winter **Summer**

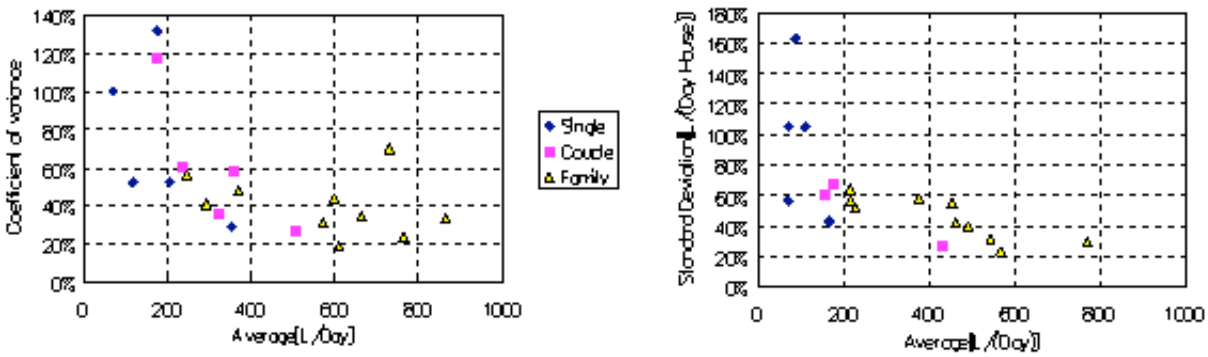

Figure 5 Average and coefficient of variance of daily "Mixed hot water" consumption

3. Pre-study for Simulation of Hot-water Consumption

3.1 Features of "Action" of "Mixed hot water"

In process of reproduction of hot water consumption, the occurrence of each "Action" of "Mixed Hot water" must be decided. Features of each "Action" are below.

- Numbers of Actions per day[Actions/day]
- Action's volume [L/Action]
- Average temperature (for evaluation of heat) [^{o}C]
- Occurrence time (for evaluation of time fluctuation)

In the method we adopted, these features are decided by "Monte Carlo method". That is, each features is produced by combination of frequency distribution and random number.

3.2 Gamma Distribution Fitting for Frequency of Each Feature

You can adopt the frequency distribution simply arranged from surveyed data. But such distribution is not flexible for application. For "Number of Action", "Action's volume". "Average temperature", we adopted fitting by "Gamma distribution", which equation is shown in (6).

Gamma distribution
$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{-x}{\beta}} \quad (6)$$

x: random variable Γ:Gamma function

α =(Sample's average) / β $\quad\beta$ =(Sample's variance)/(Sample's average)

"Erlangian distribution" is often adopted for the fitting, but "Erlangian distribution" is only one kind of Gamma distribution, which parameter "α" is restricted to positive integer. So it is predictable that Gamma distribution to be more flexible. Examples of Gamma fitting for Action's features are shown in Figure 6. Fitting is fairly good.

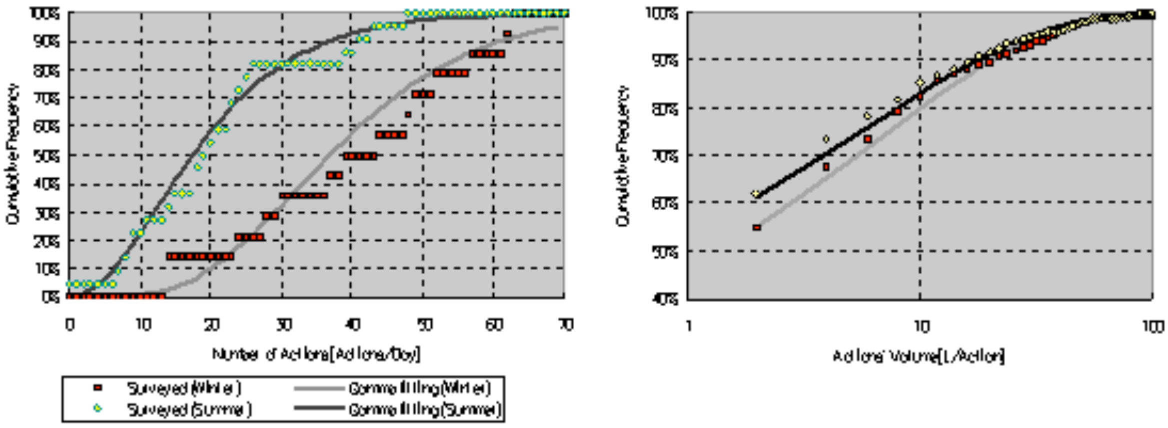

Figure 6 Fitting of Gamma distribution to surveyed frequency (F1 Kitchen)

For "Occurrence time", it was difficult to fit the particular distribution function, so surveyed data was simply adopted on this paper. Exaple is shown in Figure 7.

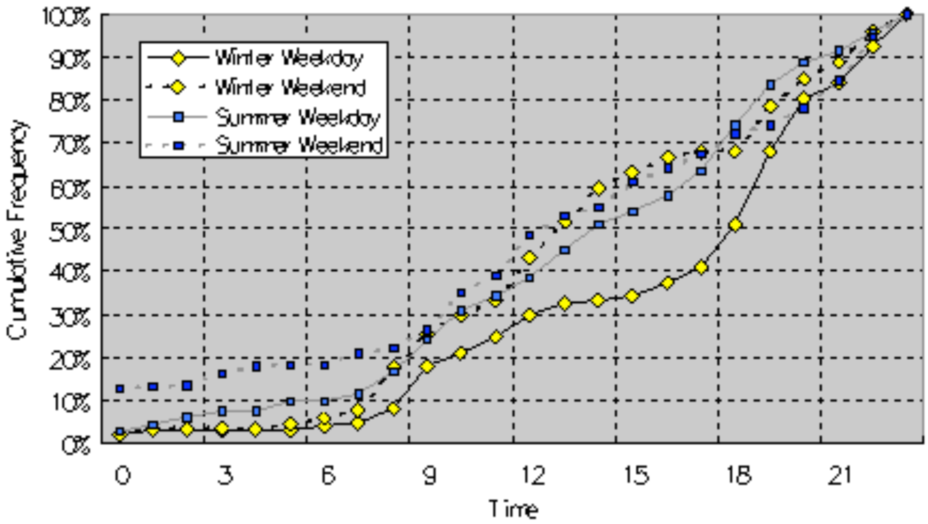

Figure 7 Example of Time Distribution(F1, Kitchen)

3.3 Simulation Flow

Computer simulation flow is shown in Figure 8. In each day on calculation period, "Number of Actions in day" is decided in faucet at first. And then, determine features of each Action. In this model, each feature is determined independently, which means one decided feature has no influence to other feature. This might be unnatural assumption, so we would check it consistency later.

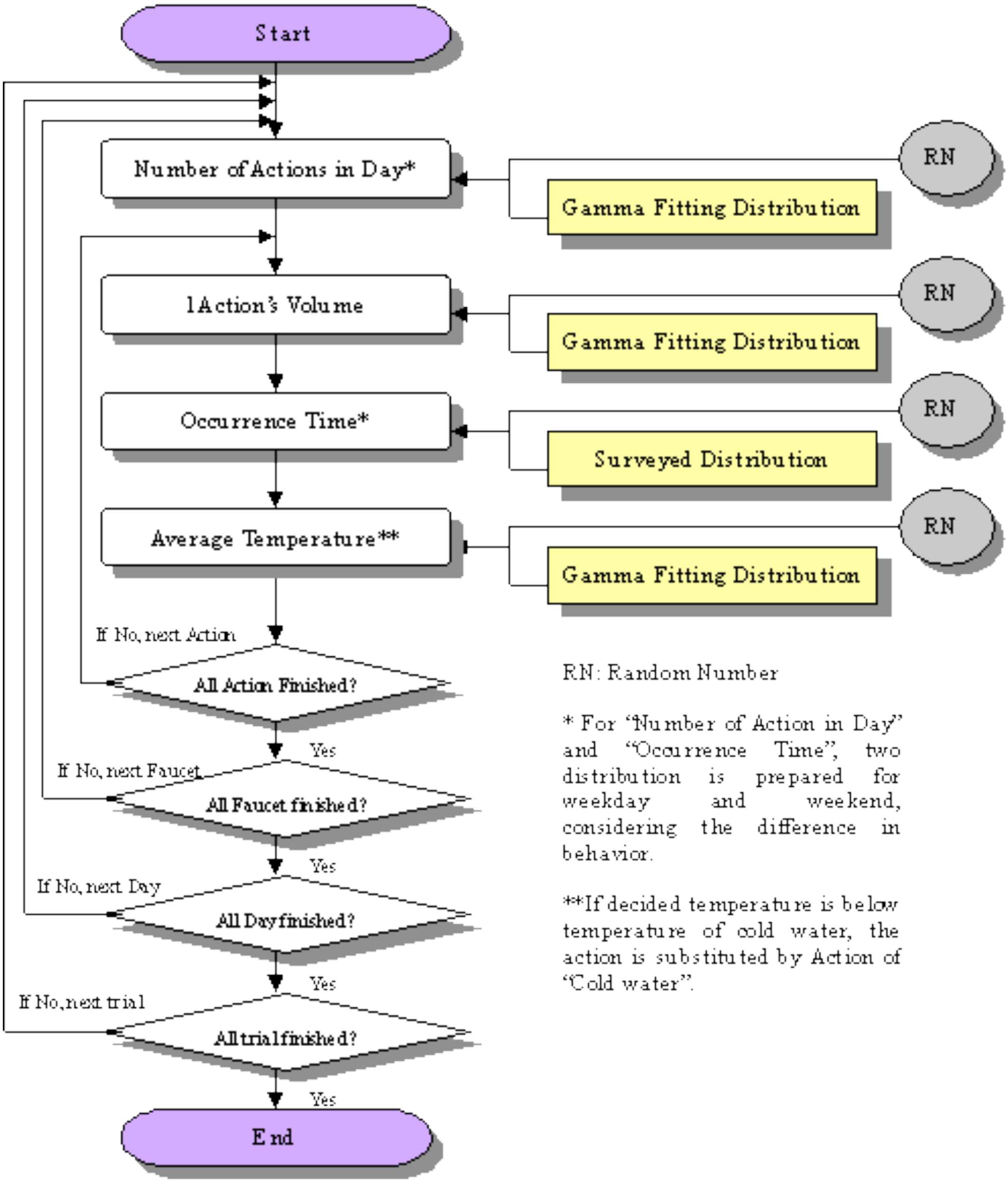

Figure 8 Simulation Flow

3.4 Comparison with surveyed and calculated result

To confirm the state of calculation's reproduction, especially the fluctuation of daily consumption, we compared the surveyed and calculated. One series of consumption is calculate in one period, same days number as surveyed(Winter 21days, Summer 31days), and average and standard deviation, hours' average volume of daily consumption are calculated in this time trial. To evaluate the Randomness, Calculation is repeated for 100 times. The comparisons are shown in Figure 9(Daily volume),Figure 10(Daily heat), Figure 11(Hourly volume). Points indicates the "Median", "Maximum" and "Minimum" value in 100 times of each house. For simplicity, we adopted the houses with more than 3 persons(F1-F10) only in this simulation.

Average of volume and heat indicates very good coincidence. And even standard deviation's interrelation is fairly good in many houses. This result may certify that even if you assume the independence of actions' features, fluctuation of consumption might be reproduced well. Result of time fluctuation shows good consistency also.

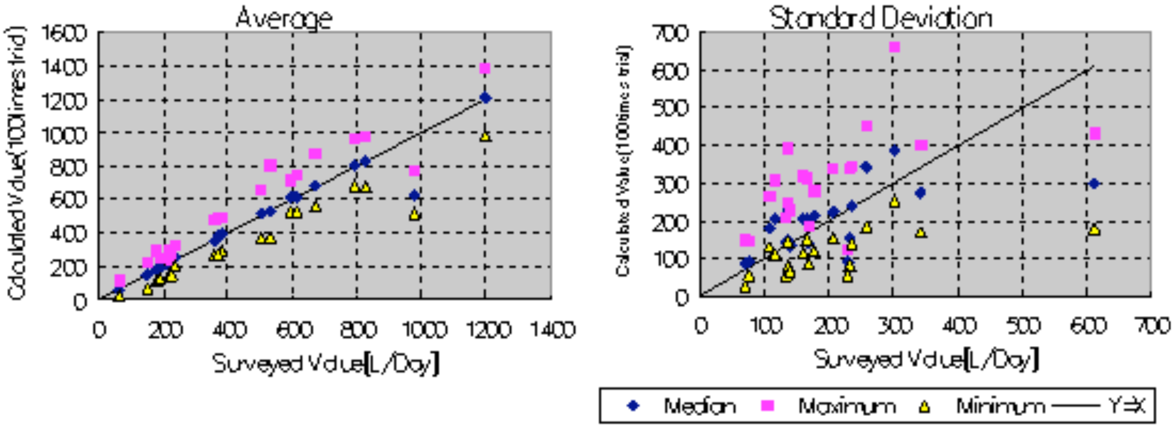

Figure 9 Volume of Mixed hot water (Sum of all faucets, Daily, Winter)

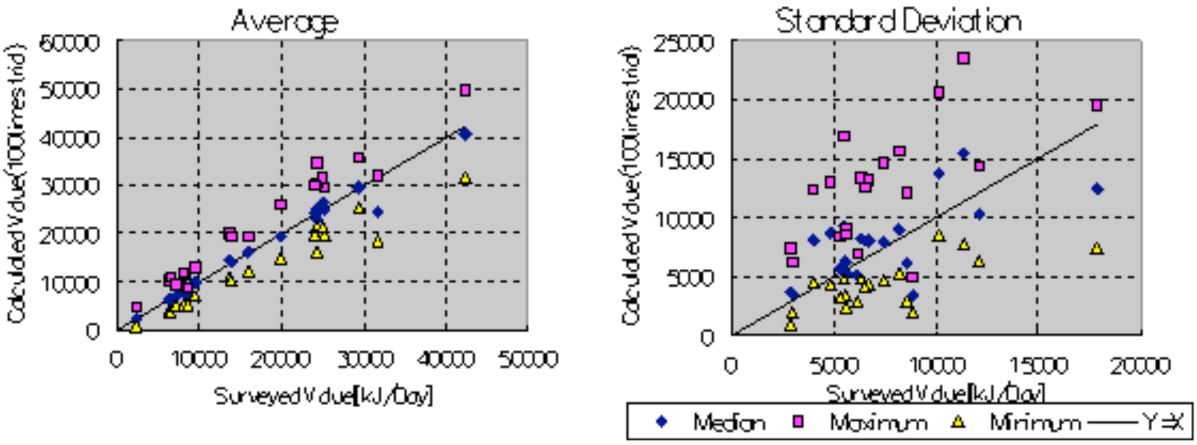

Figure 10 Heat of "Mixed hot water" (Sum of all faucets, Daily, Winter)

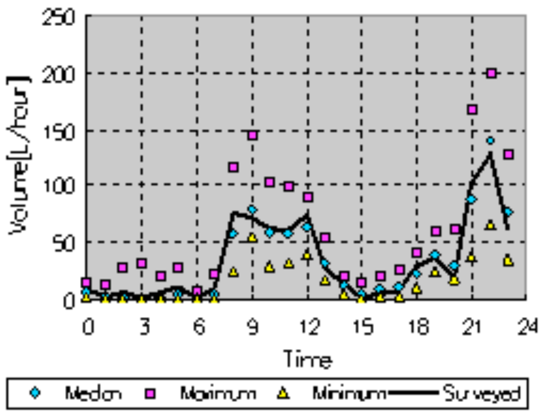

Figure 11 Volume of "Mixed hot water"(Time distribution, House F1, Winter)

4. Case study of hot water supply system in apartment.

In this chapter, we calculate the load for central water heating water supply system of apartment as a case study of evaluation model we already mentioned.

4.1 Detail of case study

Calculation condition is shown in .Table 2.

Table 2 Condition of calculation

Number of total houses, Period	200 Houses, 1Year (365days)
Inhabitants' family	More than 3 persons
Hot water supply temperature	60 ^{o}C

Region (for cold water temperature)	Tokyo, Japan
Cold water temperature	Highest 24.7 °C (Aug), Lowest 6.8 °C (Feb)

4.2 Selecting "Type" for Actions' feature

To assign the parameter combination to each houses, difference of action's features are analyzed once again and classified into typical types. As already mentioned, Gamma Distribution is decided uniquely by two parameters, and two parameters are calculated from sample's average and variance. So you only have to pick up the typical combination of average and standard deviation.

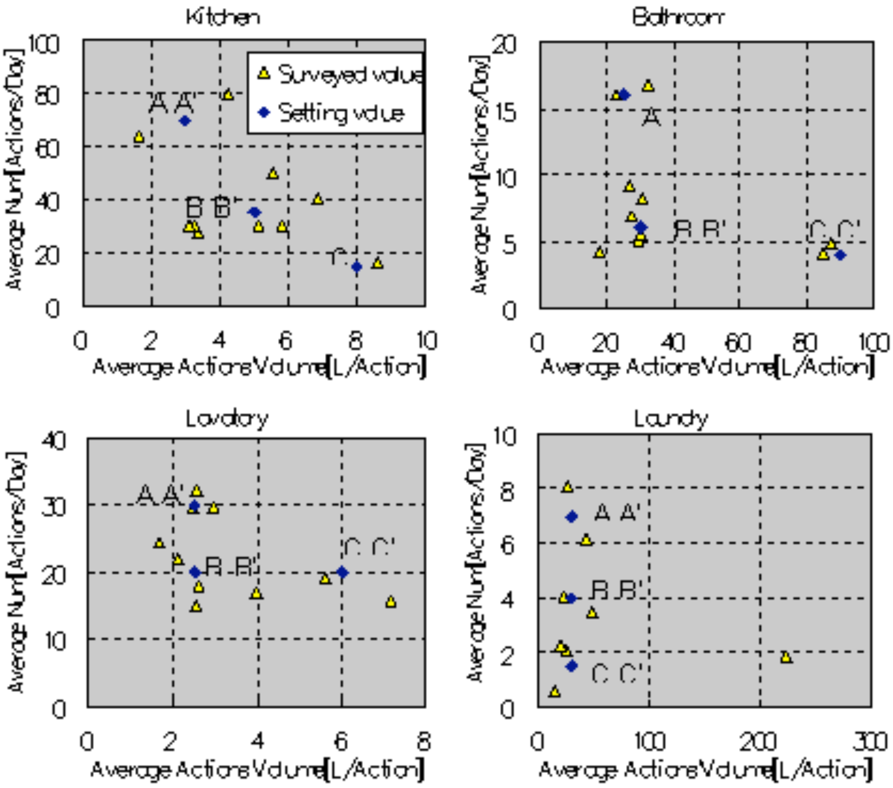

Figure 12 "Volume" and "Number" of Actions in House F1 to F10

As shown in Figure 12, houses are classified into several groups, such as "Faucet is frequently opened, but shut quickly", "Not so frequently, but kept open for longer time", in terms of relation between "Action's volume" and, "Number of Action". In this paper, former type is named "A" and latter "C", and middle type "B".

And regarding the relation between average and variance of "Numbers of Action", variance varies for same average value. So two types are arranged, such as "A" for house of stable usage, and "A(')" for more random usage. In the same way, typical type "a", "b", "c" is selected for temperature of hot water. Assigned type is shown in Table 3.

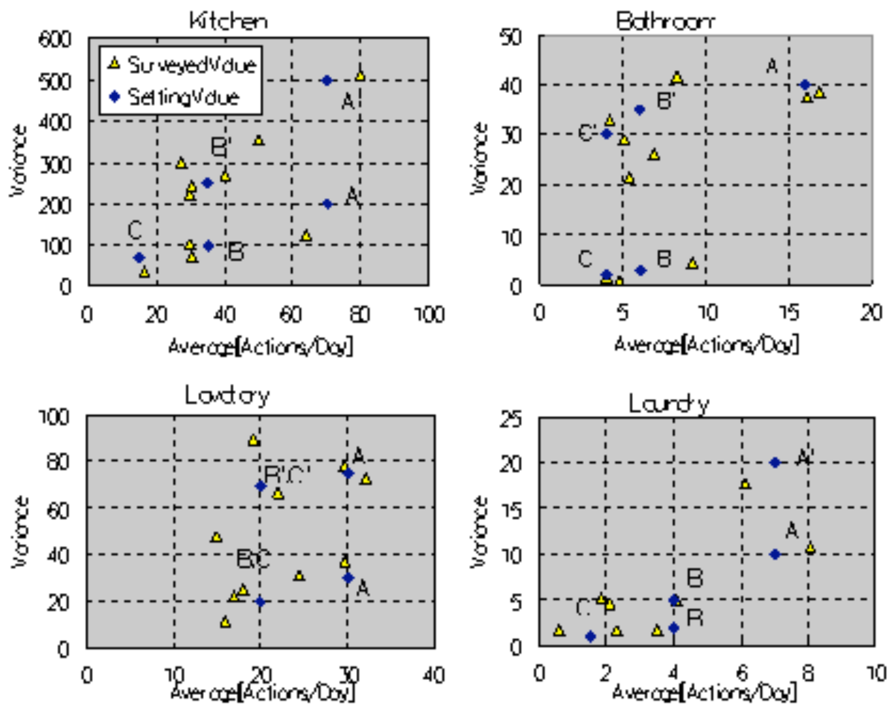

Figure 13 Average and variance of "Actions' volume" in House F1 to F10

Table 3 Assigned Type for Actions' feature

Actions' Volume and Number

	Type	Actions' Volume[L/Action] Average all day	Actions' Volume[L/Action] Variance all day	Number of Actions[Actions/day] Average weekday	Number of Actions[Actions/day] Average weekend	Number of Actions[Actions/day] Variance all day
Kitchen	A	3	30	70	90	200
	A'	3	30	70	90	500
	B	5	120	35	50	100
	B'	5	120	35	50	250
	C	8	170	15	20	70
Bathroom	A	25	1000	16	16	40
	B	30	2500	6	5	3
	B'	30	2500	6	5	35
	C	90	6000	4	4	2
	C'	90	6000	4	4	30
Lavatory	A	2.5	10	30	35	30
	A'	2.5	10	30	35	75
	B	2.5	40	20	20	20
	B'	2.5	40	20	20	70
	C	6	60	20	20	20
	C'	6	60	20	20	70
Laundry	A	30	200	7	7	10
	A'	30	200	7	7	20
	B	30	200	4	3	2
	B'	30	200	4	3	5
	C	30	200	1.5	1.5	1
	C'	30	200	1.5	1.5	1

Temperature

	Type	Average	Variance
Kitchen	a	35	70
	b	35	120
	c	45	140
Bathroom	a	41	5
	b	41	20
	c	41	40
Lavatory	a	30	15
	b	30	40
	c	42	60
Laundry	a	25	5
	b	40	20
	c	40	20

4.3 Simulation Flow

Before the calculation process of hot water consumption seen in Figure 8, Actions' features of "Mixed hot water" is allocated to each house in apartment. For "Occurrence time", surveyed distribution of F1-F10 is assigned.

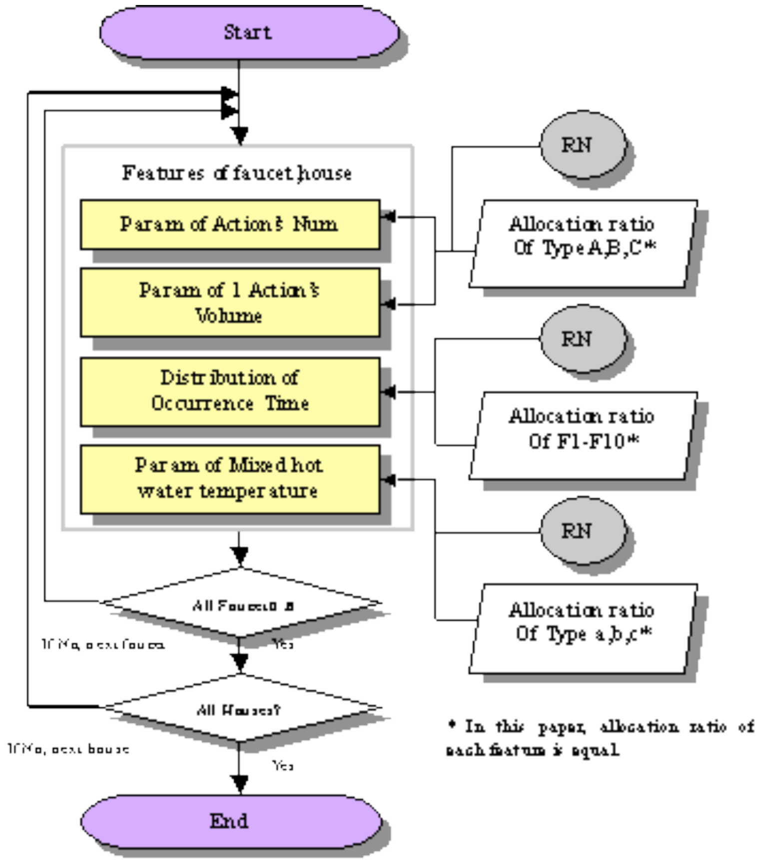

Figure 14 Allocation for each house in apartment

4.4 Result

The calculation result is shown Figure 15 and Figure 16. Result is evaluated as the volume of 60°C hot water. Figure 15 shows the examples of stabilization in daily and time fluctuation as house number increases.

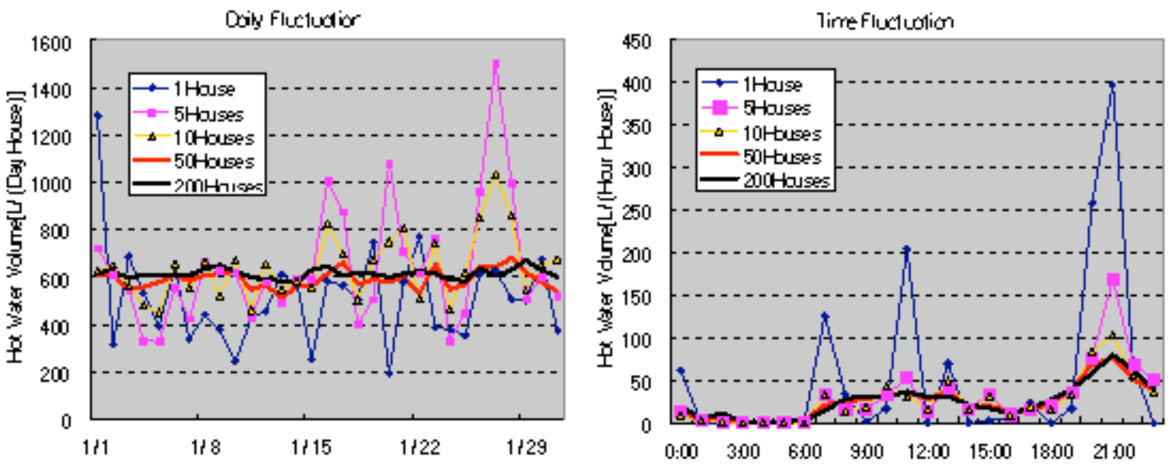

Figure 15 Leveling of fluctuation (Left:Daily, Right:Hourly)

Figure 16 left shows the frequency of daily consumption. "Average in 1 Year" indicates the difference of each house, and "Daily consumption" means fluctuation of each day also. Figure 16 right shows the peak flow rate (hourly in day) for group of certain number's houses. This result must be studied carefully afterward, but might show the prospect of this method.

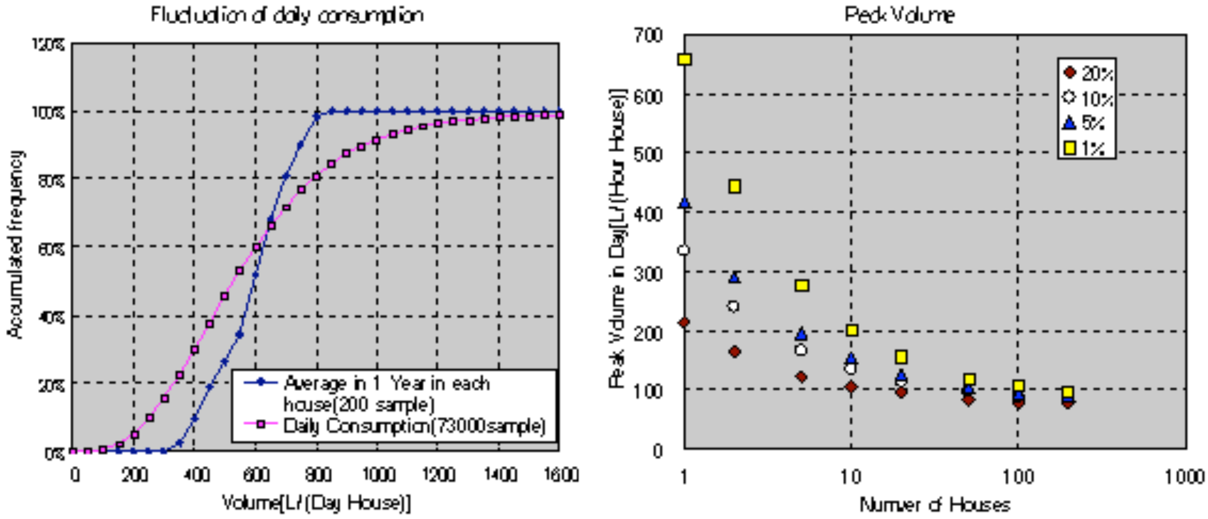

Figure 16 Daily consumption and peak flow rate (As volume of 60 ^{o}C hot water)

5. Conclusion

In this paper, we established the primitive modeling for the evaluation of hot water consumption in apartment house. Calculated result produces the fairly good coincidence with surveyed result, considering the simplicity of adopted model and assumption. There are many subjects to be resolved for total evaluation method, but we might have indicated the prospect of this simulation method for reproduction of actual usage.

Acknowledgements

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Presentation of Authors

Masayuki Mae is Research Fellow of the “Japan Society for the Promotion of Science” and belongs to “Building Research Institute”. His main field is the survey and modeling of energy consumption in houses. Assessment of Hot water consumption is his prior subject to promote the installation of “Co-generation system” for houses.

Development of the Calculating Method for the Loads of Cold and Hot Water Consumption in the Apartment Houses

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Abstract

The loads of cold and hot water consumption are changing by progress of water supply systems and spread of the water-saving fixtures aiming for energy saving in the various buildings. It is necessary to adapt the calculating method of the loads for the design and maintenance of buildings. The authors have advanced the development of calculating method based on the data of water consumption for daily, hourly and instantaneous loads in the time series through a day by using a personal computer. We have proposed the method that applies the unit model as one flat's cold water consumption loads in the apartment houses at the CIB/W62 Symposium (2002), Iasi (Rumania).

In this paper, first we present the calculating method of cold and hot water consumption loads based on the conditions of calculating model that were clarified in the Symposium of last year. The method applies to the Monte Carlo Simulation technique. As the results of calculation, we show daily, hourly and instantaneous loads in each fixture usage.

Next, we clarify the usefulness of using the flat unit model when the detail usage of water in each fixture can not be grasped. We compare the results calculated by each fixture usage model and by the flat unit model as for daily, hourly and instantaneous loads of cold and hot supply water. And, we clarify that the values estimated by both models have similarity.

Keywords

Water Consumption, Monte Carlo Simulation, Fixture Usage, Apartment Houses

1. Introduction

The authors have now developed the calculating method for cold and hot water consumption in the buildings of various types. The method is to estimate the demands in the time series such as daily, hourly and instantaneous loads. Last year, in the 28th International Symposium of CIB/W62, Iasi (Rumania), we suggested the calculating method for cold water consumption as a case study of apartment houses [1]. In that paper, we clarified that it is very useful to apply the Monte Carlo Simulation technique when we calculate daily, hourly and instantaneous water consumption loads.

Therefore, as the continuous study for the development of the calculating method, we try to estimate cold and hot water demands in apartment houses based on the calculating conditions of the model in each water usage that were clarified in the paper last year.

2. Calculating method of cold and hot water consumption loads

As the basic consideration to apply the Monte Carlo Simulation technique, the calculation starts from the occurrence by people's water usage at the fixtures installed in the building. In this case, we have a hypothesis that the number of fixtures is installed suitably for requirements. And if we have the special instruments to consume cold and hot water in the building, we will add the volume to the people's consumption.

At the beginning of the calculation, it is necessary for us to grasp the characteristics of the apartment houses such as the family size, the life-styles of people, the types of fixtures installed, the hot water supply systems, etc.

After the basic data are set up for the objective building, the calculation of cold and hot water consumption loads can be carried out according to the procedure shown in Figure 1.

In this method, we have a hypothesis that probability of the frequency of water usage occurs at random phenomena for an arranged period [2]. We have to set up the calculating model as follows:

(1) The frequency of water usage in each period through a day

(2) The average values and distributions of the duration time of water usage and the discharge flow rates

We also have to decide the cold and hot water temperature in each usage and the supplied cold and hot water temperature in case of planning the central hot water supply system.

We generate the pseudo-random numbers by using personal computer. The generated random numbers are applied to calculate the occurrence time interval of water usage, the duration time of water usage, the discharge flow rate and the hot water temperature in each water usage.

The simulation is carried out with repetition until we can get the stability for the calculating results. In this paper, the simulation is carried out one-hundred times for one hour. From these results, we can get the fluctuation patterns of cold and hot water consumption loads in the time series through a day. We analyze the data statistically, and get the standard values of the instantaneous maximum flow rate, peak hour and daily consumption. These results by the simulation will be applied for the calculation of the piping size, the capacity of cold and hot water service tanks, the capacity of water supply pumps, etc.

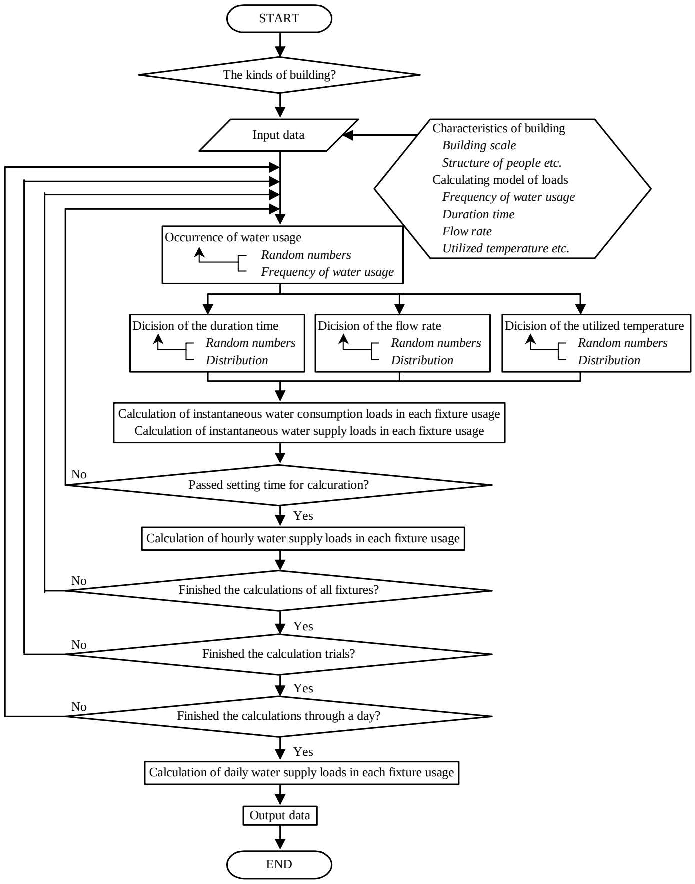


Figure 1 – Procedure for calculation of cold and hot water consumption loads

3. Calculating results of water consumption loads by each fixture usage model

3.1 The model for calculation

In order to analyze the model for calculation, we clarified the influence of factors for the calculating conditions to apply the Monte Carlo Simulation technique in the CIB-W62 Symposium last year [1].

The contents clarified are as follows:

(1) There are not so large differences among the instantaneous flow rates, when we change the combination of two factors; the operating frequency of the fixture and the duration time of water usage under the constant average values for the number of simultaneous uses of water.

(2) However, there are large differences among the instantaneous maximum flow rates, when we change the combination of two factors; the duration time of water usage and the discharge flow rate from a fixture under the constant volume of water consumption per one operation, open and close of a fixture.

Therefore, it is very important to give heed for the decision of the discharge flow rates from the fixtures.

Also, we clarified that it is suitable to apply the average values of 60 seconds interval as for the instantaneous maximum flow rates from the viewpoint of the practical plumbing design.

Based on the calculating model for cold water consumption loads shown in the symposium last year, we improve the model to put the technique for calculation of hot water consumption loads together. On the hot water usage, the duration time, the flow rate and the utilized temperature are decided by the reference of previous studies [3][4]. These conditions on the calculating factors need to set the average values and the distributions in each fixture usage.

Figure 2 shows the average frequency of water usage per flat and per hour as a percentage to the total frequency for 21 hours. The water usage patterns as an example of weekday on August were analyzed based on the investigation results in a certain apartment complex located in Tokyo area [5]. In this case, we suppose that the water usage does not occur during early morning; the time zone of 2:00 a.m. – 5:00 a.m.

Table 1 shows the calculating model of cold and hot water consumption loads in each fixture usage as an example of four people family size in weekday on August. The total volumes of cold and hot water consumption per frequency calculated by the duration time and the flow rate in each fixture usage are similar values with the calculating model for cold water consumption shown in the symposium last year.

However, the consumption of laundry per frequency, it means a cycle of washing by using a washing machine, is set 120 L as standard model in comparison with 90 L of water saving model shown in the previous paper. The ratio of fixture usage is set at the value of 1.00 with the ratio of cold water and the ratio of hot water together. But, we suppose that the behavior of filling the bathtub will not occur every day. Therefore, the ratio of fixture usage to pour into the bathtub is set below the value of 1.00, as 0.85. The usage of cold water in the bathroom and the usage of hot water in the laundry are not considered for the conditions of calculation. The random numbers are generated according to the distributions of each fixture usage shown in Table 1.

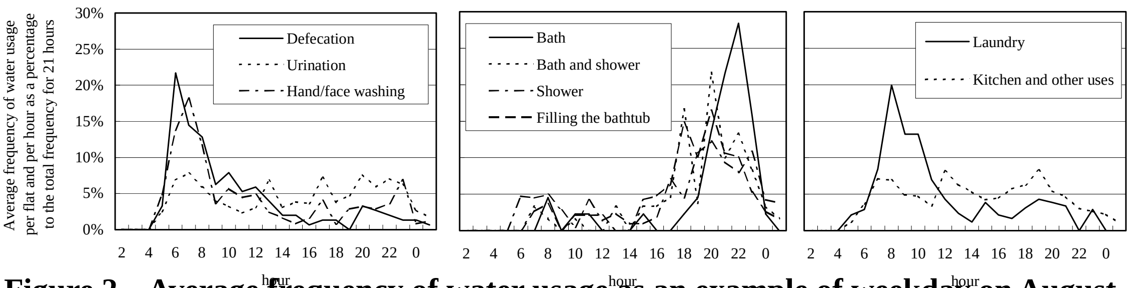


Figure 2 – Average frequency of water usage as an example of weekday on August

Table 1 – Calculating model in each fixture usage as an example of apartment houses

	Bath	Bath and shower	Shower	Filling the bathtub	Hand/face washing		Kitchen and other uses		Laundry		Bathroom	
					Hot	Cold	Hot	Cold	Hot	Cold	Defecation	Urination
Frequency of water usage (Summer/Weekday model) [frequency/flat/day]	0.74	0.65	2.04	0.61	5.35	5.35	8.87	8.87	1.70	1.70	2.78	9.17
Duration time per frequency (Distribution) [sec]	180 Exp.	420 Exp.	480 Exp.	600 Erl.15	30 Exp.	40 Hyp.5	40 Hyp.5	100 Hyp.5	480 Exp.	480 Exp.	60 Exp.	50 Exp.
Flow rate (Distribution) [L/min]	9.0 Erl.7	9.0 Erl.7	8.5 Erl.7	14.0 Erl.20	8.5 Erl.10	12.0 Erl.4	8.0 Erl.4	12.0 Erl.3	15.0 Erl.5	15.0 Erl.5	10.0 Erl.6	10.0 Erl.6
Hot water utilized temperature (Distribution) [℃]	41.0 Erl.20	41.0 Erl.20	41.0 Erl.20	43.0 Erl.20	37.0 Erl.20	―	38.0 Erl.20	―	40.0 Erl.20	―	―	―
Utilized ratio of fixture	[illegible]	[illegible]	1.00	0.85	0.40	0.60	0.40	0.60	0.00	1.00	1.00	1.00

Note : Bath:Taking a bath without using a shower; Bath and shower:Taking a bath using a shower; Shower:Taking a shower only

3.2 The results of calculation

The hourly average frequency ratios of water usage per flat and per hour, and the frequencies of water usage per flat and per day are shown in Figure 2, and Table 1 respectively. The intervals of water usage are simulated by the random numbers according to the operating ratios of fixture per minute, open and close, that are calculated with the average values and the distributions of each hourly fixture usage.

The simulation is carried out an hourly interval through a day; the time-zone of 5:00 a.m. – 2:00 a.m. The number of simulation trials for an hour is set up one hundred times.

The supplied temperatures of cold and hot water are 25 and 60 respectively. The supplied volumes of cold and hot water are calculated from the volumes of cold and hot water consumption according to the ratio of supplied temperatures of cold and hot water.

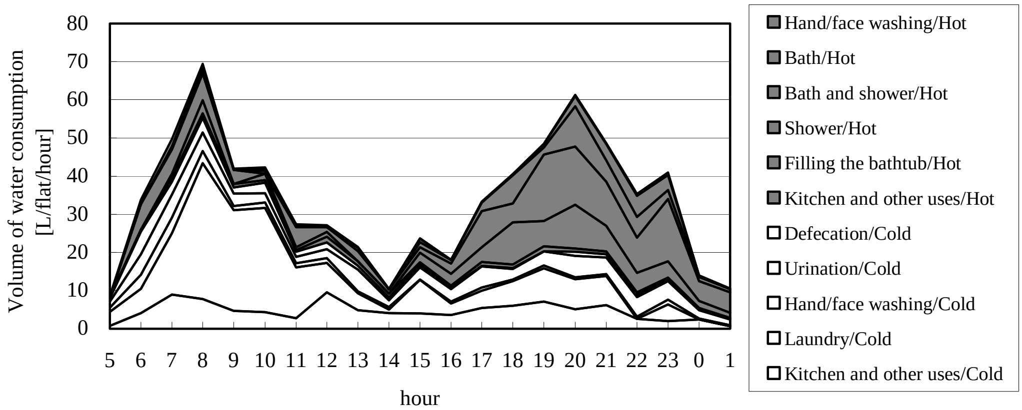


Figure 3 – Hourly consumption volume of cold and hot water in each fixture usage

Table 2 – Daily and hourly consumption volume of cold and hot water in each fixture usage

			Water consumption per flat per day [L/flat/day]	Water consumption per flat and per hour: Average [L/flat/hour]	Value of peak hour [L/flat/hour]	Peak time-zone	Peak ratio
Volume of consumption in each fixture	Defecation	Cold	28.1	1.3	6.0	6	4.46
	Urination	Cold	77.1	3.7	6.0	7	1.64
	Hand/face washing	Cold	24.4	1.2	4.1	7	3.53
		Hot	9.3	0.4	1.9	7	4.39
	Bath	Hot	20.6	1.0	5.6	22	5.67
	Bath and shower	Hot	42.7	2.0	10.6	20	5.22
	Shower	Hot	132.9	6.3	17.5	19	2.76
	Filling the bathtub	Hot	66.1	3.1	11.5	20	3.65
	Laundry	Cold	193.0	9.2	35.7	8	3.88
	Kitchen and other uses	Cold	96.7	4.6	9.5	12	2.07
		Hot	16.3	0.8	1.5	12	1.91
Volume of cold water consumption			419.3	20.0	55.3	8	2.77
Volume of hot water consumption			287.9	13.7	41.2	20	3.00
Volume of total water consumption			707.2	33.7	69.4	8	2.06

Note : Peak time-zone; For example, the figure 6 means the time-zone of 6:00a.m.-7:00a.m..

In this paper, we show the results of calculation as an example of ten flats in scale.

Figure 3 shows the hourly volume of cold and hot water consumption in each fixture usage as the average values for one flat. The average values per day and per flat, and the average and peak values per hour and per flat are shown in Table 2 as the consumption loads of each fixture usage.

When these results are calculated by using the supplied temperature of cold and hot water mentioned above, the hourly supplied volume of cold and hot water, and the statistic values are shown in Figure 4, and Table 3 respectively.

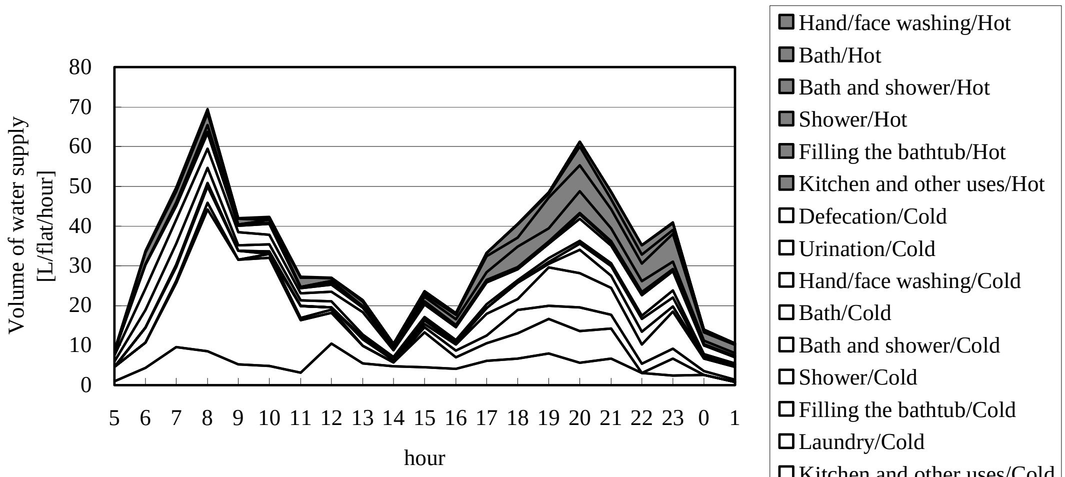


Figure 4 – Hourly supplied volume of cold and hot water in each fixture usage

Table 3 – Daily and hourly supplied volume of cold and hot water in each fixture usage

			Water supply per flat per day [L/flat/day]	Water supply per flat per hour			
				Average [L/flat/hour]	Value of peak hour [L/flat/hour]	Peak time-zone	Peak ratio
Volume of water supply in each fixture	Defecation	Cold	28.1	1.3	6.0	6	4.46
	Urination	Cold	77.1	3.7	6.0	7	1.64
	Hand/face washing	Cold	30.4	1.4	5.4	7	3.70
		Hot	3.2	0.2	0.7	7	4.37
	Bath	Cold	12.0	0.6	3.3	22	5.73
		Hot	8.6	0.4	2.3	22	5.60
	Bath and shower	Cold	24.1	1.1	5.9	20	5.14
		Hot	18.7	0.9	4.7	20	5.33
	Shower	Cold	75.4	3.6	9.7	19	2.69
		Hot	57.5	2.7	7.8	19	2.85
	Filling the bathtub	Cold	34.4	1.6	6.0	20	3.65
		Hot	31.7	1.5	5.5	20	3.65
	Laundry	Cold	193.0	9.2	35.7	8	3.88
	Kitchen and other uses	Cold	107.2	5.1	10.5	12	2.05
		Hot	5.9	0.3	0.5	12	1.88
Volume of cold water supply			581.7	27.7	63.4	8	2.29
Volume of hot water supply			125.5	6.0	18.4	20	3.07
Volume of total water supply			707.2	33.7	69.4	8	2.06

From these results, it was clarified as follows:

The peak consumption load for the total of cold and hot water in the morning occurs on the time-zone of 8:00 a.m. – 9:00 a.m. About 50 %, and about 20 % of total consumption in the time-zone account for the usage of cold water in laundry, and the usage of hot water in taking bath respectively. In this case, about 90 % of the total volume is supplied with cold water. After the time of 5:00 p. ., the hot water consumption in taking bath accounts for about 60 % - 70 % of the hourly total volume. The peak load for the total of cold and hot water consumption in the afternoon occurs on the time-zone of 8:00 p.m. – 9:00 p.m. About 65 % of the total consumption accounts for the usage of hot water in taking bath. The ratio of the supplied hot water volume at 60 against the total volume of cold and hot water is about 30 %. The highest ratio of hot water consumption against the total consumption volume appears on the time-zone of 10:00 p.m. – 11:00 p.m. because of the usage in taking bath.

The volumes of peak hour against the average volumes per hour are high ratios in the usage of “Defecation” “Bath” and “Bath and shower”, because the frequencies in these usage concentrate on the limited time-zone. The peak ratios of cold water, hot water and total consumption load have the values between 2.00 and 3.00, and have lower ratios in order to the larger volumes of water consumption.

As an example of ten flats of apartment houses, Table 4 shows the instantaneous average and maximum flow rates, and the instantaneous flow rates in each failure factor from 0.1 % to 50.0 %. The simulation was carried out at one second interval. Therefore, the values in each fixture usage shown in Table 4 were calculated as the moving average values of sixty seconds on the time-zones of peak hour in each fixture usage. The instantaneous maximum flow rates have similarity with the values suggested by Murakawa et al. in the previous studies [3][6].

Table 4 – Instantaneous maximum flow rates in each fixture’s peak time-zone

		Bath			Bath and shower			Shower			Filling the bathtub		
		Cold	Hot	Total	Cold	Hot	Total	Cold	Hot	Total	Cold	Hot	Total
Peak time-zone		22	22	22	20	20	20	19	19	19	20	20	20
Average [L/min]		4.34	3.07	7.36	4.97	4.04	8.94	5.38	4.35	9.66	7.22	6.83	13.87
Maximum [L/min]		19.20	16.80	27.00	16.80	19.80	28.99	27.00	25.20	45.00	21.00	19.20	33.60
Failure factor [L/min]	0.1%	19.20	16.80	27.00	16.80	19.80	28.20	27.00	25.20	45.00	21.00	19.20	33.60
	0.2%	18.00	16.80	27.00	16.80	17.42	26.95	27.00	25.20	45.00	21.00	19.20	33.60
	1.0%	15.00	12.60	21.60	14.40	13.80	23.40	18.00	18.00	36.08	19.80	17.40	30.60
	2.0%	13.80	10.98	18.03	13.80	10.80	19.77	16.74	15.60	27.00	15.60	15.60	28.20
	5.0%	10.34	8.40	15.60	10.20	10.20	17.40	12.60	11.40	21.00	15.00	14.40	25.20
	10.0%	8.40	6.00	13.20	9.00	7.20	15.60	10.80	9.60	18.00	12.92	12.60	22.20
	25.0%	6.00	4.20	10.20	6.60	5.40	11.40	7.20	5.90	11.40	9.60	9.60	16.20
	50.0%	4.05	2.40	6.90	4.80	3.60	8.40	4.20	3.60	8.40	7.08	6.60	13.80

		Defecation	Urination	Hand/face washing			Laundry	Kitchen and other uses			Total fixture usage		
		Cold	Cold	Cold	Hot	Total	Cold	Cold	Hot	Total	Cold	Hot	Total
Peak time-zone		6	7	7	7	7	8	12	12	12	8	20	8
Average [L/min]		5.37	5.01	3.84	1.12	4.32	15.35	7.18	1.30	7.53	13.93	5.42	15.26
Maximum [L/min]		25.20	33.00	27.48	11.16	27.48	81.00	42.03	15.00	42.03	81.00	30.42	82.40
Failure factor [L/min]	0.1%	25.20	28.20	25.53	8.88	25.53	70.50	39.60	11.25	39.60	69.74	30.00	73.24
	0.2%	21.40	25.68	25.20	7.67	25.20	60.00	38.40	7.42	38.40	65.34	30.00	70.80
	1.0%	19.47	19.52	19.04	6.24	19.04	47.40	28.80	5.94	28.80	51.60	19.80	54.00
	2.0%	18.43	16.24	16.36	5.13	16.50	41.40	27.00	5.40	27.00	45.36	17.90	47.68
	5.0%	14.40	13.75	13.20	3.60	13.20	33.60	21.60	4.20	21.60	36.66	13.80	38.40
	10.0%	11.40	10.92	10.08	2.60	10.39	29.40	17.56	3.15	17.60	30.60	11.26	31.87
	25.0%	7.80	7.42	5.13	1.56	6.00	19.82	11.31	1.80	11.61	19.80	7.60	21.06
	50.0%	4.29	3.74	2.24	0.70	2.86	12.60	4.81	0.77	5.40	11.40	4.20	12.58

4. Calculating results of water consumption loads by the flat unit

model

4.1 Suggestion about the flat unit model

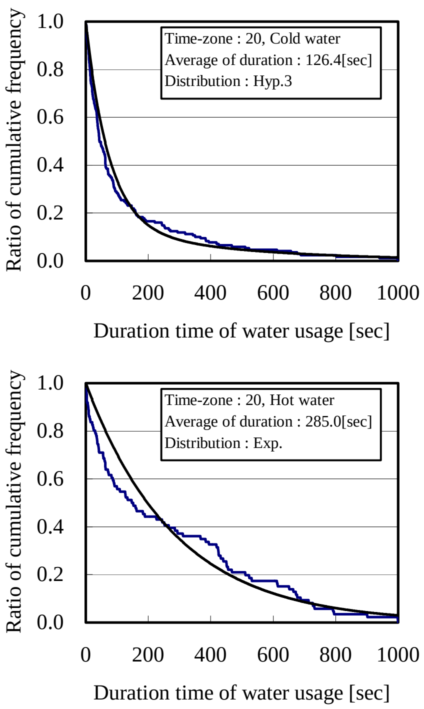
In case of the very complicated water supply pipe lines in buildings, for example commercial kitchen in restaurant, it is difficult to set up the calculating model for each fixture usage. In these cases, it is better to set up the unit model that will cover the whole fixtures usage of water as one group.

Therefore, we clarified the usefulness to make the unit model of grouping the several fixtures in the CIB-W62 Symposium last year.

In this paper, as the study continued, we analyze the calculating method of cold and hot water consumption simultaneously. In order to make the unit model, the calculating conditions of four people family size mentioned in the previous chapter are applied, and also the simulation for one flat with the same technique is carried out.

Based on the results of calculation in each fixture usage, we get the consumption loads of cold and hot water. We apply 40 unified as the utilized temperature of hot water consumption for flat unit. The distributions of duration time per frequency and the distributions of flow rate for cold and hot water usage are shown in Figure 5 and Figure 6 as an example of one flat on the time-zone of 8:00 p.m. – 9:00 p.m.

Based on the analyses for the frequency, the duration time, and the flow rate of cold and hot water usage, we made the hourly calculating models of cold and hot water consumption that are shown in Table 5. In this case, the supplied temperature of cold and hot water are set at 25 and 60 respectively. The utilized temperature of hot water is 40 .



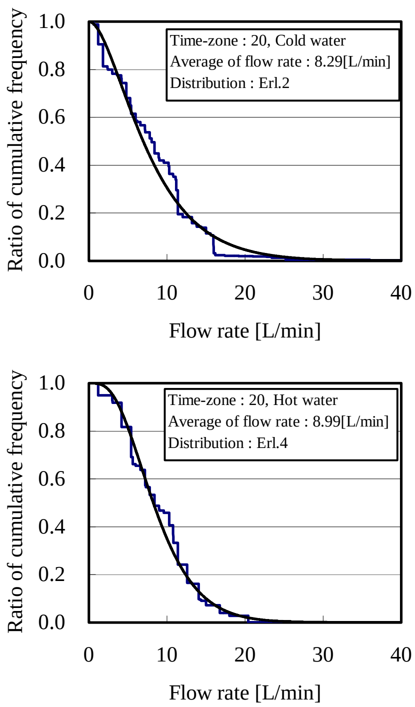


Table 5 – Calculating model of cold and hot water usage as the flat unit

Figure 5 – Distribution of the duration time   **Figure 6 – Distribution of the flow rate**

Cold water usage model						Hot water usage model					
hour	Frequency of water usage [frequency/flat/day]	Duration time [sec]		Flow rate [L/min]		hour	Frequency of water usage [frequency/flat/day]	Duration time [sec]		Flow rate [L/min]	
		Average	Distribution	Average	Distribution			Average	Distribution	Average	Distribution
05	0.54	74.6	Hyp.3	12.81	Erl.2	05	0.15	36.6	Hyp.2	4.98	Exp.
06	2.44	75.6	Hyp.3	9.33	Erl.3	06	0.67	74.3	Hyp.4	4.71	Erl.3
07	2.44	97.4	Hyp.4	9.91	Erl.2	07	0.78	152.8	Hyp.3	6.31	Erl.3
08	2.28	126.2	Hyp.3	12.42	Erl.3	08	0.67	132.7	Hyp.5	8.27	Erl.4
09	1.29	153.8	Hyp.2	12.47	Erl.5	09	0.34	54.0	Hyp.4	6.77	Erl.6
10	1.56	104.0	Hyp.4	12.78	Erl.6	10	0.39	65.2	Hyp.5	10.29	Erl.3
11	1.00	133.1	Hyp.4	10.96	Erl.2	11	0.28	148.8	Hyp.2	4.78	Erl.3
12	1.49	72.5	Hyp.3	10.54	Erl.4	12	0.44	71.5	Hyp.5	10.83	Erl.2
13	1.34	80.7	Hyp.5	10.66	Erl.2	13	0.34	146.9	Hyp.2	5.90	Erl.17
14	0.86	71.7	Hyp.3	11.03	Erl.4	14	0.21	63.6	Hyp.3	6.67	Erl.3
15	0.91	123.6	Hyp.5	11.36	Erl.3	15	0.20	112.2	Exp.	10.00	Erl.20
16	1.02	72.2	Hyp.4	9.84	Erl.4	16	0.23	190.4	Exp.	9.76	Erl.4
17	1.39	108.8	Hyp.5	6.90	Exp.	17	0.55	256.4	Exp.	8.49	Erl.13
18	1.06	115.0	Hyp.4	10.10	Erl.2	18	0.39	277.1	Exp.	9.41	Erl.4
19	1.61	113.2	Hyp.3	10.62	Erl.2	19	0.62	196.3	Exp.	9.36	Erl.4
20	1.69	126.4	Hyp.3	8.29	Erl.2	20	0.86	285.0	Exp.	8.99	Erl.4
21	1.41	155.4	Hyp.5	7.14	Erl.3	21	0.71	290.1	Hyp.2	7.23	Erl.2
22	1.48	104.2	Hyp.4	5.84	Exp.	22	0.72	274.8	Hyp.2	7.01	Erl.3
23	1.20	129.2	Hyp.4	7.40	Erl.2	23	0.81	255.9	Hyp.3	7.17	Erl.3
00	0.63	94.8	Hyp.5	5.68	Exp.	00	0.22	313.8	Hyp.2	7.07	Erl.3
01	[illegible]	[illegible]	[illegible]	7.27	Erl.2	01	0.13	358.2	Exp.	7.82	Erl.11

4.2 The results of calculation

As the simulated results, Figure 7 shows the cold and hot water consumption loads per day and per flat calculated by the flat unit model in comparison with the values calculated by each fixture usage model. The values shown in Figure 7 are plotted in order of measurements. Table 6 shows the statistic values estimated by the both models. When we compare the values calculated by each model, the maximum value by the flat unit model is smaller, and the minimum value by the flat unit model is larger than the values by each fixture usage model. Therefore, the standard deviation calculated by the flat unit model is smaller than that calculated by each fixture usage model. However, there is not so large difference between the average values per day.

The hourly average values calculated by the both models are shown in Figure 8. Also, the statistic values estimated by the both models are shown in Table 7. The hourly results of cold and hot water calculated by each model have similar values.

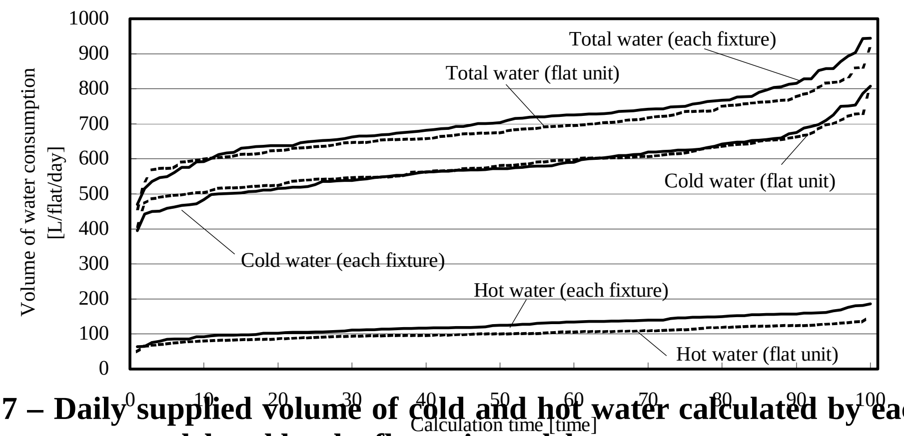


Figure 7 – Daily supplied volume of cold and hot water calculated by each fixture usage model and by the flat unit model

The instantaneous loads calculated by the both models are shown in Figure 9. The figures show the supplied volume of total and each of cold and hot water as examples of the time-zone of 8:00 a.m. – 9:00 a.m. and the time-zone of 8:00 p.m. – 9:00 p.m. The peak supplied volumes of cold and hot water occur on the time-zone mentioned above, respectively. The flow rates of total and cold water estimated in each failure factor have very similar values between each fixture usage model and the flat unit model. However, the values estimated for the supplied hot water are some differences between the two kinds of models. As for the difference, the small demands of hot water will be considered as one of reasons. The difference on the peak time-zone of 8:00 p.m. – 9:00 p.m. is smaller than that in the morning.

The instantaneous loads applied for the design of pipe size, tank and pump capacity, etc. will be estimated from the values on the hourly peak time-zone. Therefore, we suppose that it is possible to estimate the instantaneous maximum flow rates accurately from the values calculated in the time series trough a day by using the unit model as well as by using each fixture usage model.

Table 6 – Estimated daily supplied volume of cold and hot water

Estimated value [L/flat/day]	Calculated by each fixture			Calculated by flat unit		
	Total water	Cold water	Hot water	Total water	Cold water	Hot water
Average value	707.2	581.6	125.6	685.4	584.1	101.3
Standard deviation	89.3	78.1	26.4	75.5	65.1	17.7
maximum value	945.2	807.5	185.5	918.1	808.4	150.7
minimum value	469.8	394.1	63.3	457.5	408.0	49.5

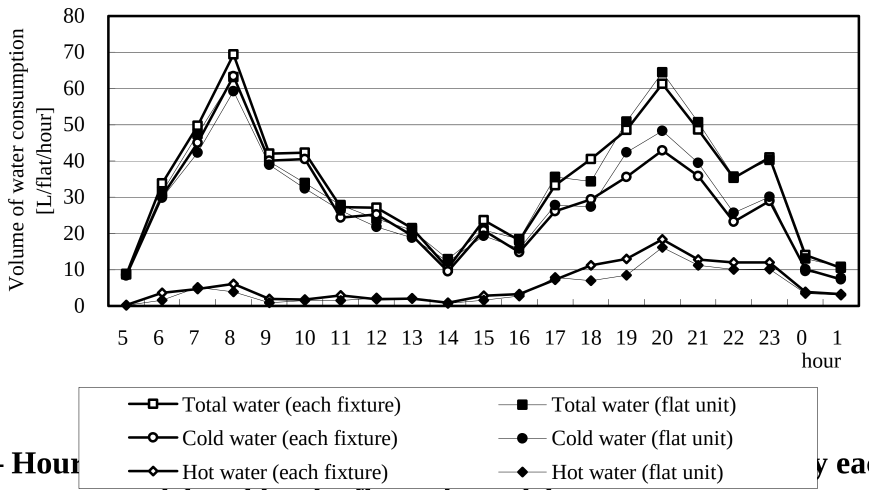
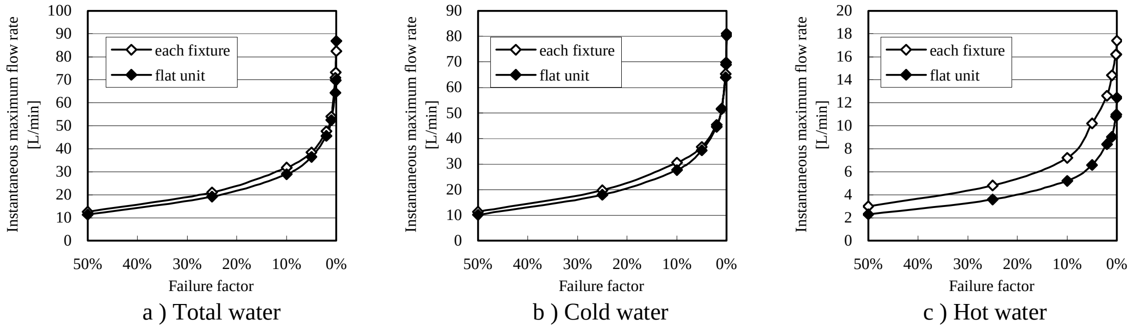


Figure 8 – Hour … y each fixture usage model and by the flat unit model

Table 7 – Estimated hourly supplied volume of cold and hot water

	Calculated by each fixture			Calculated by flat unit		
	Total water	Cold water	Hot water	Total water	Cold water	Hot water
Average value [L/flat/hour]	33.7	27.7	6.0	32.6	27.8	4.8
Value of peak hour [L/flat/hour]	69.4	63.4	18.4	64.4	59.3	16.2
Peak time-zone	8	8	20	20	8	20
Peak ratio	2.06	2.29	3.08	1.97	2.13	3.35

Time-zone of 8:00a.m. - 9:00a.m.



Time-zone of 8:00p.m. - 9:00p.m.

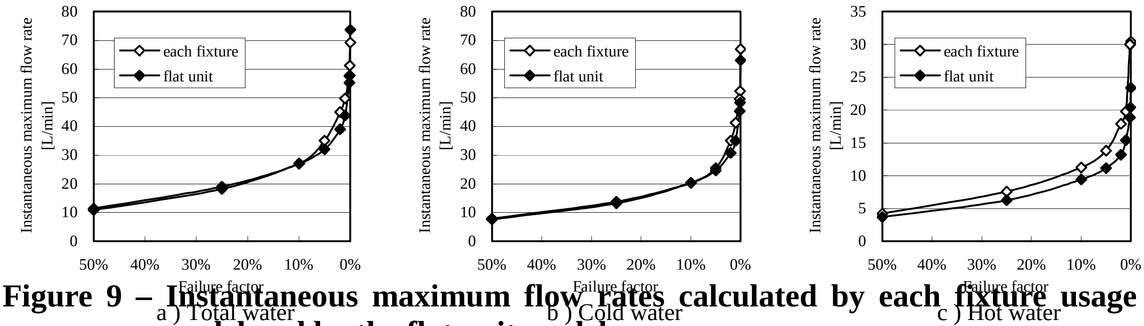


Figure 9 – Instantaneous maximum flow rates calculated by each fixture usage model and by the flat unit model

5 Conclusion

In this paper, the authors suggested the calculating methods of cold and hot water consumption loads by using the Monte Carlo Simulation technique. We simulated the cold and hot water usage of each fixture installed in apartment houses according to the occurrence of random numbers based on the distributions of water usage in each fixture. We analyzed the daily, hourly and instantaneous loads of cold and hot water in each fixture usage based on the model made by the data investigated in the apartment houses.

Also, we suggested another model called as the flat unit model instead of each fixture usage model mentioned above. The results estimated by the both models were compared. It was clarified that the flat unit model is useful and convenient to deal with the cold and hot water usage as a whole of the house.

In this paper, we showed the calculating method of cold and hot water consumption as an example of apartment houses. We will continue the development of calculating methods for the other types of buildings such as office buildings, commercial buildings, etc.

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Simplified Prediction Methods and Analysis of Water Temperature in Water Supply, Distribution Pipes and Purification Plants

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Abstract

Reducing energy consumption of the hot water supply system plays an important role in considering energy conservation in hospitals, residential buildings and hotels. Acquisition of water temperature data in water supply and distribution pipes in the region is essential to devising an energy conservation plan for the hot water supply system. Based on the statistical yearbook of the water works, we have analyzed water temperatures at 640 purification plants throughout Japan, and developed simplified prediction methods of water temperatures in distribution pipes. We further compared the predicted temperatures with actual temperatures of water in distribution pipes and tested the validity of the prediction methods.

Keywords

Hot water supply system, Water supply and distribution pipes, Purification plant, Water temperature, Prediction method

1 Introduction

In Japan energy consumption in the hot water supply system accounts for over 40% of the entire energy consumption in hospitals, 35% in residential buildings and 30% in hotels[1]. Reducing energy consumption of the hot water supply system plays an important role in considering energy conservation in these buildings. Energy consumed in the hot water supply system is equal to the amount of energy required to raise the water temperature in water supply pipes in the region up to the practical usage level, which is around 40 (℃). Acquisition of water temperature data in distribution pipes in the region, therefore, is essential to making energy conservation plans.

Japan stretches from north to south (28N to 46N in latitude), having great climatic variations from region to region. Rivers provide 70% of all water distribution, and the temperature of river water varies seasonally affected by microclimates of the regions. Water taken from rivers first travels to purification plants, and then to the water supply system in buildings through distribution pipes. We divided this water flow route from rivers to water supply systems into two sections; one from rivers to purification plants and the other from purification plants to water supply systems, and proposed methods for predicting water temperature in each section. We also looked at the correlation between air temperatures and water temperatures at purification plants in 9 cities, and devised regressions equations to extrapolate water temperatures from air temperatures[2-4].

In this study we have analyzed water temperatures of 640 purification plants throughout Japan based on the statistical yearbook of the water works, devised simplified prediction methods of water temperatures in distribution pipes and water supply pipes, and tested the validity of the prediction methods by comparing predicted temperatures with actual water temperatures.

2 Analysis of Water Temperature in Purification Plants

2.1 Outline of Analysis

Based on the statistical yearbook (April, 1999 ~ March, 2000)[5] of the water works, we picked up 640 purification plants where the temperatures of both raw water and purified water were measured at least 12 times a year. We have conducted the following analyses on 6 types of data: the highest annual temperatures, the lowest annual temperatures, and annual mean temperatures of raw and purified water.

1) Analysis of water temperatures at purification plants in Japan

Temperatures of raw water and purified water were measured and mean values of the differences between the two and standard deviation were calculated.

2) Analysis of water temperatures by region

Japan was divided into 9 regions. Temperatures of raw water and purified water were measured and mean values of the differences between the two and standard deviation were calculated for each region.

3) Analysis of water temperatures by climatic division

Japan was divided into 6 climatic divisions. Temperatures of raw water and purified water were measured and mean values of the differences between the two and standard deviation were calculated for each division.

4) Analysis of raw water by source type

Mean values and standard deviations of raw water temperature, purified water temperature and differences between the two were calculated for each raw water source type.

5) Analysis of influence of water storage time on water temp. at purification plants
31 purification plants were selected at random, and the correlation between the storage time and the rise of water temperature was studied.

6) Analysis of water temperatures at purification plants in relation to climatic divisions and raw water source types
Climatic divisions and raw water source types were cross tabulated, and mean values and standard deviations were calculated for each climatic division and raw water source type.

2.2 Results and Examination

2.2.1 Water temperatures at purification plants in Japan
The table 1 shows that the mean difference between raw water temperatures and purified water temperature is 0.79 (℃), the difference in the lowest temperature 0.19 (℃), and in the highest temperature 1.29 (℃). This shows that temperatures rise while raw water is converted to purified water, and the difference in the water temperatures is higher in summer. However, actual differences vary with the mean standard deviation of 1.37(℃).

Table 1 Water temperatures in purification plans in Japan

	Temp. of raw water [℃]			Temp. of purified water[℃]		
Whole country	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
	7.51	14.95	22.92	7.71	15.74	24.21
	Difference temperature (temp. of purified water – temp. of taw water)[℃]					
N=640	T_{dl}	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
	0.19	2.89	0.79	1.37	1.29	2.86

n: the number of samples, T_{rl}: lowest temperature of raw water, T_{rm}: mean temperature of raw water, T_{rh}: highest temperature of raw water, T_{pl}: lowest temperature of purified water, T_{pm}: mean temperature of purified water, T_{ph}: highest temperature of purified water, T_{dl}: difference (= T_{pl} - T_{rl}), T_{dls}: standard deviation of T_{dl}, T_{dm}: difference (= T_{pm} - T_{rm}), T_{dms}: standard deviation of T_{ad}, T_{dh}: difference of (= T_{ph} - T_{rh}), T_{hds}: standard deviation of T_{dh}

2.2.2 Water temperatures at purification plant by region
The table 2 shows that the temperatures of both raw water and purified water are higher in the south than in the north. The mean temperature rises vary in the region (0.43 ~ 1.05℃); the temperature rise is small in heavily populated areas, and it is large in the cold regions such as Hokkaido and Tohoku, and in the warm regions such as Kyushu and Okinawa. The standard deviations, however, vary greatly (0.94 ~ 1.81℃).

2.2.3 Water temperatures at purification plants by climatic division
As with the regional changes in water temperatures at purification plants, temperatures of both raw and purified water are also higher in the southern regions (Table 3). The mean temperature rises range from 0.60 ~ 1.20℃, showing variations among climatic divisions. The temperature rises are smaller in regions with a large population, and greater in cold regions (I, II, III) and in warm regions (V, VI). This tendency also resembles the regional changes in water temperatures at purification plants. But again the standard deviations are large and vary greatly (1.01 ~ 1.71℃).

Table 2 Water temperatures in purification plans by region

Hokkaido	Trl	Trm	Trh	Tpl	Tpm	Tph
	1.75	8.76	18.70	2.57	9.69	19.59
n=45	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
	0.82	1.46	0.93	1.51	0.90	2.82
Tohoku	Trl	Trm	Trh	Tpl	Tpm	Tph
district	4.89	12.24	21.00	5.40	13.25	22.38
	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
n=115	0.51	2.80	1.02	1.81	1.38	3.26
Kanto	Trl	Trm	Trh	Tpl	Tpm	Tph
district	9.14	16.10	23.52	9.23	16.75	24.87
	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
n=120	0.10	2.88	0.65	1.32	1.35	2.77
Hokuriku-	Trl	Trm	Trh	Tpl	Tpm	Tph
koshinetsu	5.61	12.89	21.07	4.69	13.94	23.81
district	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
n=55	-0.92	3.92	1.05	1.43	2.73	4.00
Tokai	Trl	Trm	Trh	Tpl	Tpm	Tph
district	10.14	16.42	22.78	9.27	17.08	24.75
	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
n=42	-0.87	3.66	0.66	1.54	1.97	2.78
Kinki	Trl	Trm	Trh	Tpl	Tpm	Tph
district	9.18	16.88	24.34	9.37	17.31	25.02
	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
n=96	0.20	3.09	0.43	0.94	0.68	2.33
Chugoku-	Trl	Trm	Trh	Tpl	Tpm	Tph
Shikoku	8.39	16.14	24.14	8.43	16.81	25.20
district	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
n=75	0.04	2.39	0.67	0.99	1.06	2.16
Kyushu	Trl	Trm	Trh	Tpl	Tpm	Tph
district	8.55	17.12	25.17	9.50	18.14	26.11
	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
n=87	0.95	2.26	1.02	1.19	0.94	2.44
Okinawa	Trl	Trm	Trh	Tpl	Tpm	Tph
	18.00	23.98	28.48	17.58	24.96	29.98
	Tdl	Tdls	Tdm	Tdms	Tdh	Tdhs
n=5	-0.42	0.97	0.98	1.01	1.50	1.87

2.2.4 Water temperatures at purification plants by water source type

From the table 4 it can be seen that the standard deviations for mean water temperature differences are also large and vary greatly. The highest raw and purified water temperatures at purification plants where raw water is taken from wells (both shallow and deep) and springs are lower than those of other types of water, and the lowest temperatures are higher. The differences in the lowest temperature (2.69~ 3.11 ℃) and in the highest temperature (-2.70~ -1.74 ℃) are very large. This seems to indicate that underground raw water, which more or less remained at the same temperature throughout the year, was affected by air temperature as it moved through purification facilities and its temperature either rose or dropped.

2.2.5 Influence of storage period on water temperature at purification plants

Figure 1 illustrates that water temperature tends to rise as the water storage period gets longer. This seems to be caused by the longer exposure to air and rays of the sun associated with the longer storage time. However, there is a considerable fluctuation, and the correlation by regression analysis is low with the coefficient of determination

Table 3 Water temperature in purification plans by climatic division

Division	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
I	1.75	8.76	18.70	2.57	9.69	19.59
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
N=45	0.82	1.46	0.93	1.51	0.90	2.82
Division	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
II	4.41	10.65	18.62	4.78	11.81	20.72
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
n=40	0.38	2.31	1.15	1.71	2.09	3.30
Division	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
III	6.37	13.69	21.75	6.42	14.69	23.58
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
n=190	0.05	3.32	1.00	1.65	1.82	3.35
Division	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
IV	8.98	16.68	24.43	9.12	17.29	25.42
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
n=347	0.14	2.87	0.60	1.11	0.99	2.51
Division	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
V	11.17	17.48	22.88	11.93	18.68	24.42
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
n=13	0.76	2.05	1.20	1.30	1.55	1.79
Division	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
VI	18.00	23.98	28.48	17.58	24.96	29.98
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
n=5	-0.42	0.97	0.98	1.01	1.50	1.87

Table 4 Water temperatures in purification plans by water source type

River	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
water	4.21	13.51	23.99	5.46	14.61	24.88
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
n=162	1.25	1.65	1.10	1.33	0.89	1.99
Discharge	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
water	3.73	12.95	23.43	4.94	13.94	23.59
from dam	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
N=23	1.20	1.41	0.99	1.12	0.16	1.37
Dam	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
water	6.35	14.90	23.83	7.00	15.55	24.29
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
N=46	0.65	1.25	0.65	0.99	0.47	2.00
Lake	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
water	5.56	16.44	27.93	6.43	16.80	27.43
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
N=45	-0.87	1.63	0.36	0.58	-0.49	1.11
Water of	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
shallow	11.59	16.21	21.08	9.59	16.81	23.77
well	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
N=45	-1.99	3.75	0.60	1.25	2.69	3.71
Water of	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
deep	14.34	16.71	18.71	11.64	16.83	21.82
well	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
N=57	-2.70	4.05	0.12	1.68	3.11	3.80
Riverbed	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
water	9.32	16.36	23.48	9.21	16.85	24.41
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
N=34	-0.11	1.62	0.49	0.86	0.93	1.93
Spring	T_{rl}	T_{rm}	T_{rh}	T_{pl}	T_{pm}	T_{ph}
water	11.01	12.35	13.76	9.28	12.78	16.61
	Tdl	T_{dls}	T_{dm}	T_{dms}	T_{dh}	T_{dhs}
N=8	-1.74	2.24	0.43	0.51	2.83	2.23

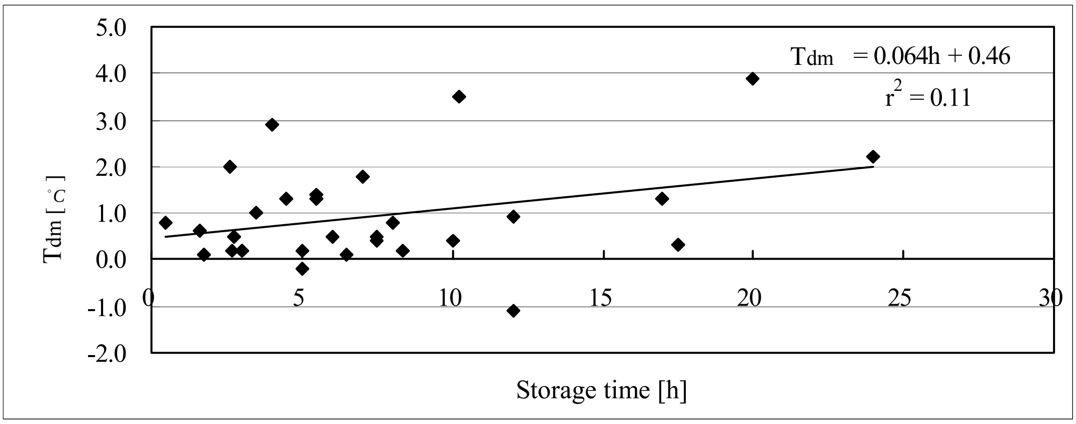

Figure 1 Relationship between mean difference temperature and storage time

Table 5 Cross tabulated mean temperatures (T_{pm}) by water source type and climatic division

Climatic Division	River water and discharge water from dam			Dam water and lake water			Groundwater (well, riverbed, artesian water)			Total		
	n	Mean	sd	n	mean	sd	n	mean	sd	n	mean	Sd
I	26	9.66	0.80	5	9.56	0.26	5	9.12	1.42	36	9.57	0.85
II	16	11.64	1.64	1	15.20	-	11	12.91	1.99	28	12.26	1.92
III	84	14.10	1.89	14	15.39	1.80	53	15.88	2.18	151	14.85	2.15
IV	82	16.67	1.56	41	16.55	1.44	96	17.70	1.09	219	17.10	1.45
V	7	18.63	1.35	0	-	-	6	18.73	1.50	13	18.68	1.36
VI	0	-	-	1	27.00	-	2	23.95	0.35	3	24.97	1.78
Total	215	14.51	2.92	62	15.87	2.78	173	16.70	2.56	450	15.54	2.94

Table 6 Cross tabulated of highest temperatures (T_{ph}) by water source type and climatic division

Climatic Division	River water and discharge water from dam			Dam water and lake water			Groundwater (well, riverbed, artesian water)			Total		
	n	mean	sd	n	mean	sd	n	mean	sd	n	mean	Sd
I	26	20.32	2.62	5	20.42	1.56	5	14.88	4.83	36	19.58	3.39
II	16	24.53	3.90	1	23.50	-	11	16.84	4.23	28	21.47	5.43
III	84	24.43	3.29	14	26.16	3.09	53	21.88	3.21	151	23.69	3.53
IV	82	26.57	2.45	41	25.23	2.28	96	23.84	2.95	219	25.12	2.92
V	7	25.29	2.49	0	-	-	6	23.42	1.86	13	24.42	2.34
VI	0	-	-	1	30.00	-	2	28.95	0.64	3	29.30	0.75
Total	215	24.78	3.49	62	25.10	2.85	173	22.58	3.87	450	23.98	3.73

Table 7 Cross tabulated of lowest temperatures (T_{pl}) by water source type and climatic division

Climatic division	River water and discharge water from dam			Dam water and lake water			Groundwater (well, riverbed, artesian water)			Total		
	n	mean	sd	n	mean	sd	n	mean	sd	n	mean	Sd
I	26	2.14	1.69	5	2.32	0.76	5	5.00	1.19	36	2.56	1.80
II	16	2.49	1.11	1	6.50	-	11	9.05	3.27	28	5.21	3.89
III	84	4.83	2.24	14	5.43	1.00	53	9.73	4.40	151	6.61	3.86
IV	82	6.75	1.93	41	7.70	1.60	96	11.39	3.25	219	8.96	3.35
V	7	11.44	1.74	0	-	-	6	12.50	3.49	13	11.93	2.63
VI	0	-	-	1	15.00	-	2	20.70	1.70	3	18.80	3.50
Total	215	5.28	2.79	62	6.85	2.38	173	10.69	3.96	450	7.58	4.10

(r^2) of 0.11.

2.2.6 Water temperature at purification plants by climatic division and water source type
As is the case with water temperatures at purification plants by climatic division, Tables 5 ~ 7 indicate that water temperatures rise as the climatic division moves from I to VI. Also similarly to water temperatures at purification plants by water source type, the highest temperature of underground water (well, riverbed, spring) is lower than those of other types of water and the lowest temperature is higher. The standard deviations derived from cross tabulation for each climatic division and water source type are also large and vary considerably. If the climatic division in which a purification plant is located and water source type processed at the plant are known, however, an approximate temperature of water purified at the plant can be deduced. This is expected to be an important index for developing a simplified method of predicting water temperature in distribution pipes.

3 Prediction of Water Temperature by Simplified Methods

3.1 Outline of Calculation

Since it is assumed that the distribution water temperature from a purification plant to a building varies little, the temperature of water supply and distribution pipes can be considered approximately the same as that of purified water. Consequently, the temperature of purified water at a purification plant can be substituted as the distribution water temperature in predicting its temperature. We have proposed two methods (Simplified Prediction Method I and II) of predicting tap water temperature based on the statistical yearbook of the water works, and tested their validity.
The highest, the lowest, and the mean temperatures at purification plants throughout Japan have been analyzed in relation to climatic divisions and water types, and tabulated in Tables from 5 to 7. In addition, the water temperatures in the service pipe from the distribution pipe to the water supply pipes were measured at the Liberty Tower on Meiji University campus in Tokyo, and to compare the predicted temperatures with the actual measurements, the values were analyzed using an equation, $\Sigma|T_p - T_m|$, where T_p is a predicted temperature and T_m is a measured temperature.

3.1.1 Simplified Prediction Method I
There is a strong correlation between air temperature and purified water temperature. Therefore the simplified prediction method I has been devised based on air temperature as described below. The prediction equation based on the assumption is shown as follows:

Case of $\theta(n) - a \geq 0$

$$T(n) = (\theta(n) - a) \times \frac{(b - a)}{(\theta_{max} - a)} + a \quad (1)$$

Case of $\theta(n) - a < 0$

$$T(n) = (\theta(n) - a) \times \frac{(c - a)}{(\theta_{min} - a)} + a \quad (2)$$

Where

n: the number of days counted from January 1, T(n): predicted water temperature in distribution pipes when the number of days is n [℃], θ(n): standard air temperature when the number of days is n [℃], θmax: highest standard air temperature [℃], θmin: lowest standard air temperature [℃], **a**: mean water temperature in distribution pipes obtained from Table 5 [℃], **b**: highest water temperature in distribution pipes obtained from Table 6 [℃], **c**: lowest water temperature in distribution pipes obtained from Table 7 [℃]

The equation (1), (2) were confirmed by the following process.
1) Daily mean air temperatures for 13 years in the region where target purification plants are located are averaged out to obtain the standard data.
2) Based on the climatic division and water source type, the highest, the lowest and the mean temperatures of purified water are obtained from Tables 5 ~ 7, and **a**, **b**, **c** in the prediction equations are determined.
3) **a** is subtracted from θ(n) and convert it into a variation pattern with 0 at its center.
4) Yearly highest and lowest temperatures of (θ(n) −**a**) are compared in terms of **b**−**a**, **c**−**a**, and their ratios are multiplied by (θ(n) −**a**).
5) Finally **a** is added again to convert to the original variation pattern, and it is used as the prediction equation for distribution water temperature.

3.1.2 Simplified Prediction Method II

Water temperatures vary considerably throughout the year, but they resemble a COS curve when they are simplified. Therefore in Method II the following procedures are adopted to predict the temperature of purified water. The prediction equation based on the assumption is shown as follows:

$$T(n) = a + \frac{1}{2}(b-c)\cos\left\{(n-n_{max})\frac{2\pi}{365}\right\} \tag{3}$$

The equation (3) was confirmed by the following process.
1) Based on the climatic division and water source type, the highest, the lowest and the mean temperatures of purified water are obtained from Tables 5 ~ 7, and **a**, **b**, **c** in the prediction equation are determined.
2) With **a** is center, **b** and **c** as maximum and minimum values, a COS curve is drawn, and it is used as the prediction equation for distribution water temperature.

3.2 Results of Calculation and Consideration

The water distributed to the Liberty Tower is purified at Asaka water purification plant on Saitama prefecture next to Tokyo located in the climatic division IV, and its water source type is surface water. Therefore, by looking at Tables 5 ~ 7, mean, highest, and lowest of water temperature can be determined as 16.67℃, 26.57℃, 6.75℃ respectively. Mean air temperatures during 1990 ~ 2002 in Saitama city were obtained from AMEDAS (Automated Meteorological Data Acquisition System) data and used as the standard air temperature data. Figure 2 and 3 indicate actual measurements and predicted water temperatures obtained by the methods I and II. Mean absolute difference between the actual measurement and predicted temperature is shown in Table 8. From this table it can be seen that both actual measurements and predicted temperatures vary similarly with the exception of highest and lowest temperatures.

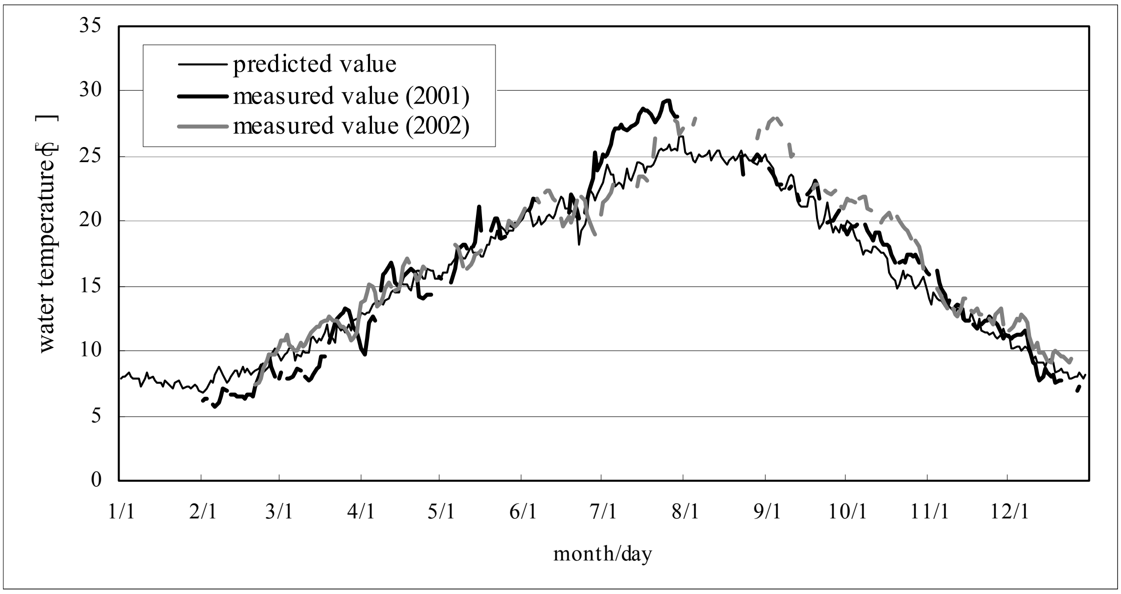

Figure 2 Comparison with Predicted water temperatures by the method I and actual measurements

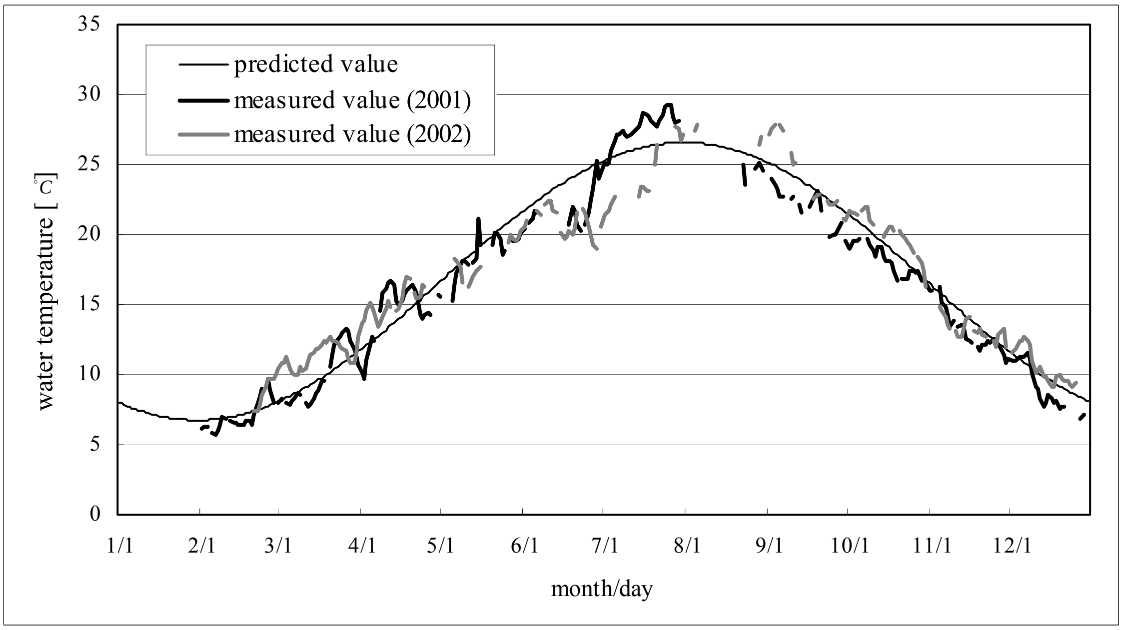

Figure 3 Comparison with Predicted water temperatures by the method II and actual measurements

Table 8 Mean absolute difference ($\Sigma|T_p - T_m|$) of predicted water temperatures by the model I and model II

Prediction model	2000 years	2001 years	2002 years
I	0.87	1.37	1.42
II	0.90	1.17	1.45

This discrepancy can be attributed to the fact that the summer in the year when actual measurements were made was hotter and the winter was colder than the year when the data for the statistical yearbook of the water works were collected. The overall accuracy of prediction, however, is considered within the allowance level with the mean absolute difference of Method I is below 1.42℃, and that of Method II, below 1.45℃.
Both prediction methods are highly simplified. The method I requires the standard air temperature data to be made from AMEDAS data near each purification plant. However, both methods can be used successfully to predict water temperature in distribution pipes throughout Japan, and are versatile in that they can even be applied to the prediction of water temperature in plants where water is collect from underground sources. The trouble is how to predict water temperature of a purification plant where water is a mixture of two different types of source i.e. a river and underground source. In this case, mean, highest and lowest water temperatures of the purification plant should be directly obtained from the statistical yearbook, and interpolated into **a**, **b**, **c** in the prediction equation.

4 Conclusion

In this study, we have collected water temperatures at purification plants throughout Japan based on the statistical yearbook, and analyzed how raw water temperature and purified water temperature vary in different climatic divisions or water sources and how much change in temperature occurred before and after water was purified. We have also developed simplified but versatile methods for predicting water temperatures in distribution pipes all over Japan, and test their validity. The results clearly show that water temperatures in distribution pipes can be predicted with an accuracy of 1.45℃ and below.
We have yet to determine if the present prediction model can be applied to other water distribution systems, and the improvement of prediction accuracy will be our main concern for the future.

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6 Presentation of Authors

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A study on predicting load of wastewater reclamation system

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Abstract

A fact-finding survey was conducted on the working status of sewage pumps at "Huis ten bosch", a theme park for a long term stay where hotels, amusement facilities, restaurants and the like are installed. Here a circulation system is adapted by treating drain (domestic wastewater including sanitary sewage) generated in the park with the Pressure Sewer System using sewage pumps.
Based on the result of fact-finding survey on the Pressure Sewer System using sewage pumps, the drainage load of each sump pit per time frame was estimated and the drainage load characteristics of various building applications (hotel, public lavatory, restaurant) are analyzed in this report. In addition, for the estimation method of the simultaneous operation unit quantity under the Pressure Sewer System, the appropriateness of the method utilizing the Poisson distribution was studied, and further a simplified method to estimate the simultaneous operation unit quantity was examined.

Keywords

Pressure Sewer System; Drainage load; Simultaneous operation quantity.

1 Outline of facilities and fact-finding survey

The "Huis ten bosch" consists of 150 buildings (excluding residences) on the land of 152 hectares where amusement facilities, shopping center/restaurants, museum, art gallery, hotel, residences and public facilities are installed of which total floor space counts for more than 210 thousand meters approximately. It can be said as an independent town accompanied with human living for 24 hours.
As a method to inflow the wastewater of this site into the sewage treatment plant, the Pressure Sewer System was employed because of many canals dug, the sewage treatment

plant located at a high ground, and the utility tunnel provided in the site and so on.
The fact-finding survey was conducted in two times, for 6 days from August 11 (Monday) to 16 (Saturday), 1997 and 8 days from August 12 (Sunday) to 19 (Sunday), 2001, presenting the operation record (starting/stopping times) of each pump as the result of this survey.

2 Drainage load characteristics by building application

2.1 Estimation method of drainage load

Assuming that the discharge flow rate of the sewage pump is constant, the daily drainage amount flowing to each sump pit was estimated by multiplying the discharge flow rate of the sewage pump with the pump operating time. In addition, the drainage load by time frame was estimated by the method shown in Table-1.

Table 1 - Estimation method of drainage load

The pump stop time zone
It supposes that the sump pit capacity is a taking advantage of value in the minimum operation time of the pump and the discharge flow rate of the sewage pump. The drainage of the quantity which is the same as the sump pit capacity flows in to the sump pit in the pump stop time zone. It supposes that the drainage flows in uniformly to the sump pit.
The pump operation time zone
It figures out the balance between the pump operation time and the minimum operation time. It supposes that the displacement during pump operation is a taking advantage of value in this time difference and the discharge flow rate of the sewage pump. It supposes that the drainage flows in uniformly to the sump pit.

Namely, first the drainage volume per time (for each 1 minute) from the initial pump operating time frame during the survey period to the final operation time frame was estimated, next the drainage amount at the same time was averaged, and last the load ratio per time frame was calculated.

In order to verify the appropriateness of the estimation method introduced here, the hourly drainage amount of all sump pits under the Pressure Sewer System of this park was calculated and totaled. And it was compared with the measured value of the drainage amount at the most downstream of the System as shown in Figure 1.

Although some difference is found between the calculated and measured values, the trend of the fluctuation by time frame is mostly agreed thus judging this estimation method as appropriate.

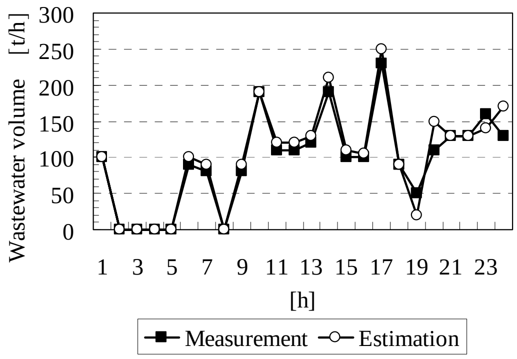

Figure 1 - The comparison of the hourly wastewater volume (at the most downstream of the System)

2.2 Hotel

Among the sump pits installed in the hotel, the load ratio per time frame of that receiving the effluent only from the guest room system was estimated. The result is shown in Figures-2 and -3.

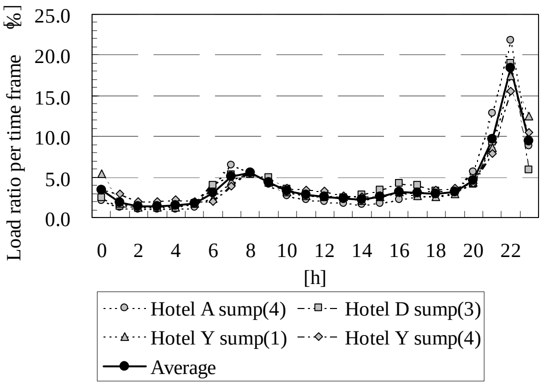

Figure 2 - Load ratio per time frame (Guest room system; 1997)

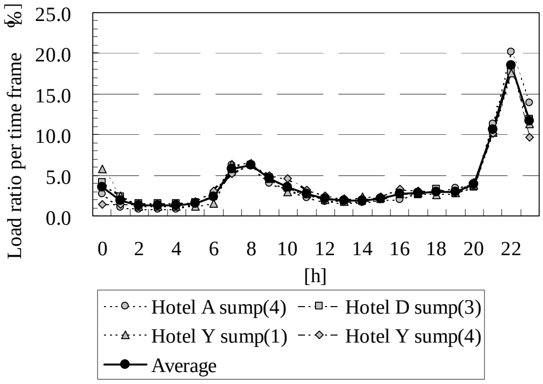

Figure 3 - Load ratio per time frame (Guest room system; 2001)

Similar load fluctuation was observed on these sump pits at four spots, and no significant difference by the year of survey was found. As the special character of the load fluctuation, the load concentrated in the level of 22:00 and one hour before and after it, and about 40% of the daily drainage amount generated in this time frame. Regarding to other time frames, about 20% generated within that from 7:00 to the level of 10:00 in the morning, and the remaining 20% generated within that from the daytime to the peak in the night time. As shown, the load concentrated after 21:00 when various events held in the facilities are finished. The trend of the load concentration in a short nighttime is remarkable when compared to that of general hotels.

Next, the relationship between the daily drainage amount and the number of the lodgers of the entire Hotel A during the second survey period is shown in Figure-4.

For the daily drainage amount, the result obtained by estimating the pump operation time from 15:00 on the day in question and that on the next day.

While the daily drainage amount represents the value including that from the hotel restaurant and that from the common space like the employee's facilities, but correlation is observed between the daily drainage amount and the number of lodgers, and the drainage amount per lodger counts for 220 ~ 260 L/Day.

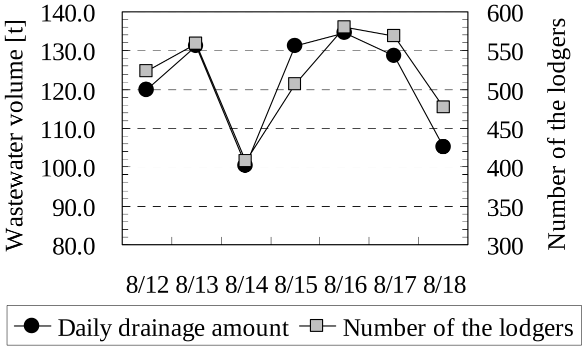

Figure 4 - Daily wastewater volume and Number of the lodgers (Hotel A, 2001)

Further relating to the drainage load of Hotel A, the load fluctuation per time of the non-guest room system was estimated based on the difference of the estimated load fluctuation per time between the guest room system and the system including the drainage load of the non-guest room system (In-hotel restaurant, employee's facility, common lavatory, etc.). And the result of the drainage load of the guest room system and the non-guest room system obtained by time is shown in Figure-5.

As shown, the drainage load of the non-guest room system marks the highest load ratio in the breakfast time frame from 8:00 to 10:00, and it tends to increase in the time frames of lunch and supper. The ratio of the drainage load of the guest room system to that of the non-guest room system is estimated as for 4 to 1.From these estimation results, it is assumed in Hotel A that the drainage amount from the guest room section counts for 200L/Day per lodger and the drainage load generated in the common space counts for 50L/Day per lodger.

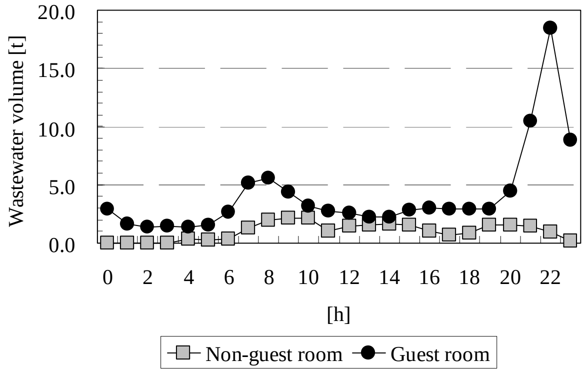

Figure 5 - Hourly wastewater volume (Guest room and non-guest room, Hotel A)

2.3 Public lavatories

Among the sump pits installed in this park, the load ratio per time frame was estimated on the sump pits for which the sewage of the public guest lavatories mainly inflows. The results are shown in Figures-6 and -7.

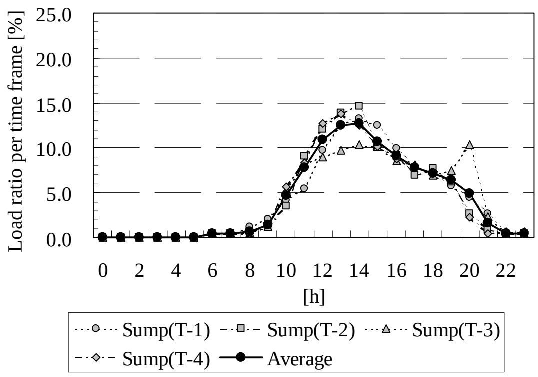

Figure 6 - Load ratio per time frame (Public lavatories; 1997)

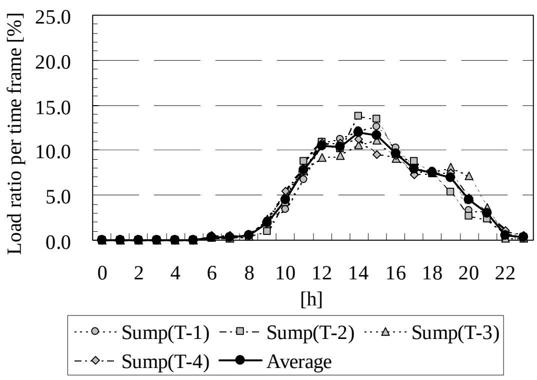

Figure 7 - Load ratio per time frame (Public lavatories; 2001)

Although a difference was found to some extent by the year of survey, almost same trend was observed. Here the peak load appears in the daytime from 12:00 to 16:00 without showing the trend to concentrate the load at a specific time.

Next among the sump pits installed in this park, the daily drainage amount of the sump pits for which the drain from the public lavatories for guests mainly inflows is shown in Figures-8.
The daily drainage amount of the public lavatory system showed serious fluctuation by day in the 1st survey period. While in the 2nd survey period, the fluctuation of the daily drainage amount decreased comparing to that in the first period. The drainage amount indicated a different value comparing to that of the 1st survey showing decreased and increased daily drainage amount by pit.
Tables-2 shows the weather condition of each year of survey.

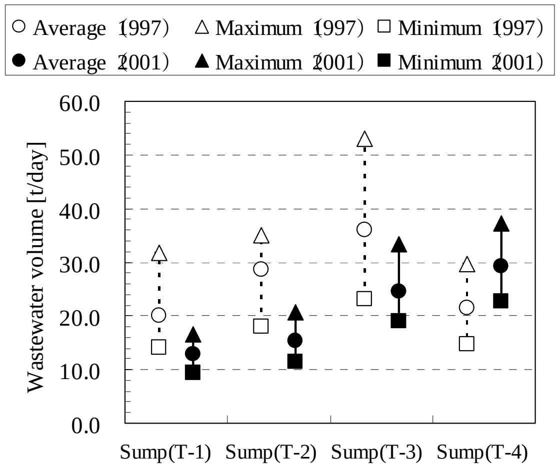

Figure 8 - Daily wastewater volume (Public lavatories)

Table 2- Weather condition

Date	1997/8/11	1997/8/12	1997/8/13	1997/8/14	1997/8/15	1997/8/16
Weather	Rain	Strong rain Later Cloudy	Cloudy Sometimes Rain	Cloudy Sometimes Rain	Clear	Clear
Precipitation mm	37.5	230.0	0.5	1.0	–	–
Temperature ℃	25.7	25.1	26.9	27.2	28.0	28.2

Date	2001/8/12	2001/8/13	2001/8/14	2001/8/15	2001/8/16	2001/8/17	2001/8/18	2001/8/19
Weather	Clear	Rain	Cloudy	Clear	Clear	Clear	Clear	Cloudy
Precipitation mm	–	43.0	–	–	–	–	–	–
Temperature ℃	27.9	27.9	28.0	30.0	30.2	29.6	29.3	30.1

The fluctuation of weather condition is not serious in the 2nd survey period than that in the 1st period. This may be considered as one of the factors causing the difference of the daily drainage amount in each period. In addition, as the daily drainage amount and the increasing/decreasing trend differ by sump pit, the change of frequency to use each public lavatory because of the different observation flow line of visitors due to a difference in holding the in-facility events may possibly be considered also. Therefore, the daily drainage amount of public lavatories is affected not only by change in the number of visitors due to weather conditions and the like. But as in the present case where the facilities are installed separately in several spots, the daily drainage amount of each public lavatory may seriously change due to weather conditions or the operation status of the facilities. However, no significant change is observed on the load ratio pattern by time frame.

2.4 Restaurants

Among the sump pits installed in this park, the load ratio per time frame on the sump pits for which the drain from restaurants mainly inflows was estimated and the result is shown in Figures -9 and -10. For the load ratio, a difference is found to some extent by the year of survey, however, almost similar pattern is shown per time frame by 3 relating sump pits.

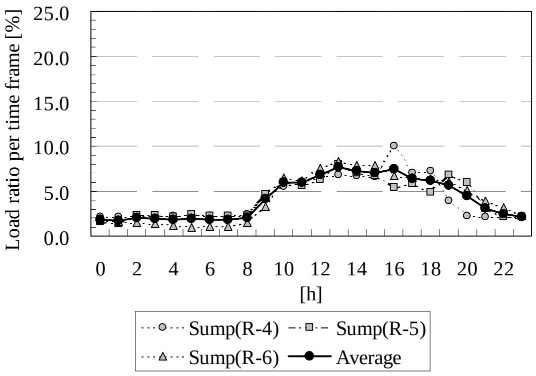

Figure 9 - Load ratio per time frame (Restaurants; 1997)

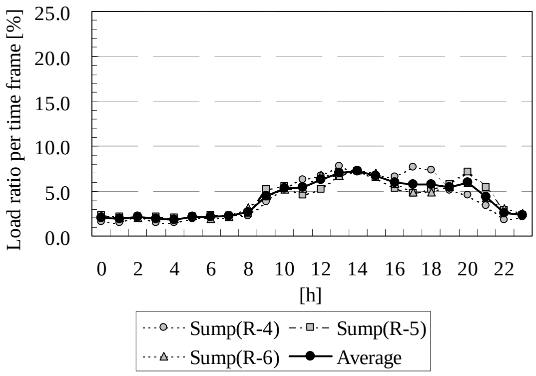

Figure 10 - Load ratio per time frame (Restaurants; 2001)

Next, the daily drainage amount of the restaurant system is shown in Figure-11. As same as the public lavatory system, different values are shown depending on the survey period, where the drainage amount was decreased at some sump pits while increased at some pits. As shown, the daily drainage amount of the restaurant system is not always affected by a change in the number of visitors by weather condition. But it may be assumed that the daily drainage amount is possibly be fluctuated by a change in the utilization status of each restaurant by weather condition or a change in the operation status of the park. However, no significant fluctuation is observed on the pattern of the load ratio by time frame.

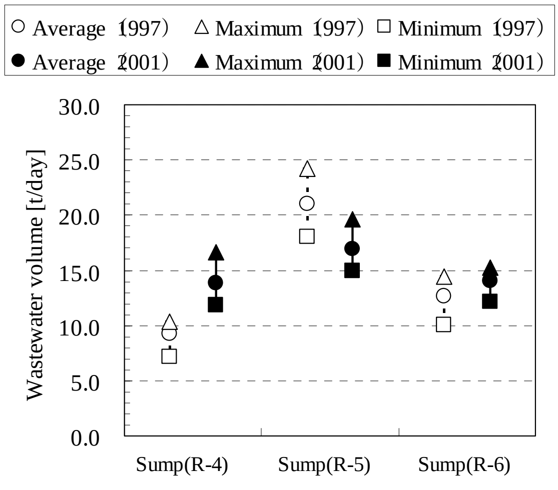

Figure 11 - Daily wastewater volume (Restaurants)

3 Estimation method for simultaneous operation unit quantity of sewage pumps

To estimate the simultaneous operation quantity of pumps under the Pressure Sewer System, the estimation method using binomial distribution is available. By applying this method, the appropriateness of the estimation method utilizing Poisson distribution is examined this time, and a simplified method to estimate the simultaneous operation quantity is studied.

3.1 Estimation by Poisson distribution

To estimate the number of a phenomenon occurred within a certain time, the probability function to estimate the probability of the number of a phenomenon actually occurs, making the mean value of a phenomenon occurred within a certain time a parameter, is utilized. Namely the Poisson distribution is used.

When making the mean simultaneous operation unit quantity of sewage pumps within a certain time the probability distribution of the simultaneous drain operation unit quantity can be expressed by the Poisson distribution of the following equation (1).

$$P_{\gamma}(\mu) = \frac{\mu^{\gamma}}{\gamma\,!}\, e^{-\mu} \qquad (1)$$

Pr(μ) : Probability distribution

μ : Mean simultaneous operation unit quantity

γ: Simultaneous operation quantity of pumps

The mean simultaneous operation unit quantity at a certain time represents the sum total of the operation probability of each sewage pump. And the operation probability of each sewage pump can be expressed as the ratio of the extended operation time of each sewage pump with the time interval of a certain time. Therefore, the mean simultaneous operating unit quantity of sewage pumps under the objective time interval can be expressed by the following equation (2).

$$\mu = \sum_{i=1}^{n} \frac{P_{f,i}}{T_0} \qquad (2)$$

$P_{f,i}$: Operation time of each sewage pump

T_0: Objective time interval

Under the circumstance, the authors examined whether the estimation by the Poisson distribution can be employed to estimate the simultaneous operation unit quantity of sewage pumps under the Pressure Sewer System.

Based on the information on pump operation obtained through the present survey(on 14 spots of the hotel system sump pit and 24 spot of other sump pits), our examination was conducted as follows. The probability distribution of simultaneous operation unit quantity estimated by the Poisson distribution with a parameter of the mean simultaneous operation unit quantity under various time intervals was compared to that of the actual simultaneous operation unit quantity in the corresponding time.

3.1.1 With the objective time interval of 24 hours

Taking all pumps surveyed this time into consideration, the probability distribution of the simultaneous operation unit quantity (hereinafter called Poisson distribution) estimated by the mean simultaneous operation unit quantity with a time interval of 24 hours was compared to that of the actual simultaneous operation unit quantity as shown in Figure-12. As shown, some difference is found between the actual probability distribution and the Poisson distribution. Meantime in order to conform to the Poisson distribution, a phenomenon shall be occurred at random. However, the drainage load will scarcely be generated in the midnight time frame except that from the hotel system, not conforming to the condition of the random pump operation.

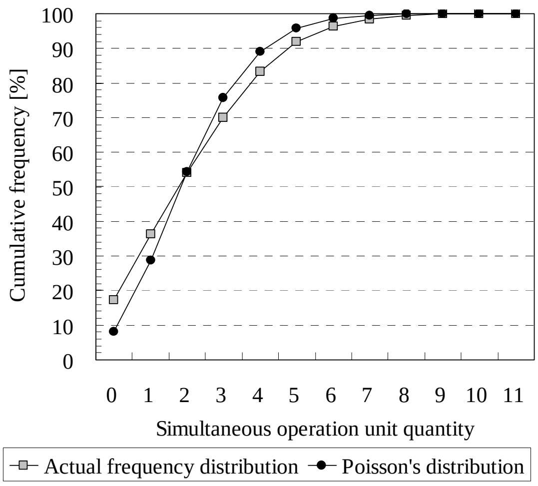

Figure 12 - Cumulative frequency distribution (Time interval of 24 hours)

3.1.2 With the objective time interval of 18 hours (6:00 ~ 24:00)

When taking the sewage pumps of all systems as an object, the actual probability distribution and the Poisson distribution will differ with a time interval of 24 hours. Because of this, the objective time frame was shortened to 18 hours (6:00 ~ 24:00) when drainage load may generate in all systems, and the similar comparison was conducted as shown in Figure-13. From the comparison result, the actual probability distribution and the Poisson distribution mostly agreed with the cumulative frequency of over 99%. Therefore, it is considered that the estimation by the Poisson distribution can be applied if the time range to calculate the mean simultaneous operation unit quantity is limited to the time frame when drainage load may generate.

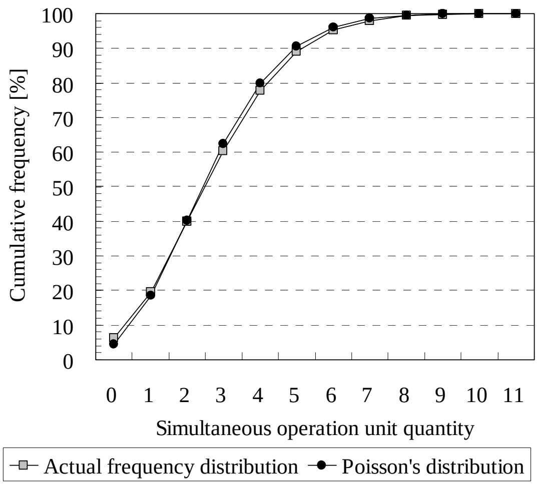

Figure 13 - Cumulative frequency distribution (Time interval of 18 hours 6:00 ~ 24:00)

3.2 Estimation method of maximum simultaneous operation unit quantity

In designing the piping diameter of the Pressure Sewer System, it is important to grasp the maximum simultaneous operation unit quantity and estimate the maximum drainage flow rate. Under the circumstance, the estimation method of simultaneous operation unit quantity for designing is examined by taking the result of the study described before into consideration.

3.2.1 Estimation method of mean simultaneous operation unit quantity

When building application differs and the time frame to generate drainage load differs by the drainage system, it is required to set the objective time interval when drainage load of all systems generates at random, and to estimate the pump operation time in this time frame. However, the estimation of the load ratio by time will presently be difficult to conduct at the planning stage.

Under the circumstance as above, a simplified method was examined. In this method, the mean pump operation probability in the drainage load generation time frame of each system was regarded as the pump operation ratio under the objective time interval. For the drainage system of this park, the objective time frame of drainage load generation was estimated as 24 hours for the hotel system and 18 hours (6:00 ~ 24:00) for other systems. In this case, 18 hours from 6:00 to 24:00 represent the objective time interval. For the mean simultaneous operation unit quantity under this time interval, 3.0 sets obtained here are employed.

The Poisson distribution estimated by the mean simultaneous operation unit quantity thus obtained and the actual probability distribution was compared in Figure-14.

In the simplified method, as an error increases in the mean simultaneous operation unit quantity more than that in Figure-13, a difference between the Poisson distribution and the actual probability distribution tends to increase. However, as they mostly agree for the cumulative frequency of over 95%, the estimation method based on the mean simultaneous operation unit quantity obtained by the simplified method can be considered to employ if it is limited to use to estimate the maximum simultaneous operation unit quantity.

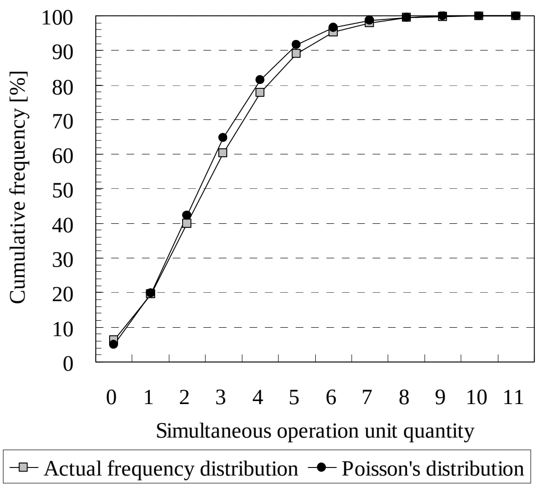

Figure 14 - Cumulative frequency distribution (Simplified method)

3.2.2 Maximum simultaneous operation unit quantity for designing

Through the above procedure to calculate the mean simultaneous operation unit quantity, the operation probability for any simultaneous operation unit quantity can be estimated by obtaining the Poisson distribution. This means to allow obtaining the simultaneous operation unit quantity below any set significance level. The simultaneous use exceeding the maximum simultaneous operation unit quantity for designing to some extent may be practiced by the judgment of a designer.

For the present system, the maximum simultaneous operation unit quantity for various significance levels estimated by the mean simultaneous operation unit quantity obtained by the simplified method was compared to the measured result in Table-3. When the maximum simultaneous operation unit quantity actually generated is to be grasped, it is necessary to set the significance level to 0.1. While the maximum simultaneous operation unit quantity usually generated is to be grasped, the estimation with the significance level of 1.0 may be employed without a problem.

Table 3 - Maximum simultaneous operation quantity of pumps

			Significance level		
			2.5	1.0	0.1
Maximum simultaneous operation unit quantity	Estimation		7 sets	8 sets	10 sets
	Measured result		11 sets		
Operation time	Simultaneous use exceeding the predicted maximum simultaneous operation unit quantity		173 min	53 min	6 min
	Number of the exceeding sets	+1	120 min	36 min	6 min
		+2	36 min	11 min	0 min
		+3	11 min	6 min	0 min
		+4	6 min	0 min	0 min
The exceeding time parcentage			1.50 %	0.46 %	0.05 %

In using this method in actual planning, the cumulative Poisson distribution is required to calculate for any simultaneous operation unit quantity. To simplify this calculation for the significance level previously set (2.5, 1.0 and 0.1 for this time), the relationship between any mean simultaneous operation unit quantity and the maximum simultaneous operation unit quantity is graphed. The result is shown in Figures-15. Through the utilization of this expression of relation, the simultaneous operation unit quantity for design against any level of significance can simply be obtained by setting the daily mean drainage amount and pump discharge volume of each drainage system and the objective time of load generation.

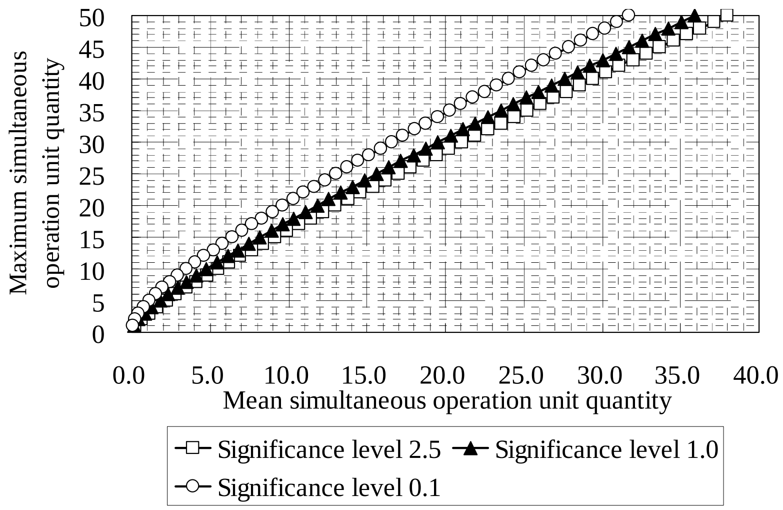

Figure 15 – Selection chart of maximum simultaneous operation unit quantity

4 Conclusion

In the Pressure Sewer System of this Park, the sewage pump installed on each sump pit was surveyed. The information obtained is given below.

(1) Drainage load characteristics by building application

The load ratio pattern by time frame shows no difference both for hotel, public lavatory, and restaurant systems but with mostly similar trend.
Correlation is found between the drainage volume and the number of lodgers. At Hotel A, it is estimated that the drainage volume per lodger from the guestroom counts for 200 L/Day, while that from the common space counts for 50 L/Day approximately.
The drainage volume by public lavatory and restaurant systems differs by the year of survey, and is assumed to be fluctuated significantly depending on a change in the weather conditions or the operation status of the facilities.

(2) Estimation method of simultaneously operating sewage pump quantity

The probability distribution of the simultaneous operation unit quantity of sewage pumps can be approximated by the Poisson distribution making the mean simultaneous operation unit quantity in the time frame when drainage load generates in all systems a parameter.
For the estimation method of the mean simultaneous operation unit quantity, the simplified method totaling the mean pump operation probability in the time frame when the drainage load of each system generates can be employed.
Therefore, the simultaneous operation unit quantity for designing against any significance level can be obtained by setting the daily mean drainage amount and pump discharge volume of each drainage system and the objective time frame of drainage load generation. However, when the pump discharge volume differs by each system, a method to estimate the drainage flow rate should be examined.

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Study of Prediction of Drainage Load Transition during Propagation through a Horizontal Drainpipe by Using Numerical Calculation

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Abstract

Flow rate transition of discharged water from a water closet during running down a drainage horizontal pipe was simulated by numerical calculation. This result enabled to obtain the transition of drainage load such as qd value, and showed this numerical calculation could be established as a method of predicting drainage load transition. Especially treating Manning's roughness factor n as a imitation variable improved the precision of the result. There are various drainage pipes' shapes and their effect to the flow were also considered, such as inlet shapes of the horizontal pipe or locations of bends, and now a wide use simulation program that can display real drainage system is aimed to develop.

Keywords

Simulation; average flow rate; drain characteristic; Manning's roughness factor

1 Introduction

In Japan, pipe diameter of drainage system is determined by the average flow rate, which is called qd value, as written in SHASE-S206-2000. Recently, Japanese buildings and houses are tend to be planned with ideas to arrange the rooms in the future to meet lifestyle of living people. When these buildings or houses are planned, length and shape of drainpipes become an important factor. Therefore, drainage load calculation method including load transition during propagation is in demand. Experimental examination is already carried out previously, but since there are amount of drainpipe conditions, the method using numerical calculation is able to use widely it is obviously and very useful. In this study, transition of discharged water from a water closet is simulated, and compared with the result which experimentally measured. To improve the precision of the calculation result, Manning's roughness factor n which appear in a basic equation is discussed to be given suitably. Here also examined the effect of the shapes of the drainpipes, such as the height from outlet of the water closet to the inlet of the horizontal pipe, and bends at each point of the horizontal pipe. These effect were also adopted into simulation result.

2 Method of Calculation and Experiments

2.1 Basic Equation

If the flow through the horizontal drainpipe can be written with equations for open channel pipeflow, they turn into energy equation(1) and continuity equation(2).

$$\left.\begin{aligned} \frac{du}{dt} &= -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\nabla^2 u && \text{(Parallel to axis)} \\ \frac{dw}{dt} &= -\frac{1}{\rho}\frac{\partial p}{\partial z} + \nu\nabla^2 w - g && \text{(Perpendicular to axis)} \end{aligned}\right\} \quad (1)$$

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \qquad (2)$$

Here, at energy equation(1), we assume that there is no pressure difference through a cross section of the flow. And take average of each term with the quantity of water passes through the cross section during a unit of time. Then we get next equation(3).

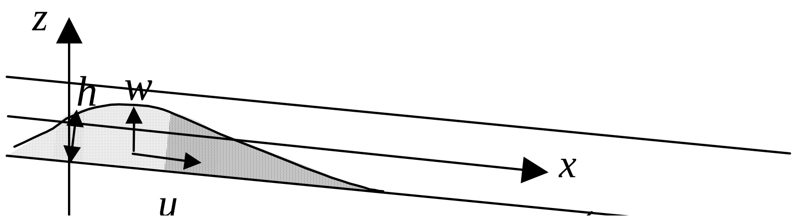
$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) = Ag(\sin\theta - \cos\theta\frac{\partial h}{\partial x} - \frac{n^2 Q|Q|}{A^2 R_h^{4/3}}) \qquad (3)$$

Notations are;

t Time[s]
x Length toward axis of a pipe[m]
z Vertical height[m]
g Acceleration due to gravity[m/s^2]
θ Pipe slope[rad]
h Flow depth perpendicular to the pipe axis[m]
n Manning's roughness factor[$s/m^{1/3}$]
R_h Hydraulic mean depth[m]
Q Flow Rate[m^3/s]
A Flow cross sectional area[m^2]
L Length of wet perimeter[m] $R_h = A/L$

Figure 1 shows simple models of this calculation.

A Side Lateral View of Horizontal Pipe



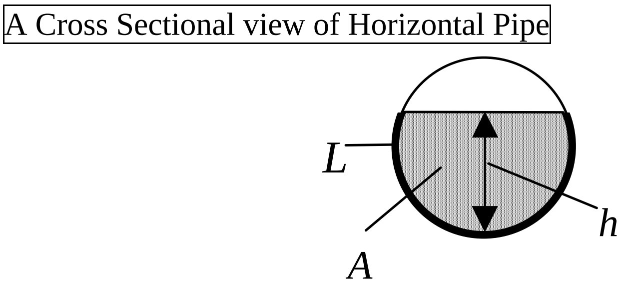


Figure 1 - simple models of the calculation

Equation(2) and (3) are numerically calculated and the flow is simulated. Two-step Lax-Wendroff's scheme is used as a numerical calculation scheme. As a initial conditions, there is a flow through the pipe which is small enough to ignore. As a boundary conditions, the calculation is started from 0.5m from the water closet, and the drain characteristic of the water closet which experimentally measured is used as an input information.

2.2 Experimental System

Experimental system is shown in Figure 2. Horizontal pipe length is changed step by step, goes like 0.5m, 1m, 2m, 5m, 10m. Drain characteristic is measured at the end of the horizontal pipe of each length, and a weighing machine is used for the measurement. A water closet used here is a 8 litter siphon water closet (CS80).

This water closet has a S-trap. From the outlet to inlet of the horizontal pipe there is a drop, which is represented by notation H, and at the inlet of the horizontal pipe there is a long radius elbow. Diameter of this drainage system is 75mm, and a slope of the horizontal pipe is 1/100.

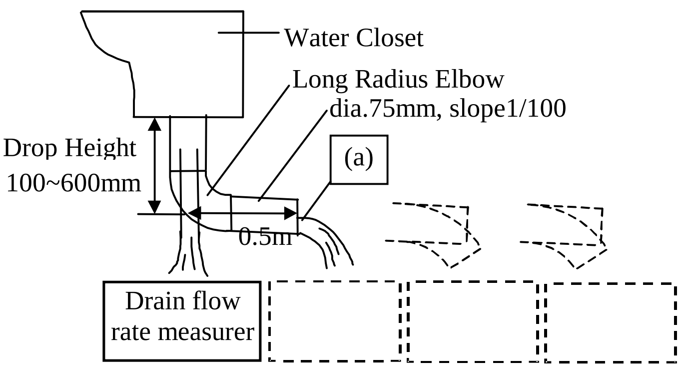


Figure 2 - Experimental System

3 Results and Considerations

3.1 Introduction of Revised-Manning's roughness factor n'

There appear in Manning's roughness factor n in the last term of equation (3).Usually, or in the past study, this n is defined as a constant value which only depends on material of the pipe. However, this Manning's roughness factor applies Manning's equation, and this Manning's equation fits the flow which is quite calm, steady and uniform. It is obvious that the flow of discharged water from water closet is no longer calm but violent, and contains a lot of turbulence, especially in a part near the water closet. Thus it could be said that using Manning's roughness factor n or Manning's equation here for the calculation of water closet drain flow is impossible. It is certain that using three dimensional turbulent flow theory leads to accurate simulation result, but this time I would like to propose the method to treat n as a variable imitatively, that means to introduce Revised-Manning's roughness factor n', and try to make the equation (3) usable at whole drainage system which means from the water closet to the lower reaches.

Flow of the discharged water from the water closet is measured experimentally, and checked the behavior of Revised-Manning's roughness factor n' according to parameters, that are each physical condition, such as velocity v or flow rate Q. This result is used as a reference of treating n as a variable imitatively. Here, Revised-Manning's roughness factor n' is plotted versus experimentally measured velocity v, as shown in Figure 3.

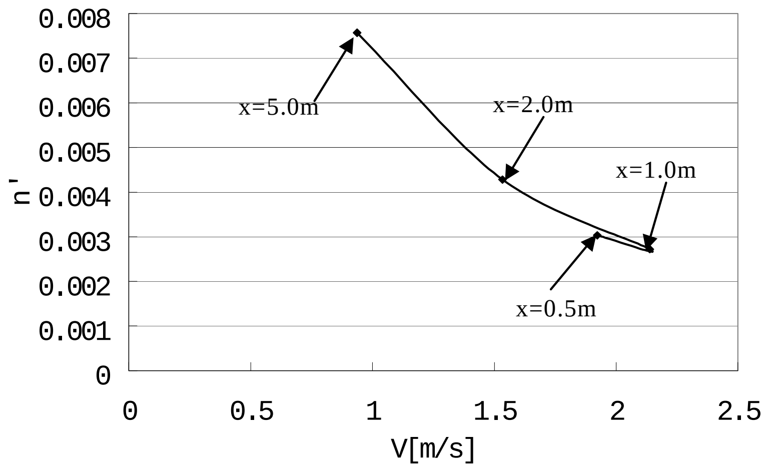


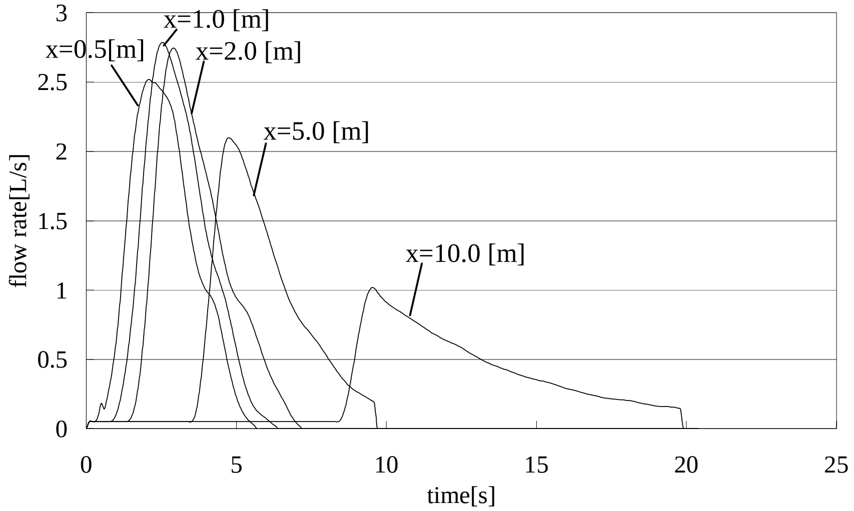
Figure 3 - Revised-Manning's roughness factor n' plotted versus velocity v

From this graph Revised-Manning's roughness factor n' seems to have relation to velocity v. Thus I assumed n' is a variable which is decided according to v, and used this variable as one of the input condition of the calculation. The result in this way is shown in Figure 4, which is compared with an experimental result.

The relationship of n' and v showed in Figure 3 is experimental result measured with a 8 liter siphon water closet (CS80). However, calculated flow whose input condition is discharged water from a different water closet and this n' and v relationship is used, is also confirmed that it shows close result to experimentally measured one. A dimension of Revised-Manning's roughness factor n' is quite complex so what is this variable according for may need to be discussed more. However I propose this way of treating

Revised-Manning's roughness factor n' as a variable imitatively as one of a useful method in numerical calculation of discharged water from water closet.

(Flow rate experimentally measured)



(Flow rate alculated, using variable n')

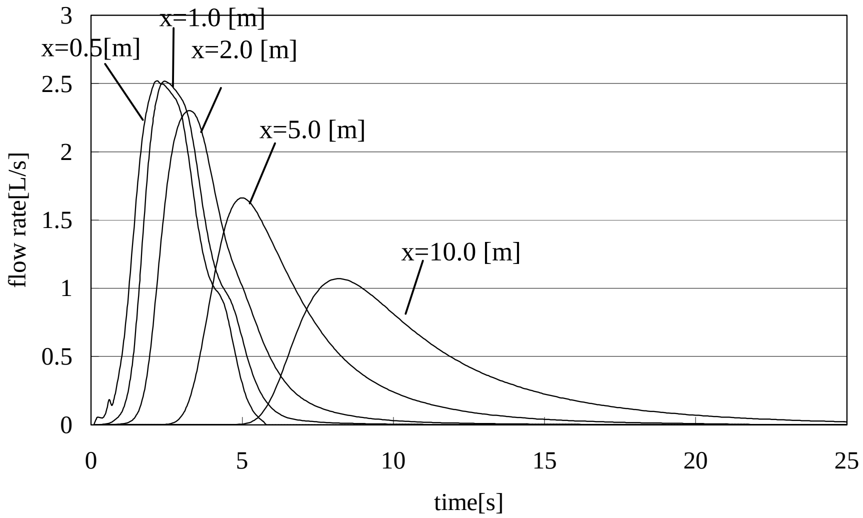
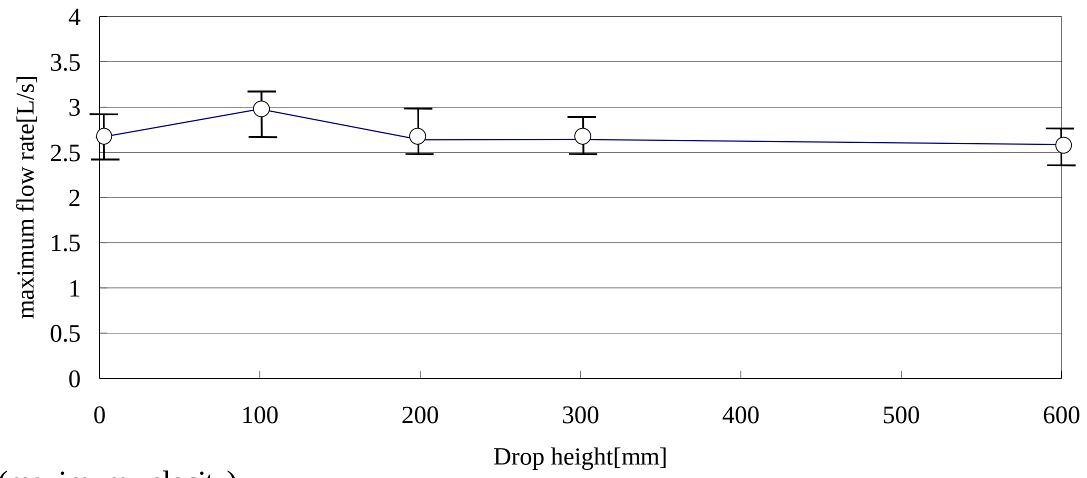


Figure 4 - Flow rate transition at each point of the horizontal pipe

3.2 Effect of drop height to the flow

From the outlet of water closet to inlet of the horizontal pipe there is a drop, which is represented by notation H. The drop height H in Figure 2 vary from 100mm to 600mm and the effect caused by this difference is examined. Drain characteristic is measured at 0.5m from inlet of the horizontal pipe, which is point (a) in Figure 2. In Figure 5, maximum flow rate and maximum velocity which is calculated from flow rate and water level are shown. Only the values when the drop height H=0mm are about the water discharged directly from the water closet, and there are no elbow or pipe connected to the water closet.

(maximum flow rate)



(maximum velocity)

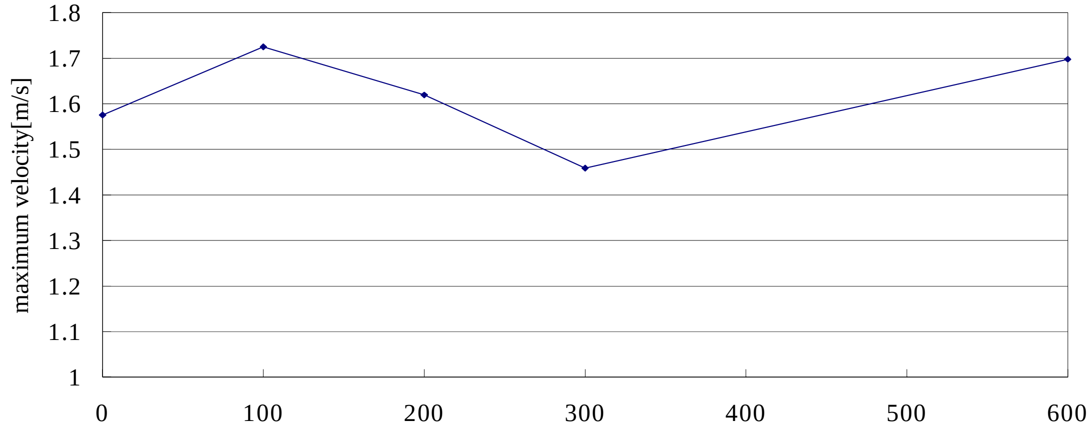


Figure 5 - Effect of drop height to maximum flow rate and velocity

All over measured result, data are almost in disorder, and it is difficult to say their tendency. Though in Figure 5 average of 20 times measured values and their standard deviations are shown. Ignoring values when the drop height H=100mm, the result can be said that flow rates are almost constant and have no relation to drop height. On the other hand, when it comes to flow velocity, the larger the drop height becomes, the higher the velocity seems to become. It may be because of increase of head that caused larger velocity.

When the drop height H=100mm, maximum flow rate takes high value. It could be said that when the drop height is small, the elbow comes very close to the outlet of the water closet, and its shape contribute to siphon cause in the water closet. This time I used siphon type water closet for the experiments, and the result may be different if wash-down water closet is used.

An elbow with different shape may be used at the inlet of the horizontal pipe, but in Japan mainly long radius elbow is recommended, and when the long radius elbow is used, the flow through the elbow is quite smooth and seemed there are very little resistance from the elbow inner wall to the flow. It can be considered that this is the reason why when the drop height is large enough, and the elbow has nothing to do with the water closet's siphon, the flow rate values are almost constant even when the drop height is changed. However if an elbow with shorter radius is used, it is possible that the result is different.

In simulation results mentioned after this, effects of drop height is not considered, but in case of that drop height is very large or small, or short radius elbow is in need to use, their effect ought to be considered, and input condition, drain characteristic should be revised suitably.

3.3 Effect of Bend at the Part of the Horizontal Pipe

As I mentioned above by using Figure 2, horizontal pipe length is changed step by step. And now, long radius elbow is connected to the outlet of the pipe to see the effect of bend to the flow. Figure 6 shows that with each pipe length, drain characteristic is measured at before the bend (point (b), means there is no long radius elbow at the end of the pipe), and behind the bend (point (c), means a long radius elbow is connected to the end of the pipe). The drop height is kept 300mm through this experiment.

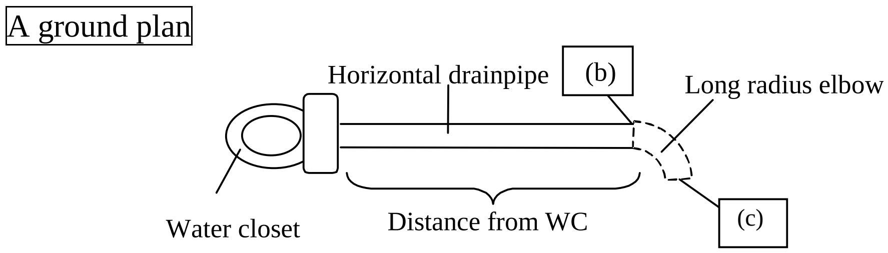


Figure 6 - Measuring point before and behind the bend

The difference between drain characteristic before the bend and behind the bend is shown in Table 1 and 2. About maximum flow rate (qmax value) is shown in Table 1, and about average flow rate (qd value) is shown in Table 2. Also, taking distance from the water closet to the bend as the horizontal axis, difference of qmax value before and behind the bend is plotted in Figure 7, and difference of qd value before and behind the bend is plotted in Figure 8.

Table 1 - Difference of qmax value before and behind the bend.

qmax value				
Distance from WC x[m]	**□ before the bend**	**□ behind the bend**	**Δ=□-□**	**□=100×Δ/□**
0.5	2.56	2.55	0.01	0.33
1.0	2.65	2.68	-0.03	-1.26
2.0	2.61	2.21	0.40	15.29
3.0	2.36	2.36	0.23	9.75
4.0	2.06	2.06	0.17	8.08
5.0	1.58	1.50	0.08	4.85

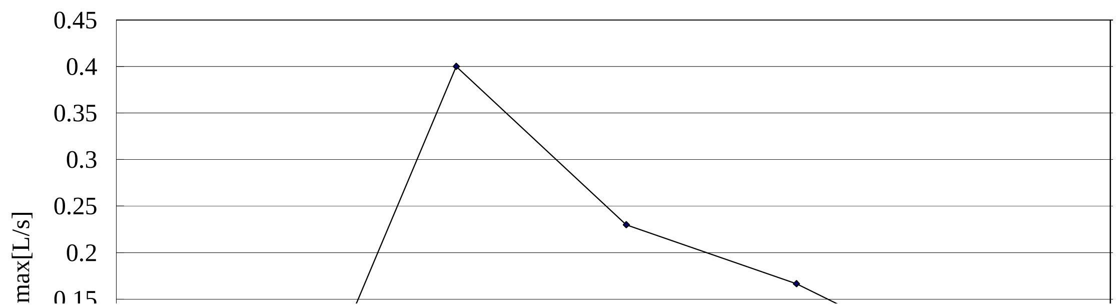


Figure 7 - Difference of qmax value before and behind the bend, against the distance from the water closet to the bend

Table 2 - Difference of qd value before and behind the bend.

qd value				
Distance from WC x[m]	**□ before the bend**	**□ behind the bend**	**Δ=□-□**	**□=100×Δ/□**
0.5	2.19	2.08	0.10	4.70
1.0	2.13	2.42	-0.29	-13.78
2.0	1.95	1.77	0.18	9.39
3.0	1.84	1.54	0.30	16.42
4.0	1.48	1.42	0.07	4.42
5.0	1.02	0.99	0.03	3.20

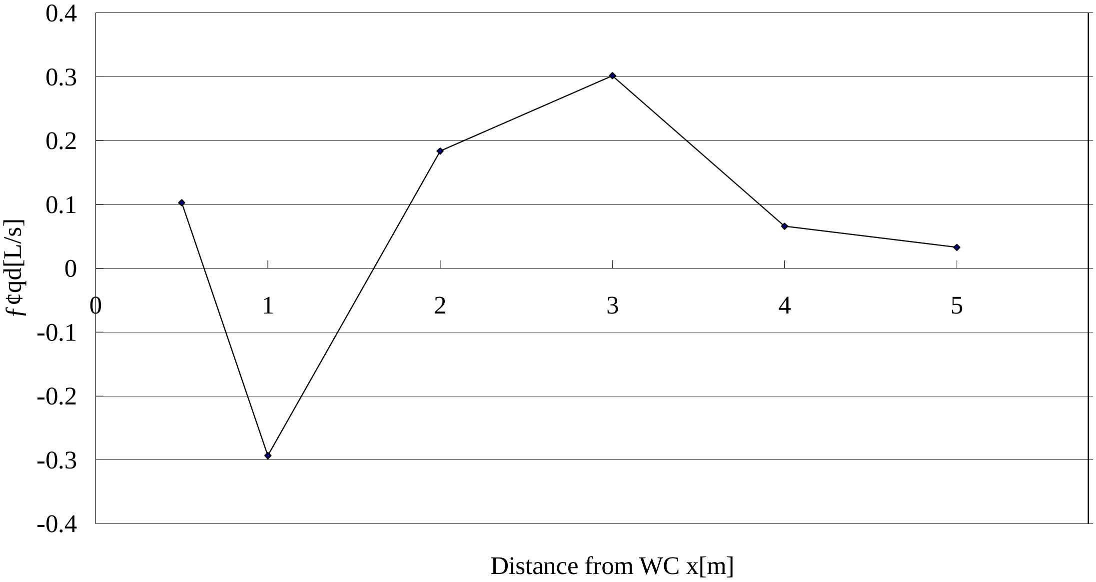


Figure 8 - Difference of qd value before and behind the bend, against the distance from the water closet to the bend

Both about qmax value and qd value, when the bend is in the distance less than 2 or 3 meters from the water closet, there isn't a tendency that when the flow passes through the bend, resistance is exerted and the values turn down. Their reduced or increased quantity also doesn't have obvious tendency. However, when it comes to next area, which is farther than 2 or 3 meters from the water closet, both qmax value and qd value reduce when the flow passes through the bend. And when it comes to reduced quantity, the smaller the distance from the water closet to the bend is, the larger the reduced quantity becomes, and the larger the distance is, the smaller the quantity becomes. That means a bend close to the water closet gives large effect to the drain characteristic. Or, it could be said that when the flow passes through a bend with a large flow rate, the bend becomes very effective.

From Table 1, when there is a bend at 3 meters from the water closet, qmax value at behind the bend is about 10 percent reduced and become 90 percent of the value at before the bend. From this result, it is assumed that when there is a bend at 3 meters point from the water closet, by passing through the bend, drain characteristic reduces 10 percent as a whole. And flow in the lower reaches is calculated. The result is shown in Figure 9. Solid lines shows flow rate when the horizontal pipe is strait without bends, and broken lines shows flow rate when the pipe has a bend at 3m from the water closet.

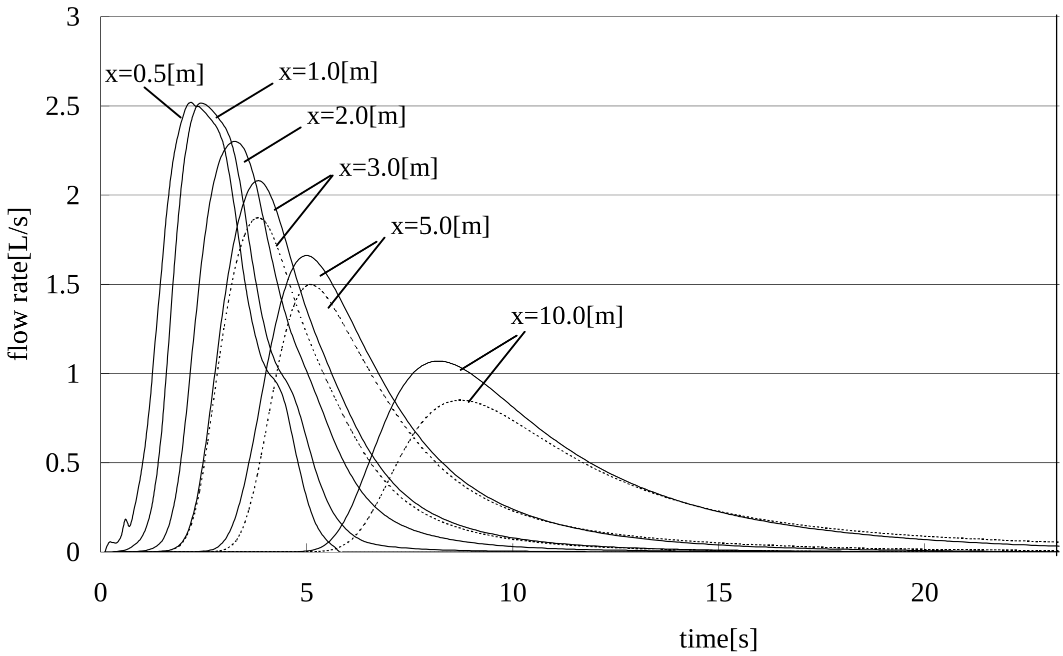


Figure 9 - Difference of flow rate transition, with or without a bend at x=3m

As we can find from Figure 9, when there is a bend at 3m from the water closet, passing through the bend cause reduce of drain characteristic. Furthermore, checking the drain characteristic of lower reaches such as 5m or 10m from the water closet, lower and lower the flow goes, the percentage of the drain characteristic reduction increases. This result shows that when there is a bend at the part of the horizontal pipe, its effect lasts toward the lower reaches, and the lower the flow reaches the larger the effect appears. So if the bend is close to the water closet, it can be said that its effect to this drainage system is relatively large.

This time the siphon water closet is used for the experiment, and it is possible that wash-down water closet shows effect of a bend clearly even in the part which is very close to the water closet. So if this is true, simulation to show the effect of a bend will be more accurate. Further, this time as a condition, it is decided that by passing through a bend flow rate reduces 10 percent as a whole, but the way of appearance of the effect and its reliability may need to be discussed more. This result can be said one of the proposal of the simulation with considering effect of a bend, and possibly will lead to a wide use prediction tool of drainage load.

4 Conclusion

Transition of discharged water from water closet through a horizontal drainpipe is simulated. Manning’s roughness factor is imitatively treated as a variable, and Revised-Manning's roughness factor n' is introduced. This method is found one of a useful method in numerical calculation of discharged water from water closet. Furthermore, the various drainage pipes' shapes were considered, such as drop from the water closet to the horizontal pipe or locations of bends, and their effect to the flow is examined from drain characteristic. Especially, when it comes to bends, one of the method of the simulation with considering their effect is proposed. From the simulation result, average flow rate qd value or maximum flow rate qmax value can be found, so that drainage load can be predicted to a certain extent in various drainage systems.

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6 Presentation of Author

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Prediction method of air pressure distribution on vertical drainage stack for apartment house

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Abstract

An aspect of the pressure fluctuations control in the vertical drainage stack was identified to be important for the insurance of drainage sanitary performance during early empirical studies. It was indicated that chaos plumbing and over-design are familiar to the utility services within the building envelope from a domestic investigation in Taiwan. Considerable progress has been made in predicting the air pressure distribution within vertical drainage stack currently. Following the previous research, this paper focuses on an empirical approach to the prediction method of vertical drainage stack, thus an experimental device which can simulate the middle-height apartment was set up for endowing the empirical parameters and model verification. As the results, the verification from comparison between measured data and calculation values reveals that the prediction model can approximately reproduce the mean value of air pressure distribution in vertical drainage stack within the conditions of single point discharge and steady flow.

Keywords

building drainage system, apartment house, trap, seal water

1. Introduction

Insurance of sanitary performance is a prerequisite to the design of drainage network and plumbing system within the building properties. The mechanism of drainage through-flow and the simultaneous air pressure fluctuations in vertical drainage stack would destroy the seal water in trap and cause many sanitary problems of building drainage network. Therefore, an aspect of the pressure fluctuations control in the vertical drainage stack was identified to be important for the insurance of drainage sanitary performance. Industries and commercial builders have made excellent progress and achievements in building science and equipment system, but progress among drainage system which is dominated by gravity has been extremely slow, due to the complication of triple phase flow feature with incorporated solid, liquid and air. In our last presentation 2002, a domestic investigation was conducted to a comprehensives that vertical drainage stack pipe is almost designed as 2 or more pipes systems, and the relief vent and vent stack type has been widely used as the drainage system for the middle-height apartment houses [1]. Owing to the lack of information and insufficient understanding about water drainage system, chaos plumbing and over-design are familiar to the utility services within the building envelope.

Considerable progress has been made in predicting the air pressure distribution within vertical drainage stack currently [2]. Following the previous research, this paper focuses on an empirical approach to the prediction method of vertical drainage stack, thus an experimental device which can simulate the middle-height apartment was set for endowing the empirical parameters and model verification. Meanwhile, the mechanism of vertical drainage flow and methodology of prediction model will firstly be described and illustrated schematically in this paper, then experimental results and verification will also be stressed on for a hypothesis appliance discharges to drain with conditions of single point discharge and steady flow.

2. Mechanism of Vertical Drainage Flow

Appliance discharges to a vertical stack of drain may be described as unsteady or time dependent flow, and the form of the appliance discharge flow contributes to this flow condition. An actual discharge of vertical drainage stack has a complex phenomenon and may consist of triple phase flow feature with incorporated solid, liquid and air. Airflow in the drainage stack is promoted by through-flow mixing as well as the interaction of friction with the falling water and air. This mechanism causes the negative pressure on the upper floors and the positive pressure on the lower floors in the building vertical drainage system.

According to the previous researches, the airflow rate (Q_a) was identified as a critical parameter for a prediction model which can express the mechanism of vertical drainage flow. Therefore, the airflow performance in vertical drainage stack is the dominated issue and it needs to be solved. Hence while air flow rate is dominant in the vertical drainage stack it plays a critical role in the subsequent operation of vertical drainage stack where the mechanism may be assumed to be a quasi-fan machine, thus the laws of fan can be introduced to link with the vertical drainage flow. The laws of fan can be expressed by the hydraulic parameters such as air density, pressure, velocity, gravity, resistance coefficient, lift, and et al. Practically, the operation energy for airflow within fan is mainly from electric power, thus potential energy of height is the dominating power for conducting the airflow in vertical drainage stack. This antithesis mechanism can be expressed as quasi-fan theory, namely the initial model of vertical drainage flow was conducted from the lows of fan machine alike.

The mechanism of flow within vertical drainage is now schematically understood. Air pressure in vertical drainage stack is caused by series interactions between downstream water and through-flow air in vertical pipe. Fig.1 illustrates the image of flow state and the modified interaction, thus it conducts the main parameters with air pressure, airflow rate, and resistance coefficients, and they are the essential factors for prediction model of air pressure distribution in vertical drainage stack.

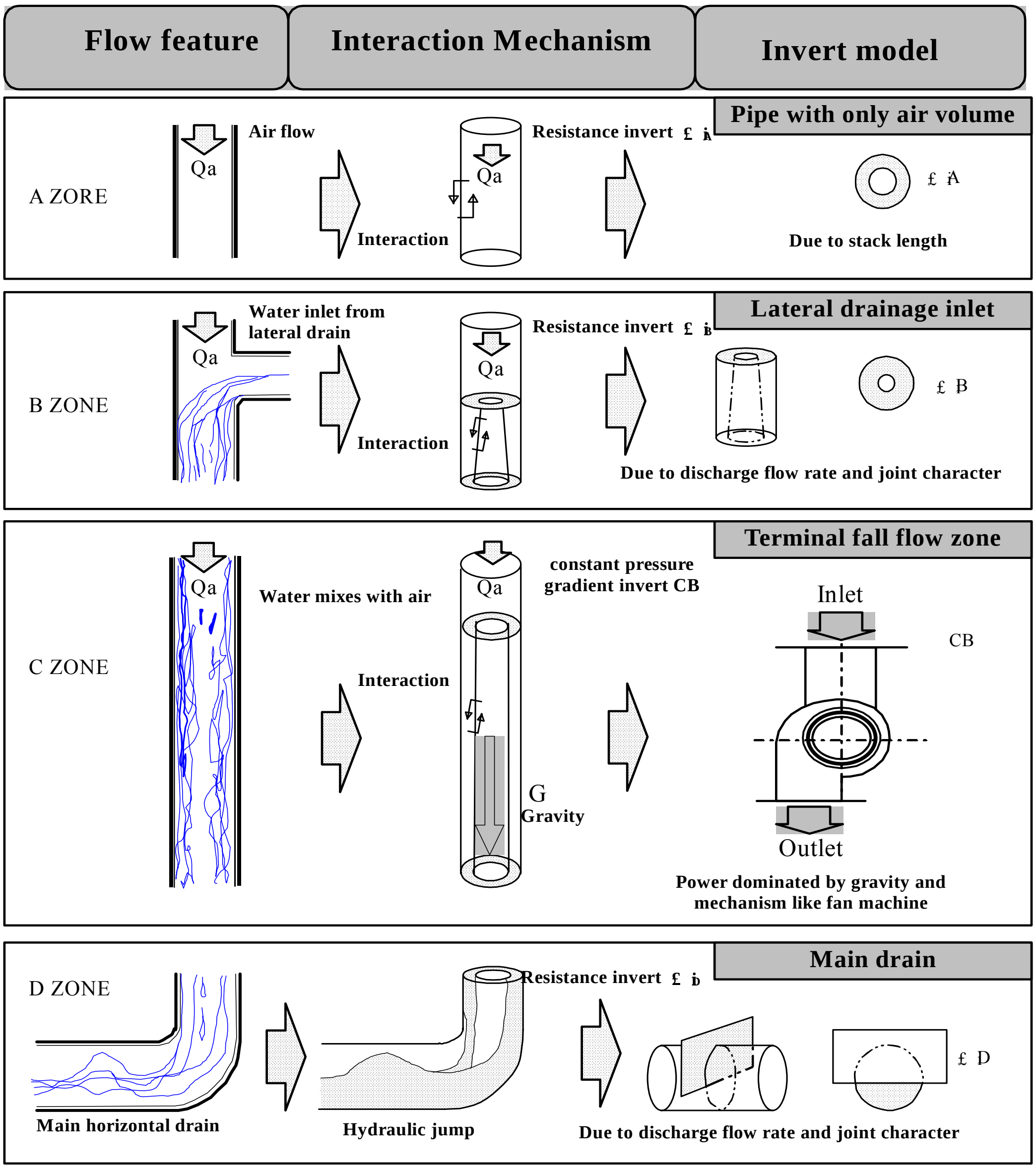


Fig.1 Mechanism of vertical drainage feature and inverted model

3. Theoretical Reviews

The guideline of National Plumbing Code (NPC) of US was used to set the permit flow rate as the regulation of drainage system [3]. Following initial work of the HASS 203 of Japan in 1970s, the method of steady flow condition was merged as the provision reference and evaluation technique, hence it conducted a series researches of steady flow method with reference to building drainage network. Consequently, a prediction model about the air pressure distribution, which occurred in the drainage stack by high-rise experiment tower (108m) and middle-high experiment tower (30m), was developed in Japan from 1990, then considerable progress has been made in predicting the air pressure distribution within vertical drainage stack [4][5].

According to the mechanism and feature of vertical drainage flow from the theoretical reviews, the profile of drainage stack was divided into four zones, as shown in the following diagram Fig.2, 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. Consequently, the features of each zone may be described as the following.

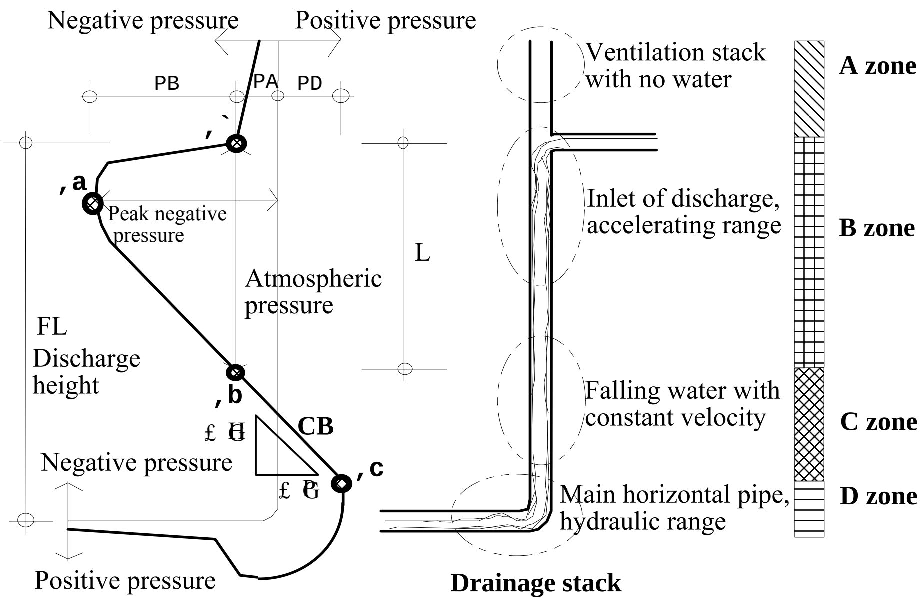


Fig. 2 Profile of air pressure distribution zones in drainage stack [5]

(1) A zone

This zone is located at the upstream part of the stack vent from the discharge entry, thus it consists of only airflow. That may allow us to employ the following air duct model with a constant drag coefficient ξ_A to calculate the air pressure P_A of A zone as shown in equation (1).

$$P_A = \xi_A \times (\gamma \div (2g)) \times V_a^2 \quad \ldots\ldots (1)$$

(2) B zone

B zone is from the discharge entry to the downstream point where air pressure recovered after it reached its negative peak. According to the mechanism of quasi-fan machine, we can also employ the air duct model with a constant drag coefficient ξ_B to calculate the air pressure P_B of B zone, thus the function may be expressed as the following equation (2).

$$P_B = \xi_B \times (\gamma \div (2g)) \times V_a^2 \quad \ldots\ldots(2)$$

The previous researches indicated that drag coefficient ξ_B of air duct model in equation (2) is not likely to be constant due to the air flow rate in some extremely range. As the hydraulics observation, it is inherently with accelerating and decelerating performance and almost in same phase with complicated interaction of incorporated water and air. However, the drag coefficient ξ_B may be calculated as an independent parameter with direct ratio to water flow rate in general discharge condition, and the calculation deviation is still acceptable excluding the extremely range of condition.

On the other hand, a new parameter L, i.e. length scale of the B zone, was also conducted to modify the perdition model of B zone. It was identified that ξ_B and L are both dependent on the stack air flow Q_a or V_a. Therefore, the function of pressure P_B may be also expressed as the following equation (3), namely parameter L can be determined from equation (3) due to the calculation value of P_B by equation (2).

$$P_B = C \times L^{0.7} \quad \ldots\ldots(3)$$

(3) C zone

Similar to the laws of quasi-fan machine, the variation of air pressure in stack is conducted by the transformation with potential energy of height to kinetic energy. The downstream water flow drags the airflow and conducts the air pressure fluctuation in vertical drainage stack. The modification feature of this interaction is shown in Fig.1 and airflow in C zone gains energy as a form of static pressure increment through decelerating work against falling water. Constant positive pressure gradient (CB) toward downstream direction means constant momentum transfer from the falling water to the airflow.

According to the early empirical work, it was assumed that the frictional force acting on the water surface to be proportional to the square of the bulk velocity difference between water and air, namely it is equal to the square root of constant pressure gradient CB in this zone. As the results, it may be expressed in terms of an equation of airflow rate as in equation (4) with two empirical constants of α and β, that is what we call two parameters method during early researches [5].

$$CB = \Delta P \div \Delta H = \alpha^2 \times (\beta - Q_a)^2 \quad \ldots\ldots(4)$$

(4) D zone

Owing to the hydraulic jump at the connection of vertical stack pipe and horizontal drain pipe, D zone works as air resistance as A zone does. Hence, the following equation with the constant drag coefficient ξ_D is appropriate to calculate air pressure P_D and the air pressure distribution in D zone as shown in equation (5).

$$P_D = \xi_D \times (\gamma \div (2g)) \times V_a^2 \quad \ldots\ldots(5)$$

Therefore, it is demonstrated that the stack airflow rate Q_a or V_a plays a key factor to the prediction model of air pressure distribution in building vertical drainage stack. It conducts a method to calculate air pressure profile of each zone in Fig. 2 as a function of Q_a or V_a, and assembles them to introduce the whole air pressure distribution in building vertical drainage stack. As a prediction model, however, this calculation method is not completely theoretical solution but semi-empirical approach with the experimental parameters. The following contents, which verify the designed calculation scheme by experiment results, can be successfully applied to simulate the air pressure distribution of vertical drainage stack within middle-height buildings under conditions of single point discharge and steady flow.

4.Experiment and Initial Results

In order to conduct a calculation system and verify the prediction model, this research following the previous study performed an experiment upon a full-scale drainage experimental tower. As an empirical approach, the experiment tower which is adhered to a real building of 40 m height can simulate a drainage system within a middle-height apartment houses around 12 floors height.

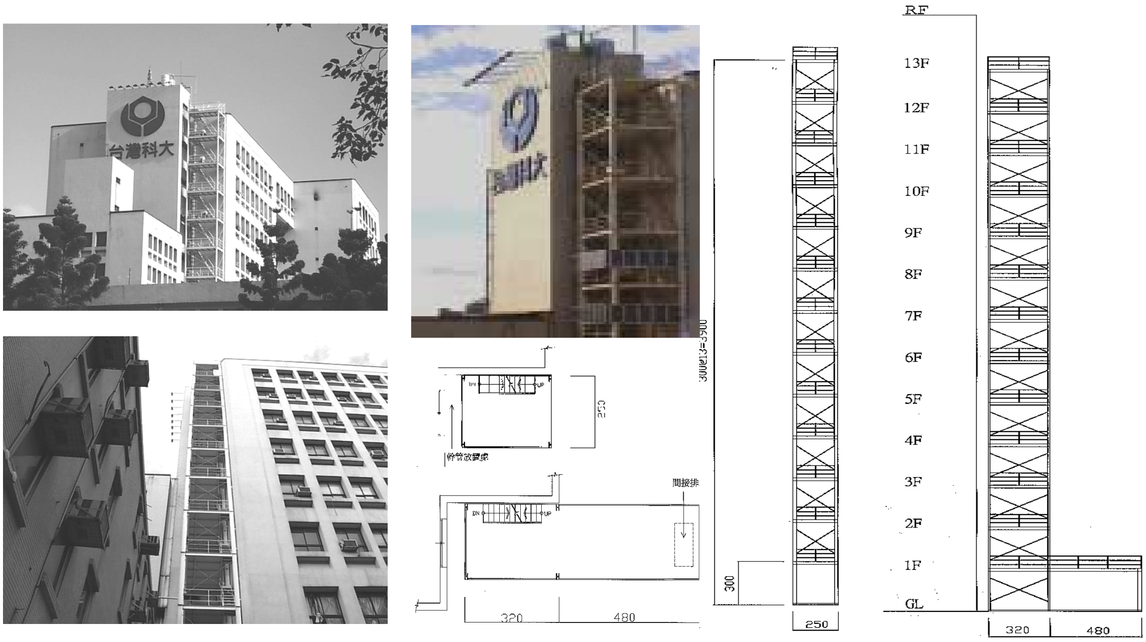
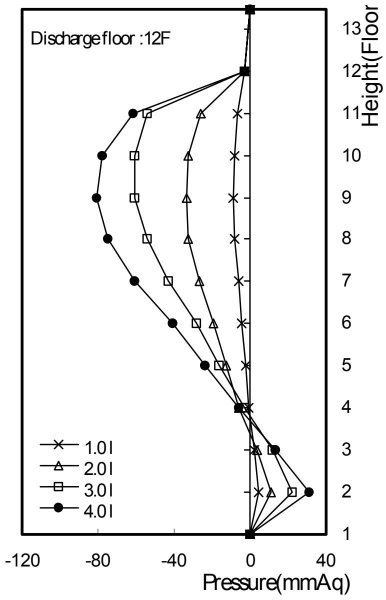


Fig.3 Layout and views of this middle-high experiment tower

The details of this experiment device and measuring issues were introduced in our previous paper and Fig.3 shows the layout and views of this experiment tower [6]. Concerning the recording data format, the mean value of air pressure was surveyed from 40 seconds for each measurement with 10ms sampling time, then the central 20 seconds samples with 2000 data are adopted for the mean value of air pressure performance.

The initial experimental results, which discharged from 9F to 12F with conditions of water flow rate from 1.0 l/s to 4.0 l/s, are shown in Fig. 4~7. They show the elementary results of air pressure distribution in drainage stack with condition of single-point and steady discharge flow. These figures reveal that the value of negative air pressure distribution conduct a direct ratio with the height of water entry floor and the volume of water discharge flow rate.



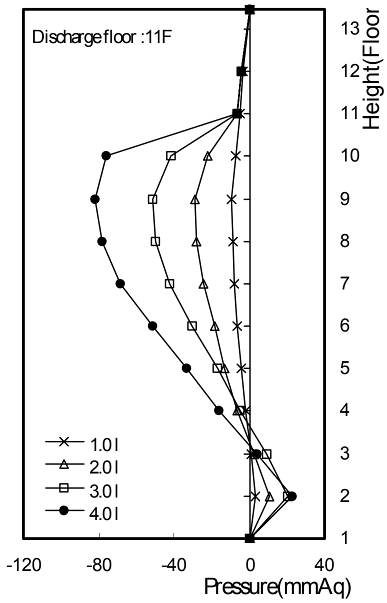
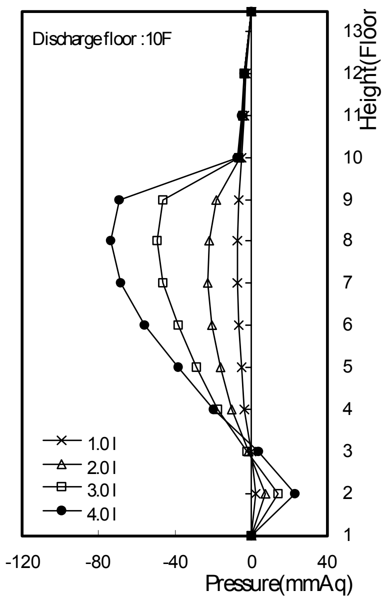


Fig. 4 Average air pressure distribution (discharge floor: 12F, 1.0 ~ 4.0 l/s)

Fig. 5 Average air pressure distribution (discharge floor: 11F, 1.0 ~ 4.0 l/s)



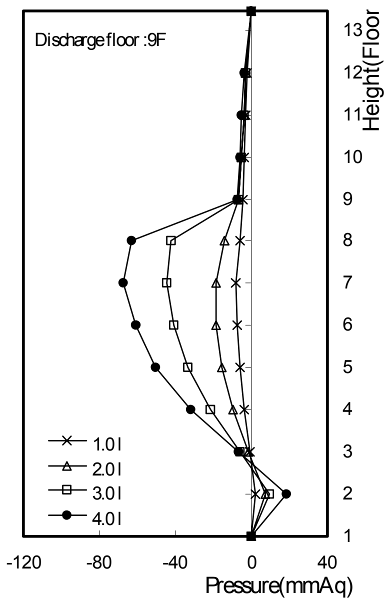


Fig. 6 Average air pressure distribution (discharge floor: 10F, 1.0 ~ 4.0 l/s)

Fig. 7 Average air pressure distribution (discharge floor: 9F, 1.0 ~ 4.0 l/s)

5. Methodology: Determination of Empirical Parameters

As an empirical approach, the experimental parameters must be firstly determined. According to the arranged calculation procedure, the drag coefficients of each zones (ξ_A, ξ_B, ξ_D) may be calculated, then the air pressures distribution of each zones can be determined. The empirical operations of each zone are expressed as the following descriptions.

(1) A zone

The mechanism of A zone is a partial stack with merely airflow and be dominated by resistance affection of airflow and piping surface. The drag coefficientξ_A of A zone is a parameter, which depends on partial stack length of A zone due to the results as shown in Fig.9, thus it can be determined by a regression function as shown in the following equation (6).

$$\xi_A = 0.3751 \times Ah \quad \text{..................................(6)}$$

Therefore, air pressure distribution in A zone can be also determined due to equation (1). Herein, Ah denotes length from the top of stack vent pipe to the discharge height in meter. Table 1 shows the height of stack vent within this experiment condition.

Table 1 The height of stack vent within this experiment conditions

Discharge inlet floor	12F	11F	10F	9F	8F
Ah (m)	5.26	8.26	11.26	14.26	17.26

(2) B zone

Following the methodology of this prediction model, the mechanism of B zone was confirmed in this experiment range. As the results, the drag coefficient ξ_B is almost independent to the airflow rate Q_a as shown in Fig.10. Meanwhile, the peak negative air pressure P_B almost depends on water discharge flow rate Q_w and be with direct ratio to the Q_a^2 or V_a^2, thus it can be determined by a regression function as shown in the following equation (7).

$$\xi_B = 3.0521\ Q_w^{\ 2} + 1.728\ Q_w \quad \text{..................(7)}$$

Fig.11 illustrates the relationship between ξ_B and Q_w and the regression curve, namely the prediction method is satisfied in the condition of this experiment range. Therefore, the peak negative air pressure in B zone can be also determined due to equation (2). Moreover, the position of peak negative air pressure occurred differs upon flow rate and mostly in 1~4 floors straightly under the discharge floor from empirical observations.

On the other hand, it was identified during early empirical work that P_B may be with direct ratio to the parameter $L^{0.7}$ as shown in Fig.12. Hence parameter L may be expressed as depends on water discharge flow rate Q_w with constant C_L as shown in figure 13. Thus it can be determined by a regression function as shown in the following equation (8).

$$C_L = 0.4903\ Q_w{}^2 + 0.2297\ Q_w \quad \text{................(8)}$$

According to the continuity feature of distribution, we conducted a regression function for completing the air pressure distribution of B zone. By the method of least squares upon three boundary conditions, a regression function curve with fifth power may be obtained from empirical data, thus the air pressure distribution of B zone can be conducted to complete the whole distribution profile in vertical drainage stack. The boundary conditions included air pressure of P_A in water inlet point, peak negative pressure value of PB in B zone and the length of B zone L. The prediction method of air pressure distribution curve in B zone is schematically shown in Fig.8.

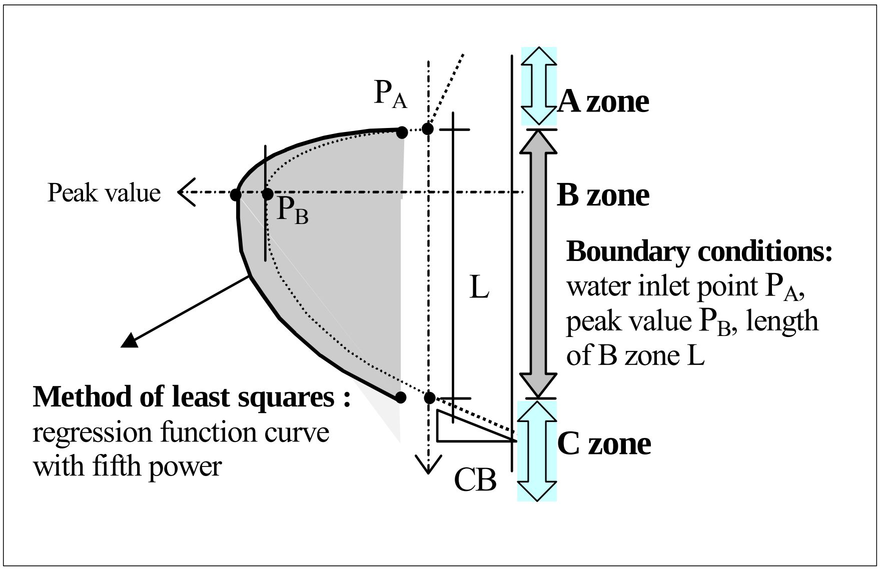


Fig. 8 Prediction method of air pressure distribution curve in B zone

(3) C zone

The mechanism of C zone may be described as the constant momentum transfers from the falling water to the airflow within stack by affection of water flow and gravity. The constant positive pressure gradient of C zone may be determined by two parameters method that was described in above section. However, as a practical performance two parameters method, which has a critical procedure in determining the empirical constant for each application system, is sometimes unavailable for optimization. Therefore, we conducted an empirical relation from Q_a and CB as shown in Fig.14, then it reveals that CB may be described as a negative linear function which depends upon Q_a and Q_w. Namely, a empirical two-parameters function was conducted to be a substitution of calculation method as shown in the following equation (9)

$$CB = a \times Q_a + b \quad \text{...} (9)$$

Where the factor of "a" and "b" are also dependent upon Q_w as shown in Fig.15, then they may be expressed as the following regression functions. Therefore, the constant positive pressure gradient in C zone can be also determined.

$$a = -16.259\ Q_w^3 + 37.502\ Q_w^2 - 35.672\ Q_w \quad \text{.....................} (10)$$

$$b = 0.5665\ Q_w^3 - 0.9211\ Q_w^2 + 1.8487\ Q_w \quad \text{.....................} (11)$$

(4) D zone

The mechanism of D zone is an abrupt decelerating performance zone with hydraulic jump and be dominated by resistance affection of water flow and gravity. Consequently, the drag coefficient ξ_D of D zone is a parameter, which depends on water discharge flow rate Q_w and discharge floor height due to the empirical observations as shown in Fig.16, thus it can be determined by a regression function as shown in the following equation (9). Therefore, air pressure distribution in D zone can be also determined due to equation (6).

$$\xi_D = 0.0005 \times (Q_w \times FL)^2 + 0.092 \times Q_w \times FL \quad \text{..........} (9)$$

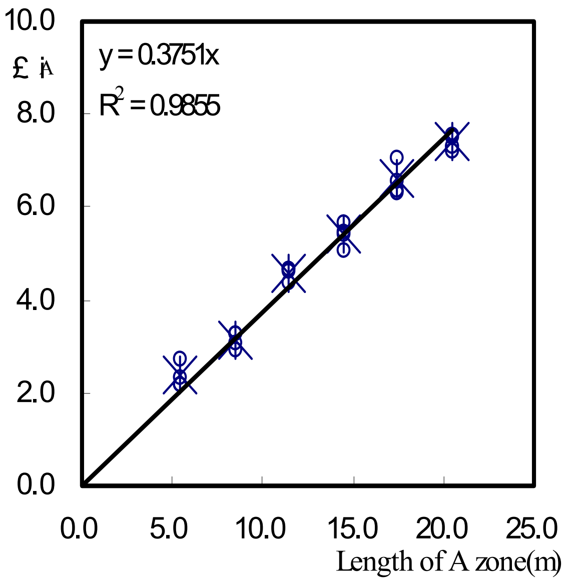


Fig.9 Relation between ξ_A and partial stack length of A zone

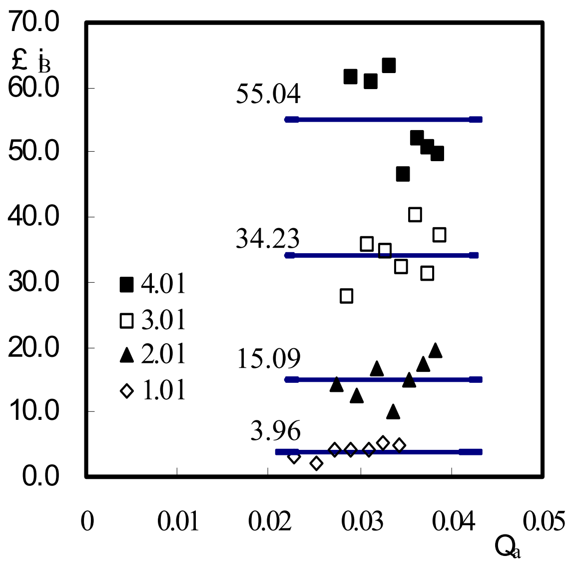


Fig.10 Relation between ξ_B and Q_a (B zone)

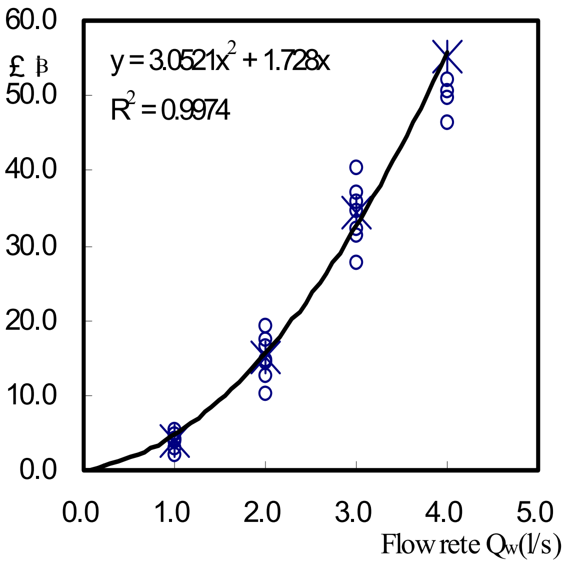


Fig.11 Relation between ξ_B and water discharge flow rate Q_w(B zone)

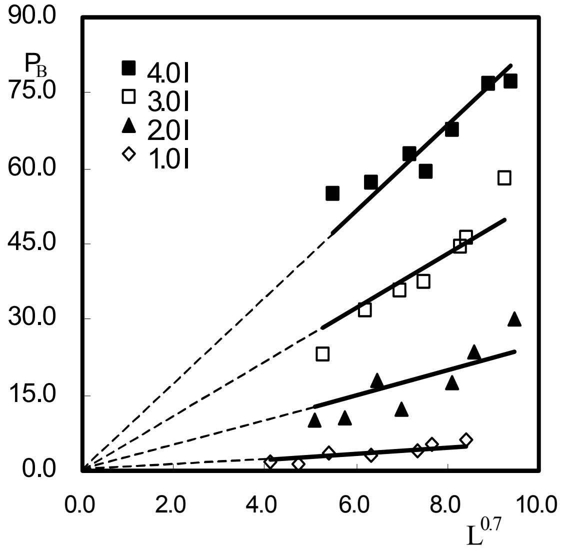


Fig.12 Relation between $L^{0.7}$ and P_B (B zone)

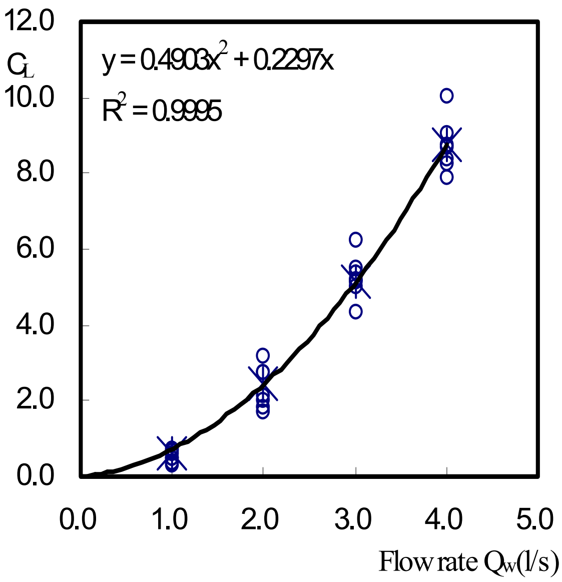


Fig.13 Relation between C_L and water discharge flow rate(C zone)

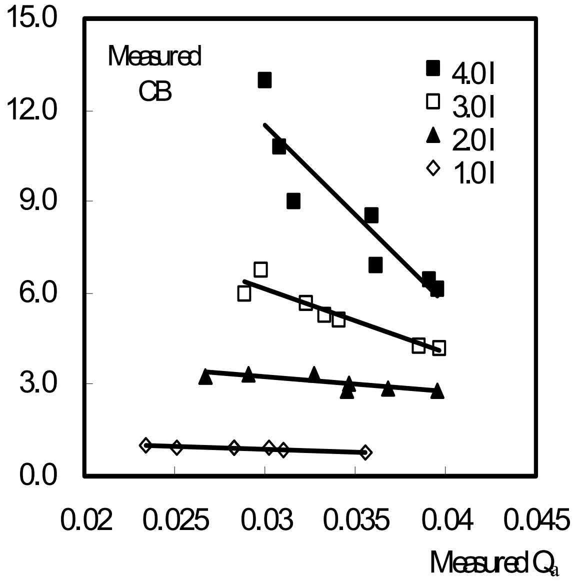


Fig.14 Relation between CB and Q_a (C zone)

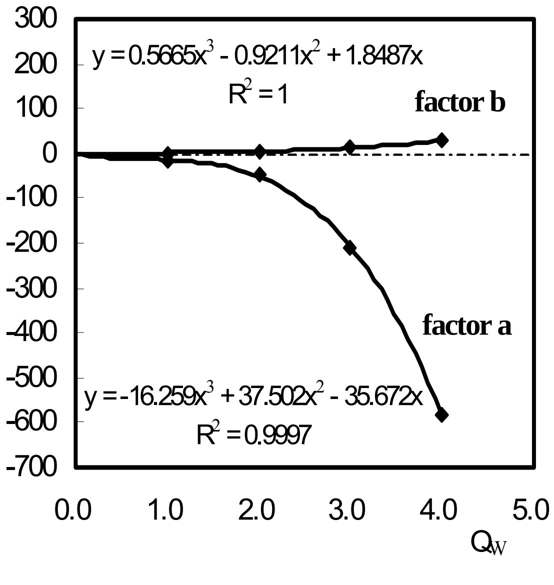


Fig.15 Relation between C_L and water discharge flow rate(C zone)

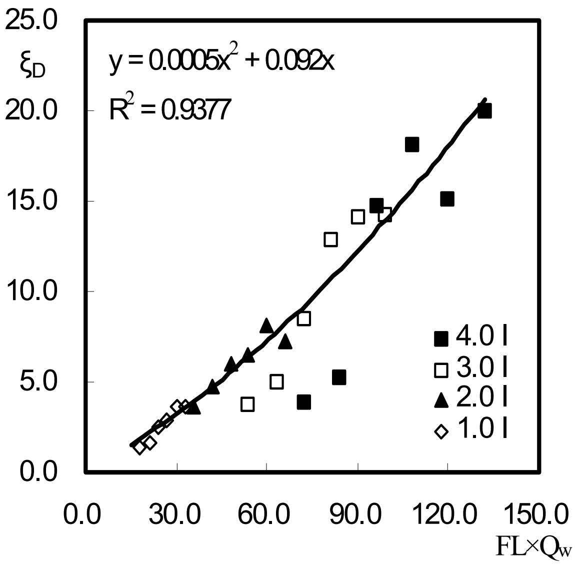


Fig.16 Relation between ξ_D and $FL \times Q_w$ (D zone)

In order to clarify this prediction methodology, a calculation procedure was undertaken to determine the empirical parameters of each zone within the vertical drainage stack under the condition of steady and sequential discharge. Due to the flow mechanism of vertical drainage stack and prediction methodology, the airflow rate Q_a would be the dominating parameter for this calculation system.

First of all, the water discharge flow rate Q_w and discharge floor should be set as initial input condition, then to assume the airflow rate Q_a as a crucial parameter for the first loop calculation. Therefore, the calculation system can start to determine all the parameters and conduct the air pressure distribution for each zone under the assumed condition. Owing to the sequential distribution feature of vertical drainage, only the correct Q_a can make the air pressure distribution diagram to reveal the closed feature, thus the loop calculation can search the approximate correct airflow rate Q_a to satisfy the feature condition and stop the calculation. Herein, the calculation procedure is summarized as Fig. 17.

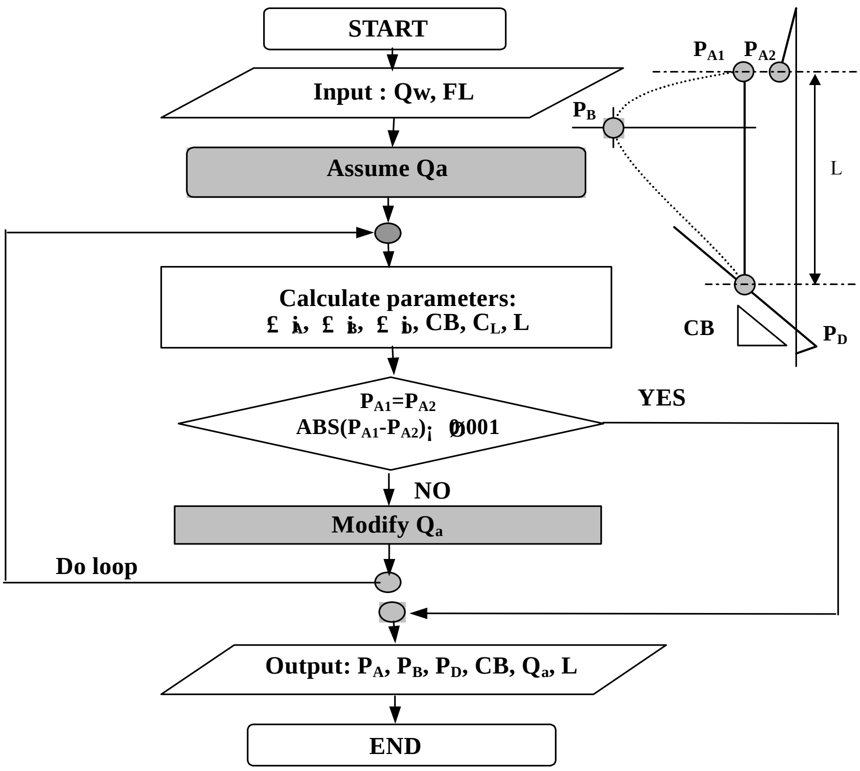


Fig.17 Calculation procedure and flow chart

6. Verification: Reproduction of Experiment Data

Following the previous research, the experiment device was set up to simulate a middle-height apartment house with 12 floors height, and then performed a single-point discharge under steady flow condition. Parallel laboratory observations involved noting the maximum and minimum air pressure fluctuation, hence the pressure variety in drainage stack upon discharge of 2.0 l/s would frequently over the regulated value and may possible destroy the seal water in trap.

Herein, we focus on the verification of this prediction model with the reproduction performance of experiment data. Owing to the boundary conditions of this experiment device, 28 testing patterns of water discharge included the varieties of discharge height from 6F to 12F and water flow rate from 1.0 to 4.0 l/s were performed. Verification from comparison of measured data and calculation results are shown in Fig.18-23. As the key factor of the prediction model, Q_a must be confirmed firstly. Fig.18 shows the comparison between calculated results and measured data of airflow rate Q_a. Then, the calculation of parameter L is also identified as good performance.

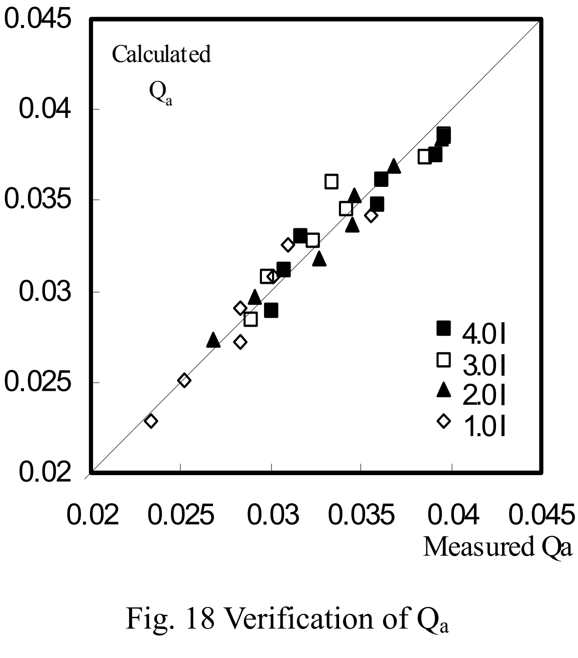


Fig. 18 Verification of Q_a

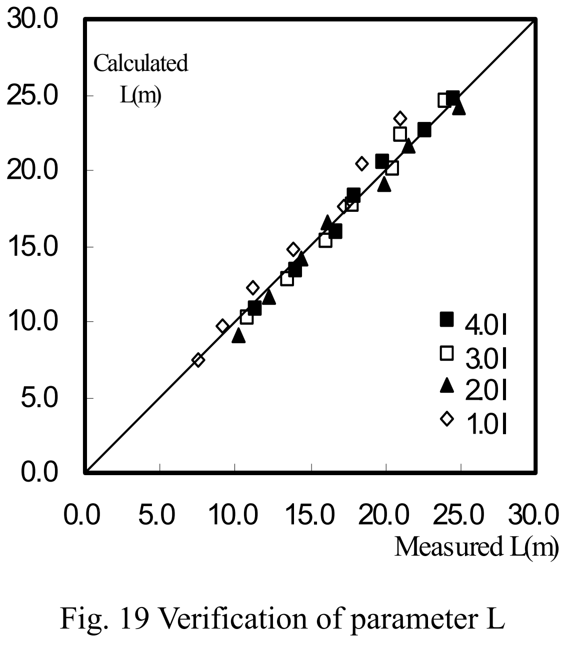


Fig. 19 Verification of parameter L

Furthermore, we reproduced the data of P_A P_B P_D and CB, hence verify the reliability of this prediction model. These results reveal that the calculation procedure can approximately reproduce the experimental data for each zone of vertical drainage stack and the deviations are also acceptable under this experiment conditions.

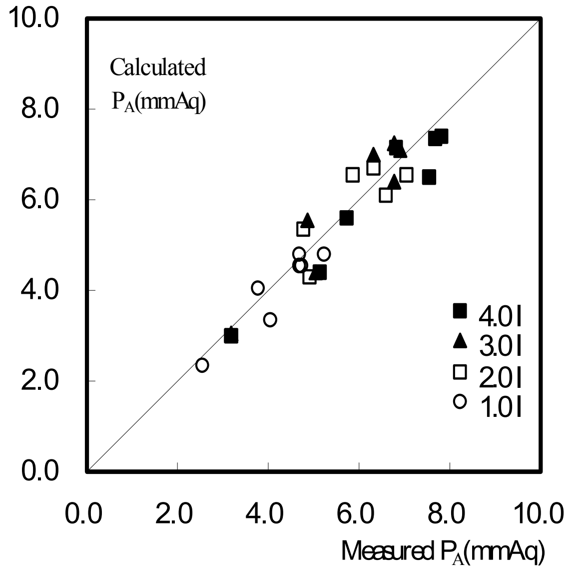


Fig. 20 Verification of P_A

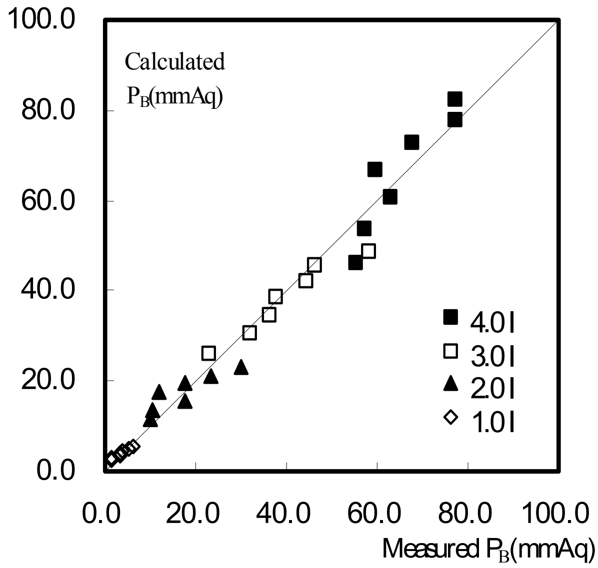


Fig. 21 Verification of P_B

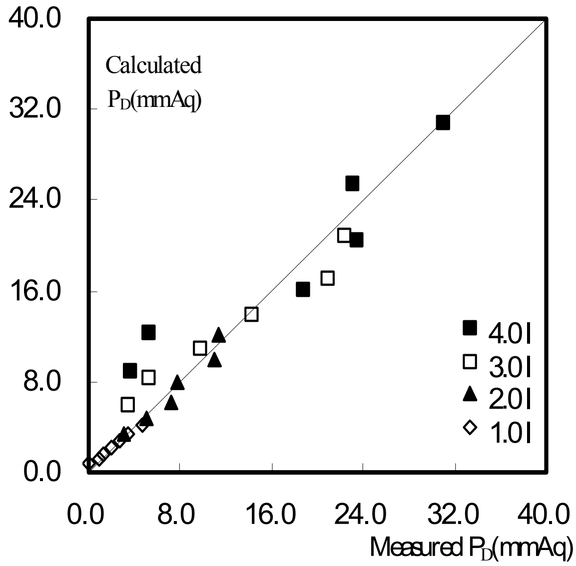


Fig. 22 Verification of P_D

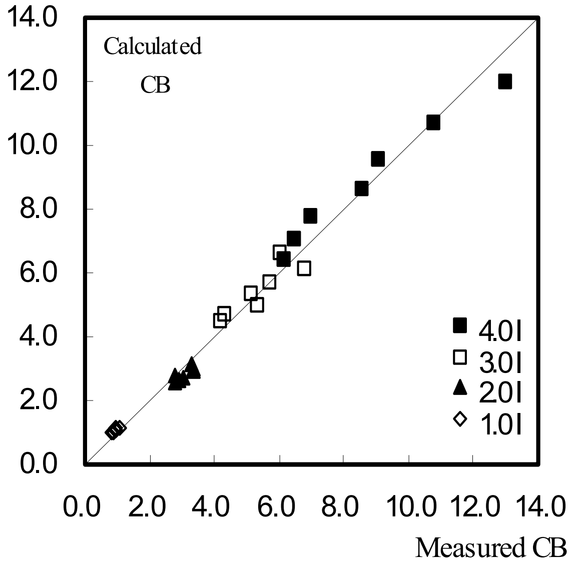
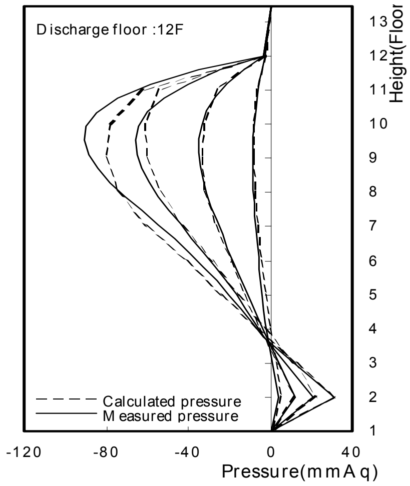


Fig. 23 Verification of CB

According to the prediction method and calculation procedure, a series of reproduction of experiment data were conducted to verify the reliability of this prediction model. The comparison profiles were shown in Fig 24-29. These figures indicate that the calculation results can approximately reproduce the experiment data and the profiles of air pressure distribution in vertical drainage stack. It reveals that the model is reliable for these water drainage patterns and can apply to others application alike under the similar boundary conditions.



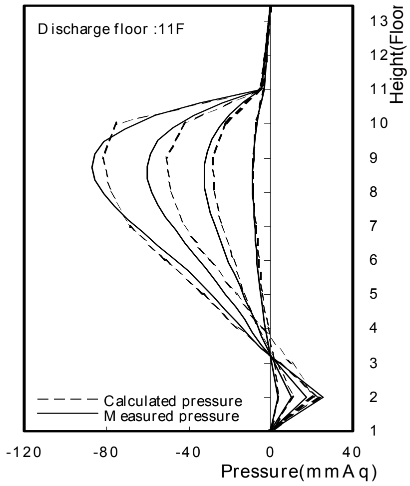
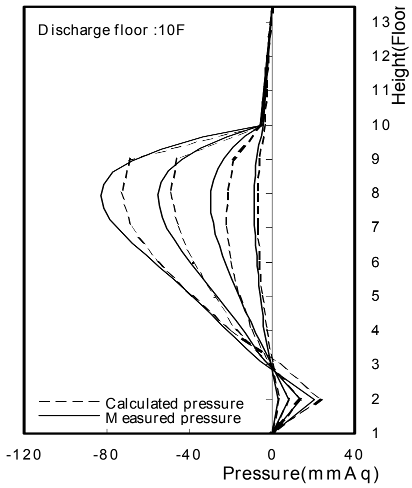


Fig.24 comparison profile (discharge from 12F) Fig.25 comparison profile (discharge from 11F)



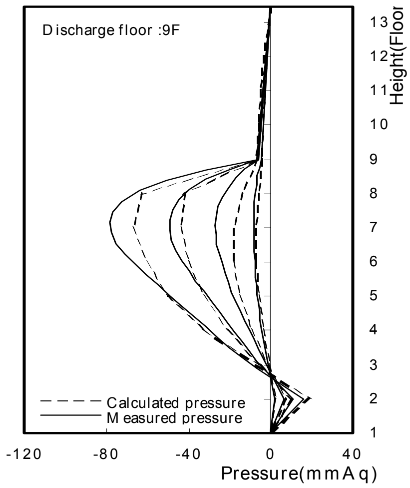
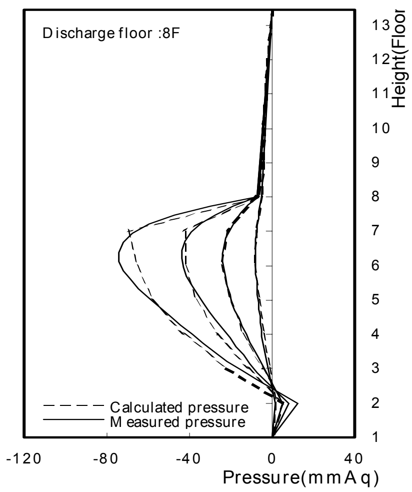


Fig.26 comparison profile (discharge from 10F) Fig.27 comparison profile (discharge from 9F)



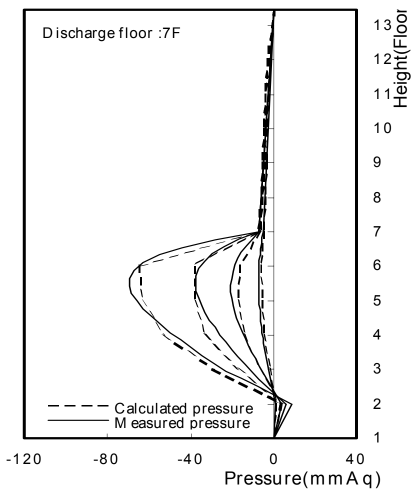


Fig.28 comparison profile (discharge from 8F) Fig.29 comparison profile (discharge from 7F)

7. Conclusions

Airflow in the drainage stack is promoted by through-flow mixing as well as the interaction of friction with the falling water and air. The comprehensive understanding of this complex phenomenon, which causes the negative pressure on the upper floors and the positive pressure on the lower floors in the building vertical drainage stack, was identified as an inherent requisite to building vertical drainage stack by early empirical work. The pressure fluctuation in drainage stack would destroy the seal water in trap and cause many sanitary problems in building drainage network. This paper focuses on the feature of vertical drainage flow, which is a complicate interaction phenomenon, and it was described as a mechanism of quasi-fan machine alike, hence a prediction model was developed and verified as a practical method in this research.

The prediction model based empirical parameters is an essential study however offers a reference to drainage system designers at keeping the function of trap for the building properties. As the results, the verification from comparison between measured data and calculation values reveals that the prediction model can approximately reproduce the mean value of air pressure distribution in building vertical drainage stack within the conditions of single point discharge and steady flow. The importance of trap function within building drainage system has been confirmed during early researches. Meanwhile, more related studies included appliance discharges with unsteady flow and multiple points of water discharge need to be conducted for linking to the reference of building regulation.

Nomenclature

Ah length from the top of stack vent pipe to the discharge height (m)

P_A pressure of A zone

P_B pressure of B zone

P_D pressure of D zone

P_O pressure of outside interaction ($=P_A + P_D$)

P_I initial total pressure of drainage stack ($=P_A + P_B + P_D$)

γ specific weight of air(kgf/m3)

V_a velocity of air flow at stack vent (m/s)

Q_a air flow rate in stack vent (m^3/s)

Q_w water flow rate (V/s)

ξ_A drag coefficient of A zone

ξ_B drag coefficient of B zone

ξ_D drag coefficient of D Zone

CB constant pressure gradient (mmAq/m)

α β empirical constant of constant pressure gradient in C zone

g acceleration of gravity (m/s^2)

FL Discharge floor height (m)

L Length scale of the B zone (m)

C_L Constant of L

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The Standard for Evaluation of Energy Saving on Hot Water Supply System in Japan

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Abstract

As one of the energy saving policies for buildings in Japan, it is now mandatory to evaluate energy saving performance in each of the buildings to set it to a level not more than the standard value as set forth by the law. CEC/HW (Coefficient of Energy Consumption for Hot Water supply) is an index for the evaluation of energy saving in hot water supply system. It is given by a ratio of the actual energy consumption in hot water supply system to the virtual energy consumption. In a central hot water supply system of a building with floor area of 2,000 m2 or more, the system must be designed in such manner that the value of CEC/HW is not more than the maximum value determined by the standard as prescribed by the law. In this paper, we will discuss and report on the following items relating to CEC/HW:

1) Outline of the calculation method for CEC/HW.
2) The procedure to determine the standard value of CEC/HW.
3) Important points for energy saving in the design of hot water supply system.

Keywords

Central hot water supply system; energy saving; standard and index; simulation.

1 Introduction

As one of the energy saving policies in Japan, it is now mandatory by the law that the efforts and measures should be carried out to save energy in various facilities and systems for air-conditioning, air ventilation, lighting, hot water supply, and elevators in buildings (private houses excluded) and to set the level of energy saving to not more than the standard value as provided by the law [1]. In this paper, we discuss the procedure to calculate CEC/HW for the evaluation of energy saving performance in hot water supply system as set forth by the law and we also review the background of how the standard was determined according to CEC/HW.

CEC/HW was enacted in July 1993. Up to now, it has been revised twice, i.e. in March 1999 and March 2003. The details are summarized in Table 1 below. In the following chapters, we will discuss general problems including the procedure to evaluate energy saving performance in entire system, the procedure to calculate the hot water consumption used in each building as added in the revision of March 2003, and the evaluation of the introduction of hot water saving device and the utilization of solar energy. We will also discuss how to calculate energy consumption in the entire hot water supply system and how to determine an adequate energy saving standard.

Table 1 - Transition of the standard value of CEC/HW

Enacted in	Buildings and applications	Standard values and others
July 1993	Hotels and hospitals	CEC/HW≦1.6 for hotels; CEC/HW<1.8 for hospitals
March 1999	Sales stores added	CEC/HW≦1.5 for hotels; CEC/HW<1.7 for hospitals and stores
March 2003	Expanded to all applications	Determination of standard values based on new index Ix; Addition of specification standard

2 Procedure to evaluate energy saving performance of hot water supply system

The quantity of hot water used by the users through hot water supply faucets is called “hot water consumption” V [L/day]. If it is assumed that hot water temperature is Tu [°C] and water supply temperature is Tw [°C], the energy to supply hot water per day q0 [kJ/day] can be given by:

$$q0 = cV\,(Tu - Tw)$$

where c [kJ/(LK)] represents volume specific heat of water. Hot water consumption V is the quantity of hot water obtained via hot water supply faucets. It is the quantity of hot water after the hot water supplied from the hot water supply system is mixed with water in the hot water supply faucets. It should be noted that this is not the quantity of hot water supplied by the hot water supply system.

The value of Tw varies according to each season, and the value of q0 must be evaluated over the entire period of the year. As to be described later, city water temperature is given for each month. The value of q0 is calculated on a representative day in each month from January to December and the values are summed up. By multiplying this with the number of days in each month, annual value is obtained. Hereinafter, the heating value is calculated by the same totaling procedure. If this totaling procedure is expressed by S [calculation formula], annual energy consumption Q0 can be given by:

$$Q0 = cS\,[V\,(Tu - Tw)] \quad \dots (1)$$

It is difficult to evaluate energy saving in hot water supply system by the equation (1). To decrease this value means to decrease the temperature at the time of use or to decrease the hot water consumption. For instance, in a resort hotel, it is essential that hot water can be used as much as the users want, and this is also important to determine the grade of the hotel. In hospitals, hot water is used for the disinfections and other purpose in the care of the patients, and it may not be adequate to discuss the use of hot water supply in hospitals from the viewpoint of energy saving. Therefore, we must discuss how to reduce the energy consumption of the entire hot water supply system.

For the energy consumption of the entire system, we must evaluate the heat loss in the system in addition to the equation (1). Hot water supply system generally comprises a heat source to produce hot water to be supplied, piping systems and hot water storage tanks on the way to supply the hot water to faucets, and pumps for circulating the hot water. Heat loss at each of these elements must be calculated. The energy to be supplied to the heat source is expressed as primary energy, and this is regarded as consumption energy of the entire system. When a gas boiler as shown in Figure 2 is used and if heat source efficiency is defined as EB and heat exchange efficiency is EH, consumption energy Qs of the entire system is given by:

$$Qs = (Q0 + QLOSS)/(EB \times EH) + Qe \ldots (2)$$

where Qs is annual consumption energy of the entire hot water supply system, Q0 is annual heat load to produce the hot water supply used (this is called “hot water supply load”), QLOSS is annual heat loss from the hot water supply system, and Qe is annual power consumption of the pumps converted to primary energy. To save energy is to decrease of the value of Qs in the equation (2). Depending on the application purpose and the scale of each building, the values of Qs and Q0 both increase, and it is not practical to set the standard for the value of Qs.

By giving consideration on the case of water supply preheating and the case where it is tried to reduce the hot water supply quantity used by improving and modifying hot water supply faucets, the value of Q0 is calculated from the hot water supply consumption V and the water supply temperature Tw.

$$Q1 = cS\,[VD\,(Tu - Tin)] \ldots (3)$$

This is called “virtual hot water supply load”, and this is distinguished from the equation (1). Here, VD is virtual hot water consumption, and Tin is city water temperature in the building area. CEC/HW is evaluated by the value obtained by dividing the equation (2) by the equation (3):

$$CEC/HW = Qs/Q1 \ldots (4)$$

3 Procedure to calculate consumption energy Qs of the entire hot water supply system

3.1 Determination of virtual hot water consumption VD

In the investigations and the studies performed in the past, relatively more cases were related to the hot water supply quantity at hotels, hospitals, restaurants and buffets, toilets, etc. The number of investigations is not necessarily sufficient, and it is difficult to consider seasonal changes. Therefore, annual average of daily hot water consumption VD [L/day] is determined as given below without taking seasonal changes into account.

3.1.1 Hotels

Virtual hot water consumption VD at hotels can be obtained by dividing it to the system for guest rooms and to the system for common use. For the system for guest rooms, the value of VD is calculated through multiplication of the hotel capacity by hot water supply per unit (default: 190 – 220 L/(person×day)) and operating efficiency (default: 0.75). For the system for common use, the value of VD is calculated through multiplication of floor area of the commonly used portions (kitchens, restaurants, buffets, tearooms, etc. to which hot water is to be supplied) by hot water supply per unit (default: 50 L /(m2×day)) and operating efficiency (default: 0.70). In case the floor area to be supplied with hot water cannot be clearly defined, it may be obtained as: total building floor area × 0.17. In case swimming pools and big-scale bathrooms are included, the design engineer calculates by estimating the additional value.

3.1.2 Hospitals

The value of VD is calculated through multiplication of the number of hospital beds by hot water supply per unit (default: 290 L/(bed×day)) and operating efficiency (default: 0.98).

3.1.3 Stores

Virtual hot water consumption of the stores is calculated separately for restaurants and toilets. Restaurants are classified to three types: restaurants, buffets / tearooms, and fast food stores. The value is calculated through multiplication of floor area by 48, 32, and 16 [L/(m2×day)] respectively as hot water supply per unit. For toilets, total number of customers is multiplied by hot water supply per unit (default: 3.8 L/(person×day)). Total number of customers is obtained by estimating the daily average number of customers. Or, it can be obtained through multiplication of sales floor area by average occupants density (default: 0.045 persons/m2).

3.1.4 Buildings for other applications

For the buildings used for applications other than the above three applications, no adequate data relating to the hot water consumption is available, and hot water supply per unit is not indicated. Therefore, the hot water consumption is estimated when the design engineer provides standard facility. In this case, if there is an application similar to the building with default, the same calculation procedure is used, and unit requirement may be corrected properly and used. However, the material source and basic concept for the estimation must be indicated.

3.2 Virtual hot water supply load and hot water supply load

The value of Q1 is obtained from the equation (3). Here, city water temperature is used as supply water temperature Tin. Monthly average city water temperature Tm is approximated by the following equation for monthly average air temperature Ta:

$$Tin = Tm = a \times Ta + b \quad \ldots (5)$$

where Tm is monthly average city water temperature [°C], Ta is monthly average outside air temperature [°C], a and b each represents a coefficient determined for each area by dividing the entire country to 25 areas. When the building is located in Tokyo, the coefficients are: a = 0.8516, and b = 2.473.

The hot water supply load is calculated by the equation (2). Calculation must be made by giving full consideration on the supply water preheating and the device to reduce hot water supply quantity. If both are not adopted, V = VD and the hot water supply load Q0 = virtual hot water supply load Q1 (as given above).

3.2.1 Supply water preheating

When supply water is preheated by utilizing solar energy or exhaust heat, supply water temperature increment dTup evaluated on a representative day in each month is obtained, and hot water supply load may be calculated by adding the city water temperature in the equation (5). However, supply water temperature after preheating must not be higher than the hot water temperature TH (default: 60°C) supplied by the hot water supply system. That is:

$$Tw = \min [Tin + dTup, TH] \ldots (6)$$

Here, min [x,y] is a function, in which x or y is adopted, whichever is smaller.

When solar energy is utilized, simulation is often performed by the design engineer. Thus, the procedure and the conditions for the simulation, given for 6 items of hot water supply load, weather data, conditions to install heat collector, specifications of heat collector, heat storage tank and brine pipes, must be indicated and the results may be used.

3.2.2 Device to reduce hot water supply quantity

Some devices are now used, which can reduce hot water supply quantity without causing detrimental effects to convenience and comfort of the users. Energy saving effects can be indicated by recent investigations and researches. Hot water saving type shower [4] and automatic hot water supply faucet are discussed here.

When a hot water saving shower is used, hot water supply quantity can be saved by 25% compared with a combination or an ordinary type shower and a 2-valve faucet. "Hot water saving shower" is defined as a shower head with water spray opening area of 40 mm2 or less, or a combination with a shower head with water stopping mechanism, combined with a mixing type faucet with thermostat or an equivalent to these. In this case, the value of V may be calculated by assuming that hot water supply per unit is reduced by 10% for guest rooms in hotels and by 5% for hospitals. For the applications in other types of buildings, adequate hot water supply quantity for shower is set and it is assumed that this quantity is reduced by 25%.

When hot water supply faucets in toilets in the commonly used portion of the building, the hot water consumption for toilets can be reduced by 40% compared with 2-valve mixing type faucet. The hot water supply quantity for the toilets is generally determined by design engineer. Similarly to the case of stores, if the number of the persons using the toilets per day is N, the value of VD is obtained as 3.8 × N (L/day). Depending on the number of the toilets using automatic faucets, the value 3.8 may reduced to 2.3 to calculate the value of V.

3.3 Procedure to calculate Qs

3.3.1 Calculation of heat loss from the hot water supply system

Heat loss from the hot water supply system is calculated by dividing to three types of heat loss: annual heat loss due to dead-end pipe Qy, annual heat loss from circulation pipe and heat source side pipe Qp, and annual heat loss from hot water storage tank Qt.

$$QLOSS = Qy + Qp + Qt \ldots (7)$$

In the following, the procedures to calculate Qy, Qp and Qt respectively are given.

3.3.2 Heat loss due to dead end piping

This pipe is to connect the hot water supply faucet with the circulation pipe. Because hot water in this pipe is not circulating, hot water temperature is decreased to the level of room air temperature within 2 – 3 hours. If water temperature is decreased, it cannot be used as hot water and must be abandoned. Thus, the energy used to produce the hot water in the dead-end pipe is wasted. When the length of the dead-end pipe is increased, heat loss is increased and more time is required until hot water comes out of the faucet. This means the loss of convenience for the users and the waste of water. Generally, design engineers do not adopt such wasteful piping plan. However, by introducing such case into the calculation, it may be useful to warn the design engineers to take special care. If the hot water temperature in the pipe is TH, the heat loss is given by:

$$qy = Ny \times cS\ [Vy\ (TH - Tw)] \ldots (8)$$

where Vy is hot water volume in the dead-end pipe (L). This value is summed up for all of the dead-end pipes in the system. It is assumed that the hot water is abandoned by Ny times. For the value of Ny, 1.0 – 2.0 is used depending on the insulation level of the dead-end pipes.

3.3.3 Heat loss from circulation pipe and heat source side pipe

Heat loss qp [kJ/day] from pipes can be obtained by the equation given below by assuming that Tp is hot water temperature in pipe, and Tap is air temperature around the pipe:

$$qp = c1 \times U \times Lp\ (Ta - Tap) \ldots (9)$$

where U represents heat loss per 1 K per 1 m of the pipe [W/mK], Lp is the length of pipe [m], and C1 is conversion coefficient [= 86.4]. For each month, these are summed up for each pipe type and pipe diameter, and the value of Qp [kJ/year] is calculated. Depending on insulation level of each pipe, the value of U is determined by the design engineer, or the data shown in the reference [2] is used. In the circulation pipe, Tp = TH. In the heat source side pipe, water temperature at boiler inlet and outlet for design is used as Tp.

Valves and flanges contained in the piping are the component parts that are not easily insulated. Because the circulation of hot water lasts for long time, heat loss is not very low. It is assumed that pipe length is 1.0 m and 0.5 m respectively when surface area will be equalized for each diameter of the pipe to be connected. If insulation is done well, the value of insulated pipe is used. If not, the value of U of a naked pipe is used, and the values are summed up by the calculation similar to the equation (9). For instance, in case of a valve with flanges, the length of the corresponding pipe is: 0.5 × 2 + 1.0 + 0.5 × 2 = 3.0 m. This is added to the length of the diameter of the corresponding pipe.

3.3.4 Heat loss from hot water storage tank

For convenience, it is assumed that hot water temperature in hot water storage tank is always equal to TH during the operation of the hot water supply system. Heat loss from the tank qt [kJ/day] is given by:

$$qt = C1 \times C \times At\ (TH - Tat) \ldots (10)$$

Where Tat [°C] is ambient air temperature around the tank, At [m2] is surface area of the tank, and C [W/m2K] is heat conductance of the tank. By summing up the values of qt for all months, the value of Qt is calculated.

3.3.5 Consumption energy of circulation pumps

To calculate consumption energy of the circulation pumps, total annual power consumption is obtained by: operating time [hour] × rated power. Then, electric power is calculated by multiplying with a coefficient to convert the power to primary energy. In a pump A for the circulation piping system in Figure 2, it is calculated by multiplication of daily operating hours (24 h), 365 days, and the rated power. Daily average conversion coefficient is set to 9,830 kJ/kWh for calculation of energy saving. For a pump B on heat source side as shown in Figure 2, total load corresponding time ETF [hour] is calculated as:

$$ETF = (Q1 + Qy + Qp + Qt)/(3600 \times QB \times EH) \ldots (11)$$

where QB is the rated output of heat source [kW]. A value of 1.5 times of ETF is set as the operating hours.

3.3.6 Intermittent operation

For the application used in daytime operation, hot water supply system operating time and stopping time per day are set. For the heat loss of (2) – (5) and Qe, only the heat loss during operation is calculated. Further, at the initiation of the operation, energy is required, which is needed to increase the temperature of the hot water in the circulation pipe, the heat source side pipe and the hot water storage tank to the level of TH. Temperature decrease in each of the circulation pipe, the heat source side pipe, and the hot water tank during the stopping time is calculated. For instance, as shown in Figure 1, hot water temperature decrement dT in case of a pipe is given by:

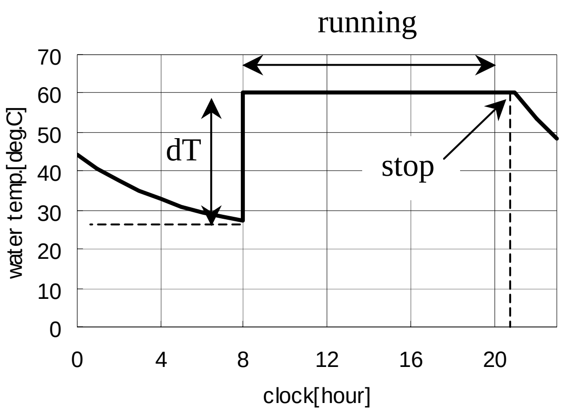

Figure 1 - An example of hourly change of hot water in pipes during intermittent operation

$$dT = (TH - Tap) \times \exp(-Bt) \quad , \quad B = U \times Lp/(cVp) \quad \ldots (12)$$

where Vp is hot water quantity in the pipe [L]. At the initiation of the operation, heat of dT × cVp for temperature increase is needed. This is calculated for all of the pipes and the hot water storage tanks. These values are summed up for a year, and this is added to QLOSS.

3.3.7 Hot water supply temperature TH and temperature of hot water actually used Tu

Normally, the temperature TH of the hot water produced at the hot water supply system is set to 60°C or more in order to prevent proliferation of Legionella bacteria. If the temperature is set to a level lower than this, energy can be saved. By confirming that there will be no problem from hygienical viewpoint, the temperature level is set to this level. In the temperature of the hot water in the pipes or in the hot water storage tanks, changes over time and spatial distribution must be considered, but it is assumed here that the temperature is constant at the level of TH for simplifying of calculation as described above.

The temperature Tu of the hot water actually used may vary according to each season or to each application, but this is also assumed as constant throughout the year regardless of the application purpose of the hot water because no adequate data is available for proper evaluation and also because seasonal difference is relatively low in the air-conditioned rooms. For safety of calculation, it is set to a level higher than the temperature of hot water at the hot water supply faucets, through which large quantity of hot water is consumed for the purposes such as showers, baths. Default value is set to 43°C.

3.3.8 Setting of ambient temperature

The values of ambient temperature Tap and Tat in the pipes and the hot water storage tanks used in (9) and (10) above are set by giving full consideration on pipe shafts and machine room conditions based on monthly outside air temperature Ta and monthly average room air temperature Tr. In case of a shaft not in contact with outside air, it may be set to the room air temperature Tr. The value of Tr is used as air temperature in an air-conditioned room. For the period from June to September, it is set to 26°C as the temperature in cooling. It is set to 22°C for other seasons.

3.3.9 Calculation of rated efficiency of heat source equipment

In case of boilers using gas or oil, the rated efficiency may be used throughout the year. In case a heat pump with air heat source is used, there may be influence from outside air temperature and water temperature, and the efficiency must be determined for each month. Thus, the first term of the equation (2) must be calculated for each month and the results must be summed up. In many cases, the heat pump is driven by electric motor. In such case, similarly to the procedure as given for the circulation pump in (5) above, it is necessary to multiply the power consumption with a coefficient to convert to primary energy.

3.3.10 Calculation example

Table 3 - Calculation results of a small-scale city hotel

Specification of hot water supply system	Rated output of boiler: QB=93X2 boilers; Boiler efficiency EB=0.78; Heat exchanger efficiency EH=0.95Hot water tank capacity 4,500 L; Rock wool 75 mm for heat insulation; Pump for circulation pipe 0.25 kW, Circulation pump for heat source 0.40 kW; 24-hour continuous operation					
Items	Q0=Q1	Qy	Qp	Qt	Qe	Qs **
Unit [MJ/year]	1.598E+06	1.120E+04	1.600E+05	2.706E+04	-	-
Primary energy*	2.130E+06	1.492E+04	2.131E+05	3.605E+04	3.819E+04	2.432E+06
Ratio to Qs[%]	87.6 %	0.6 %	8.8 %	1.5 %	1.6 %	**CEC/HW = 1.52**

* The value of Q0 to Qt divided by EB and EH is the value converted to primary energy [MJ/year].

** A sum of the above values and Qe is Qs.

In an example of calculation for a case of a small-scale hotel relying on a relatively simple heat source as shown in Figure 2, it is as summarized in Table 3. It is merely an example, but it is apparent from the table that the value of Qp is about 10% of Q0, and that each of Qy, Qt and Qe is about 1 – 2% of the value of Qs respectively.

3.4 Essential points of energy saving

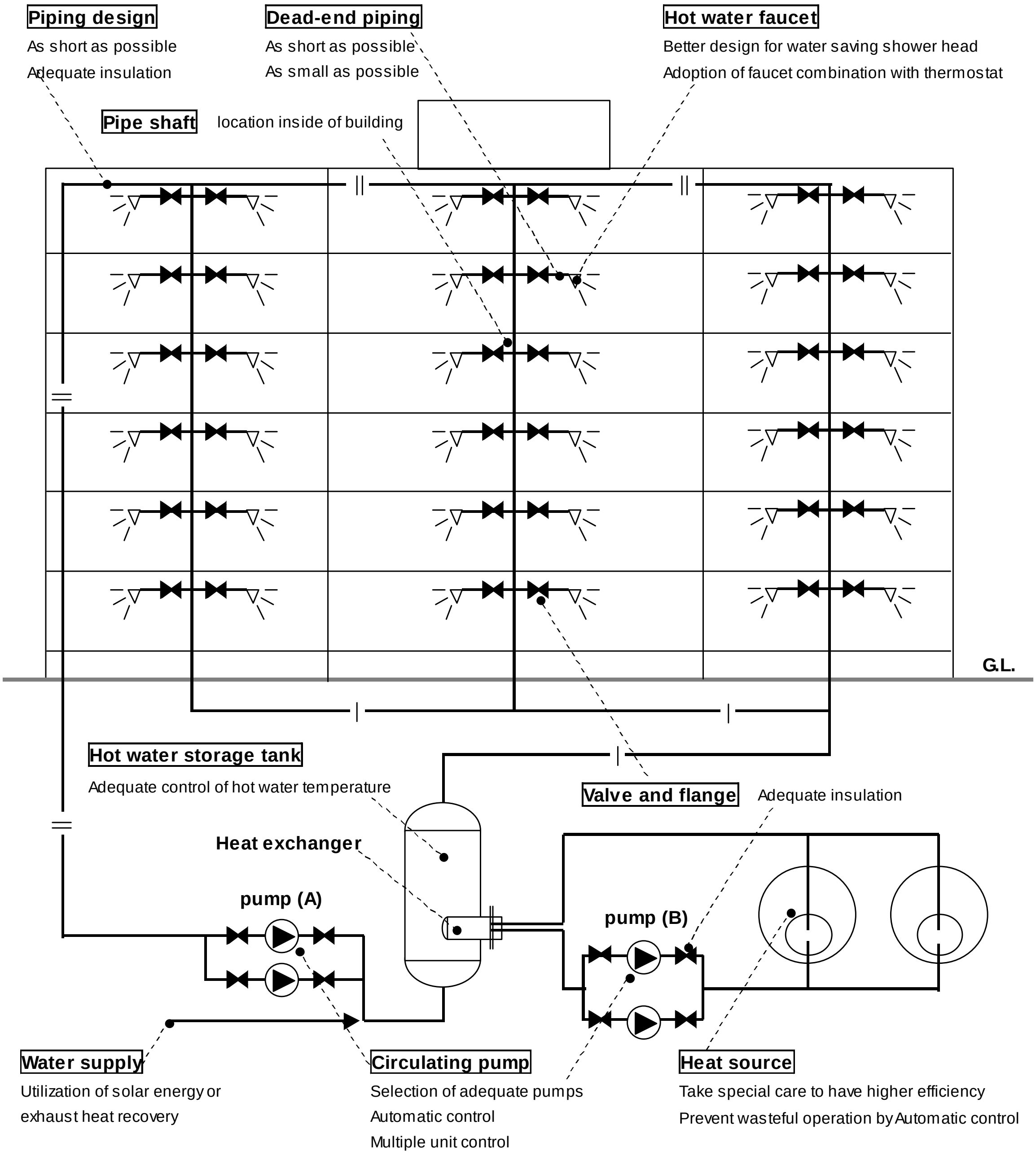

Figure 2 - Important points of energy saving in hot water supply system of a small-scale business hotel

From the above, it is possible to obtain consumption energy Qs of the hot water supply system. If essential points of energy saving for the entire hot water supply system are arranged by giving full attention on each term of QLOSS, the result is as shown in Figure 2.

4 How to determine the standard value for energy saving

4.1 Standard value for energy saving

As shown in Table 1, the standard value has been initially set for each application of the building. Large-scale, medium-scale and small-scale city hotels were selected for benchmark test. For hospitals, large-scale hospitals using steam boilers were selected and these were divided to outpatient buildings and inpatient buildings. As representative examples of cold region and warm region in Japan, Sapporo and Kagoshima were selected. As a representative example of a large city, Tokyo was selected as an area for calculation. By giving full consideration on regional features, adequate standard value was determined according to the results of case study.

In the revision of 1999, these values were decreased by about 10%. Also, for the sales stores, case study was performed using actually existing buildings, and the values were determined in similar manner. As a result, it was determined as 1.5 for hotels, and 1.7 for hospitals and stores.

In the revision of 2003, these standards were applied to all buildings for all applications. As described in 3.1 (4), hot water supply quantity per unit cannot be set for the buildings other than the hotels, hospitals and stores, and it is not possible to carry out the case study to determine the standard values of CEC/HW. Also, for the small-scale building with floor area of 2,000 – 5,000 m2, the values of Q0 and Q1 are decreased, while the value of Qs is not proportional to these values. Even after taking sufficient measures to save energy, problems have risen because the value of CEC/HW is not decreased very much and also because the standards must be set up with full consideration on the scale, and the procedure may be more complicated. In this respect, instead of setting the standard values based on the application of the buildings, it was attempted to determine the standard value of CEC/HW by finding an index to indicate property of the hot water supply system and to determine the standard value of CEC/HW from this index.

4.2 Approximation of CEC/HW

For the purpose of finding an index, which may specify property of the hot water supply system, the determinant of CEC/HW is estimated from approximation formula. In QLOSS, it is assumed that the important factors to determine consumption energy Qs for hot water supply include the hot water supply load Q0 and heat loss Qp from circulation and heat source side pipes, and also that other consumption energy increases approximately in proportion to Qp. That is:

$$Q0 = cS\,[VD\,(Tu - Tin)] = c \times dTm \times VD \quad , \quad dTm = S\,[Tu - Tin]/12 \ \ldots \ (13)$$

Here, dTm is annual average value of Tu – Tin.

The heat loss in circulation and heat source side pipes varies according to the length of pipe and insulation level. When it is assumed that adequate insulation is provided, the heat loss per unit length can be calculated through multiplication of the standard heat loss per unit length by correction coefficient based on pipe diameter, supposing that hot water temperature is at constant level. It is also assumed that heat loss other than Qp and pump power can be expressed through multiplication of the standard heat loss by a proportional coefficient. In such case, QLOSS = rqL. Here, r is a correction coefficient, q is standard heat loss per unit length, and L is the total length obtained by summing up the lengths of circulation and heat source side pipes.

From the above assumption, the value CEC/HW can be approximated from the following equation assuming that E is a product of heat source efficiency EB and heat exchange efficiency EH.

$$CEC/HW = (c \times dTm \times VD + rqL)/(E \times c \times dTm \times VD) = (1 + x\,(L/VD))/E \quad \dots (14)$$

If it is assumed that x and E are approximately constant, CEC/HW can be expressed as linear function of L/VD with x/E as a factor. Here, $x = rq/(c \times dTm)$. The values of x and E may vary according to the application of the building. However, in the design of hot water supply system with high energy saving performance, adequate upper limit value of CEC/HW may be present in response to L/VD in the buildings for all applications. This value of L/VD was used as an index to indicate the property of the hot water supply system.

4.3 Confirmation by case study and determination of standard value of CEC/HW

The cases of hotels, hospitals and stores have been used in benchmark test of CEC/HW. These cases are now utilized. Instead of calculating the cases for other applications, only the hot water supply pipes are changed in length by 0.5, 1, 2 and 3 times respectively, and calculation is made on the design conditions where energy saving measures are taken to meet the standards of CEC/HW, and the relation between CEC/HW and L/VD is assessed. This can be explained as shown in Figure 3. The values of L [m] and VD [m3/day] are selected in such manner that the value of L/VD will be an integer of two digits or so.

Table 4 – New index Ix and CEC/HW standard value

Range of Ix	CEC/HW standard value
$0 < Ix \leqq 7$	1.5
$7 < Ix \leqq 12$	1.6
$12 < Ix \leqq 17$	1.7
$17 < Ix \leqq 22$	1.8
$22 < Ix$	1.9

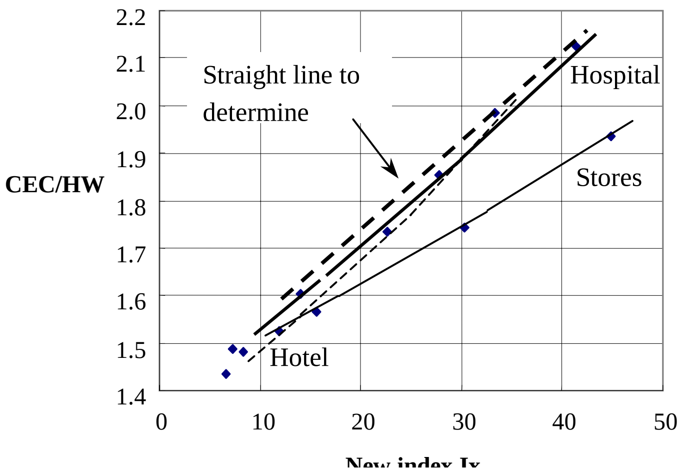

Figure 3 - The relation between index Ix based on the existing calculation cases and CEC/HW

General trend may be slightly different in the stores, for which hot water supply system is intermittently operated, while the values are similar for hotels and hospitals, and the straight line to determine the standard value is drawn to meet all of the requirements. Bases on the results of the evaluation, the index is set to Ix = L/VD regardless of the application purpose of the buildings, and the standard values are determined stepwise as shown in Table 4.

5 Conclusion

In this paper, we have thoroughly explained calculation procedure and features of CEC/HW as energy saving standard currently used in Japan and the procedure to determine the standard value. The background for adequate calculation procedure was also described. CEC/HW value is easily calculated by using spreadsheet calculation software available now.

In future, further investigation must be performed on hot water consumption and temperature of the hot water actually used. Also, the relation between CEC/HW value and consumption of energy in the building must be evaluated by the actual measurement. The procedure to evaluate energy consumption for hot water supply in private houses should be also determined.

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7 Presentation of Author

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Rainwater Use Guideline Link to Building Code in Taiwan

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Abstract

The problem of fresh water shortage is becoming a critical issue currently in Taiwan. Obviously, we need more active and powerful decision to deal with this crisis. Owing to an abundant supply of annual rainfall, an efficient use system for rainwater in building is strongly expected. This new rainwater use guideline offers a design standard for saving water and rainwater use system under satisfying to the basic demand of health, safety and amenity. It also involves a quantitative methodology to evaluate and improve the function of rainwater use system in building. This paper would introduce this new guideline and the practicable evaluation system.

Keywords

rainwater use, water conservation, guideline, design standard, evaluation system

1. Introduction

The growing pressures of fresh water shortages and pollution are becoming one of the most critical global problems. Nowadays, water conservation is an inherent pre-requisite to the sustainable provision of utility services within the building design. Taiwan National Building Code review committee recognized this imperative therefore conducted a series research for introducing a new guideline of rainwater use system for architectural design and planning work. Taiwan is located in the Asian monsoon area and has an abundant supply of rainwater with annual precipitation averages around 2 500 mm. However, water shortages still rise up to be a critical problem during the dry season.

Many metropolitan areas in Taiwan have experienced water shortages in recent years, due partly to droughts, economic development, and rapid urbanization. They have resulted in an anxious consciousness to existing water supplies and became economical barrier of development. Consequently, it is clear that alternative water resources must be investigated to alleviate water shortage problem in urban areas. The use of rainwater as a supplement for portable water supply in Taiwan has been demonstrated to be practical and promising alternative in where traditional groundwater or surface water is limited. For implementing the rooftop rainwater harvesting systems for domestic water-use, Water Resources Bureau, Ministry of Economic Affair (2000), has published the "Rainfall Catchment and Dual Water Supply System-Handbook" to provide as a reference for engineers in preliminary building design. However, it lacks comprehensive and detailed investigation the impacts of major parameters.

This paper will therefore introduce a simplified evaluation program for rainwater harvesting systems for domestic water-use and link to national building code as a new guideline and legislation. The importance of utility performance will be stressed and progressing capability that allow reliable verification for general kinds of building categories will be presented.

2. Green Building Evaluation System

Taiwan government departments are endeavoring to spread publicly the concept of water conservation. While industry and commerce have made excellent progress in water conservation, progress among the public for toilet or building water surrounds has been extremely slow. Due to the global trend, the Architecture & Building Research Institute (ABRI), Ministry of Interior in Taiwan, proposed the “Green Building Label” award system and introduced a definite evaluation method from 1998. In order to save water resources through building equipment design, this system primarily prioritizes water conservation as one of its seven categories. After four years’ performance, the assessment indexes of evaluating system are refined from seven categories to nine in 2003. Meanwhile, the water conservation is still the most critical item. The purpose of this program is not only aimed at saving water resources, but also at reducing the environmental impact on the earth.

Green Building is called Environmental Co-Habitual Architecture in Japan, Ecological Building or Sustainable Building in Europe. Many fashionable terms such as Green consumption, Green living, Green illumination have been broadly used in Taiwan currently, “Green” has been used as a symbol of environmental protection in the country. The Construction Research Department, Ministry of the Interior of the Executive Yuan, has decided to adopt the term “Green Building” to signify ecological and environmental protection architecture in Taiwan.

The evaluation system with seven-index of Green Building was carried out well in Taiwan until 2002. The mechanism of evaluation theory is based on the life cycle assessment of buildings' impacts on the environment with the interaction of “Earth Resource Input” and “Environmental Waste Output”. Figure 1 illustrates the conceptualization of this general idea. Practically, the definition of Green Building in Taiwan can simply to be described as “buildings which consume the least earth resource and create the least construction waste”. Theoretically, each country has individual way for environment assessment therefore Taiwan created a unique evaluation system for Green Building among subtropics areas. The new version of evaluation system with nine-index of green building implies not only the basic evaluation on “Low environment impact” but also higher-level issues such as biological diversity, health and comfort and community consciousness will be evaluated. This system provides a basic, practical and controllable environmental protection tool for inclusion in the government’s urgent construction environment protection policy. The “Green Building Label” is set to award the Green Building design and encourage the government and private sector to pay attention to sustainable development.

In order to solve the water problems we are developing new system and taking action. As mentioned above, the evaluating categories of our green building label are refined form

2003. Meanwhile, the authorities also intend to link new water conservation guideline into National Building Code. In architectural design, architects and engineers rely heavily on Building Code. For a long-tern inspection in sustainable development, that will be an important performance for stepping into a saving water society. The content of this new guideline is not only water cycle for toilet and water surroundings of building but also including soil water content of landscape.

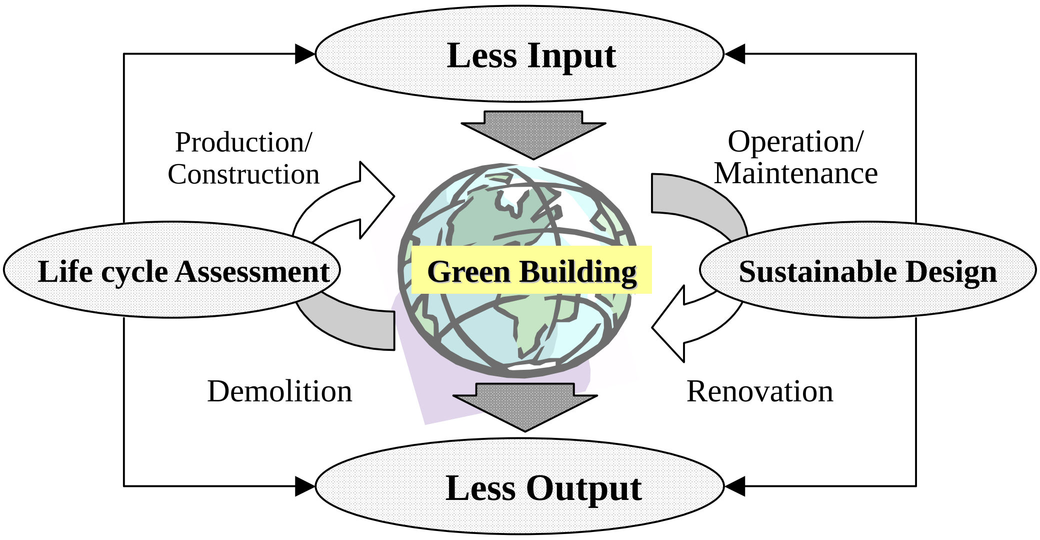


Figure 1 – Conceptualization of Green Building

3. New Provision for Building Code

Implementing water conservation is difficult if it is reliant upon achieving changes in public attitudes. However, all buildings have to comply with their governing building codes in order to receive building permits. Building permits are a way employed by public authorities to protect public safety and health, therefore building codes must specify the minimum standards to pass permit checks. Consequently, building code not only plays a role as a planning and design information provider but also has a dictating role in any architectural design. According to the growing pressures of fresh water shortages, public authorities intend to conduct the water conservation into national building codes. The main purpose of this new provision will stress on water saving and efficient water utilization under satisfying to the public basic demand of health, safety and amenity. Meanwhile, a quantitative evaluation system and practicable procedure as a guideline of rainwater harvesting systems for domestic water-use have to be determined. The new provision will be twofold as the following statement.

(1) Building facilities for water utility, which included all water closets and public faucets, have to adopt the equipment with water conservation function. The public faucets are not including the special utilities or professional performance which comply with governing confirmed procedure, such as those faucets for cleaning, watering, medical function, and etc..

(2) Architectural projects, which are with total floor area exceeding 20 000 m^2 or with site plan exceeding one hectare, have to set up the rainwater harvesting system with tap water substitution rate Rc of at least 4%. The calculation of R_c (tap water substitution rate) has to comply with evaluation system of the rainwater use guideline.

According to this new provision, an evaluation system of rainwater use as a governing guideline which can link to building code is a prerequisite to the building permits. As a quantitative evaluation system, rainfall data must be determined from the local precipitation records and transferred to be basic rainfall parameters calculated by the statistic method.

4.Rainfall Data

4.1 Long-term observations

According to the annual rainfall sequence records from the Central Weather Bureau of Taiwan, 6 measuring stations which have a sequence rainfall records for over 100 years are adopted for long-term precipitation observation and analysis. The long-term variation from 1901 to 2000 is shown in figure 2. The feature in Taiwan rainfall sequence records implies a regular variation pattern and plenty-dry cycle of about 10-20 years. Overall review in this long-tern observation, the variation tendency is neither decreasing nor increasing, namely the total rainfall situation in Taiwan is almost unchanged in this long period of 100 years. The results seems not to reflect the public consciousness and anxious in water resource which is caused by water shortage in recent years, hence series of research in individual measuring station variation tendency have progressed from initial sequence observation. Table 1 shows the individual feature of 14 selected measuring stations. We found that some areas mostly in northern and eastern part of Taiwan are of increasing tendency and some areas mostly in western and southern part of Taiwan, which have more metropolitan areas and comparable high density of population, are of decreasing tendency. Consequently, these individual areas variation tendency dominate the public consciousness. These results also closely meet the conclusion of previous researches and authority's documents. Furthermore, the growing demand for domestic water use in urban areas and the difficulties in building new reservoirs are also critical factors.

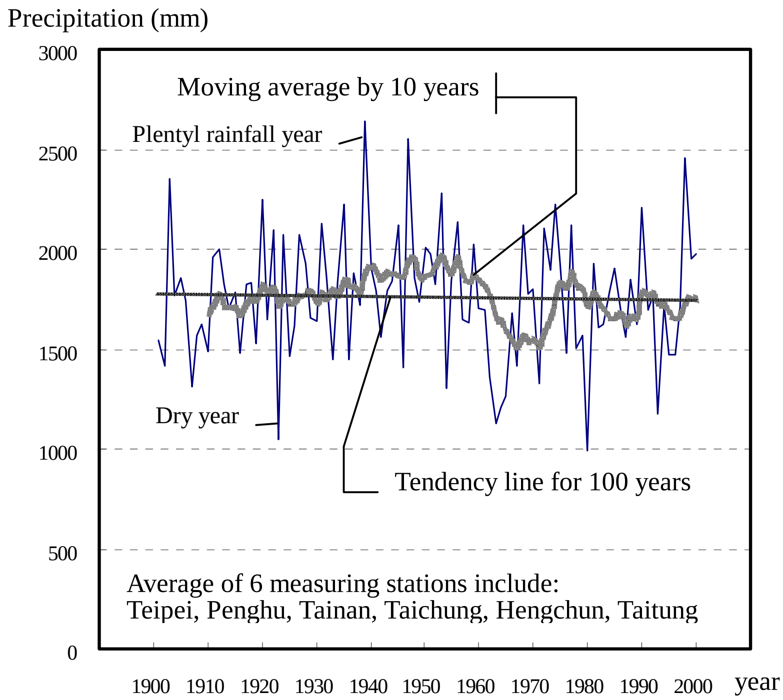


Figure 2 - Long-term precipitation observation (1941-2000)

Table 1 - Individual areas precipitation variation tendency (1901-2000)

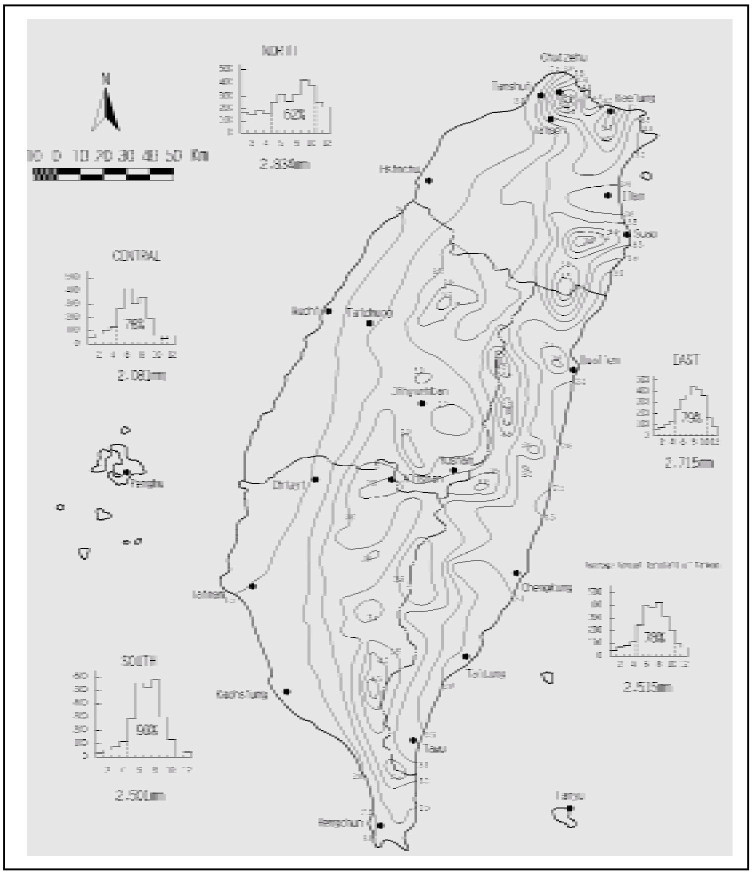
Average	Taipei	Keelung	Hualien	Ilan	Penghu	Tainan	Kaohsiung
In 100 years	2123.7	*	*	*	996.8	1736.2	*
In 50 years	2198.7	3727.1	2159.3	2797.6	962.6	1636.2	1707.9
In 30 years	2324.7	3755.0	2156.8	2815.2	950.6	1673.9	1784.8
In 10 years	2404.9	3708.8	2139.0	2861.5	885.0	1706.2	1846.4
In 5 years	2787.1	4144.6	2381.0	3230.3	1001.0	1749.5	1998.5

Average	Chiayi	Taichung	Alishan	Hsinchu	Hengchun	Jihyuehtan	Taitung
In 100 years	*	1701.3	*	*	2168.4	*	1830.1
In 50 years	*	1636.4	3898.4	1721.4	2064.4	2349.5	1841.0
In 30 years	1725.9	1647.3	3909.6	1782.8	2015.8	2397.2	1855.9
In 10 years	1706.6	1622.9	3586.7	1596.3	2018.7	2244.2	1807.4
In 5 years	1853.0	1788.9	3758.5	1714.0	2259.1	2470.9	1905.6

* No data

4.2 Zoning for Regulation

Nowadays, over than hundreds of rainfall measuring stations are built up in Taiwan for many purposes, however, only the records of authorities or public sectors are confirmed and adoptable. According to annual rainfall records published by Water Resources Bureau, Ministry of Economic Affair in 2000, the average annual rainfall for Taiwan is about 2 512 mm. The average annual rainfall for the northern parts is about 2 934 mm, with about 62% in wet season (between May to October). The conditions of other areas are central part about 2 081 mm with about 78% in wet season, southern part 2 501 mm with 90% in wet season, eastern part 2 715 mm with 78% in wet season as shown in figure 4. So far, the northern and eastern part of Taiwan, subject to the seasonal influence of northeasterly wind, is usually dry in summer and wet in winter. Majority of rainfall is concentrated in June to August in the southern part of Taiwan due to typhoon; winter is usually dry and lack of rainfall. Spatial and temporal rainfall variation becomes larger towards the southern part.



Sources: Water Resources Bureau, Ministry of Economic Affair, Hydrological Year Book, Taipei, Taiwan, R.O.C.(2000)

Figure 3- Average annual rainfall isohyets map of Taiwan

In practical application for evaluation guideline, the precipitation zoning is schematically arranged due to the average annual rainfall isohyets map as shown in Figure-3. As a governing tool, the zoning arrangement must due to the districts for regulation therefore the major precipitation zoning is roughly divided into three level with A, B and C. A zone is high precipitation area with record above 3000 mm; B zone is middle precipitation area with record 2001-3000 mm; C zone is low precipitation with record below 2000 mm. Each zoning area has correspond measuring station and can offer reference data sequence for rainwater system evaluation. The zoning diagram and location of measuring station are shown in Figure-4.

Zoning	Measuring Station
High **(A)** (□3001mm)	A1 Keelung
	A2 Ilan
	A3 Suao
	A4 Yushan
	A5 Alishan
	A6 Lanyu
Middle **(B)** (2001-3000mm)	B1 Chutzehu
	B2 Tanshui
	B3 Taipei
	B4 Jihyuehtan
	B5 Hengchun
	B6 Tawu
	B7 Chengkung
	B8 Hualian
Low **(C)** (< 2001mm)	C1 Hsinchu
	C2 Wuchi
	C3 Taichung
	C4 Chiayi
	C5 Tainan
	C6 Kaohsiung
	C7 Taitung

Figure 4- Zoning due to district for regulation

5. Evaluation method

In the past rainwater use system is mostly an empirical technology for building designer or engineer. The equipment for application may include collection facilities, piping, treatment and storage device. The quality of rainwater is adoptable in many ways of water use besides drinking. In order to encourage people adopt this system, an evaluation method and guideline for rainwater use in building is necessary. Tap water substitution rate may be described as acceptable category for evaluating system efficiency. Herein, the tap water substitution rate R_c can be defined in terms of substitution volume and water demand, i.e. R_c equals to W_s divides by W_t, hence we offer an convenient evaluation method for practical application.

5.1 Calculation

Owing to the "daily" water utilization are adopted as reference for public consciousness, rainwater use index should be set as daily reference for simplified methodology. Firstly, tap water substitution volume must be confirmed from planning process. The tap water substitution volume (W_s) is decided by two conditions. The one is daily rainwater use volume (W_d), which is the flexible results up to design requirement and may be expressed as the following equation.

$$W_d = \Sigma UR_i \qquad (1)$$

The other condition is daily rainwater collection volume (W_r), which is limited by local precipitation and the determined collection area may be expressed as a function of the following parameters:

$$W_r = (R_d \times P_d \times A_r) \qquad (2)$$

where parameters R_d and P_d are determined by local precipitation, and A_r is up to the design requirement. The local precipitation parameters R_d and P_d are pre-arranged in Table 2 for application. The parameters are arranged by free precipitation database cited from the Central Weather Bureau of Taiwan with 10 years sequence data from 1991 to 2000. The tap water substitution volume (W_s) must adopt the less one between the daily rainwater use volume (W_d) and collection volume (W_r). That is

if $W_r < W_d$ then $W_s = W_r$

or $W_r > W_d$ then $W_s = W_d$

where parameter W_d may be determined by design requirement and W_r may be calculated from reference of local precipitation as shown in Table 2 and Table 3. For a simplified evaluation index therefore the tap water substitution rate (R_c) may be expressed as the following equation.

$$R_c = W_s \div W_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

where parameter W_t is the total water demand of the application building. Technically, the total water demand of building is dependent upon building category and scale. For an evaluation method as guideline standard it must be postulated that calculation is in a prescribed database. A prescribed calculation database have progressed from initial empirical studies through to the previous researches and reviews, hence those data are shown in table 3.

5.2 Minimum provision for storage tank

The evaluation mechanism of tap water substitution rate for rainwater use system is now clarified, however, as a practical provision in building design process the minimal volume for rainwater storage tank must be regulated. Therefore, a rational multiple number of daily rainwater use volume (N_s) is developed to be a determined parameter that endows the minimal volume of rainwater storage tank can reflect the feature of local precipitation in this evaluation system. The minimal volume of rainwater storage tank (V_s) may be expressed as the following function.

$$V_s = Ns \times W_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$N_s = 3.0 \div P_d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

List of symbols and definition used in Formula (1)~(5) and Table 3

A_r	rainwater collection area (m^2)	V_s	volume of rainwater storage tank(m^3)
N_f	the numbers of dwelling families	W_d	daily rainwater use volume (l/day)
N_s	multiple number of daily rainwater use volume due to empirical function	W_f	water demand for individual building category (l/ m^3/day)
P_d	probability rate of raining (-)	W_r	daily rainwater collection volume (l/day)
R_c	Tap water substitution rate (-)	W_s	tap water substitution volume (l/day)
R_d	daily precipitation of site(mm/day)	W_t	daily total water demand of the application building (l/day)
UR_i	rainwater use volume dependent on the design requirement or confirmed purpose with due devices (l/day)		

Table 2- Prescriptive database from authority's stations, Taiwan (1991-2000)

Zoning category		Measure station							
A: High precipitation	Statistic items	A1	A2	A3	A4	A5	A6		
	Rd(mm/day)	10.16	7.84	12.96	7.57	9.83	8.45		
	P_d (-)	0.534	0.541	0.475	0.355	0.440	0.499		
	Ns	5.62	5.55	6.32	8.44	6.82	6.02		
B: Middle precipitation	Statistic items	B1	B2	B3	B4	B5	B6	B7	B8
	Rd(mm/day)	11.20	5.53	6.59	6.15	5.53	6.27	5.84	5.86
	P_d (-)	0.450	0.339	0.463	0.427	0.296	0.299	0.331	0.400
	Ns	6.66	8.84	6.48	7.02	10.12	10.02	9.06	7.49
C: Low precipitation	Statistic items	C1	C2	C3	C4	C5	C6	C7	C8
	Rd(mm/day)	4.37	3.39	4.45	4.68	4.67	5.06	4.95	2.42
	P_d (-)	0.315	0.198	0.312	0.273	0.233	0.251	0.330	0.235
	Ns	9.53	15.15	9.63	10.97	12.87	11.94	9.10	12.78

Source: the Central Weather Bureau of Taiwan

Table 3 – The prescriptive reference of water demand for due building category

Category	Type/scale	W_f [*2] (l/m^2□day)	W_t (l/day)
Office[*1]	Reserved typical use	7	W_t $W_f \times A_f$ (m²) Where A_f would not include the non-dwelling area for parking, machine, storage, lobby, stair, …..etc..
	Composite use	9	
Commercial building	With restaurant	20	
	Without restaurant	10	
Hotel	Business hotel	15	
	Typical hotel	20	
	Resort hotel	25	
Hospital	Dispensary/Sanatorium	15	
	General hospital	21	
	Teaching hospital	24	
School	Administration/Teaching	10	
	Others	Same as others category	
Dormitory	----	10	
House	W_t = 250(l/person/day)×4(person/family) ×N_f, where N_f is parameter of assumed typical family with 4 person.		
Others	Evaluation is dependent upon the practical water demand.		

*1. Office is one kind of commercial building and which of composite use type is with coffee shop, restaurant or other commercial function.
*2. Parameter of water demand for per floor area per day W_f is empirical data from existed document and investigation.

5.3 Procedure of evaluation

The calculation system of rainwater use evaluation for building design is now well understood and would be adopted in building regulation. Figure 5 illustrates the flow chart of evaluation procedure by four schematic steps. Firstly, we have to arrange the basic data and documents for the evaluation process including site location, building scope, total floor area, rainwater collection area, weather data, and etc. Then a series calculation and condition have to be set from initial design concept through to the development of a comprehensive decision-making step by step as shown in Figure-5.

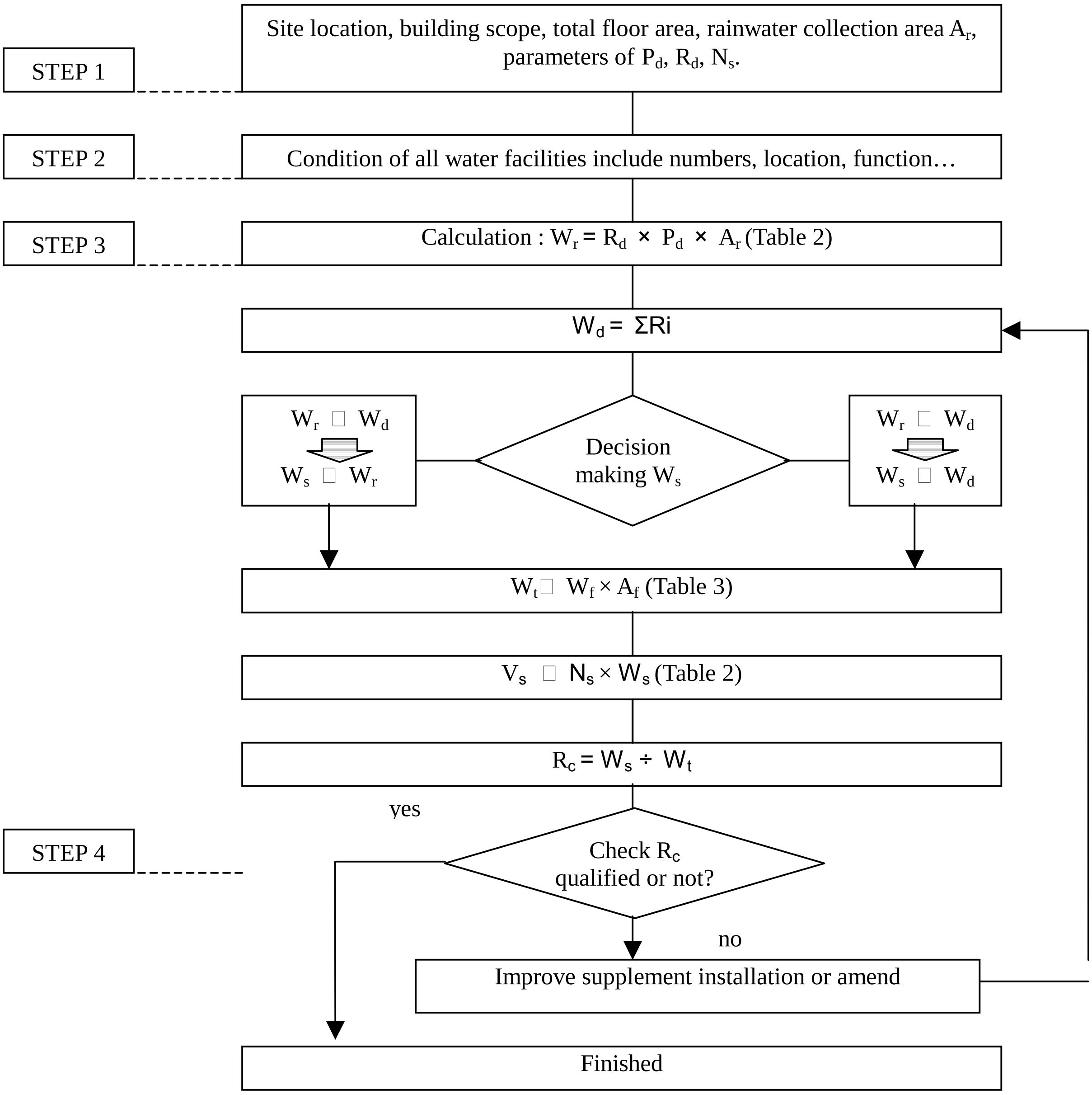


Figure 5 - Evaluation procedure and flow chart

6. Verification

As a guideline and reference for building code to do planning and design work, the proposed legislation needs to be confirmed for specifying the minimum standards and the evaluation procedure must be practicable. Three categories of buildings were used in broader study as the following content.

6.1 Dwelling houses case

The first case of dwelling house is located in suburban districts of Taipei with totally 200 inhabitant units. The general data of this case is site scope of 0.9 hectares with 22 500 m^2 of total floor area, construction-covering rate of 60% and cubical capacity rate of 250%. Figure 6 is the site plan of these dwelling houses.

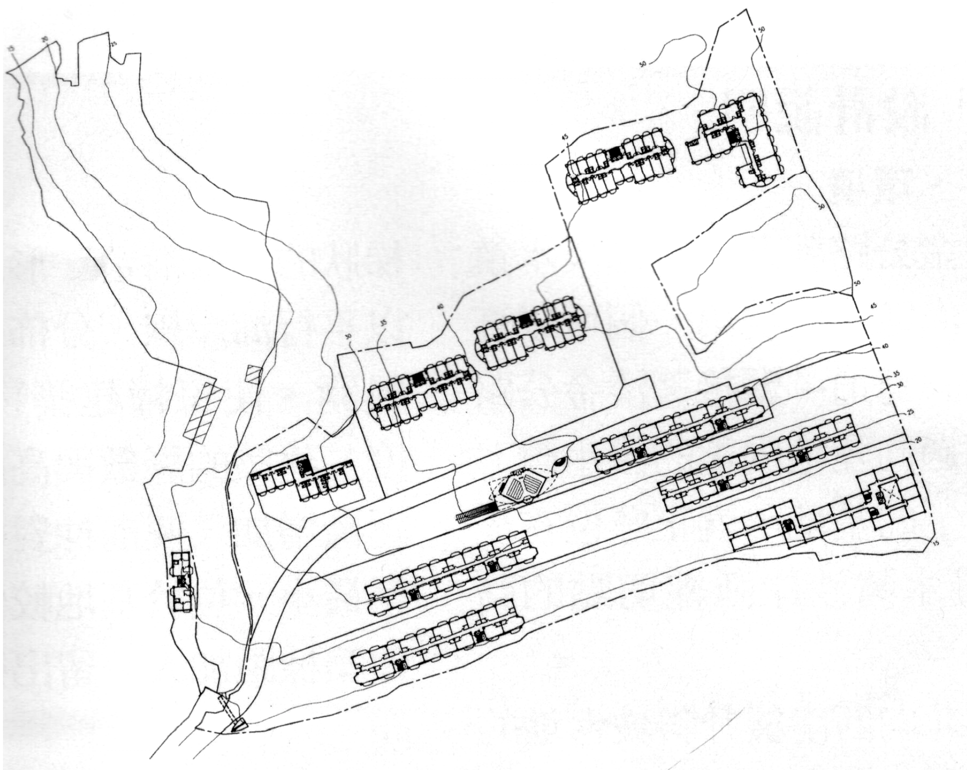


Figure 6- The site plan of dwelling house case

According to the provision of new building regulation, this case is of total floor area over 2 000 m^2, hence it must set up a rainwater use system with tap substitution rate (R_c) above 4%. The rainwater use system is requested for a supplement fitting to reduce environmental impact. Consequently, this dwelling house case fit a rainwater use system

with substituting tap water for gardening and cleaning. Within the dwelling house tap water for gardening and cleaning is assumed as 20 l/day for prescriptive reference, which has possession of 8% within assumed total 250 l/day for an inhabitant. The rainwater use system is therefore qualified due to the substitution volume of 20 l/day for gardening and cleaning.
Concerning the rainwater collection area setting is 5 000 m^2 of total roof area due to the construction-covering rate (60%). The calculation procedure may be expressed as following description.

$W_r \square R_d \times P_d \times A_r \square 6.59 \times 5\,400 \times 0.463 \square 16\,476$ l/day
$W_d \square 20 \times 800 \square 16\,000$ l/day
As $W_r \square W_d$ then $W_s \square W_d \square 160\,00$ l $\square$ 16 m^3
$Vs \square N_s \times W_s \square 6.48 \times 16 \square 104$ m^3
$R_c \square W_s \div W_t \square 16\,000 \div \square 250 \times 800 \square\square 0.08 \square 4 \square$ (OK)

Therefore, the tap water substitution rate of this case passes the standard and can be qualified for administration procedure.

6.2 Commercial building case

The second case of commercial building is a office building located in central district of Taichung city with eight floors height and three floors basement. The general data of this case is of site scope 3 000 m^2 and 21 000 m^2 of total floor area, construction- covering rate of 80% and cubical capacity rate of 650%. Figure 7 is the site plan of this commercial building case.

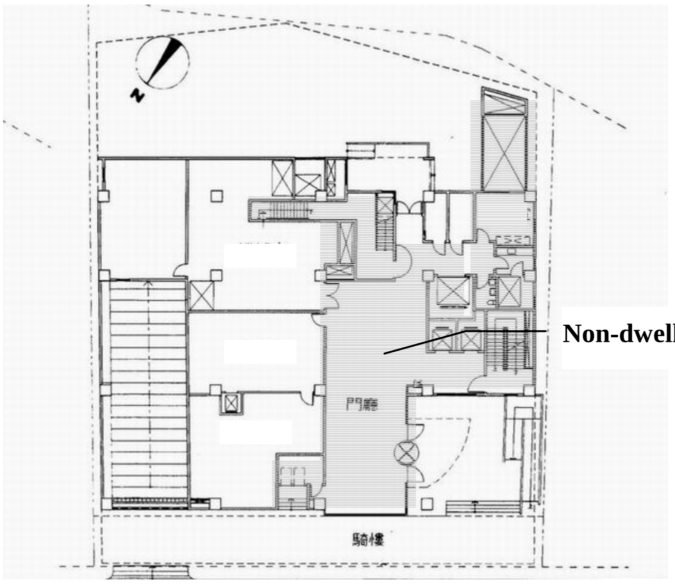


Figure 7 -The site plan of commercial building case

The same as the first case, this building is of total floor area over 2 000 m^2, hence it must set up a rainwater use system with tap substitution rate (Rc) above 4%, namely a supplement fitting of rainwater use system is necessary. Consequently, this office building built a rainwater use system with substituting tap water for partial water demand of w.c. The rainwater collection area setting of this case is 2 400 m^2 of total roof area due to the practical construction-covering rate. Firstly, the water demand can be determined by the product of total floor area and standardized unit water demand from table 3. For a practical investigation in this office building and due to the prescribed data, the basement of 2 500 m^2 per floor and the non-dwelling area of 4 100 m^2 could be take out from the total floor area. The calculation procedure may be expressed as the following.

$$W_t = 7 \times (21\,000 - (2\,500 \times 3) - 4\,100) = 65\,800 \text{ l/day}$$

Assumed 50% of water demand is utilized in w.c., 30 000 l/day can be set for replacing by rainwater. Then,

W_d □ 30 000 l/day
W_r □ $R_d \times P_d \times A_r$□□□4.45 × 2 400 × 0.312□□ 3 332 l/day
as W_r □ W_d then W_s □W_r □ 3 332 l/day □ 3.33 m^3/day
V_s □ $N_s \times W_s$ □9.63 × 3.33 □ 32.068 m^3/day
R_c□ $W_s \div W_t$ □ 3 332 ÷ 68 000□ 0.051 □ 4□ (OK)

Therefore, the tap water substitution rate of this case passes the standard and can be qualified for administration procedure.

6.3 School building case

The third case of school building is located in Kaushon city the southern part of Taiwan. The general data of this case is of landscape scope 3.5 hectares and 10 200 m^2 of total floor area, the building area is 4 000 m^2 and 600 persons of students, teachers and staffs. Figure 8 is the site plan of this school case.

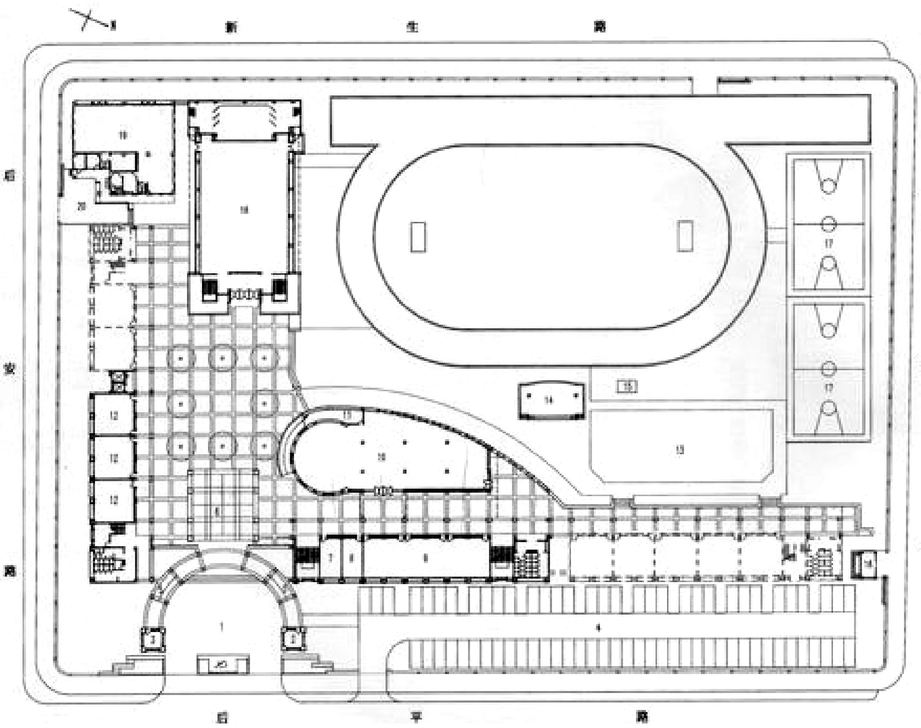


Figure 8 - The site plan of school case

According to the proposed legislation, this school site scope area is of over 2 hectares, hence it must set up a rainwater use system with tap substitution rate (Rc) above 4%, namely supplement fitting of rainwater use system is necessary in this case. Consequently, this school built a rainwater use system with substituting tap water for gardening and cleaning. Within the school building the prescribed tap water demand can be determined by product of total floor area and standardized unit water demand from table 3. The calculation procedure may be expressed as the following.

$$W_t = 10 \times 10\,200 = 65\,800 \quad \text{l/day}$$

Assumed 40% of water demand is utilized in school gardening and cleaning, therefore 26 000 l/day can be set for substitution by rainwater. Then,

$W_r \square R_d \times P_d \times A_r \square 5.06 \times 4\,000 \times 0.251 \square 5\,080$ l/day

$W_d \square 26\,000$ l/day

As $W_r \square W_d$ then $W_s \square W_d \square 5\,080$ l/day $\square$ 5.08 m^3/day

$V_s \square Ns \times W_s \square 11.94 \times 5.08 \square 60.66\ m^3$/day

$R_c \square W_s \div W_t \square 4\,800 \div 65\,800 \square 0.073 \square 4\square$ (OK)

Therefore, the tap water substitution rate of this case passes the standard and can be qualified for administration procedure.

7. Review

The introduction of an evaluation procedure into the calculation method requires a prescriptive reference of water demand for every building category. Table 3 pre-arranged the parameters of general building category water demand with per square meter of floor area and per day, which is empirical data from existed document and investigation. Each applied case can conveniently get the total water demand from individual floor area. Herein, the total floor area A_f would not include the non-dwelling area such as those for parking, machine, storage, lobby, or stair. However, the buildings, which are not included in the listed category such as museums or auditoriums, can submit a appropriable water demand for application. On the other hand, the water demand is not correlative to the floor area in dwelling house category is well understood therefore dwelling house is prescribed upon per person per day with criterion value of 250 (l/person/day) and four members in one family.

The reason why tap water substitution volume (W_s) must adopt the less one between the daily rainwater use volume (W_d) and collection volume (W_r) is a rational consideration for practical performance. If the daily rainwater use volume larger than collection volume will lead to unsatisfied situation, and on the contrary the surplus rainwater will overflow and waste away therefore not benefits to the owner or environment. Rainwater as a substitution water resource is prohibited as drinking water or high quality requested utilization. Consequently, tap water substitution rate of dwelling house may not exceed 32% as shown as table 4.

Table 4- Dwelling house water demand estimation for each purpose (l/day/person)

Purposes /demand	Irreplaceable rate 68□				Replaceable rate32□			
	Shower	Wash	Basin	Kitchen	W.C	Cleaning	Others	Total
Daily average	50	60	20	40	60	10	10	250

Within the application of rainwater use system storage tank volume is considerable parameter for the utilization efficiency. Herein, the minimum criterion volume is set through the product of tap water substitution volume (W_s) and multiple number of daily rainwater use volume (N_s). The parameter N_s implies a feature reflection of rainfall variation for individual districts such as larger storage volume for comparable dry area or smaller volume for plenty rainfall area. The accurate calculation for rainwater collection volume and tap water substitution rate is seen as an inherent program through rainfall dynamic analysis and demand feedback process. In this research we offer a simplified scheme through daily raining probability to progress the evaluation procedure in new guideline for water conservation. This system also reveals the real situation that the utilization of rainwater in northern part of Taiwan is more advantageous than the southern/western part of Taiwan.

8. Conclusion

Green Building evaluation is a life cycle assessment system in which water conservation is prioritized as one of its nine categories for saving water resources through building equipment design in Taiwan. Water conservation as a prerequisite to the sustainable built environment is a long-term consideration for designer. We have to take actions in water conservation for solving our problems and recognize the imperative of globalization issues. Owing to an abundant supply of rainwater, an efficient use system for rainwater in building is strongly expected in Taiwan. This paper introduces a new guideline for rainwater use and evaluation methodology. A quantitative and practicable evaluation system is identified to be important step for linking to building regulation, and more related research needs to be conducted.

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Main author presentation

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Sculptural water elements of traditional buildings in central and southeastern Anatolia

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Abstract

Dry regions of Anatolia often suffered shortage of precipitation and lack of water. Piped water was very valuable and only available in street fountains, Turkish baths and large residences. Hence, special care was given for the design of water sources and surfaces in public and private buildings. This paper deals with private fountains, *selsebil*s, decorative tiny channels on horizontal surfaces nearby pools, decorative interior and exterior pools in town and summer resort houses as well as gargoyles in central and southeastern parts of Anatolia. In all these examples, stone or marble was used masterfully and exhibit simple but sculptural expressions of beauty, carrying some features from Hittites, Romans and Seljuks.

Keywords: Central and southeastern Anatolia; fountains; pools; *selsebils*; gargoyles.

1 Introduction

Architectural water elements like gargoyles, fountains, as well as pools and *selsebil*s used as microclimatic devices in rooms and courtyards exhibit certain sculptural character in most parts of Anatolia, but especially in the central and southeastern parts. Stone is widely used in traditional buildings in most parts of the country; in fact, with the exception of the Black Sea and Marmara regions as well as some forested areas, it used to be the major building material. It is used so widely and masterfully in the central and southeastern regions that floors, even roofs turn into stone; stone in arches, vaults and domes is regularly utilized. Although some of the architectural and decorative elements like projections of various kinds, pedestals supporting overhangs, columns, capitals, balustrades, scalactics, bird houses and many inscriptions or decorative surface carvings may not be considered as pure sculptures in the western sense, they all exhibit sculptural features and extraordinary stone workmanship. Remnants and traces of a long tradition of Roman and Seljuk architecture can easily be observed in many of the traditional stone buildings in Turkey (İmamoğlu, 1980, 1992).

Central and southeastern Anatolia in general have an arid climatic character. Due to poor plant cover on the ground and low levels of annual precipitation (which varies between 400 to 800mm. a year), these regions have cold winters and hot summers. Since relative humidity is 30 percent or lower and hence, the diurnal temperature differences are high, traditional buildings exhibit the architectural character of arid regions: Houses are formed around courtyards and they all have flat, earthen roofs; thick stone or mudbrick walls, small openings generally protected by shutters (İmamoğlu, 1980). Among the two basic building materials, stone is used in cities and mudbrick in rural areas. But in all of the buildings, gargoyles are utilized to eliminate the precipitation falling on roofs.

Apart from northern Anatolia, the coastal regions and high plateaus in the east of Turkey, a great portion of the country has hot and dry summers with intense solar radiation, low relative humidity and extreme diurnal temperature variations for the whole summer. In order to increase relative humidity and create livable microclimatic environments, people utilize evaporative cooling effects of water wherever possible. This requires design of water surfaces, pools, decorative channels and fountains in and around buildings.

This paper examines the use of water in dry regions of Anatolia from 13th century until the 1950s and gives examples of water elements of traditional buildings which were surveyed by the first author through four projects as well as three M.Arch. theses supervised in the Department of Architecture on the same subject: 1. A survey of houses and settlements that was started in 1978 in Diyarbakır, Mardin, Gaziantep, Şanlıurfa and dry regions of Turkey-mainly southeastern Anatolia-. 2. Survey of traditional town houses in Kayseri that started in 1986. 3. Survey of summer resort houses in Kayseri that started in 1992. 4. Survey of the village of Gesi and settlements in its vicinity nearby Kayseri, that started in 2001. All of these surveys aimed to understand and record living conditions of people, principles of settlements, general characteristics of houses, interior and exterior space usage as well as architectural components of buildings.

2 Fountains and wells

The most common type of water fountains in Anatolia is public fountains which are generally located on streets. They are usually self-standing structures in a strategical location in a neighborhood or in a small square. Sometimes they are built as parts of a mosque or a building complex. Although such fountains may have a number of sculptural features, they are independent public buildings themselves and need to be examined as separate structures as Önge has done (1997). Hence, they will not be considered here. This paper illustrates fountains of smaller scale in private domains of houses and *konaks*, generally located in courtyards. Various sources illustrate several elegant examples of such fountains from Şanlıurfa (Akkoyunlu 1989; Ören 1996), Gaziantep (Onat 1992) and Diyarbakır (Tuncer, 1999). Here only fountains recorded by the authors are presented (Figures 1 & 2).

Figure 1- Marble fountain of Balaban Konak, in Hisarcık -a summer resort of Kayseri- built between 1916-18 (İmamoğlu, 2001, p.219).

Figure 2- A garden fountain reused in a contemporary house in Ankara. 19th century.

Wells are also common in these two regions (Akkoyunlu, 1989; Kürkçüoğlu, 1992). While the ones used in central Anatolia are headed by simple and straightforward stone wellheads in various geometric forms, they are further elaborated in southeastern parts. What usually happened was that an extra canopy or a special fancy structure of columns, arches even domes were employed to cover the wellheads and emphasize the physical as well as symbolic importance of water in such locations. In some of the houses in Şanlıurfa for example, a special design of columns and an arch define the top of the well, usually to accommodate a pulley system for pulling water (Figure 3), or a self-standing structure covered by a dome to define and honor the location of the water (Figure 4).

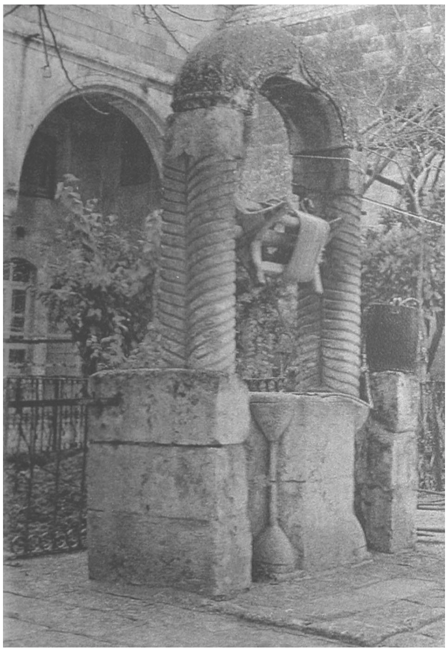

Figure 3- A decorative arch supported by split spiral columns used on top of a well of a Şanlıurfa house. 19th century (Kürkçüoğlu, 1992, p. 70).

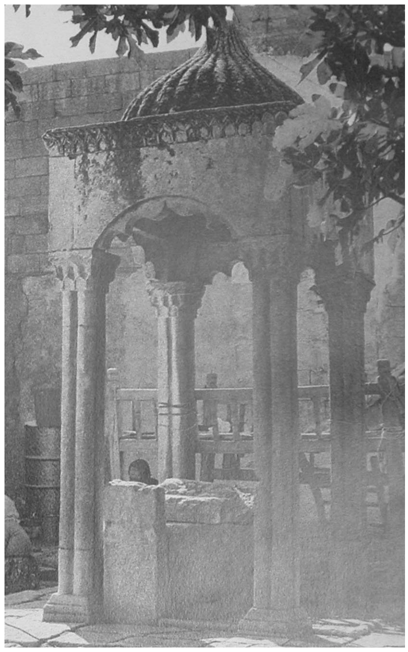

Figure 4- A dome carried by quadripartite colonnettes over the well of Mehmet Kandıran House in Şanlıurfa (Kürkçüoğlu, 1992, p. 71).

3 Selsebils

Selsebil (or *selsal* or *su mihrabı)* is a kind of ornate fountain in an interior or exterior space with water running down a marble or ceramic surface and terminating in a bowl or a small pool underneath (İmamoğlu, 1980; Önge 1997). While the water slides or pours down, it splashes and creates a pleasant sound; its ondulating movement reflects the changing light and creates play of color; additionally it evaporates and helps the room or the surroundings to cool down. Selsebils were used in institutional as well as domestic architecture in Anatolia since 13th century in living rooms, *sofa*s, *köşk*s, courtyards or gardens. When it is used in a room, it becomes the focal point of the room; if used outside, it attracts the attention of people and creates an aura around it.

Earliest examples of selsebils are composed like a *mihrap*, the center of it being a decorated sloping surface surrounded by tiny columns, capitals and corniches. Selsebil in the north eyvan of Marufiye Medrese (or Beyt-ül Artuki) in Mardin was built in 13th century, probably by Artukoğulları (İmamoğlu, 1980; Önge 1997). Water pours down the sloping surface decorated with black, white and colored mosaics (Figure 5). Later examples of selsebils, especially the ones built between the 18th and 19th centuries were designed as part of a vertical wall. They were generally made of a large white marble "mirror" (main surface) framed with decorative figures and profiles, with a series of symmetrically arranged cantilevered bowls at different levels. The pouring water from the bowl at the top, filled and splashed towards the bowls at the lower levels and collected in the small pool at the ground or floor level (Figures 6 & 7).

Figure 5- Selsebil of Marufiye Medrese in Mardin. Construction date: 13th century. Greyish sloping surface was embedded with fine black, white and colored marble pieces (İmamoğlu, 1980, p.48).

Figure 6- Selsebil of Mevlana Dergah/complex (now Mevlana Museum) Konya. 19th century.

Figure 7- Selsebil of Zennecioğulları Konak (a), and its detail (b), Kayseri. Although three central bowls stayed in their positions, all of the eight side bowls were dismounted in time. Zennecioğulları Konak was constructed in 1573 but the selsebil might have been sculpted and erected a little later, perhaps by an artist from İstanbul, for it resembles very much the selsebils and fountains in İstanbul. Additionally a similar opinion was stated by Çakıroğlu (1952, p.33).

4 Pools and water jets

Wherever water is available, small pools or water elements are provided within courtyards or gardens. Although having a pool was highly desirable for central regions, it was a must for southeastern Turkey: A pool and a planted area were essential parts of courtyards in Şanlıurfa, Diyarbakır and Gaziantep (Akkoyunlu, 1989; Onat 1992; Ören 1996; İmamoğlu 1980). Regardless of the size of the house, at least a pool and some greenery exist and make the court climatically and psychologically more livable (Figures 8, 9 & 10).

Figure 8- Courtyard pool in front of the eyvan of a house in Şanlıurfa. 19th century.

Figure 9- Courtyard pool of a house in Gaziantep. 19-20th century.

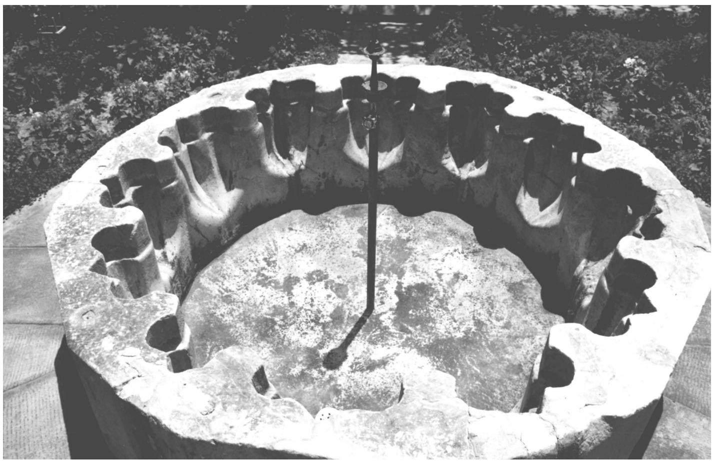

Figure 10- Pool in the garden of Karatay Medrese, Konya (This pool was originally in the men's section of Türbe Bath-house but later moved to its present location).

Water games or intricate arrangements of tiny channels for the flow of water was also widespread. Water coming from a source was directed to a pool by the help of such arrangements. The geometry and the order of such designs resemble those of earlier Anatolian civilizations like Seljuk, Roman and even Hittites (Figures11 &12).

Figure 11. Decorative tiny channels leading to the pool of the harem section of Güpgüpoğulları Konak, Kayseri. Construction date: 1419-1497.

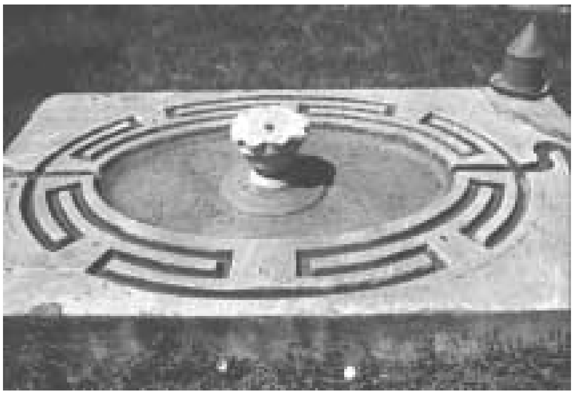

Figure 12. Garden pool of Cimcimler Konak in Meram summer resort of Konya, 19th century.

Pools are not restricted to courtyards only; in some buildings there are interior pools as well. In large houses or *konak*s, rooms, *eyvan*s or *köşk*s used in summer time were equipped with small pools too. The cool room of Cahit Sıtkı Tarancı House in Diyarbakır has a decorated circular pool in the middle of the floor (Figure 13). A similar approach can be seen in some of the summer resort houses in many parts of these regions, where evaporative cooling and psychological effects of water was extensively used. For example lower floor *köşk* of a summer resort house in Talas illustrates such an example: An octagonal, shallow small pool with sculptural quality decorates the center of a semi-circular floor (Figure 14). It is surrounded by stone sitting platforms, generous openings; all architectural elements acting in a tectonic manner, forming almost a monolithic stone sculpture.

A different approach is seen in Cimcimler summer resort house in Konya. Parallelling the long tradition of Turkish ceramic tile usage, a rectangular pool in the summer living room (*köşk*) was designed with turquoise tiles of floral figures (Figure 15).

Figure 13- Cool room and the small pool (called *şadırvan*) of Cahit Sıtkı Tarancı House, Diyarbakır (İmamoğlu, 1980, p. 48).

Figure 14- Interior pool at the ground floor of Devir Köşk in Talas, Kayseri. Construction date: 19th century (İmamoğlu, 2001, p.70).

Figure 15. Turkish tile covered pool of the summer living room (*köşk*) of Cimcimler Konak in Meram, Konya.

When a pressure difference was possible in supplied water, pools were equipped with water jets. Generally a number of marble bowls were erected around the pressurized water pipe in the center of a pool and springing water fell on these cascading bowls. The smallest bowl being at the top and larger ones towards bottom (Figure 16). Sometimes a similar arrangement was made by square sections (Figure 17). A water jet probably designed for an interior pool exhibits an interesting design: A pedestal supported by three toes of a beast holds a bowl at the top; a semi-spherical decorative head placed over the bowl springs water to its surroundings (Figure 18). In Mevlana complex a self-standing sculptural animal figure in a dragon or sea-horse shape, pours water from its mouth (Figure 19).

Figure 16- A typical water jet from the summer resort house of Cemal Hattat in Gülle. 20th century (İmamoğlu, 2001, p. 100).

Figure 17- A small pool and its cascading shelves, all out of basalt in Talas summer resort, Kayseri. 20th century.

Figure 18- A marble water jet of a small pool reused in a contemporary house in Ankara. Its probable date is 18th century.

Figure 19- Şebb-i Aruz Pool.The pool and its water jet in a stylized form of a dragon or sea horse in the courtyard of Mevlana Dergah, Konya.

5 Gargoyles

Flat roofs of traditional buildings in such regions were utilized for certain activities; they were used at night for sleeping, drying fruits or various winter food, drying laundry, wool or clothes at other times. They were made of earth with certain portions covered with stone slabs. The rain and snow water was drained mainly by levelling the dirt on the roof, directing the flow towards the gargoyles or gutters. Gargoyles were generally carved out of stone and shaped in endless forms. Although they had a simple function, they gained sculptural identity and expression contrasting with the plain character of elevations; they projected out and cast shadow on the surfaces.

Since Islam did not allow the sculpting of human or animal figures, muslim houses utilized simpler gargoyle forms, while christian houses had a variety of them. Masons of christian houses shaped the gargoyles in animal figures, dragons or other fantastic imaginary creatures (Figures 20, 21, 22 & 23).

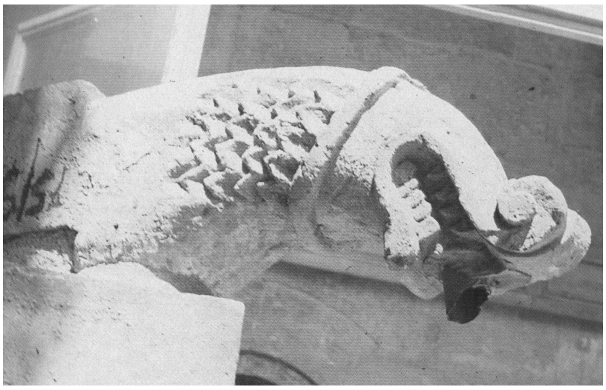

Figure 20- A gargoyle shaped as a dragon. Kayseri Museum (İmamoğlu, 1992, p. 81).

Figure 21- A gargoyle from İnceminareli Medrese (Museum), Konya. 13th century.

Figure 22- A gargoyle in dragon shape, Şakir Özalp House in Gesi, Kayseri. 19th century.

Figure 23- A dramatic projection of a gargoyle in a house in Büyükbahçebaşı neighborhood, Kayseri (İmamoğlu, 1992, p.25).

6 Concluding remarks

A simple, expressive use of material gave shape to fountains, *selsebil*s, water channels and other water elements or devices in dry regions of Turkey. Nothing was exaggerated in form or shape. Except the structures covering wells in Şanlıurfa where a self standing canopy, dome or an arch was utilized. Otherwise one can state that nothing was against the nature of stone or marble. In general, designers with strong traditional ties with their past, stuck to unwritten laws of artistic attitude and design, and searched for purity and maturity in their products. They tried to exhibit the elegance and beauty of water in or around horizontal or vertical surfaces by the help of mouldings or carvings to enrich the visual field; as well as bring physiological comfort and psychological peace and tranquility to the users.

Since fountains and selsebils were constructed as parts of vertical or inclined walls or built into small alcoves, in principle they had two dimensional or picturesque character. Although they included various sculptural components -like cantilevering bowls, small projecting columns, capitals, cornices- these elements did not change the nature of fountains or selsebils very much. A similar statement may be made for tiny horizontal water puzzles or channels where horizontality was dominant.

Pools were designed in simple, plain forms in general; they utilized basic geometric shapes like squares, circles, octagons. Although garden pools were deep and straightforward with respect to their design, interior pools were shallower and more ornate. They were carefully designed with some emphasis on three dimensionality. Their designers also searched for the creation of a unity with the space they were in. On the other hand water jets used in pools, perhaps had more sculptural character. They generally portrayed a well-settled traditional form -perhaps a common pattern- repeated in time and in many locations, or a stylized animal figure (as in the case of the water jet in Mevlana Museum), which is not any different than a contemporary sculpture. Since water jets are made of smaller pieces they could be demounted and reused in new pools and last longer than pools.

Another sculpture-like architectural elements are definitely the gargoyles used on roofs. Although their function was quite simple, they exhibited a large glossary of forms. Simple or complex, realistic or imaginary, ornate or plain, they were all stone sculptures themselves. They were shaped according to the religious or socio-economic-status levels of the owners and expressed the fantasies or rationalities of their designers.

One can easily state that, water whether in still or flowing state, enriched the living environments of Anatolian people as well as their architecture. Its nature, movement, color, sound and evaporative cooling effects were carefully integrated with the love of material that surrounded it. Many environments that could be considered mundane, became livable, pleasant, tranquilizing or sometimes exciting because of the careful and subtle treatment of water. In the end, water became a device used to increase the sensitivity of people to sculptural forms, surfaces and materials. It also helped of course, to have better microclimatic conditions within the rooms, semi-open spaces, courtyards and gardens and provide relatively more comfortable, pleasant and enjoyable life for people in towns as well as in summer resorts.

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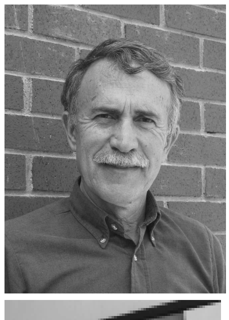
8 Presentations of authors



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A Constructional Detailing Proposal For Drainage System of A Steel Frame Structured Building

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Abstract

A system detailing for a steel frame structured building with curtain walling is studied in details of 1/20 and 1/5 scales with an emphasis given on construction details of its rainwater drainage system. The main discussion was on the positioning of the downpipe. Considering advantages and disadvantages of the following cases, a decision is made:

Case 1: The downpipe is on the exterior
Case 2: The downpipe is a part of curtain walling near the corners
Case 3: The downpipe is inbetween the structure and curtain walling
Case 4: The downpipe is in the interior, accessible from the inside
Case 5: The downpipe is in the interior, accessible from the outside

The evaluation criterion were mainly the cost, accessibility and architectural concerns for facade design.

Keywords

Rainwater drainage system, positioning the downpipe, construction design, system detailing.

1 Introduction

One storey high steel frame structured building with externally glazed curtain walling , reinforced concrete raft foundation and flat roof is given which has four meter span distance inbetween its structural axes in both directions.

A system detailing for this building with curtain walling is studied in details of 1/20 and 1/5 scales with an emphasis given on construction details of its rainwater drainage system. During the design period, the discussions were mainly on the positioning of the downpipe. Considering advantages and disadvantages of many cases of positioning, a decision is made.

After evaluation of each case, their problems are realized. By retrospections, each following case is proposed as a solution for the problems in the previous case. The evaluation criterion were the cost, accessibility and architectural concerns for facade design.

“Managing the costs of a project is a task that starts at the conceptual phase and continues throughout the project.” As Nashed stated. (Nashed,1996, p.76) In this study, some design strategies are employed while deciding between the cases in order to avoid cost overruns.

Building maintenance is the activity that prevents buildings from deteriorating rapidly, falling into disrepair and losing their value. Many components need to be detailed to allow for maintenance access throughout the life of the building. (2) This necessity should also be kept in mind during the whole design process. Depending on this reality, each case is discussed in terms of accessibility of the downpipe.

The details of a building play a large role on its aesthetic value. A building with a splendid thematic idea can fail as architecture if it has poor details that do not contribute to its primary aesthetic. (3) That is why, architectural concerns for facade design happen to be one of the criterion for the evaluation of each case of detailing design.

2. Cases:

Here are the following cases which are solutions of one another:

2.1 Case 1: The downpipe is on the exterior

2.1.1 With concealed gutter inside the structural frame

*since the downpipe is seen from the outside, it distracts the unity of the facade,
*the downpipe is exposed to damage by external impacts on ground floor level
*there is risk of frost in Ankara due to prevailing climatic conditions. If the water in the downpipe freezes , the flow might even stop which means delay on roof drainage. The longer the water stays on the roof, the faster the roofing material deteriorates. In this case; since the downpipe is exposed to external climatic conditions, the risk is higher.

Figure 1 The downpipe is on the exterior, with concealed gutter inside the structural frame

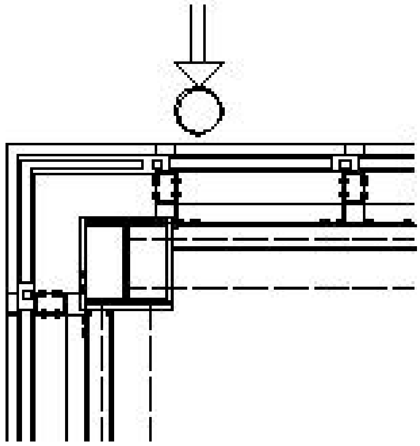


Figure 1a –in plan

*it is needed to drill a channel on the elements of curtain walling for the discharge of rainwater from gutters into downpipes as it is shown in Figure 1b. This means special detailing and use of custom designed components.

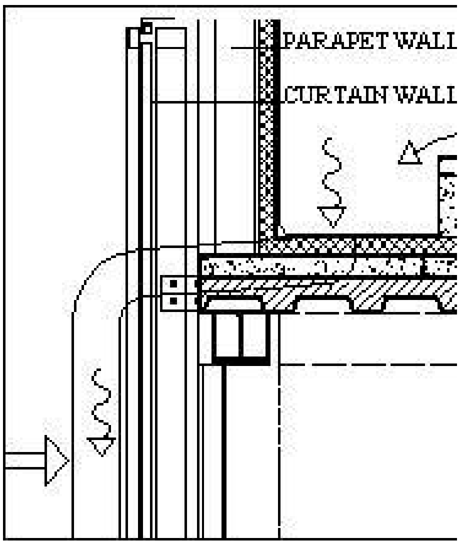


Figure 1b- in section

Special detailing for the use of custom designed components takes time and usually ends up with a higher cost. In addition, using custom designed components instead of off-the-shelf products is risky.This is because being used for the first time, the custom designed components may lead to unpredictable problems that may develop later, while the possible problems of off-the shelf products are easily handled due to familiarity gained throughout the long years of use.

2.1.2 With concealed gutter projecting out of the structural frame

*there is no need to drill a channel on the components of curtain walling, so no need for special detailing.
* there is projection on the facade which increases the area (d as shown in Figue 2b) to be cladded. As the amount of the material used increases, the cost increases.

Figure 1 The downpipe is on the exterior, with concealed gutter projecting out of the structural frame

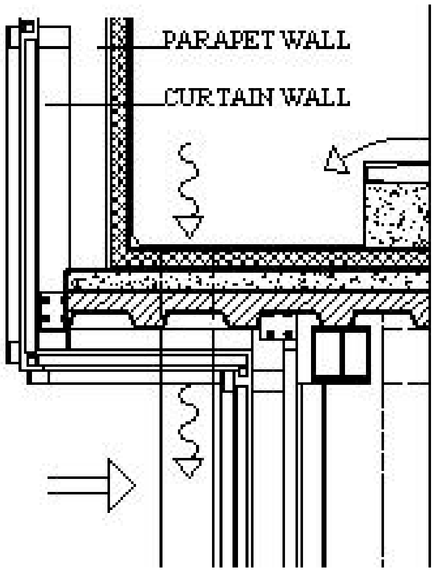


Figure 2a in section

2.2 Case 2: The downpipe is as a part of curtain walling near the corners

***the downpipe is not directly exposed to open air. It is partially hidden and protected against frost. Because they are covered with special aliminium U-profiles.
*due to the placement of downpipes, there are projections near the corners as shown in Figure 3a. This means more ins and outs on the facade which increases the area of expensive cladding material. In addition, these projections distracts the aesthetic unity of the facade owing to interruptions on the modulation of the facade near the corners.
*above all, the elements used infront of the downpipes are custom-designed components which need special detailing. This brings along inefficient use of time and a higher cost.

Figure 3 The downpipe is as a part of curtain walling near the corners

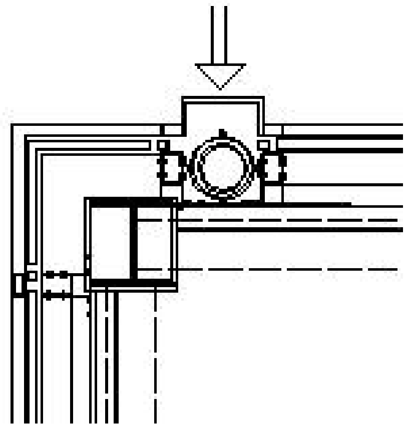


Figure 3a –in plan

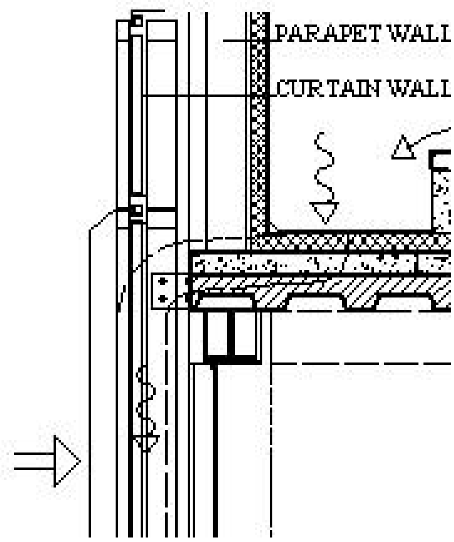


Figure 3b- in section

2.3 Case 3: The downpipe is inbetween the structure and curtain walling

*****the downpipe is not perceptible from the outside, therefore there is no interruption on the unity of the facade.
*as the downpipe gets closer to the interior space which is heated , a better protection of it against the frost is provided.
*it is possible to clad the whole facade with off-the shelf products employing no special detailing which is an increasing factor for cost.
*for the placement of the downpipe , the void inbetween the structure and the curtain walling (d as shown in Figure 4b) should be increased.This means increase in the dimensions of the components of curtain walling, which inevitably increases the cost.

Figure4 The downpipe is inbetween the structure and curtain walling

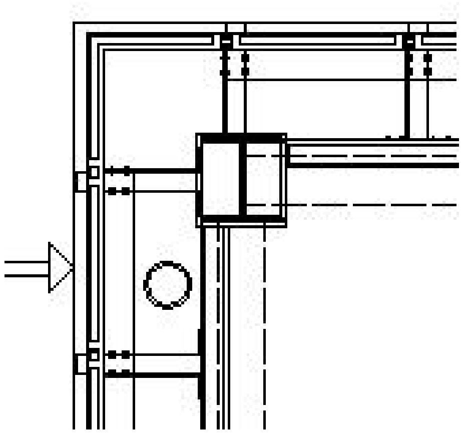


Figure4a- in plan

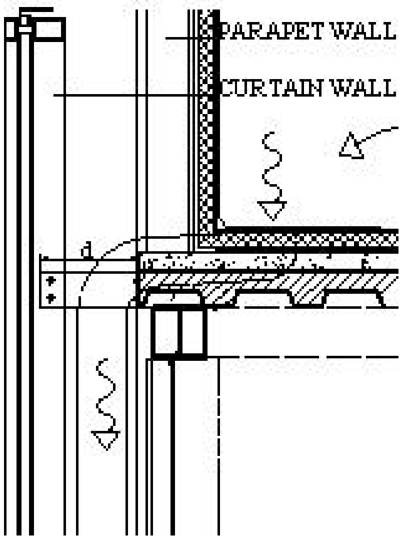


Figure 4b- in section

2.4 Case 4: The downpipe is in the interior, accessible from the inside

*since the downpipe takes space from the interior space, the void inbetween the structure and curtain walling can be minimized. This means the dimensions of the components of curtain walling can be taken as minimum which reduces the total cost when compared to case 3.

Figure5 The downpipe is in the interior, accessible from the inside

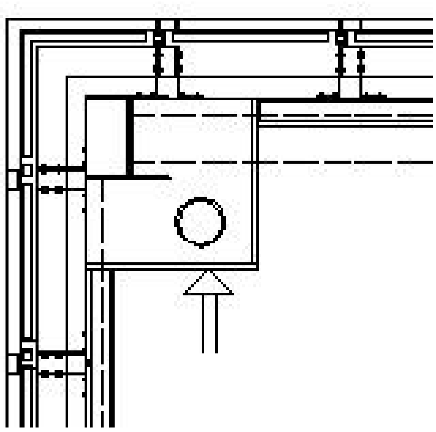


Figure5a- in plan

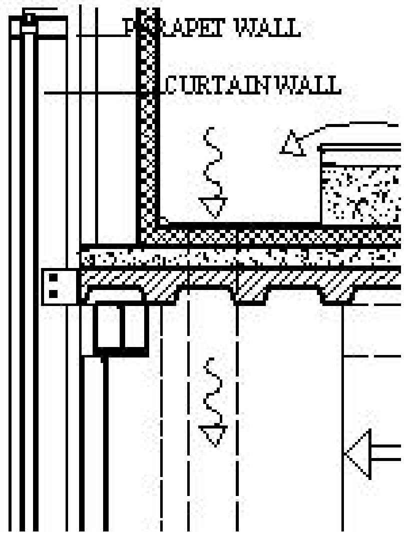


Figure 5b- in section

*the downpipe is closer to the interior space so it is protected more against the frost.
*In case of any problem or for periodic maintenance, there will be interruption in interior life. If the building is a dwelling, the privacy will be disturbed. If an office is the subjectmatter, this means the building will not be used at night.Since the downpipe is accessible only from inside, any problem should wait for the day-time in order to be dealt with.This may lead to great losses.

2.5 Case 5: The downpipe is in the interior, accessible from the outside

Figure 6 The downpipe is in the interior, accessible from the outside

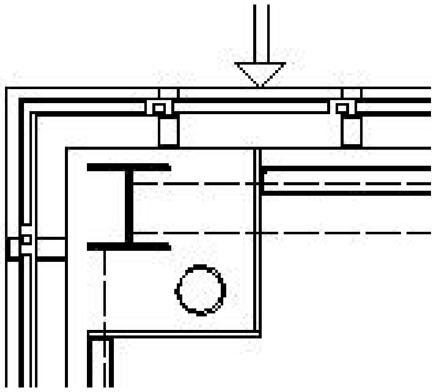


Figure 6a- in plan

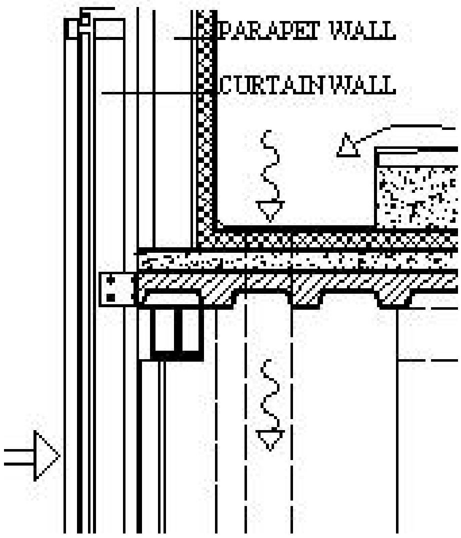


Figure 6b- in section

* In case of any problem or just for periodic maintenance, there is no need to disturb interior life. As it is known, the components of externally glazed metal and glass curtain wall systems can be replaced by workers on outside scaffolding in buildings not higher than 3-story height.(5) Here, the system is externally glazed curtain walling and the building is 1-story high, so the elements can easily be removed and the downpipe can be accessed fom the outside.
*As the downpipe is in the interior, the flow of rainwater leads to sound problem and thereby disturbs interior life. This problem is solved by the use of sound insulation material around the downpipe. The increase in cost for the provision of this material is acceptable when compared to increasing factors of cost in previous cases.

Figure 7 The system detail of case 5:
The downpipe is in the interior, accessible from the outside

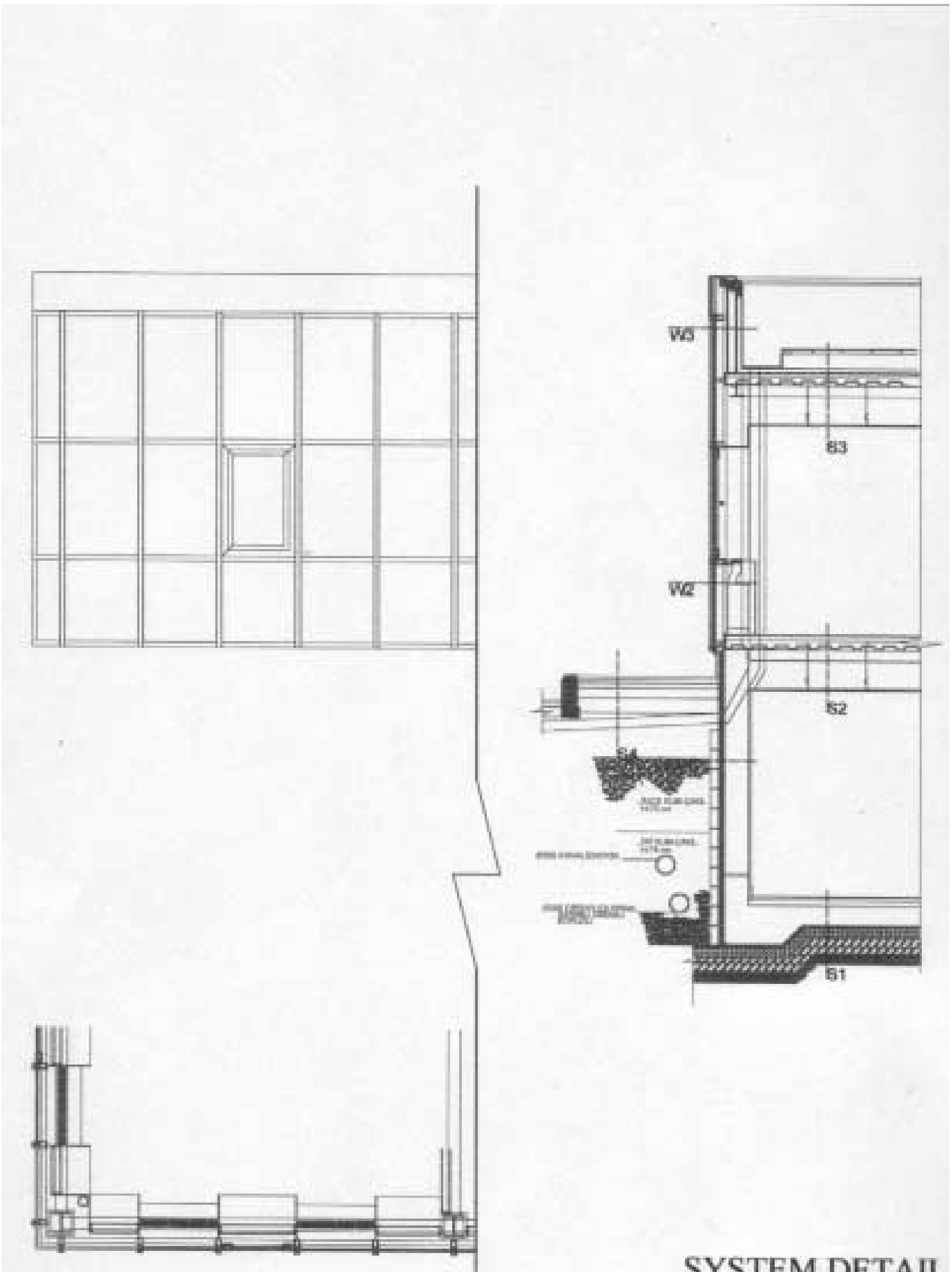
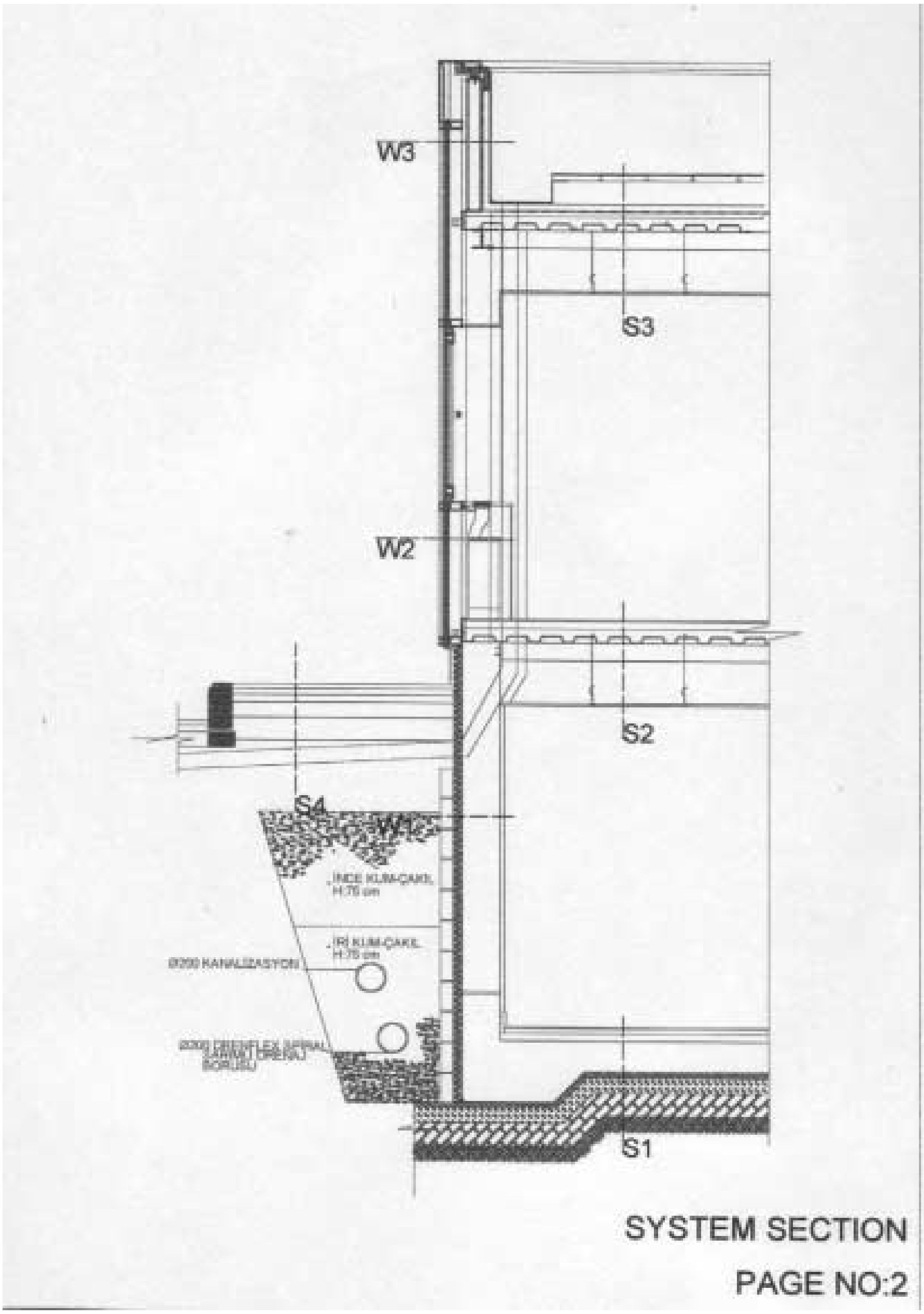


Figure 8 The system section of case 5:
The downpipe is in the interior, accessible from the outside



3 Conclusion

During this study, by zooming till smaller scales "the building" is seen more clearly. It is realized that the design process includes much more complexity in itself than expected by witnessing how detailing design can contribute to ruin or contradict with architectural concerns.

As a conclusion, it appeared that "architecture" should not be defined as being art only, since it includes also "science" in itself which gives habitable form to the design. A well-thought out concept should serve both for aesthetic considerations and functional necessities, otherwise it is hardly surprising that substantial changes to a design are often required in stages of practice.(6) What is the worst of all is that these later changes may lead to contradictions with the design statement which happens to be the starting point. This may even cause the failure of the whole project due to inconsistencies in itself. That is why, from the very early stages of design on, form giving should be understood more deeply as an activity of making sense together (6). This attitude is aimed to be followed by searching for an end product which makes sense together with its aesthetic taste and fullfilled serviceability requirements.
In addition, we faced with the fact that there is no "the most profitable, aesthetic and serviceable detailing solution" for a design problem. The search for "*better*" covers an unlimited period of time. We only tried to catch this sequence of comparisons at an acceptable stage in time. Above all the most striking thing that we learned was the ability to criticise our solutions and to accept this as the inevitable design process.

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Water Hammer Simulation For Practical Approach

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Abstract

The theory for the water hammer is well know in the field, but for the practical approach, the authors consider that the graphical methods available in Romanian standards are difficult to be applied. Using MATLAB software with SIMULINK, like an open platform for dynamical simulations and numerical analysis, some original function and dynamical models was developed. The theory remains the same, but the solving method is very new. The first application is the valve closure, witch generates the pressures well over the steady state values. The boundary conditions consist of a large reservoir at the upstream end of the pipeline and a valve at the downstream end discharging to the atmosphere. An other important situation is the pump failure. Our calculation computes not only the maximum and minimum piezometric pressures (relative to atmospheric), but it reveals the evolution of the process. Mass conservation and momentum conservation are the fundamental equations used to analyse hydraulic transients. A fast model, with reasonable precision was developed for pipelines with pumps. This model represents an original contribution, the graphical programming improving the possibilities to analyse the phenomenon and giving more realistic results. The simulation remains open to the specific configuration, and in order to validate the software, some measurement (founded in literature) was used. Graphical interface was friendly designed, and details about the graphical programming was given, in order to be easy to be used and understanding.

Keywords

Water Hammer, Simulation, Graphical Programming.

1 Introduction

There are many programs available to analyse water hammer problems [1,2]. A general condition for a specialized software to be accepted is to be simple to use, requiring short time to learn. In the authors opinion, this condition is restrictive and introduce an important limitation for the modelling system. If we need a highly accurate simulation, the learning process need a long time if we want that such software to be used by the engineers. This aspect is an important disadvantage if we accept that this kind of problem is rare, and the learning must be repeated every time. Also, the solving method remains hidden.

This paper has a different approach, using an open platform for dynamic simulation, developed for general purpose, but frequently used by the civil engineers. Using the classical theory, the calculus is accessible to be understand and improved with details.

2 The traditional graphical solution for water hammer

A large number of authors [4, 5, 6] present the basic physics of conservation of momentum and conservation of mass. As partial differential equations they have a solution domain that is two dimensional, with one spatial dimension and the time dimension. Applying conventional solution techniques to these equations often results in divergence and large errors.

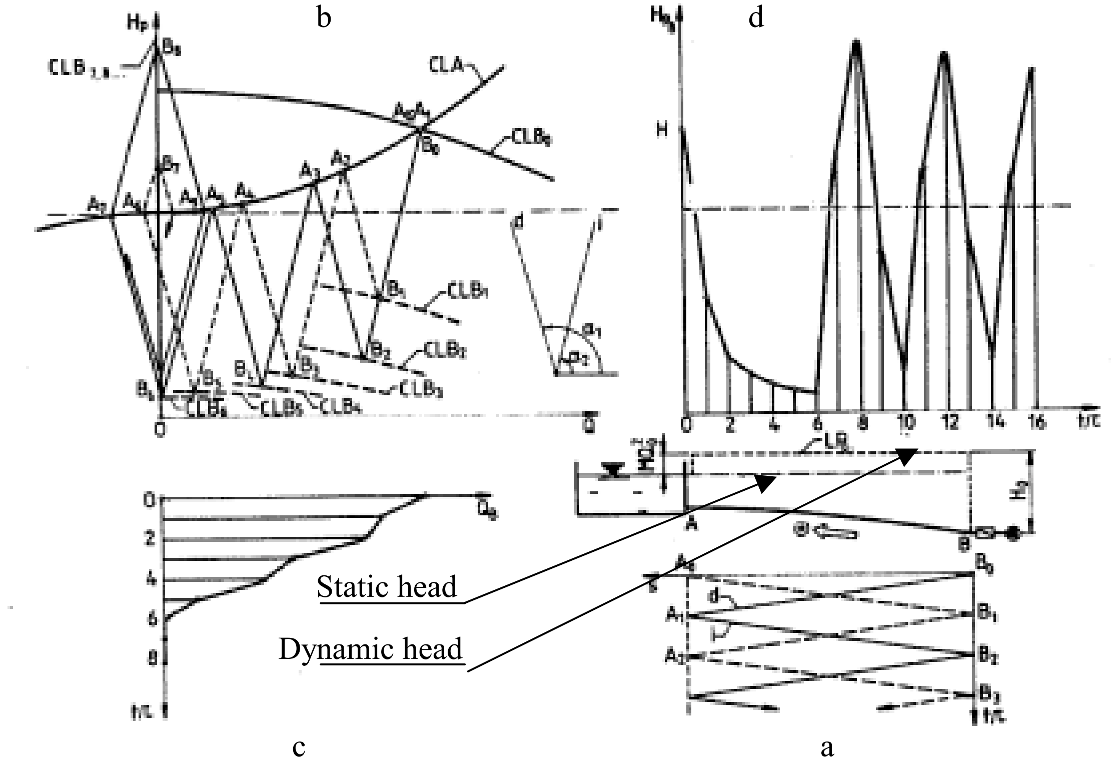

Figure 1 - The method of the calculation waves applied on the graphic form at a system with pump station:

a – the scheme of the system and the propagation of the calculus waves; b – the graphical solution; c – the variation in time of the over flow in section B; d – the variation in time of the statical head in section B.

Applying the method of characteristics allows these equation to be converted to ordinary differential equations, with a simple solution, obtained in general using graphical methods.

The figures 1, a, b, c, d, [6] illustrate the case of a pump equipped with a back flow preventer which closes it self instantaneously at the bock flow tendency.
We can remark two types of boundary conditions: characteristic curve (CLA) in section A (at the tank), and the characteristic curve (CLB) in B, in which it is concentrated the pressure loss at the power failure of the pump, at different moments t = kπ.
This method has important limitation, offering only some limited information about the phenomenon.

3 Theoretical consideration

Further on we will use a direct demonstration [6] for the *Jukovschi* [4] relation between the waves velocity and pressure which doesn't use differential equations and then the relations used for the pipes.

Jukovschi relation is a particular form deduced from Riemann invariants, adapted for faint compressible fluids (water and the others liquids). In this case, the compressibility can be treated like a linear phenomenon that leads to linear relations.

For demonstration, in figure 2, we consider a semi-infinite pipe through the right, horizontal, with liquid at rest. At the left extremity, on apply constantly a over flow injection which generates a wave. Alternatively, we can imagine the perturbation being induced by the uniform motion through the right, with speed v, like a piston.

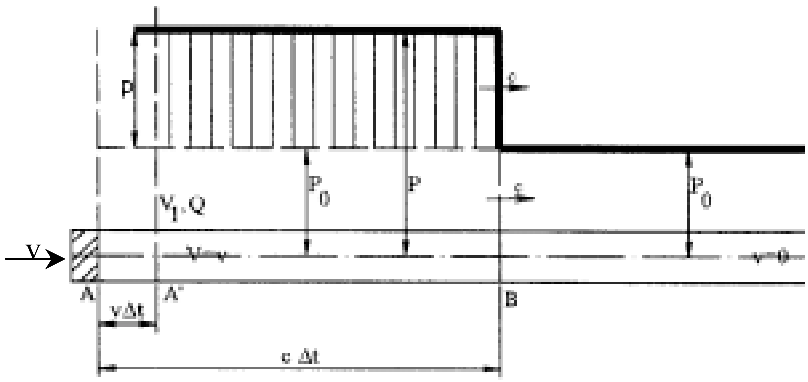

Figure 2 – The diagram for the Jukovski equation

Figure 2, like a reference for the demonstration which follows, represents the situation of the pipe at one time: $T = T_0 + \Delta T$, with T_0 – the initial moment. The liquid which is initial in rest in section AB, with the length *c x ΔT* (with $\Delta T = T - T_0$), suffered the action of the waves: the speed and pressure will be modified from $V_0 = 0$ and $p = P_0$ to V = v and P = P0 + p. By the increasing of the pressure, the liquid compress itself and at the moment T will occupy the section A'B. At the left extremity, in A', the pressure is P0 + p and in B is P0, the initial pressure un modified.

We apply the pulse theorem ($\Delta(m \times V) = F \times \Delta T$) for the liquid mass which is initially in the section AB and finally in A'B:

$$\rho \times A \times c \times \Delta T \times (V - 0) = (P_0 + p - P_0) \times A \times \Delta T \qquad (1)$$

where: ρ – liquid density and A – area of the cross section.

It results the simple relation:

$$p = \rho \times c \times v \tag{2}$$

or

$$p = z \times q \tag{3}$$

with the notation

$$z = \frac{\rho c}{A} \tag{4}$$

The value *z* is called *wave drag* [6].

For the calculation of the transient motion on use, as usual, like descriptive parameters, the piezometric head *(PN = P/(ρ x g), HN = ZN + PN)* and the flows Q, respectively *h* and *q* for waves:

In this case, for *h* and *q* we will obtain:

$$h = m \times q; \qquad m = \frac{c}{g \times A} \tag{5}$$

For *m* on use the name *modulus of the wave drag* or, more simple, *wave drag*.

The relations from upper side are deduced using figure 2 for a direct wave. If we operate with a piston placed in the right of the figure and we move it through the left, the development of the phenomenon is physically the same, with the difference that the generated primary wave is an inverse wave and the value of the over flow wave is negative while the pressure wave remain positive. For concordance, for the inverses waves, the waves relations has to be written in the form:

$$p_i = -z \times q_i; \qquad h_i = -m \times q_i \tag{6}$$

To establish the formula of the propagation speed we apply to the same liquid mass a preserving relation. The liquid mass which is initially on the section AB of the pipe will be at the moment $T = T_0 + \Delta T$ in the section included between A' and B.

In the section AA' we have the mass *ρ x q x ΔT* introduced, in the interval ΔT, with the over flow injection.

We write that the volume occupied by the injected liquid is equal with the deformation by compression of the liquid being initially between A and B, with *B* compressibility coefficient:

$$A \times v \times \Delta T = B \times p \times (A \times c \times \Delta T) \tag{7}$$

Taking out *p* from the equation (7) we obtain:

$$c = c_0 = A\sqrt{\frac{1}{B\rho}} = \sqrt{\frac{\varepsilon}{\rho}} \tag{8}$$

where ε is modulus of elasticity of the liquid.

We obtained the well known formula of the propagation velocity of the waves in continuous mediums and, respectively in the undeformable pipe.

For the motion in real pipes, the equation has to be completed with the influence of the pipe deformability. At the modification of the liquid pressure it takes place not only the modification of the volume of water, but also of the pipe, in the section subdued to the waves actions. If in the right side of the equation (8) is introduced the second term which had to express the volume modification because of the pipe deformation on the wave action *p*, it obtains the formula which take account only of the cross deformation.

$$c = \frac{c_0}{\sqrt{1 + \frac{\varepsilon \times D}{E \times e}}} \tag{9}$$

where: *D* – is the pipe diameter;
E – modulus of elasticity of the pipe material;
e – the width of the walls of the pipe;
ε - the wave velocity in the non-deflecting pipe, in concordance with the equation (8).

In order to validate our results, the value the wave velocity is c_0 = 1439 m/s in continuous medium, respectively the non-deflecting pipe and c = 1000 m/s, in average, in real pipes.

This equation will be use directly in the SIMULINK models.

4 The slowly closure of the downstream valve

This situation is frequently presented in the manuals. For water distribution systems, the situation is not very typical (in opposition with hydraulical power plant). For this reason, we use this simple water hammer problem in order to verify the possibilities of the simulation tools.

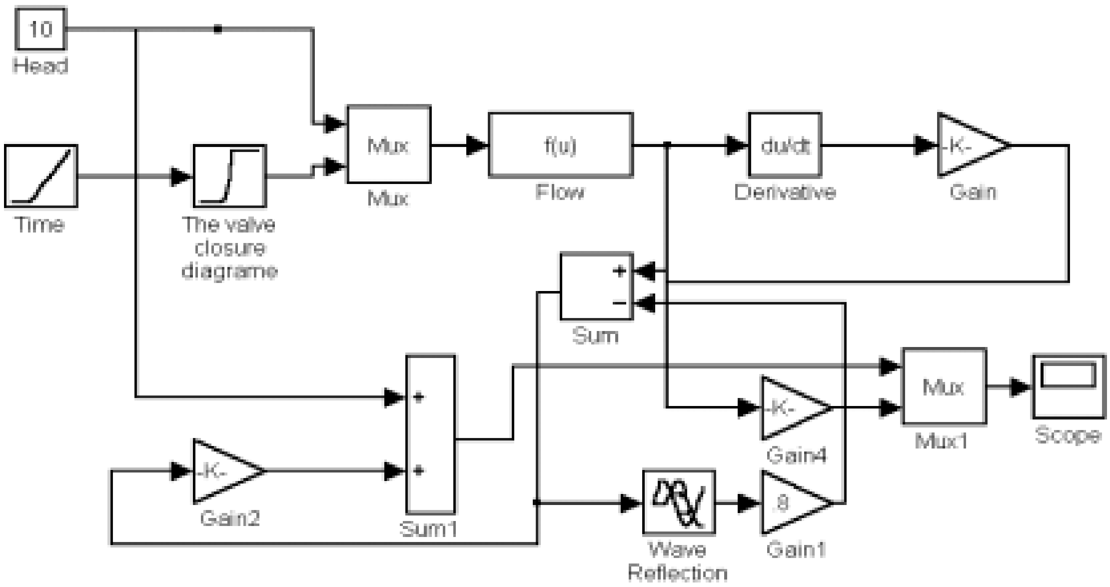

Figure 3 – SIMULINK model for the valve closure

The main aspect revealed is that in every step (with autosize option, but smaller than 0.01s) suppose that the flow is calculated. The block “Flow” use the valve closure characteristic. A very powerful block is “Wave reflection”, witch introduce a transport delay of the input values.

The results are available in figure 4. The particular aspect of the output is generated by the valve characteristic and the speed of the closure.

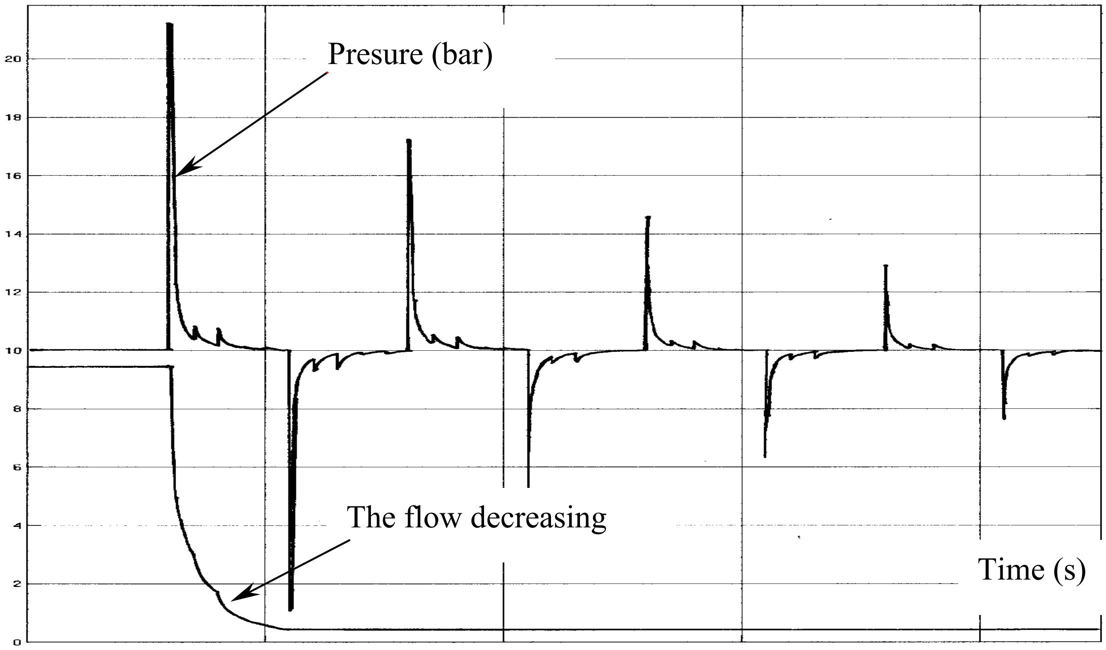

Figure 4 – Water hammer simulation for the valve closure

5 The pump failure

The SIMULINK model is presented in figure 5. Apparently is very complex, but the connections are realised in a logical way, close to the phenomenon.

The principal calculus stages which can be observed in the SIMULINK model (figure 5) are :

- the pump work coupled at the equalizing tank. The pump characteristic is a polynomial type, modelled by the coefficients : k1, k2, k3, k4. (Matlab function “Pump with tank”);
- pump head depends by the rotative speed of the pump (lowering, after the second 1);
- kinetic energy of the pump is consumed during the water flow is evacuated (block “Kinetical Energy”) ;
- rotative speed of the pump is corresponding with the remaining kinetic energy;
- at the lowering of the flow through zero, a back flow preventing blocks the back flow (block “Saturation “);
- variation of the flow (of the pulls) generates an overpressure (blocks “Derivative”, “Gain”, “Gain 2”);
- failure condition is generated in the moment 1 (block “Step”) .

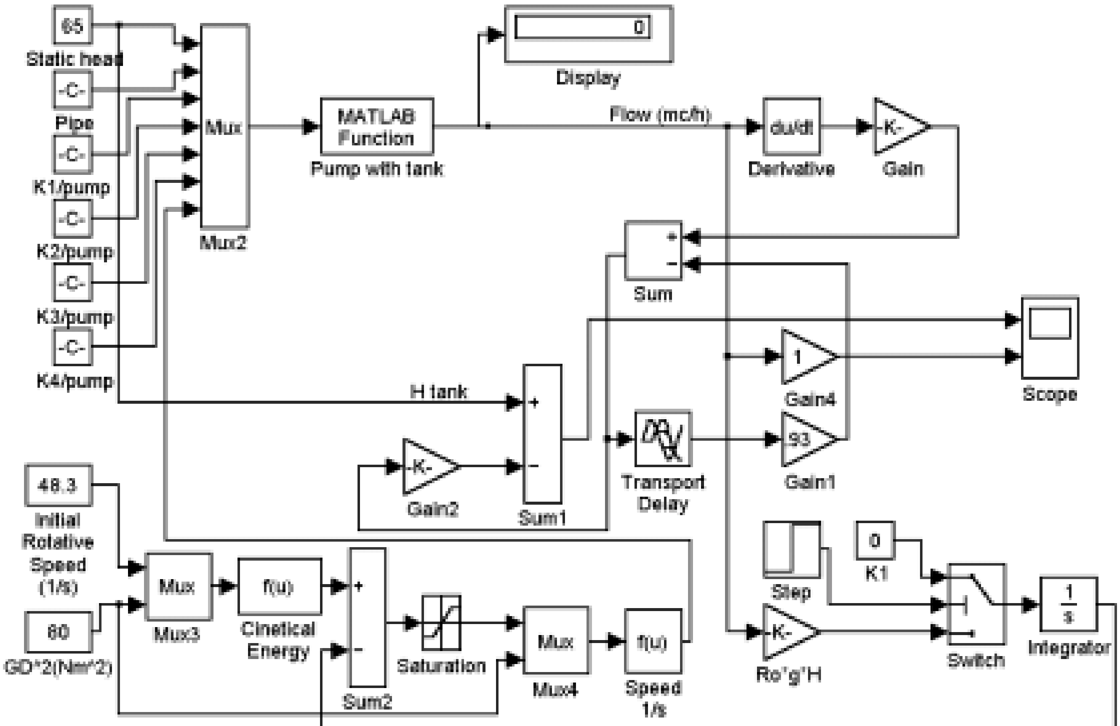

Figure 5 – SIMULINK model for the pump failure

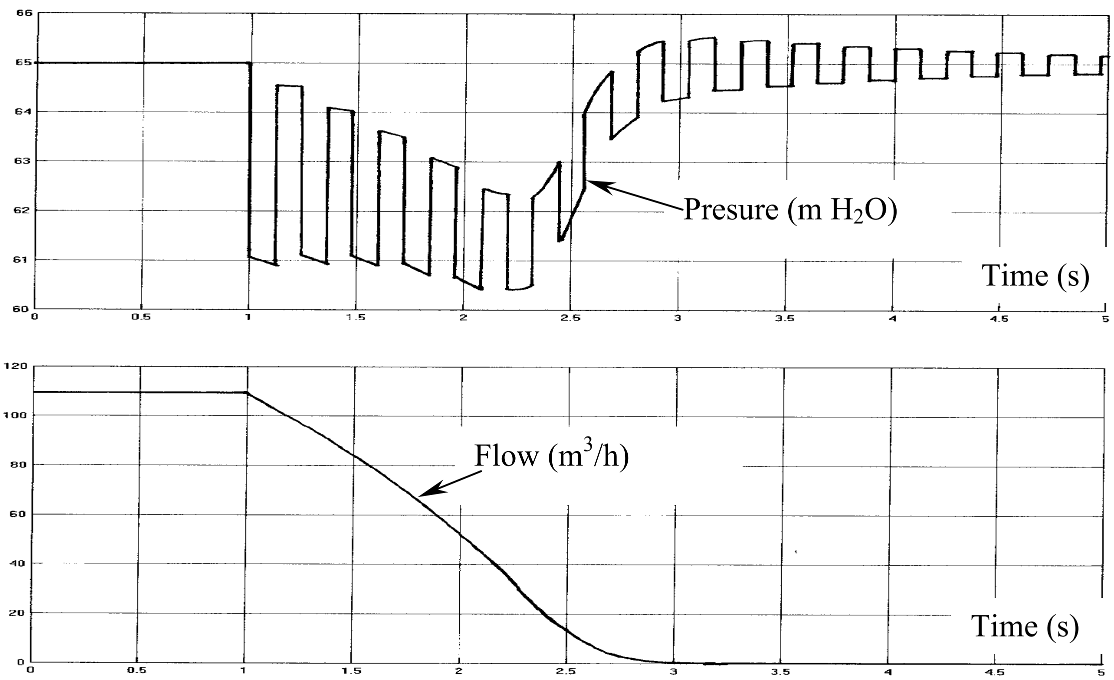

Figure 6 – The pump failure simulation

6 Conclusions

The utilization of SIMULINK for the modeling of transient process is apparently difficult. The graphical programming, with specialized blocks available for calculations and visualization allows the modeling of the elementary phenomenons which cooperate to the development of the phenomenon on the whole .
Using the theories of the energy and the pulls conservation, the obtained results are realistic. The reflection of the waves, for instance, is realized by specific SIMULINK blocks, which introduce a delay.
The advantage of this approach method is the fact that it can be applied at different systems without need of specific knowledge of programming. The simulation remains open to the specific configuration, and in order to validate the software, some measurement will be realised in water distribution system.

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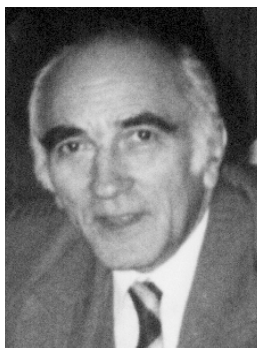

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Application of LP in optimizing Qeysereq single-purpose reservoir volume

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Abstract

Limitation of water resources and higher cost of hydraulic structures intensify the need for an optimum volume and operation for Iranian reservoir systems. Due to the complexity of water resources systems and some constraints, application of mathematical models and optimization techniques for computing the optimum reservoir volume seems to be necessary. For optimum computation of Qeysereq reservoir volume, an optimizing mathematical model was applied. This model was only used for within-year regulation. Qeysereq reservoir is an off-river system and applied for irrigation of 325 ha farmlands with a channel from the Cheki-Chay River. The objective function is to minimize reservoir volume Ka during a specific demand and reservoir inflow in request months. This volume is the active storage capacity; therefore for computing the total reservoir capacity the dead storage capacity must be added to Ka. The result of the model shows that the Ka is 2464318 m^3.

Key words

Mathematical models; Optimization techniques; Reservoir management and Single-purpose reservoir system

1 Introduction

As water resources have been limited in Iran, building hydraulic structures costs more, so it is of high necessity to have optimum volume and operation for reservoir system. Due to the complexity of water resources systems and the presence of many constraints and limitations, application of mathematical models and optimization techniques for computing the optimum reservoir volume are necessary. In Iran water resources and water needs are not always compatible and the regulation is carried out by storage reservoirs. Although water resources are called renewable, the average usable amount is constant. To consider the optimality of capacity of reservoirs and effective use of them is so important that have not seriously noticed in Iran yet. The reservoir planning and operation studies, which have made progresses in recent decades, are based on Rippl's graphical method. The weakness of this method, which can only consider a constant need, was overcome by Thoma's Sequent Peak algorithm. How to design the capacity of water reservoir systems and operate them is a multi-stage decision problem. Dorfman first used the Linear Programming (LP) for the solution of those problems. After Yeh's (1985) state of the art study, Dynamic Programming (DP) and Linear Programming (LP) methods have commonly been used in the solution of that problem. Rogres (1969) and Mclaughlin (1967) proposed LP formulation to obtain optimal capacities of reservoirs. Revelle et al.(1969) proposed a linear decision rule(LDR) to make release decisions for a single reservoir system. Louks (1968) proposed a stochastic linear programming model to determine a strategy for release, giving the current state of the system and previous inflow. Lund (1996) applied the application of deterministic optimization to the Missouri River reservoir system in order to deduce optimal operation rules. Philip D.Crawley (1993), applying a monthly planning and operational model, developed a model for the Adelaide head works system in South Australia, Australia. This model used linear goal programming to aid in the identification of optimum operating policies for the system. Abbas Afshar (1991) developed a mixed integer linear optimization model for irrigation. The model was chance-constrained optimization models which considered the interaction between design and operation parameters (reservoir capacity, delivery system capacity, etc.). Needhom (2000) applied LP to flood control on the Iowa and Des Moines River reservoirs. Teixeira (2002) developed a forward dynamic programming (FDP) model to solve the problem of reservoir operation and irrigation scheduling. The typical scenario in application of the model was composed of a system of two reservoirs in parallel supplying water to as many as three irrigation districts.

2 Research location

Qeysereq dam is located in Azerbaijan, a state in Iran. The dam height is 1680 m above the sea level. This basin lies between east latitude 45° 16' and north latitude 38° 4'. The nearest climatologic station in which 27-year statistical data have been recorded is Mirkuh. It has semi-dry and cold whether. Maximum temperature is 36 C° in August and minimum temperature is 25 C° in January. Annual average temperature in all statistical period is 8.4 C° and the average of monthly evaporation from free surface is shown in table 1.

Table 1-Rate of evaporation from free surface (mm)

Month	O	N	D	J	F	M	A	M	J	J	A	S
EV	109.4	55.2	9.5	1.3	1	2	55.4	93.5	146.4	189	226.7	211.5

Average annual precipitation is 315mm; its maximum that achieved in 1968 was 539mm and its minimum that achieved in 1998 was 179.5mm. The maximum of monthly average precipitation in the region is 63.2mm that is 20% of all annual precipitation in May, and the minimum of monthly average of precipitation is 6.4mm that is 2% of all annual precipitation in August. Therefore the spring season with 48% of precipitation is considered as the wettest season in the year. Average precipitation on reservoir area is shown monthly in table 2.

Table 2-Rate of precipitation on reservoir area (mm)

Month	O	N	D	J	F	M	A	M	J	J	A	S
PP	23	31	23	19	20	30	51	63	33	9	6	8

2.1 The Chaky-Chay River

The Chaky-Chay River is a sub-river of the Aji-Chay River and streams from Mount Yaghli. This river, near the Alan village, flows from Alan diversion dam in East-North into the Aji-Chay River in West-South. The area of basin in the Alan dam point is 189.8 km^2. According to 46-year statistical data, the rate of inflow was calculated with some probability as shown in Table 3.

Table 3-Discharge of river inflow (m^3/s)

Month	O	N	D	J	F	M	A	M	J	J	A	S
75%	0.19	0.26	0.23	0.32	0.3	0.58	2.53	4.35	2.25	0.58	0.17	0.07
90%	0.09	0.14	0.13	0.2	0.24	0.45	1.83	3.32	1.23	0.35	0.08	0.04

The water of the river after stored behind the Alan Dam has been divided into two parts. One part has a fixed amount of water which flows into the concrete channel as an input of Qeysereq reservoir (table 4).

Table 4-Volume of inflow to the reservoir ($1000m^3$)

Month	O	N	D	J	F	M	A	M	J	J	A	S
QF	0	50	200	200	200	400	1330	400	50	0	0	0

Qeysereq reservoir is an off-river. Some of water, which is totally 800000 m^3, from sub-basins in wet seasons added to the reservoir as an inflow (Table 5).

Table 5-Volume of inflow from sub basin to the reservoir ($1000m^3$)

Month	O	N	D	J	F	M	A	M	J	J	A	S
IN	11.55	39.6	55.55	44.55	33.55	39.6	51.15	84.15	150.05	57.75	18.7	8.8

Meanwhile, some of water as a result of leakage loss could not be controlled. After empirical assessment the amount of this water was computed (Table 6).

Table 6-Volume of outflow as a loss from the reservoir ($1000m^3$)

Month	O	N	D	J	F	M	A	M	J	J	A	S
O	15.48	15.48	15.48	24.9	24.9	24.9	39.84	39.84	39.84	19.8	19.8	19.8

In this plan, totally irrigated area is 325 ha. Many kinds of products are to be cultivated in this land. Whole water demand was calculated using Cropwat4 software (Table 7).

Table 7-Volume of Demand ($1000m^3$)

Month	O	N	D	J	F	M	A	M	J	J	A	S
D	113.1	0	0	0	0	0	79.95	230.1	568.75	768.6	671.78	290.88

3 Model developing

Linear programming models have been applied extensively to optimal resource allocation problems. As the name implies, LP models have two basic characteristics, that is, both the objective function and constraints are linear functions of decision variables. In this research GAMS[1] Software applied for running of model. Due to the reservoir storage-area relationship is nonlinear; an alternatively linear programming model is possible using a linearization of the storage-area relationship as shown in Eq.1.

$$A = A_0 + \eta \times ST \qquad (1)$$

$$A = 68608 + 0.18 \times ST \qquad R^2 = 0.98$$

Where A is reservoir area and ST is the storage volume. A_0 and η are parameters of linear equation. The essential feature of an optimization model for reservoir capacity determination is the mass balance equation,

$$ST_{t+1} = ST_t + QF_t + PP_t - R_t - EV_t + IN_t - SP_t \qquad t = 1,2,...,12 \qquad (2)$$

Where ST_t is the reservoir storage at the beginning of time period t, QF_t is the reservoir inflow in period t, PP_t is the precipitation amount on the reservoir surface in period t, R_t is the reservoir release in period t, EV_t is the evaporation and SP_t is the seepage loss during period t. IN_t is the a mount of water that flowes from sub basin to the reservoir. A model to determine the minimum active storage capacity (K_a) for a specified release as a demand formulated as

O.F Minimize Ka (3)

Reservoir capacity cannot be exceeded during any time period, thus:

$$ST_t \leq (K_a + K_d) \qquad (4)$$

$$ST_1 = ST_{13} \qquad \text{(Reservoir is within-year)}$$

Where k_d is dead storage ($100000m^3$).

In case that evaporation and precipitation volumes are a function of surface area of the reservoir which, in turn, depends on the reservoir storage, one could incorporate the storage-area relationship in the optimization model. The storage-area relationship can be derived from conducting a topographical survey that determines the storage volume and surface area for a given elevation. For almost all reservoir sites, the relationship between storage volume and surface area is nonlinear. Therefore, the model represented by Eq. (2) is a nonlinear optimization model. The nonlinear storage-area relation can be approximated by a linear function (Eq. 1) to facilitate implementation of linear programming. Thus EV and PP can be simplified using the linear approximation:

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1 - General Algebraic Modeling System

$$EV_t = e_t\left[A_0 + \eta\left(\frac{ST_t + ST_{t+1}}{2}\right)\right] \quad (5)$$

$$PP_t = p_t\left[A_0 + \eta\left(\frac{ST_t + ST_{t+1}}{2}\right)\right] \quad (6)$$

Where p_t and e_t are the deterministic depths of precipitation and evaporation per unit area during period t, respectively. In this model QF_t, IN_t, SP_t and R_t (as a demand) are known parameters. The model was solved and the value of the objective function was computed.

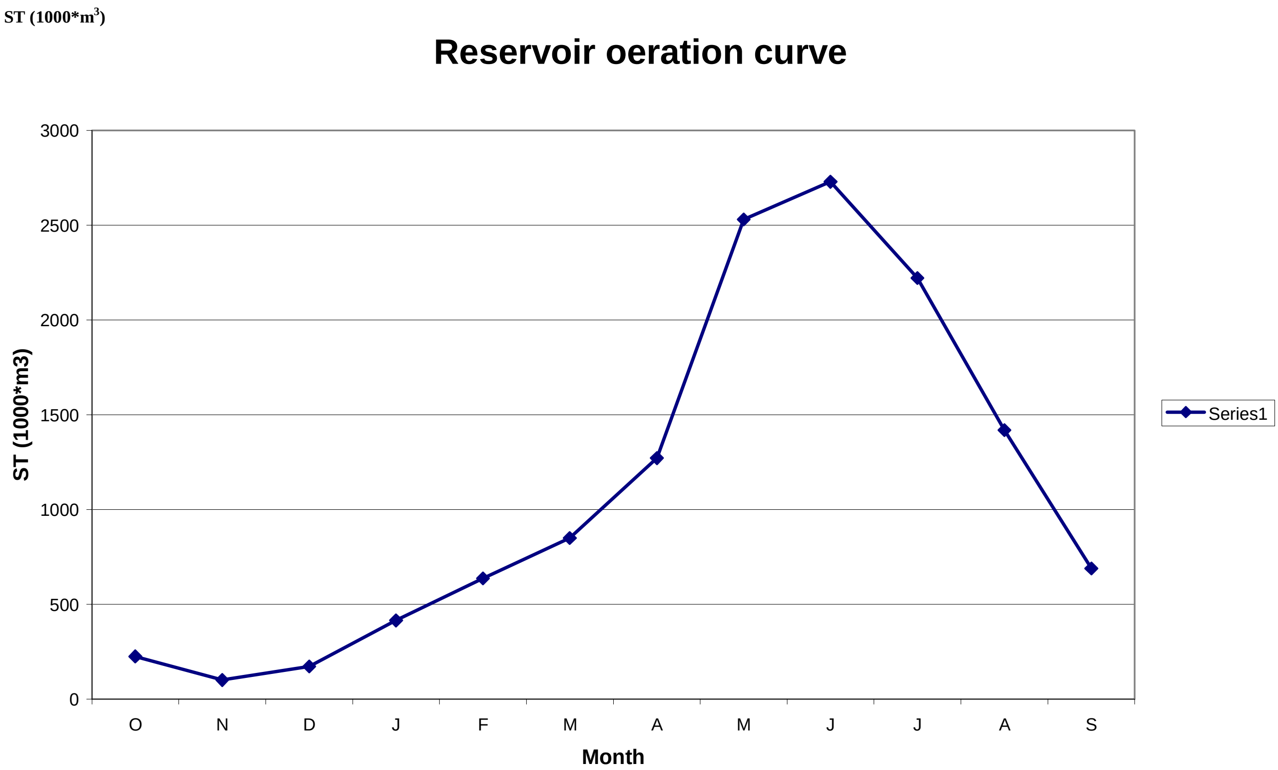
4 Results

The result of the model shows that the Ka is 2627702 m^3. Meanwhile, the volumes of decision variables delivered (Table 8).

Table 8- Results of model

Month	O	N	D	J	F	M	A	M	J	J	A	S
ST (1000*m^3)	225	100	172	414	636	849	1271	2530	2728	2221	1419	689
PP (1000*m^3)	2.3	2.9	2.8	3.1	4	7.8	21	34	17	3.6	1.6	1
EV (1000*m^3)	11	5	1.2	0.2	0.2	0.5	2.26	51	75	75	59	39

Reservoir operation curve for all month in a year was drawn.



The above curve shows that in June, due to less demand, ST has the highest amount.

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6 Presentation of Author

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Systematic Approach for Investigation of Water Demand in Buildings

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Abstract

The investigation of the water consumption for the purposes of updating the National water supply norms requires the application of systematic approach that allows identification of the influence of the basic technical, economical, social-demographic and habitat factors with minimum data surveying.
The paper describes the approach, which is applied for investigation of the water demand of the various consumers in the public building in Bulgaria.
The developed decision supporting data base is structured in such away that allows analysis of:

- various types of consumers and their classification;
- water demand factors;
- water losses;
- statistical assessment of the demand.

The period of updating of the national water supply norms is dependant on the change of the factors mentioned above and should be established, based on the monitored water consumption of representative consumers.

Keywords

Water demand, water supply norms, plumbing, modelling, design.

1. Introduction

The investigation of the water consumption for the purposes of control and updating the National water supply norms requires the application of systematic approach that allows consideration of the influence the basic technical, economical, social-demographic and habitat factors with minimum data surveying.

Consumption in the public building sector depends on various factors:

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

Developing of the supporting input data base is of a great importance for the realistic analysis and future forecasting of water demands of various consumers (residential, commercial, administrative, public and industrial buildings.

The applied approach should correspond to the purposes of the investigation. There are two basic approaches that are used for such an analysis [1, 5]:

- statistical and;
- engineering .

The basic differences include:

- viewing at the process of water consumption in completely different ways;
- use different types and amounts of data;
- based on sharply contrasting mathematical approach.

The statistical approach views at the process of water consumption as a ”black box” with set of overall inputs and a set of total outputs. The “completely black” box goes with implicit assumption that there are no internal differences over the sampled demands activities.

The engineering approach, on the other hand fills the black box with unit processes, which makes it more complex but very often in practice the edges between the methods soften and blur.

For the purposed of the analysis of water consumption in buildings, due to the influence of so many factors, which are difficult to be identified, assessed and predicted, the statistical approach is more appropriate to be applied [2].
This approach uses data on inputs to and outputs from the perimeter of the activity box and includes:

- organizing of adequate input data base;
- implement a sampling procedure that allows minimizing of the surveying expenses;
- applying an adequate theoretical mathematical model, which facilitates to a very big extend the understanding of the process and make it predictable.

The changes of socio-economic, cultural and technical conditions predetermine the necessity of applying this approach for operative processing the data, fast analysis and achieving results.
Currently in Bulgaria there is no systematic strategy and understanding for the necessity of monitoring the water consumption for regular updating the water demand norms per consumer for the distribution urban water supply systems and the different types of buildings.

During the last years the improvement of the technical means for construction of the water supply and drainage systems for buildings, implementation of water conservation measures lead to dynamic change of the water consumption of different users. When we add also the socio-economic and even climatic changes it become obvious the necessity to implement a systematic approach for control, monitoring and upgrading the applied water supply norms.

2. Classification of the commercial, administrative and public buildings

There is a big variety of classifications of the commercial, administrative and public buildings and also the specification of the different consumers depending on the way water is consumed. For the purpose of the investigation many sources from different countries were reviewed [3, 4, 5, 7, 9]. Bulgarian and Russian norms are more detailed in aspect of separating the different type of commercial, administrative, public and industrial buildings. German, British and American sources show less variety of building type and consumers. After the performed analysis, reflecting the local peculiarities of water use a classification of the commercial, administrative and public buildings is proposed. The results are shown in tables 1 and 2.

Table 1 – Classification of the commercial buildings

I. COMERCIAL BUILDINGS
1. Administrative buildings (offices)
2. Shops
2.1 Food
2.2 Industrial goods
3. Hotels and Motels
3.1. Room without bath
3.2. Room with bath
4. Restaurants and Clubs
5. Other activities
5.1. Hair dresser, cosmetic centre
5.2. Laundry
5.3. Garage

Table 2 – Classification of the public services buildings

II. PUBLIC SERVICE BUILDINGS
1. Hospitals
1.1 With shower and toilet in every room
1.2 With common shower and toilet
2. Polyclinic and ambulance
3. Schools
3.1. Without showers and cafeteria
3.2. With showers
3.3. With cafeteria
3.4. Kindergarten
3.5. Boarding School
4. Cinemas, libraries, theatres
5. Swimming pools
6. Stadiums and sport halls

The proposed classification could be different for the different countries and depends on the culture, local habitats, sanitary level of equipment and maintenance etc.

3. Theoretical water demand model

The availability of adequate theoretical water demand model is of very big importance for the analysis, control and future forecast of the consumption. There are a lot of sources, which describe the different models [2, 10].

The statistical model, which views at water demand as stochastic process has a lot of advantages:

- It is universal and can be applied for all types of buildings and consumers;
- It is valid not only for a particular defined period of time;
- The model describes not only the peak but also average and minimum demand;
- Possibility to receive results depending on specified confidence level etc.

For the purposes of the current analysis only the hourly variation of the demand is considered.

The proposed theoretical model is based on the understanding that water demand is a sum of two non-correlated processes with different means and variances [2, 10]:

- a constant (harmonic) process related to the daily life cycle of the consumers. For the estimation of the parameters of this process the hourly water consumption files are used: the mean is equal to the average annual hourly consumption and the variance $Var(Q_h^c)$ is determined from the average daily patterns;

- a centred hourly stochastic process with mean value equal to zero and variance, $Var(Q_h^r)$.

The model is represented by the following equation:

$$Var(Q_h) = Var(Q_h^r) + Var(Q_h^c), \qquad (1)$$

where $Var(Q_h)$ is the variance of hourly consumption time series;

4. Statistical Data base

As it was already mentioned in item 1, currently in Bulgaria there is no governmental policy for monitoring of water consumption that allows identification of the water dependant factors change.
It will show, when the factors have sufficient impact on the water consumption and there is a need for updating of the National demands norms.
One of the main objectives of this paper is to determine the basic characteristics of statistical database, which will be maintained and updated periodically.
The decision supporting data base should be structured in such away that allows analysis of:

- various types of consumers and their classification;
- water demand factors;
- water losses;
- statistical assessment of the demand.
- The period of updating of the national water supply norms is dependant on the change of the factors mentioned above and should be established, based on the monitored water consumption of representative consumers.

4.1. Data requirements

A common requirement is a realistic current data base. Without an estimate of what is currently consumed prediction of future water use can not be made.
For data collection the two-stage sampling procedure is employed [1].

- first water connections of various types are to be chosen to be sampled within each utility on the basis of water use (i.e., lot size, plumbing fixtures, number of consumers etc.);
- second, a set of utilities (locations) are chosen on the basis of climatic zone in which they are located and the pricing policy which they employ.

For the analysis and updating of the daily and hourly water supply the primary data should respond to the following requirements:

- collect metered water-use data only;
- collect data that are disaggregated by user class by taking a stratified random sample of individual users each class (a sample of 20 within each user class should be adequate);
- for estimation of the seasonal periodicity collect daily water use over a time series (30 days each season; at least one year);

- for estimation of the hourly demand collect random samples of hourly water consumed time series (for the size of the sample please see 4.4);

4.2. Seasonal effect

Seasonal effects could be negligible for most of the industrial, commercial, administrative and public buildings. The seasonal effect can be determined by the analysis of the autocorrelation function and the average daily consumption. The results from the analysis will give the answer how many seasons will be monitored. In many cases it appear that the one year period, when having enough big sample is enough but in all cases depend on the applied accuracy.

4.3. Socio –economic data

Socio-economic data aims to provide information for the analysis and identification the social profile of the different type of consumers and to allow their classification.
The data required for the analysis are [1, 2]:

- type of building;
- building age and maintenance level;
- socio-economic characteristics;
- consumers dynamics;

The sources which can provide relevant data are:

- censuses;
- field observations at various periods of the day and the week;
- interviews with the consumers.

For each of the surveyed building it is necessary to produce a synthesized data base, containing relevant census data corresponding to the statistical units.

4.4. Sampling

The size of the samples of water consumption depends on the accuracy, confidence level and statistical results for the type of the probability density function.
The necessary minimum number of measurements is calculated using the following mathematical expression:

$$n_{\min} = \left[\frac{\alpha}{\varepsilon}\right]^2 \sigma^2, \qquad (2)$$

where $n_{\min}$ is the minimum number of measurements
α – the confidence level;
ε – the error for estimation of the mean value;
${\sigma_h^r}^2$ –standard deviation of the stochastic component of the demand.

5. Water demand per consumer

In order to determine the disaggregated water consumption per consumer, the process of water use is considered as a sum of two components:

- real consumption
- water losses.

The water losses are defined as leaks from not properly operating fixtures of the plumbing systems in the buildings. The investigation in the near past showed that their amount can be sufficient (30 - 50% of the daily consumption [2].

In order to analysis the real consumption we have to separate the part of the losses in the whole process.

The total consumption averaged for a period of 1hour is represented by the following equation:

$$Q^h_{i(t)} = Q^h_{r(t)} + q^h_{i(t)}\text{, dm}^3\text{/h,} \qquad (3)$$

where

$Q^h_{i(t)}$ is the total flow for time interval of day *i*;

$Q^h_{r(t)}$ - the real consumption for time interval *one hour* of day *i*;

$q^h_{i(t)}$ - the water losses for time interval *one hour* of day *i*.

5.1. Water losses

Water losses are determined by the following equation [1, 5}:

$$q^h_{i(t)} = b_i \int_0^h P_{ef\,(t)} dt\text{, dm}^3\text{/h,} \qquad (4)$$

where

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

On the base of the input total water consumption data one produce hourly water losses time series.

5.2. Real Water Consumption

The water demand per consumer is defined in the Bulgarian norms for design of the water supply and drainage systems for buildings for two time intervals [7]:

- day;
- hour.

Separation of losses from the real consumption is of a great practical importance.

Estimation of the water demand can be established by performing standard statistical analysis of the consumed water time series.

The investigations of the dimensionless consumption in most cases show that data is drawn from lognormal distribution, with rather high levels of significance (test hypothesis using the Kolmogorov-Smirnov statistic). Figure 1 shows the histogram and

theoretical density function of the dimensionless daily consumption in schools without showers.
The data for the consumption is extracted easily from the recorded flows, where water losses files subtracted.

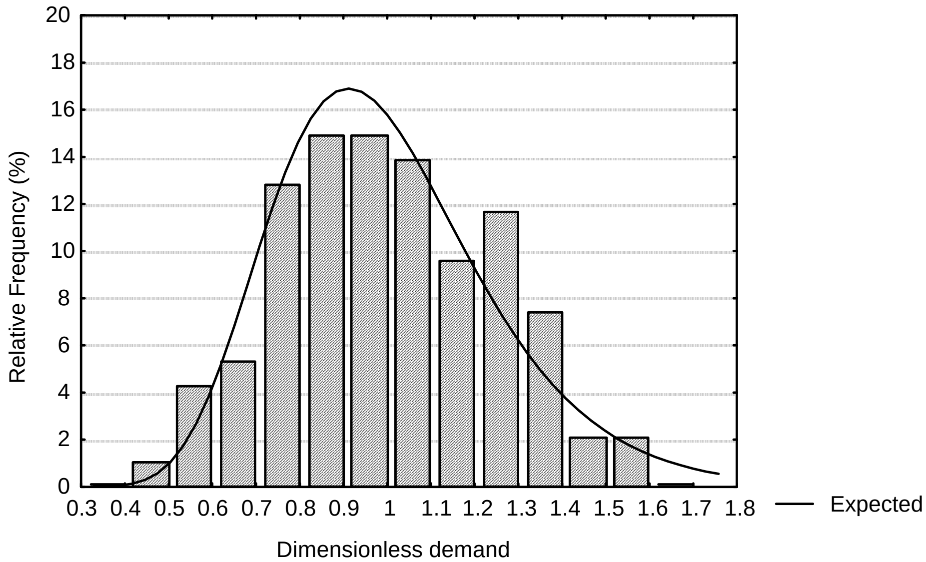

Figure 1 - Histogram of the dimensionless daily consumption in schools

6. Standardised daily demand patterns

Daily demand patterns are important basis for design of the regulation volumes of water supply system. It is necessary to remove the influence of the water losses on the dailydemand pattern.

The basis of the method for creating standardized daily profile is their functional similarity for one and the same class (type) of building.
If we use Shopenskii model[8]:

$$Q_i = K \bar{Q}_h T^{K-1} \qquad (5)$$

where $\bar{Q}$ is the average hourly water demand .
We can produce for every class the ascending hourly demand series. Always the maximum probability of appearance of demand Q_i *(i=1, 2, ...24)* is connected with the particular T_j *(j=1, 2, ... 24)* hour of the day as seen from figure 2.

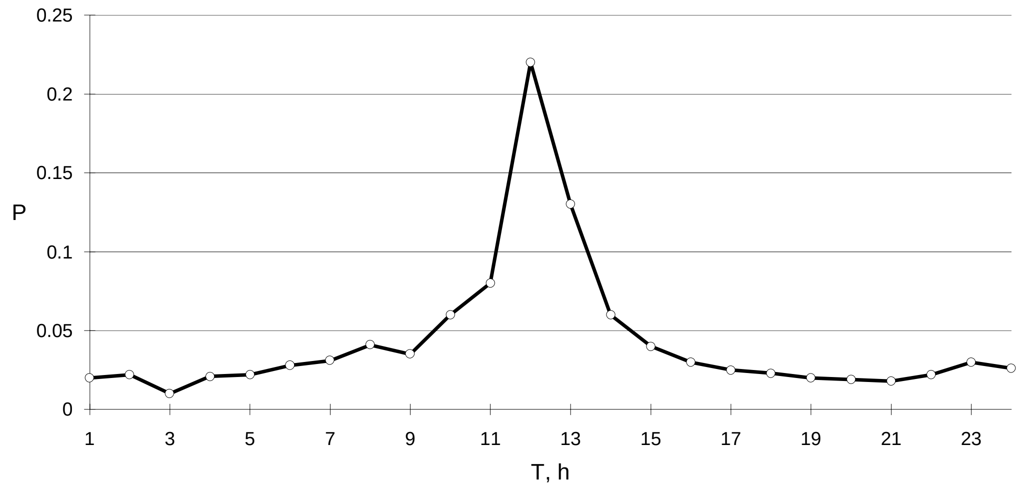

Figure 2 Probability of appearance of expected demand Qj

For every member of the ascending series of a given class of the objectives we can estimate T_j.
The size of the building (number of the consumers) is taken into account by the coefficient *K* [8]:

$$K = 1 + V_c^2 + 2V_c\sqrt{\left(1 + V_c^2\right)}, \tag{6}$$

where $$\mathrm{V_c} = \frac{\sqrt{\mathrm{Var}\left(\mathrm{Q_h^c}\right)}}{\bar{\mathrm{Q}}_\mathrm{h}} \tag{7}$$

6.2.Estimation parameter M of the water demand model

Applying the regression analysis technique to the data without water losses we can establish the parameter *M* depending on the number of consumers [10]:

$$M = \frac{Var\left(Q_h^c\right)}{Var\left(Q_h^r\right)} = f(N); \tag{8}$$

For the different user classes of buildings this relationships can be obtained rather quickly from the data of consumption without water losses.

7. Conclusions

1. A systematic statistical approach for investigation and analysis of water consumptions in the buildings is proposed;
2. The requirements for development of statistical data base, which will allow monitoring of the water consumption in the buildings are specified;
3. The main procedures for processing of the input database are proposed. They can be used for operative analysis and control of water demand in the buildings.
4. It was emphasized the necessity of establishing national policy for updating the water demand norms;

5. Method for creating standardized daily patterns of different type of buildings dependant on the number of the consumers is proposed.

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In-situ test results of sewer renewal by relining

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Abstract

Relining (cured-in-place method) is an economical and environment-protecting technique for the rehabilitation of damaged sewer systems in urban districts. By using this technique, the permanent sealing of sewers and the stability of soil – old duct – liner - system should be fulfilled. For investigating the static interaction and bearing capacity of the combined system, a large-scale in-situ test has been done by using a sewer in the downtown of Nuremberg. Lots of field measurements such as temperature, strains in liner, soil pressures as well as vertical displacements of the sewer under earth pressure and vehicle have been made for about one half of a year. The time-dependent behavior of the liner has also been observed.

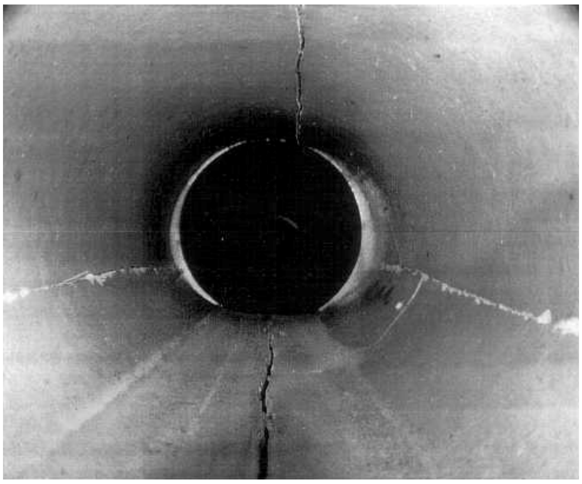
Keywords

Sewer; relining, in-situ test; soil pressure, pipe deformation; time-dependent behaviour.

1 Introduction

According to investigation, quite part of the existing sewers in Bavarian are defect, see Figure 1. In this case, the resulted leakage can lead to the infiltration of groundwater in sewers and also to the exfiltration of waste water in underground. For the rehabilitation, cured-in-place method, that is, placing plastic pipes into damaged sewers by relining, shows economical and environment-protecting advantages. At present, the cost-cutting is about 60% in comparison to the method of laying new ducts according to the experience in Germany.

An environment-protected waste water disposal needs a high quality standard for rehabilitation. That is, high requirements of planning, material quality and construction procedure should be established. For this purpose, a pilot project has been carried out by LGA Nuremberg in co-operation with the waste water disposal department of city Nuremberg as well as the construction companies KMG and Insituform, in order to work out a exemplary pattern for the bidding procedure, quality controlling of liner materials, construction supervision, static analysis of liners, as well as ending inspection of rehabilitation, see [2].



a) circular concrete profile

b) egg-shaped concrete profile

Figure 1 - The damage of the host pipes (qualitatively): longitudinal cracks at the crown, invert and springs, ingress of soil support into the pipe due to groundwater

In the following, the principal of sewer renewal by relining, the planning, boundary conditions and establishment of the pilot project, as well as the test results of liner material and in-situ measuring results are described and discussed.

2 Principle of sewer renewal by relining

The cured-in-place process is defined as follows:

“A hose of carrier material that can be coated with foil is soaked with reaction resin and inverted into the sewer through a manhole by means of water or compressed air or is pulled into the sewer with the aid of a winch. The hardening is carried out at normal temperature, by the application of heat or UV light with application of internal pressure. A sleeveless liner is created that must take up the shape of the sewer and must be able to be connected with it”

Depending on the manner of insertion of the liner hose into the section of the sewer to be rehabilitated, it is differentiated between “insertion by means of inversion” and “insertion by means of pulling in”.

The plastic liners, which are installed in the old sewers, increase the resistant capacity against physical, chemical, biochemical, biological actions. That is, they should fulfil generally the requirement of leaktightness and bearing capacity under the action of such as external and/or internal water pressure, earth pressures and vehicle loads.

Depending on damage grad, sewers can be classified as three groups according to [1]. :

Condition I: The sewer is mostly free of cracks and has full bearing capacity. Rehabilitation is necessary for establishing the leaktightness. The liner must adsorb only the external and /or internal water pressure.

Condition II: The sewer has one or more continuous longitudinal cracks and is alone no longer able to bear the earth and vehicle loads. Because of a sufficient bedding effect of the soil of the embedment, however, it is still stable as a pipe-soil-system. As in general it is necessary to restore the leaktigness so that the liner must be sized against external and/or internal water pressure.

Condition III: The pipe-soil-system has no load bearing capacity any more, see Figure 2. Rehabilitation is necessary for the replacement of the bearing and leaktightness function.

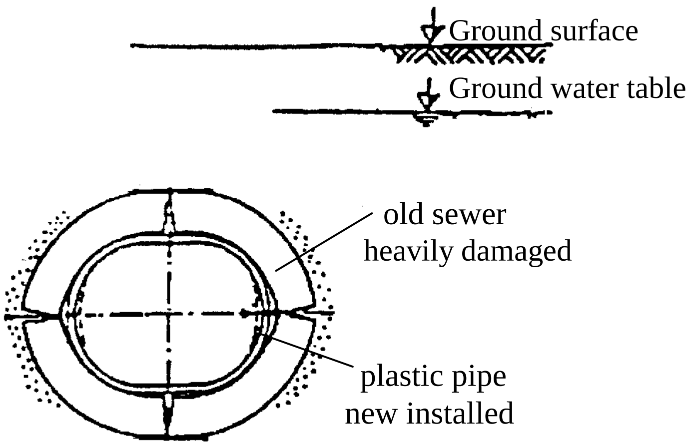


Figure 2 – Cured-in-place plastic pipe, condition III according to [1]

3 Short description of the pilot project

In frame of the pilot project, a test pit was laid out in the Veilhof street, see Figure 3. It has an area of 6 m × 7 m and a depth of about 5 m. In the zone around the test pit, no ground water table has been encountered.

The old sewer DN 600 with masonry substructure is a reinforced concrete sewer (B45) and has a wall thickness between 65 mm and 80 mm. The overburden of the sewer is about 3.5 m. For simulating the condition III (see Figure 2), the old sewer was firstly laid open. By using a concrete saw, one cut at the crown and two cuts at the side walls were produced into the sewer.

Figure 3 – Test pit in the Veilhof street, city Nuremberg

The cured-in-place method was applied by using the technique "insertion by means of inversion", see Figure 4 and 5. Die installed Liner is made up of resin impregnated plastic and has a wall thickness of about 15 mm.

In order to investigate the behavior of the liner and bedding soil during construction and in operation, lots of measuring elements were installed. On the outer surface of the crown/side walls of the liner, totally 10 strain gauges were put up, see Figure 6. Five of them were in the longitudinal direction, the other were in circular direction.

For observing the soil pressures in the bedding zone, three load cells were installed in the zones of sewer crown and side walls, respectively. Two electronic displacement gauges were used for measuring the vertical displacements near the crown of the sewer. In addition, the measurement of temperature within the sewer and in the open air was made.

Figure 4 – Inversion process of the plastic liner from a cooled transport container

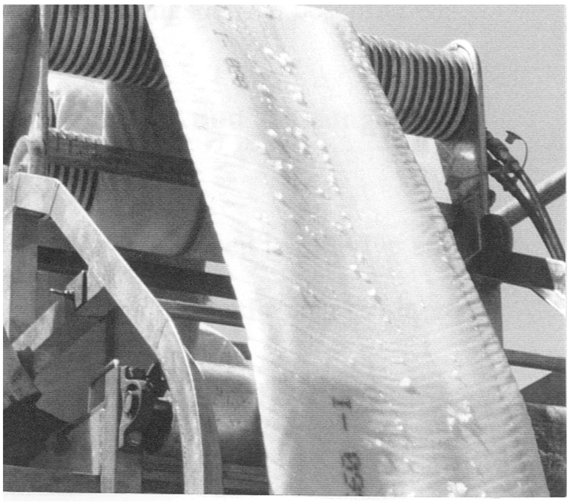


Figure 5 – Installation of the liner (soaked with reaction resin): for an exact placement through sewer manhole

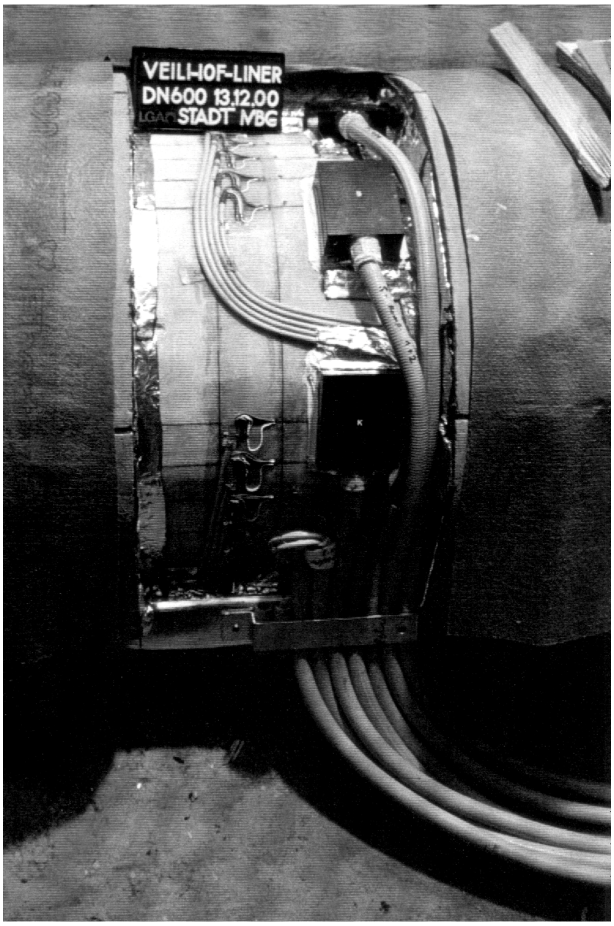


Figure 6 – Strain gauges on the outer surface of the line

4 Soil mechanical investigation in the project zone

In the project zone, totally three core drillings and three drop penetration tests were done. Based on the investigation, some basic soil mechanical parameters were evaluated for the soils in the zone of the test pit and illustrated in Table 1.

Table 1 – Soil mechanical parameters

soil	unit weight γ/γ' [kN/m³]	effective friction angel φ' [°]	cohesion c' [kN/m²]
sand	20/11	32.5	0.0
silt	19/10	30.0	5-10
sandstone bröckelig	21/11	35.0	10
sandstone hard	22/12	37.5	10-100

5 Laboratory tests on the applied plastic material

The resin impregnated plastic pipe was tested in Laboratory by using compression technique (see Figure 7) and 3-Points flexural technique, in order to determine the material parameters such as elastic modulus as well as flexural and compression strength in short-term and long-term condition.

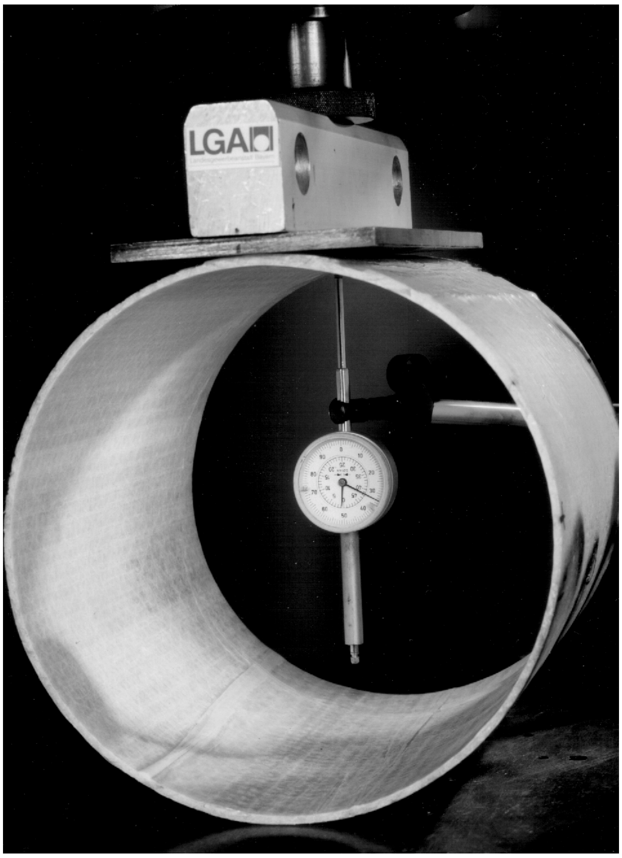


Figure 7 – Long-term compression test on plastic pipe

From the laboratory tests, following parameters were determined for the applied plastic pipe:

short-term

	flexural E-modulus	$E_{f,s}$ = 3675 N/mm²
	flexural compression strength	$\sigma_{fc,s}$ = 64 N/mm²
	flexural tension strength	$\sigma_{ft,s}$ = 23 N/mm²

long-term

	flexural E-modulus	$E_{f,l}$ = 1400 N/mm²
	flexural compression strength	$\sigma_{fc,l}$ = 25 N/mm²
	flexural tension strength	$\sigma_{ft,l}$ = 20 N/mm²

Three long-term compression tests on the plastic pipe were done under different pipe diameters and wall thickness as well as different loads for a creep time of 1000 h:

Test no. 4: d_m = 298,6 mm; s = 5,7 mm, L = 302 mm, F = 167 N;
Test no. 8.1: d_m = 575,4 mm; s = 18,0 mm, L = 324 mm, F = 1952 N;
Test no. 8.2: d_m = 575,8 mm; s = 18,8 mm, L = 324 mm, F = 1854 N.

Arising from the test results (see Figure 8), following creep parameters were deduced by using back-analysis:

$a_1 = 4{,}0\times10^{-4}$;	$b_1 = 1{,}0\times10^{-4}$;	$k = 2{,}0\times10^{-4}$;
$n = 5{,}5$;	$B_1 = 1{,}0\times10^{-9}$;	$k_2 = 0{,}2$,

where a_1, b_1, k, n, B_1 and k_2 are the parameters of the so-called ORNL-creep law:

effektive creep strain: $\varepsilon^c = A(\sigma)\cdot\left[1-e^{-R(\sigma)\cdot t}\right]+H(\sigma)\cdot t$
creep time: t [h]
effective stress: σ
function A: $A(\sigma)=a_1\cdot\exp(b_1\cdot\sigma)$
function R: $R(\sigma)=k\cdot\sigma^n$
function H: $H(\sigma)=B_1\cdot\exp(k_2\cdot\sigma)$.

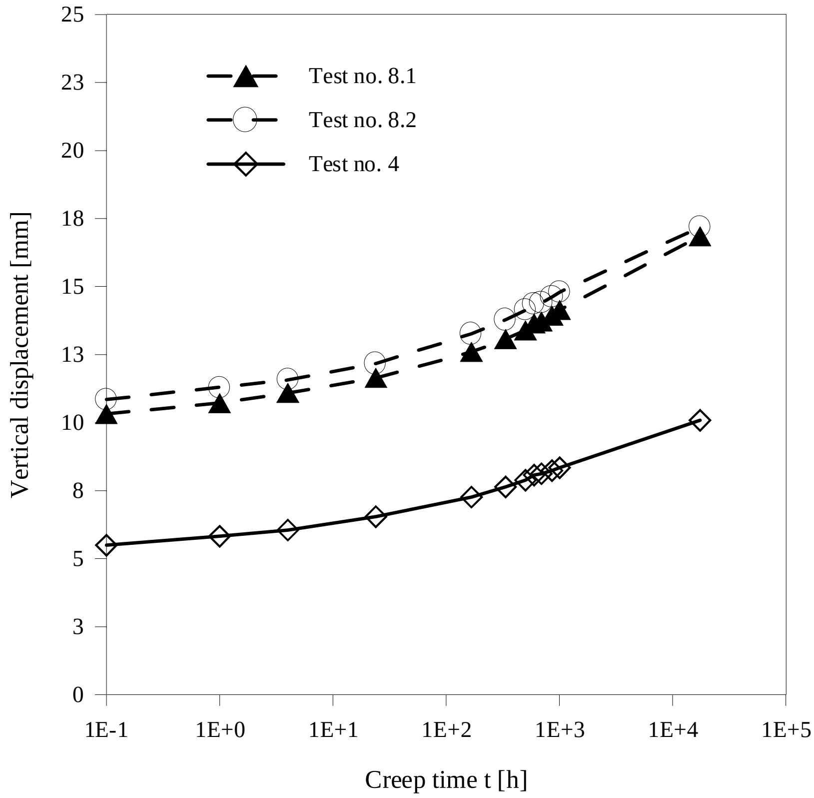


Figure 8 – Long-term compression test results

6 In-situ test results

6.1 General

The reference measurement was made at the beginning of backfill in the bedding zone on the 18. December 2000. The backfill of the test pit including the rebuild of road superstructure was finished on the 05. January 2001. The arrived overburden was about 3.6 m. Then, the measurement has been further made for about 4 months. In the following, the measuring results are illustrated.

6.2 Soil pressures

Arising from the reference measurement on the 18. December 2000, the time-dependent (backfill-dependent) soil pressures are shown in the Figure 9.

It can be seen that the soil pressure at the crown of the sewer was measured to be about 20 kN/m² after finishing the reconstruction of road superstructure. The pressure value increased up to 40 kN/m² in the following 3 weeks. Then, the soil pressure stayed almost constant at about 35 kN/m². In the same time points, the measured soil pressures on the side walls of the sewer were ca. 19/26 kN/m² and 30/35 kN/m² respectively. As at the crown, they remained almost unchanged after that time.

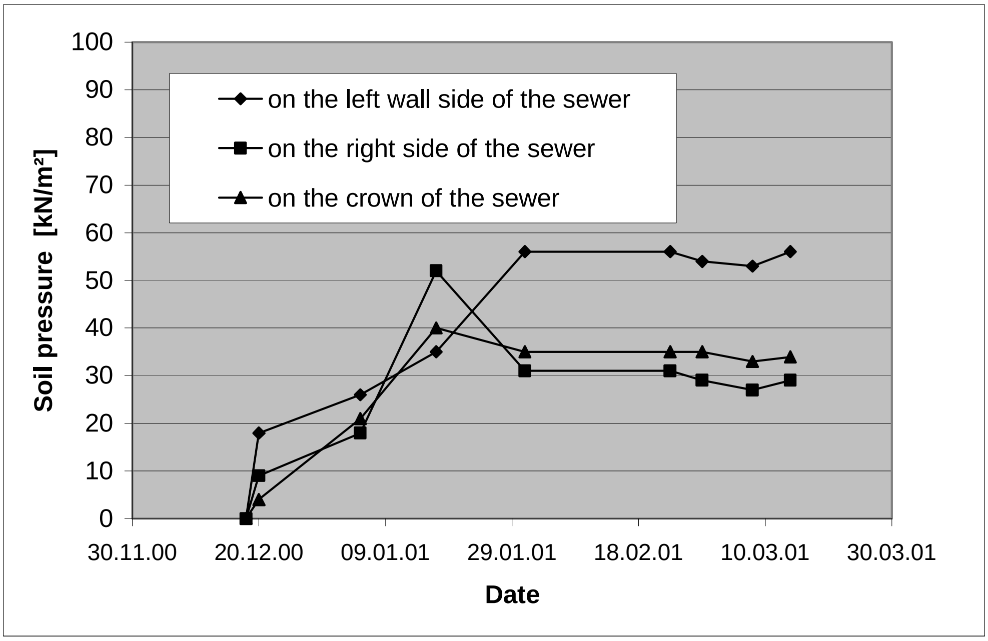


Figure 9 – Soil pressures in the bedding zone

6.3 Temperature

The development of the temperature on the liner and in the open air is illustrated in Figure 10. As expected, smaller fluctuation in temperature (about +10°C to 14°C) was measured on the liner in comparison with that in the open air (about -2°C to +20°C).

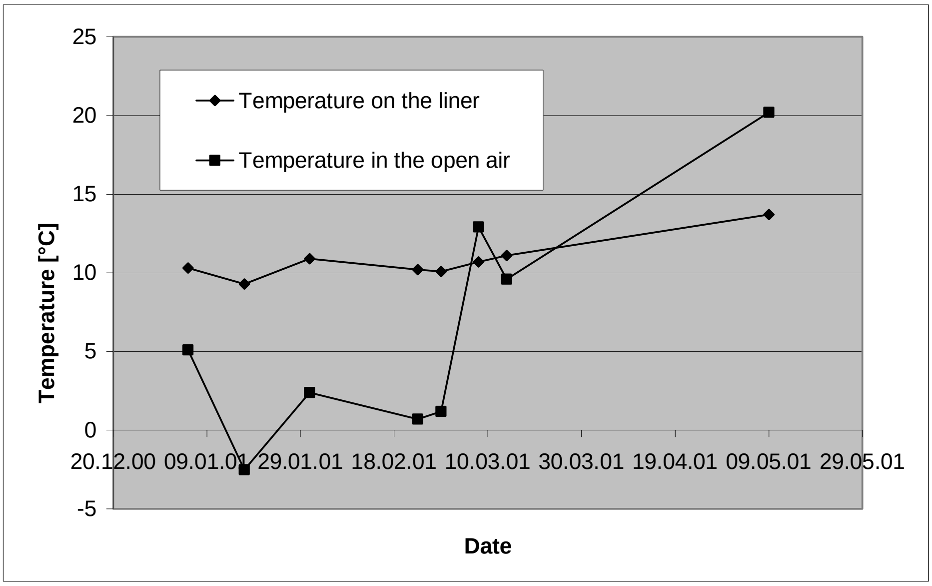


Figure 10 – Temperature fluctuation on the plastic pipe and in the open air

6.4 Vertical deformation of liner

By using the measured displacements of the liner and in the bedding zone, the deformation of the liner has been calculated and is shown in Figure 11. The vertical deformation of the liner reached maximum of about 7 mm after finishing the rebuilding of road superstructure. It corresponds about 1.2% of the inner diameter of the sewer. After that time, it remained almost constant as soil pressure.

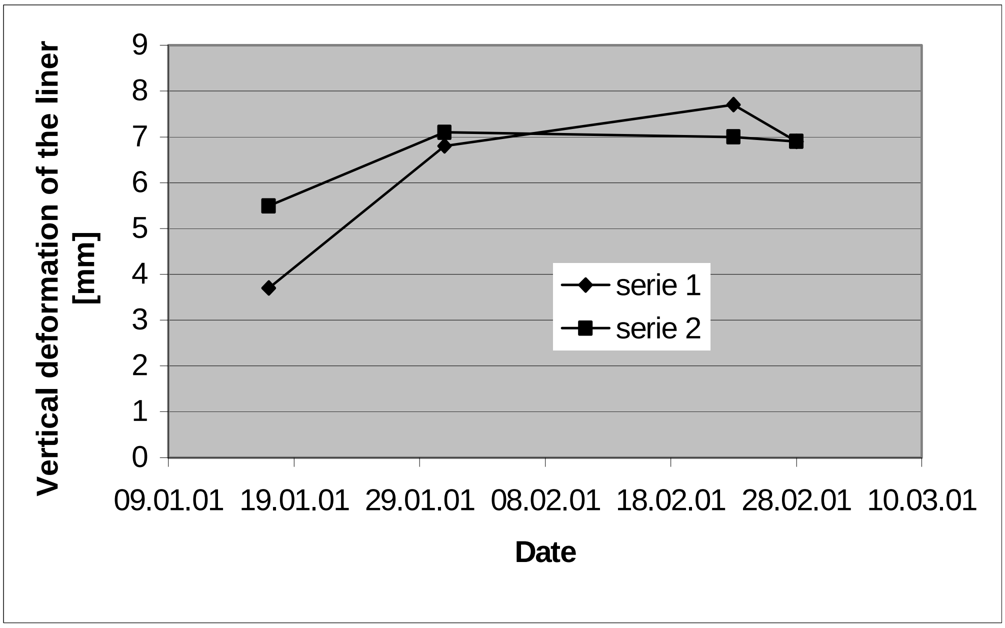


Figure 11 – Vertical deformation of liner

6.5 Creep strain of the liner

For the evaluation of the creep strain, we have chosen the 31. January 2001 as reference day, because the measured soil pressure and displacement indicated an increase before the day and nearly unchanged after the day. That means that the strains before the day are elastic strains depending on the increase of backfill and vehicle.

The circular creep strains on the outer surface of the liner crown is shown in the Figure 12 (up to 2352 hours). In contrast to soil pressure and pipe displacement, the strains of the liner decrease with time after the establishment of all loads. The measured creep strains are very small (about 5.5×10^{-4} after t = 2352 hours) and increase slowly and slowly.

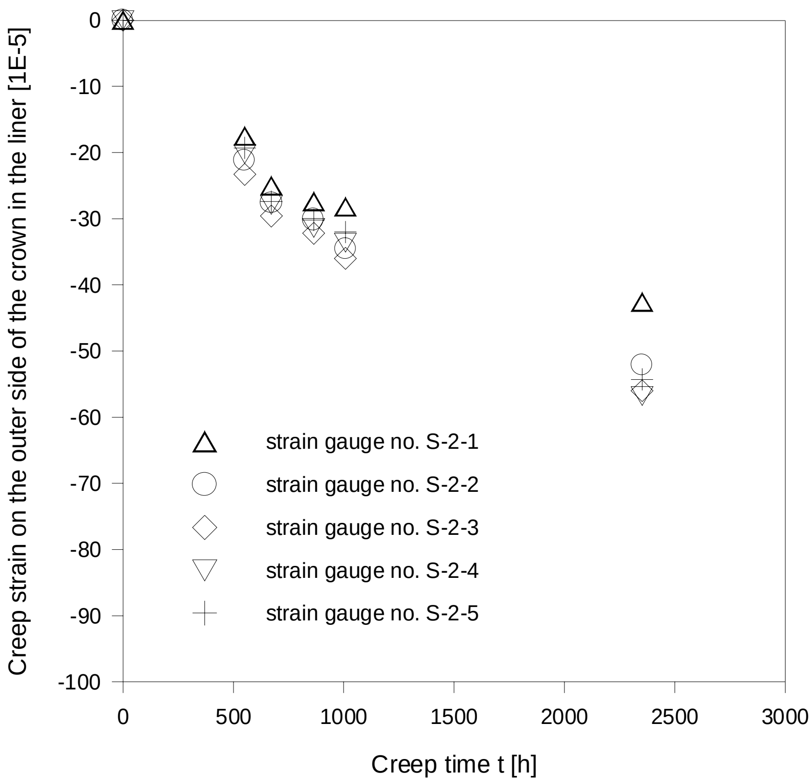


Figure 12 – Measured creep strains on the outer side of the crown in the liner.

Acknowledgments

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8 Presentation of Authors

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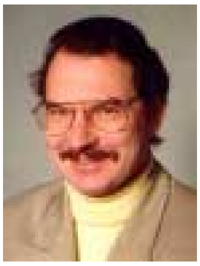

A Computational Simulation Model for Sizing and Evaluating a Water-Distribution Systems in Buildings

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Abstract

This paper presents a complete simulation model for water-distribution systems in buildings that uses a calculation of distribution piping network under real flow and takes into account not only the simulation of fixtures operation, but also the simulation of the number, the behavior and preferences of the users. The model also considers the dynamics of the population and the restrictions faced by the users to access the fixtures.
In addition, a complete application of the model is applied in 7 floor apartment building with 28 dwellings, where some parameters were recorded, as for example the flow rates. In this case, it was possible to study some aspects like population distribution and dynamics during a time period, user access to the fixtures, pressures, etc. As a consequence, it was possible to evaluate the maximum flow rates at the most interesting network sections or fixtures. The paper shows the tuning process for the building mentioned above, based on the action over "tuning points" located in the system, searching for the best performance.

Keywords

Water piping systems; distribution pipes; real flow; system's simulation.

1 Introduction

Computer powered simulation models are used to study and solve many problems. Simulation models can be found in different fields of engineer but it's not usual to find these models applied in water supply and drainage systems in buildings, Guided by the basic approach presented in (Petrucci & Gonçalves, 2001) and (Petrucci & Gonçalves, 2002), a residential building was simulated, developed and improved in a computational environment.

2 Fixtures access restrictions.

Stochastic models used to determine maximum flow rates usually treat the problem considering the simultaneous use of fixtures. Each fixture has a probability of use under a determined flow rate. Combining the individual probabilities it is possible to obtain the maximum flow rate in a given piping section.

The above consideration focuses on how fixtures are assembled in the piping network, and not how they are distributed in rooms. This means that in a public sanitary room with the following piping configuration: an exclusive pipe for lavatories, and one exclusive piping for showers, the use of the shower will not affect the maximum flow rate achieved on pipe that feeds exclusively the lavatories. But, if the same configuration occurs in private sanitary rooms, the use of a shower implies in a closed door, which denies the access to the lavatory. In this case, there is no statistical independence among fixture uses, and when it occurs, its degree depends on how fixtures are arranged in rooms. Other restrictions can be caused by fixtures which use retains the user during its use, affecting strongly the statistical independence (Petrucci & Gonçalves, 2002).

Figure 1 shows a possible diagram of users' rights to access fixtures. A given user can access only fixtures contained in same container of the user. In fact this diagram is like a tree, where the user who is in a given branch can access fixtures in that branch or in any lower branch, but not in a sided or upper branch.

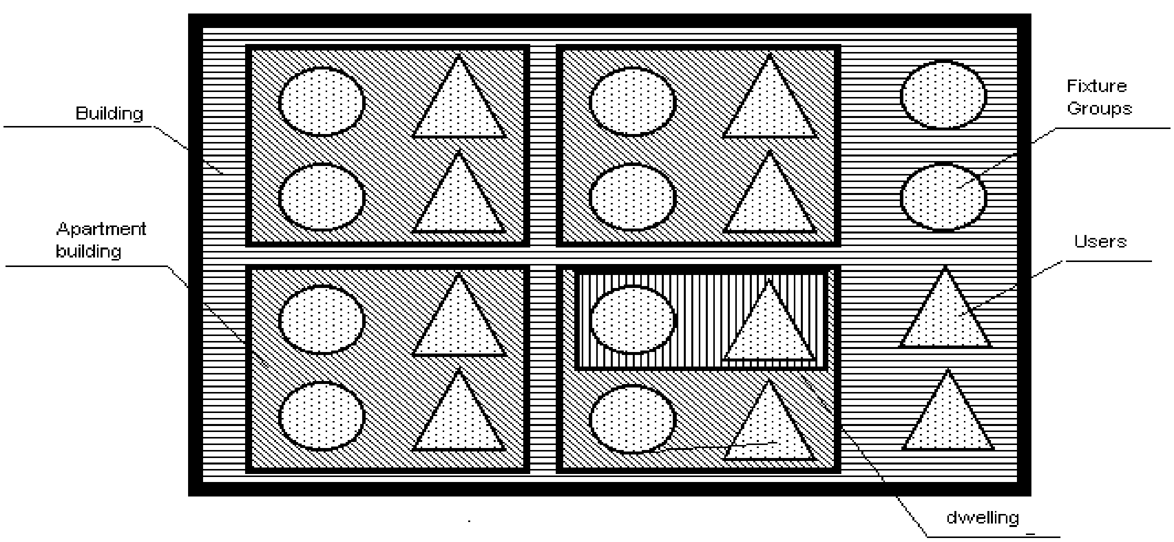

Figure 1 – Diagram of users' rights to access fixtures.

Figure 1 shows that the use of a fixture located in a fixture group denies the use of other fixture located in the same group.

Motivated by cultural or hygienic habits, some fixtures have “sequential use”. Sequential use is observed when the use of the first fixture generates the necessity of the use of a second fixture. For example: the use of lavatory after the use of urinals or toilets. Murakawa et alli, 2000, treat this issue in Railway Stations.

3 Timers and Records.

For a complete simulation process it is necessary to have two types of software elements: a timer, and some recorders.

A software component to simulate a date-time clock may be implemented with at least two characteristics: a) to run over seconds, minutes, hours and days in a non-real time basis, under operational speed greater than real time, in order to accelerate the simulation time; and b) to stop simulated time, between seconds, to set or record operational parameters about users, piping, fixtures, and so on, resuming simulated time and running it again;
With a component like this it is possible to control or predict users’ behaviour over days and over hours of the day.

More accurate timers for simulation process may control day of week, holidays, and other date-time related issues which have influence over users’ behaviour, and then, over fixture´s operation.

Recorders are software elements that record, sort, save and export data under a three-field format: date, time and value. With an array (or other data structure) of recorders, between one second and the next (simulated time), it is possible to record any desired parameter of the simulated object.

4 Building and piping data used for the simulation model

The 7 floor residential building has 28 dwellings, each dwelling with one restroom with shower, lavatory, and toilet with tank; one kitchen sink; and one laundry sink besides the washing machine.

Figure 2 shows the piping for laundry kitchen and restroom.

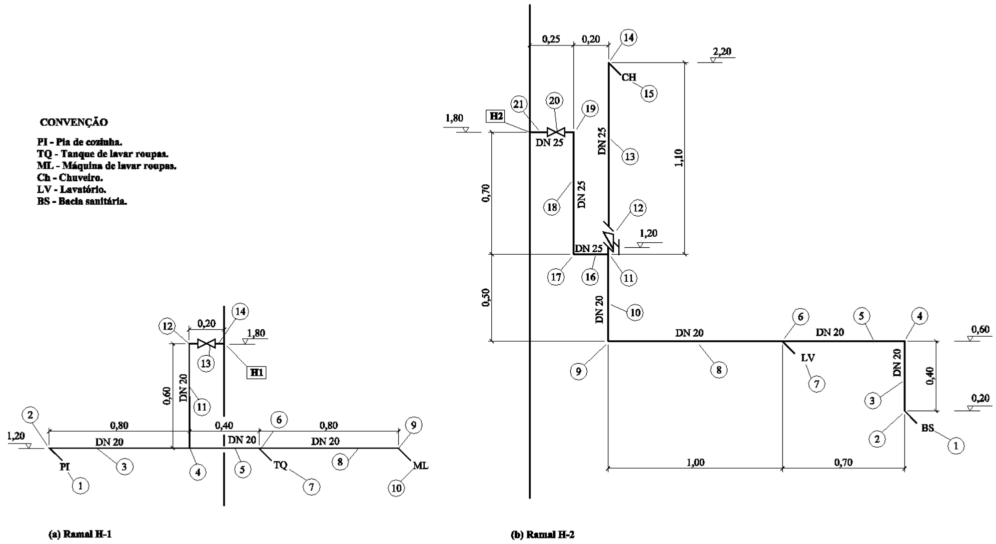

Figure 2 – Piping for laundry/kitchen and restroom

Each dwelling is supplied by two risers: odd numbered risers supplying laundries/kitchens and even numbered ones supplying restrooms.

A main pipe, on the roof, carries water from a reservoir to the 8 risers. Figure 3 shows the main pipe (a), and hydraulic schemes for risers (b).

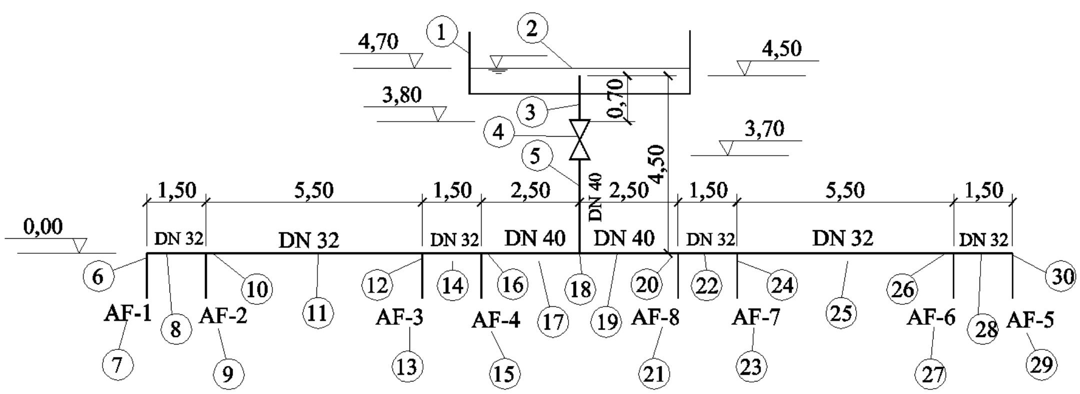

Figure 3a – Main pipe, reservoir, odd and even numbered rises.

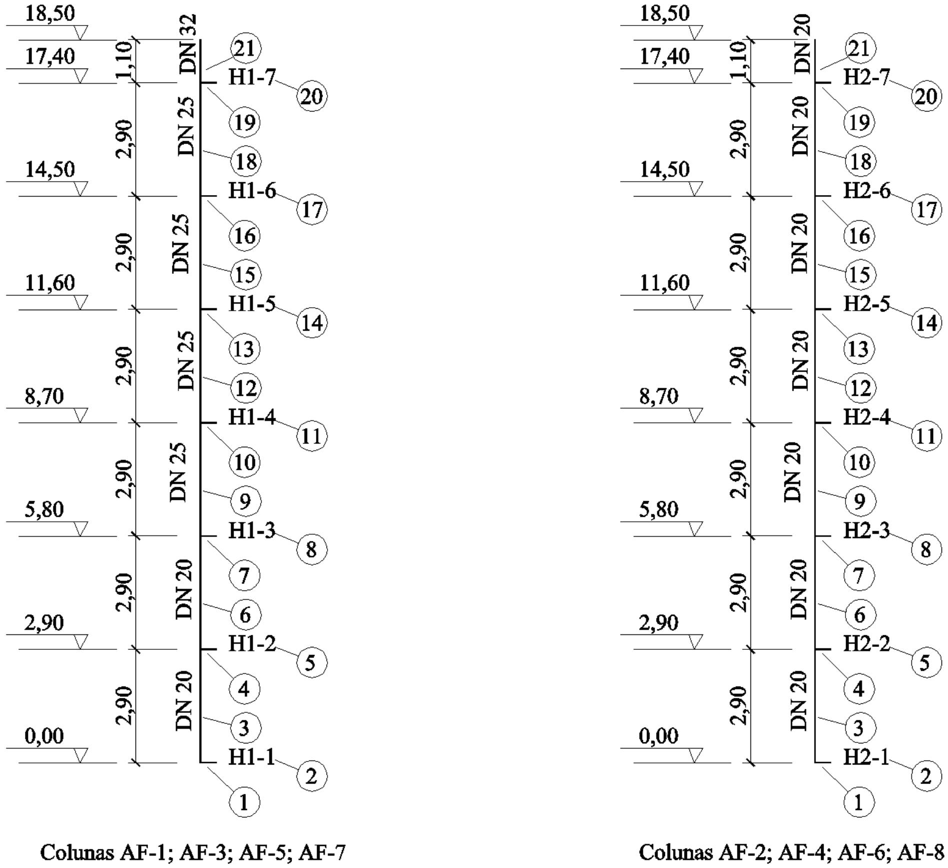

Figure 3b – Main pipe, reservoir, odd and even numbered rises.

The pipe diameters were established following Brazilian standard NBR5626/98 (ABNT, 1998), which considers the maximum limit of water velocity equal to 3,0 m/s. For an initial approach for diameters, almost every reasonable criterion would be appropriated.

Head losses were calculated using Darcy-Weisbach equation, considering water at 20°C and piping in PVC, according to Brazilian Standard NBR5648/99 (ABNT, 1999).

5 Fixtures flow rate, times and population

For a real flow rate approach in the network analysis, it's necessary to establish the coefficients of flow rate for each fixture, performing tests to determine hydraulic parameters as presented in (Petrucci & Gonçalves, 2002).

For these tests, commercial fixtures available in Brazil were used. Two types were used: an electrical showerhead - a low pressure electrical showerhead unit; and a water-save model, as shown in section 7.

Characteristic times and flow rates of operation of each kind of fixture was taken from (ILHA, 1991), (MURAKAWA et ali, 2000) and (SAKAUE et alli, 1987), except for washing machine, that was obtained in laboratory, for a traditional Brazilian model, as shown in (Petrucci e Gonçalves, 2002).

People distribution was obtained by means of Brazilian statistical data. The probability distribution of the number of people per dwelling is shown in figure 4.

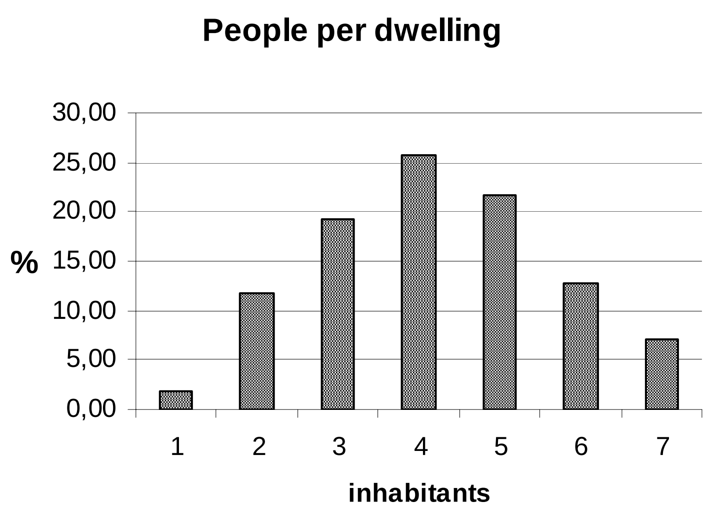

Figure 4 – Brazilian distribution of people per dwelling (IBGE[1]).

The actual number of people per dwelling is generated by simulation system, according to figure 4. Age, gender and other specific characteristics for each individual user are generated according to statistical IBGE data.

6 Implementation

For testing the simulation model, it was developed an application software. In this software, the main elements for simulation are integrated, as presented in previous papers (Petrucci & Gonçalves, 2001) and (Petrucci & Gonçalves, 2002): a real flow rate approach for piping networks, fixtures time and pressure x flow characteristics, users characteristics and population characteristics, as showed above.

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[1] IBGE-Instituto Brasileiro de Geografia e Estatística. (Brazilian Institute for Statistics and Geography).

The main window of this software is showed in figure 5. In this window the simulated time (at left), real clock time (at right), and the simulated state of any fixture in any dwelling (main white grid) can be seen. By this window the time increment, record time and other parameters can be set.

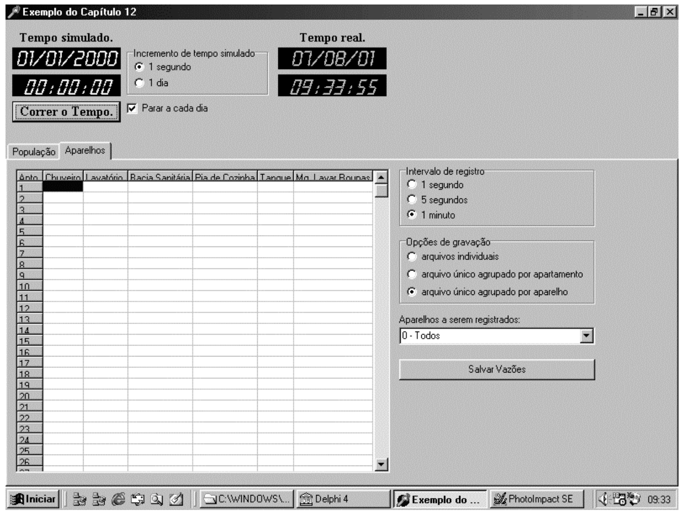

Figure 5 – Main window of the application software

By the "population" tab, it's possible to verify the total number of users in each simulated day, in each dwelling (Figure 6).

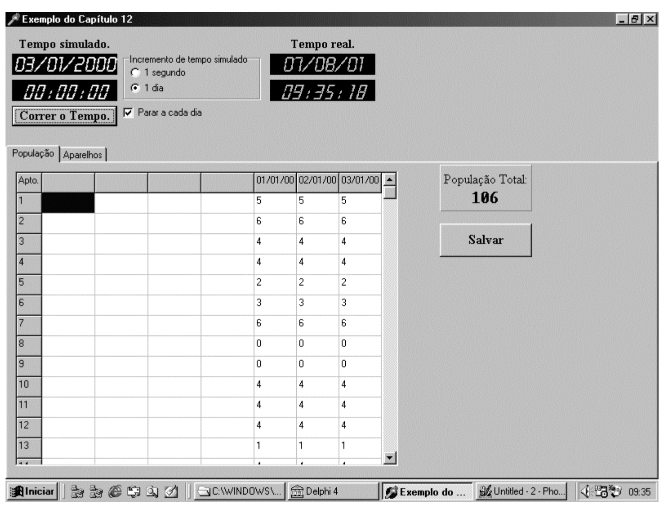

Figure 6 – Simulated population

During the simulation process, the fixtures operation can be followed through "X- marks" in main window, as shown in figure 7.

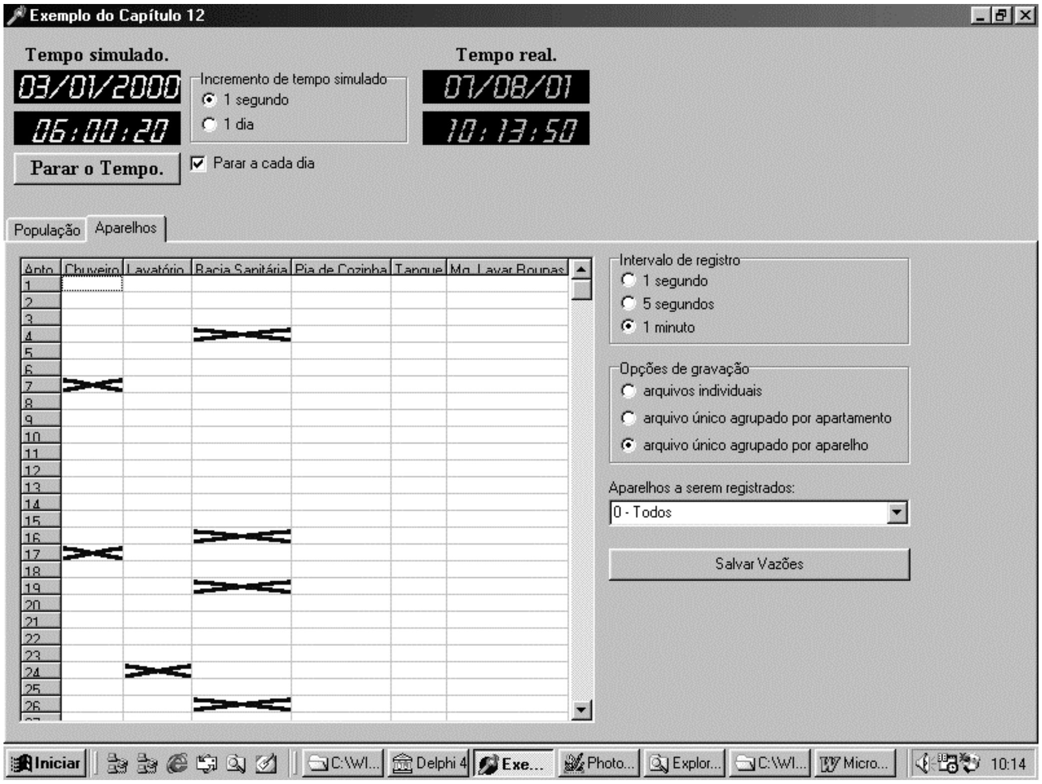

Figure 7 – Visual simulation aspect.

Figure 7 shows the simulated date of 01/03/2000, at simulated time of 6:00:20 am, with 2 showers in operation (at dwellings #7 and #17), 1 lavatory at dwelling #24, and 4 toilets (at dwellings #4, #16, #19 and #26).

7 Main results

It would be possible to set many simulated recorder elements, to record many parameters (i.e. the real flow of each fixture or of each section of pipe). But, for this purpose, to exemplify this technique, flow rates and total consumption of water were recorded.

Figure 8 shows the flow rate for the main outlet in the top reservoir.

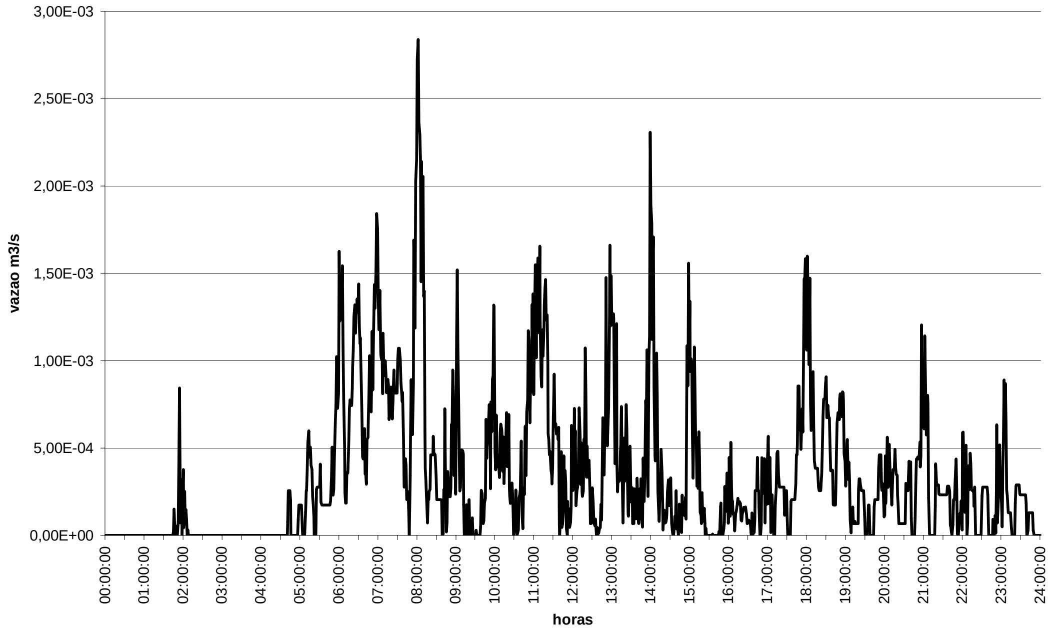

Figure 8 – Reservoir outlet flow rate.

The maximum flow rate occurs at 8:00 am, with flow rate of 2.84 L/s (2.92 m/s). The integration of this curve gives us the water consumption for this day: 29.2 m^3, for 122 inhabitants, circa of 258 L/inhab./day – what is a very high value.

Facing this unusual value, it was taken the recorded flow rate of each fixture (168 fixtures under one record per minute in a total of 242088 records). The analysis of this records shows that there is a great consumption of water in showers.

This high consumption may be due to the use of low pressure regular electrical showerheads existing in every dwelling. It's necessary to note that this misuse of regular showers would be possible, and maybe common, in real building. So, the model shows a potential problem that only simulation methods under real flow might show.

For a second simulation, showers were replaced for a "water-save" model. Water-save model for shower heads has a flatter pressure x flow curve. It's necessary to observe that users' preference for flow rate at bath was not changed.

Figure 9 compares these two kinds of showers.

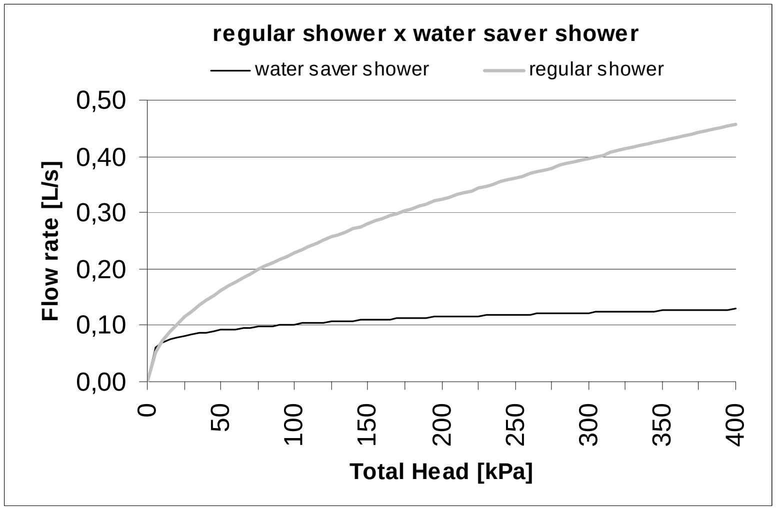

Figure 9 – Flow rate x pressure comparative of showers.

A new cycle of simulation with this kind of water save showerhead shows a flow rate x time diagram like that in figure 10.

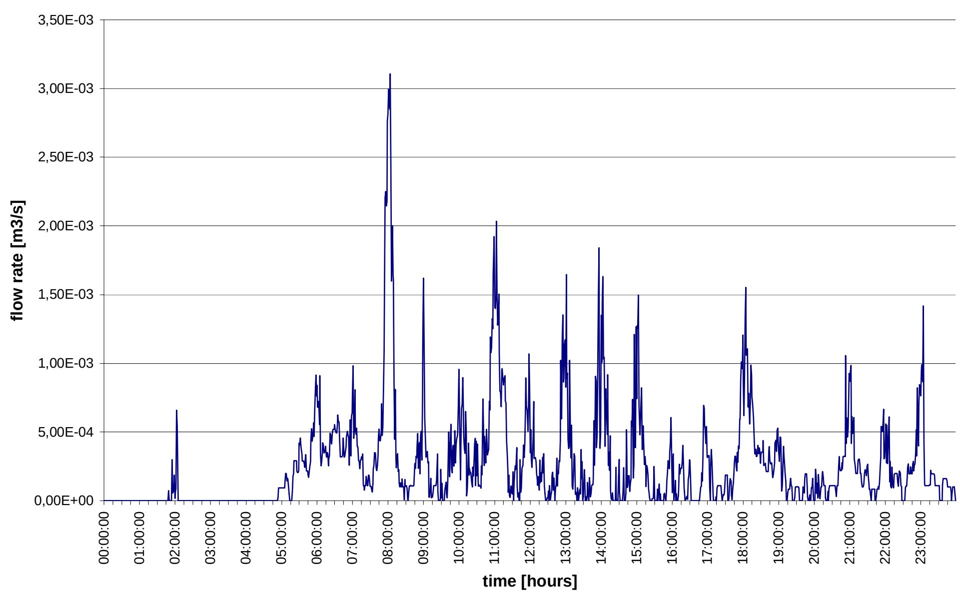

Figure 10 – Flow rate at top reservoir output with water save showers.

Maximum flow rate occurs at 8:00 am, with flow rate of 3.11 L/s (3.20 m/s). The integration of this curve gives a consumption of this day of 22.8 m^3, for 109 inhabitants, circa of 209 L/inhab/day. This value is 19% bellow of that presented with regular showerheads.

Maximum flow rate, is almost the same (6% greater in fact), and it occurs at the same time. This result may point out that maximum flow rate are not due to showerheads, but showerheads have significant influence in consumption values.

8 Conclusion

The technique presented here can show results that traditional methods can not. Traditional methods for design and evaluation of building water distribution systems can forecast about maximum flow rate, but can not do it about expected water consumption and its relation with hydraulic characteristics of fixtures.

It was possible to demonstrate a specific tuning point (the showers), but there are too many points to tune in a system like this. This clause shows the necessity of an automatic search for non-conformity aspects, since there are thousands of points to record analyze and adjust.

It would be appropriate to develop a friendly interface or a specific programming language to describe piping and users' data, due to the great amount and diversity of these data.

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10 Presentation of Authors

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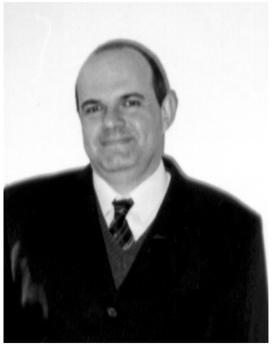

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