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Escola Politécnica da Universidade de São Paulo
Departamento de Engenharia Civil

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# A Study on the Estimation Method of the Maximum Load of Water Supply System in an Office Building by the Neural Network Model

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## ABSTRACT

In this paper the authors investigated the flow rates of water supply system at the office floors of a building the constructed in Tokyo Metropolitan district. The flow rates of the cold water, the hot water and the non-portable water in the pipes had been measured by pulse dispatch type water supply meters every 1 second. For resolving the problems in measuring the instantaneous flux in the actual buildings, the authors thought out the prediction model to estimate it by the flux of long time units. The model was constructed by neural network.

The maximum value of the flow rate in a pipe for 1 second could be predicted to high accuracy from the total volume used for 24 hours, it for 10hours, the maximum value of the flow rate in 1 minute. The predicted values were compared to the actual values by the statistical methods. And, the values predicted by neural network model had been fitted more than the values predicted by the linear regression analysis model.

## Keywords

Water supply; estimation of the maximum load; neural network; office building

## 1. Introduction

This paper shows the estimating method of the maximum flow quantities in a second for water supply in an office building. The instantaneous flow quantities were calculated in surplus for planning the water supply system in according to the conventional method. It is characteristic in Japan, because almost buildings have the receive tanks. However, for water conservation, energy conservation, saving space, keeping hygiene and so on, the direct water supply system became spread widely. In the Tokyo metropolitan district, booster pumps were added. The instantaneous flow quantities must be accurate enough for practically for this system.

In this report we investigated the flow quantities at the actual water supply system, and analyzed the maximum load. Then, an estimating model, which has calculated the maximum load of water supply system, was constructed using non- linear regression analysis. The investigated results agreed to the theoretical estimate.

## 2. A summary of Investigation

We show building equipment outlines of T- office building in Table 1. The water supply and drainage system of this building is shown in Figure 1, which has a multi-dimensional water supply.

We measured the flow quantities in all lavatories and hot water chambers at the 20$^{th}$ floor and the 36$^{th}$ floor two floors of this building, during December 17$^{th}$ ~ 24$^{th}$ in a winter term of 1996 and August 25$^{th}$ ~ 29$^{th}$ in a summer term of 1997. We show the plans of lavatories at those two floors in Figure 2 and Figure 3 There are two lavatories on the south side and the north side of the 20$^{th}$ floor, which are same plans. Flow meters were set up at 36 points of each pipe- lines for taking the data of flow quantities out of all fixtures of every lavatories and hot water chambers, and those were measured in a second, and recorded. We show a sight of the investigated places in Table 2.

## 3. The findings and the maximum loads of water supply

### 3.1 The number of existent persons on test floors

We show the number of existent persons on each floor averaged during a month, and variances, statistics in Table 3. Since a testing statistical hypothesis at 0.1- level significance was treated, it became clear that the number of existent persons on the 20$^{th}$ floor varied in seasons, but it on the 36$^{th}$ floor could not be decided to vary in seasons. Next, the testing statistical hypothesis at 0.05- level significance was treated for testing the seasonal variation of the ratio of female to male. It became clear that those on the 20$^{th}$ floor and the 36$^{th}$ floor could not be decided to vary with the seasons. In this report we decided that the ratio of female to male on the 20$^{th}$ floor was 21:79, and it on the 36$^{th}$ floor was 19:81.

**Table 1. The outline of building and building equipment.**

| | |
|---|---|
| **Address** | Tokyo Metropolitan |
| **Building scale** | 48 floors above ground, 3 floors below grade |
| **Total floor area** | 195,764.31m$^2$ |
| **Total quantities of water usage (design value)** | Potable water: 300m$^3$/day<br>Miscellaneous water: 300m$^3$/day (8 hour used) |
| **The bore of the water supply pipe** | Potable water: ϕ150mm<br>Miscellaneous water: ϕ150mm |
| **The water receiving tank** | Potable water: 2 places,180m$^3$<br>Miscellaneous water: 1 place,340m$^3$ |
| **Auxiliary tank** | Potable water: 7 places,43m$^3$<br>Miscellaneous water: 7 places,57m$^3$ |

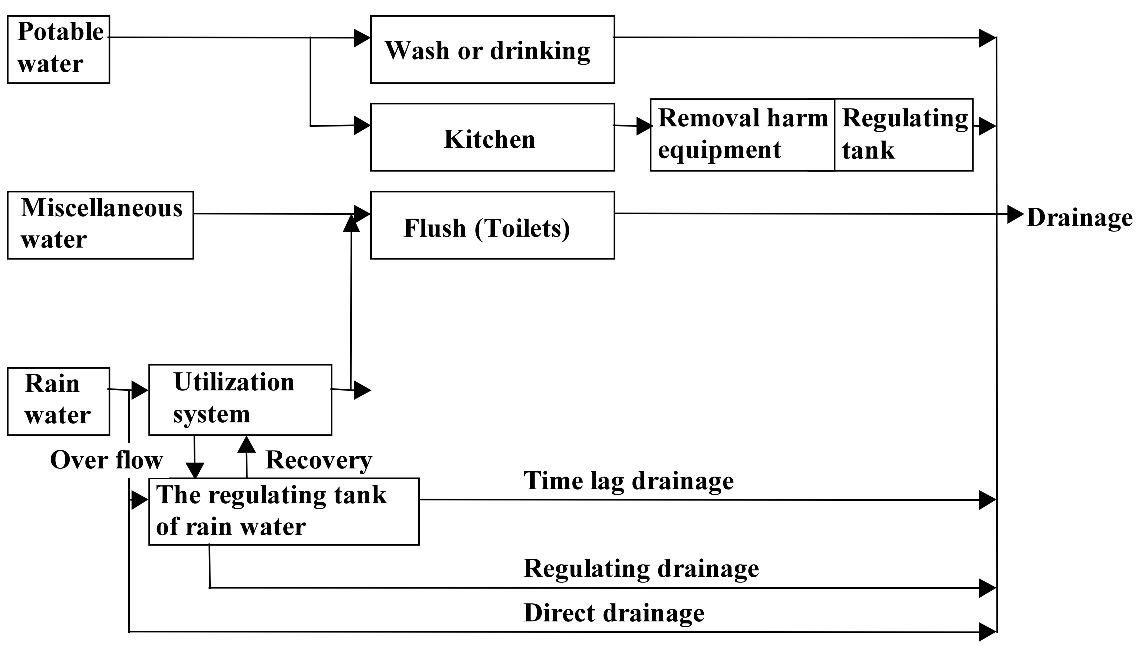


**Figure 1. Flow chart of the water supply and the drain water.**

**Table 2. A list of the investigated places.**

| The classification for use | | | | Usage | Diameter of a pipe | The classification for use | | | Usage | Diameter of a pipe |
|---|---|---|---|---|---|---|---|---|---|---|
| 36F | | Male lavatory | Sinks | Potable water | 20 | | Lavatory for the handicapped. | Sinks | Potable water | 20 |
| | | | | Hot water | 20 | | | | Hot water | 20 |
| | | | Urinals | Miscellaneous water | 30 | | | Toilets | Miscellaneous water | 30 |
| | | | Toilets. | Miscellaneous water | 30 | | Janitor's closet | | Potable water | 20 |
| | | Female lavatory | Sinks | Potable water | 20 | | Hot water room | | Potable water | 25 |
| | | | | Hot water | 20 | | | | Hot water | 20 |
| | | | Toilets | Miscellaneous water | 30 | | | | | |
| 20F | North | Male lavatory | Sinks | Potable water | 25 | South | Male lavatory | Sinks | Potable water | 25 |
| | | | | Hot water | 25 | | | | Hot water | 25 |
| | | | Urinals | Miscellaneous water | 30 | | | Urinals | Miscellaneous water | 30 |
| | | | Toilets | Miscellaneous water | 30 | | | Toilets | Miscellaneous water | 30 |
| | | Female lavatory | Sinks | Potable water | 25 | | Female lavatory | Sinks | Potable water | 25 |
| | | | | Hot water | 25 | | | | Hot water | 25 |
| | | | Toilets | Miscellaneous water | 30 | | | Toilets | Miscellaneous water | 30 |
| | | Janitor's closet | | Potable water | 20 | | Janitor's closet | | Potable water | 20 |
| | | Tea room | | Potable water | 20 | | Tea room | | Potable water | 20 |
| | Lavatory for the handicapped | | Sinks | Potable water | 20 | Hot water room | | | Potable water | 25 |
| | | | | Hot water | 20 | | | | Hot water | 25 |
| | | | Toilets | Miscellaneous water | 30 | | | | | |

**Table 3. The number of persons on each floor.**

| | | Winter | | Summer | | Statistics t-value | t-boundary value |
|---|---|---|---|---|---|---|---|
| | | Average | Variance | Average | Variance | | α=0.1 |
| 20F | Male | 166 | 18.2 | 147 | 51.7 | 6.74 | > 2.1 |
| | Female | 46 | 14.7 | 37 | 4.3 | 5.18 | > 2.1 |
| 36F | Male | 68 | 11.0 | 70 | 8.0 | -0.82 | < 2.1 |
| | Female | 15 | 5.2 | 18 | 1.0 | -2.01 | < 2.1 |

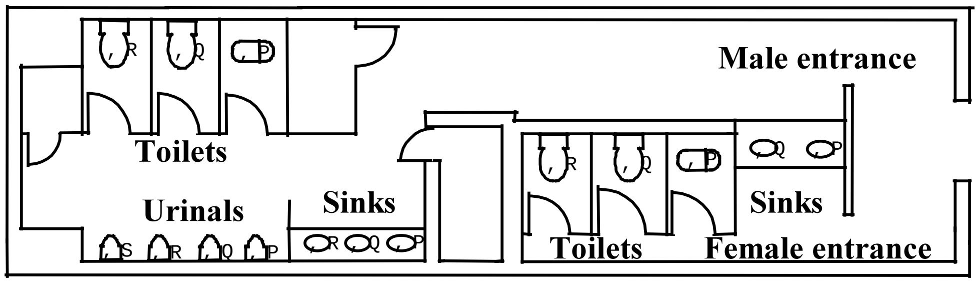


**Figure 2. Lavatory floor plan on 20F.**

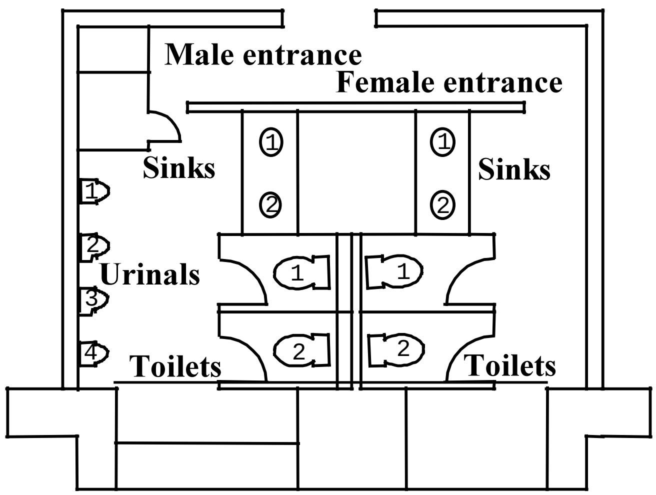


**Figure 3. Lavatory floor plan on 36F.**

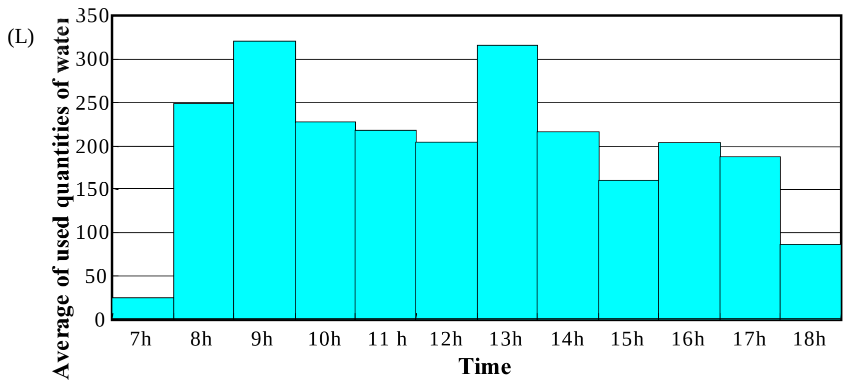


**Figure 4. The average of used quantities of water year-round.**
**(North male's lavatory on 20F)**

### 3.2 The maximum loads of water supply

We explain the technical terms as follows.

(1) The sum in a day: the total amount of used water in 24 hours from 0 to 24 o'clock.
(2) The sum in 10 hours: the total amount of used water in 10 hours from 8 to 18 o'clock.
(3) The maximum value in an hour: the value when the total amount of used water in each hour from 8 to 18 o'clock was the largest.
(4) The maximum value in a minute: the value when the total amount of used water in each minute at the case of (3).
(5) The maximum value in a second: the value when the total amount of used water in each second at the case of (3).
(6) The estimated maximum values in a second: the determined values after estimation of the population distribution with sampled values, which were the 95% value, 99% value and 99.5% value of the estimated maximum value.

We calculated each values of used water in 6 lavatories through each season and through a year. The variations of the total amount of the used water in an hour are shown in Figure 4 and Figure 5, those are averaged through a year. Figure 4 is the case of male lavatory on the north side of 20$^{th}$ floor. There were two peaks, which appeared at the office-going hour and after lunch hour. Figure 5 is the case of female lavatory on the north side of 20$^{th}$ floor. There were two peaks, which appeared after lunch hour and the closing hour.

We show the sum in a day, the sum in 10 hours, the maximum value in an hour, the maximum value in a minute, the maximum value in a second and the estimated maximum values in a second at every lavatory investigated in Table 4. After the testing statistical hypothesis at 0.05- level significance was treated about the maximum values in a second investigated in each season, it became clear that the total amount of used water in winter season might be more than in summer season. But there was no difference only as to the estimated 95% maximum values in a second.

If the maximum value investigated was treated as the maximum load in water supply system, we could not design the water supply system, taking special care of reliability, and the scale of system might be calculated larger. In this report we think that the estimated 95% maximum value in a second is the maximum load to water supply system.

### 3.3 Water amount used by one person

The mean value, variances and statistics, which were calculated in the sum in 10 hours divided by the existent persons on each floors are shown for Table 6. After the testing statistical hypothesis at 0.05- level significance was treated about the water amount used by one person investigated in each season, it became clear that there were no differences in the case of male at 20$^{th}$ floor and female at 36$^{th}$ floor.

### 3.4 The profiles of used water amount

The daily movement and the seasonal movement are important to design the water supply system. We treated analysis of variance to the hourly changes of amount used water. The findings of the analysis to the lavatory for male on the north side of 20$^{th}$ floor are shown in Table 7. When we built up a hypothesis that the population means of the data of the all investigated day are coincident, the variance ratio-F was calculated as1.357. Since this is smaller than the boundary value (1.966), the hypothesis could not be rejected. Then

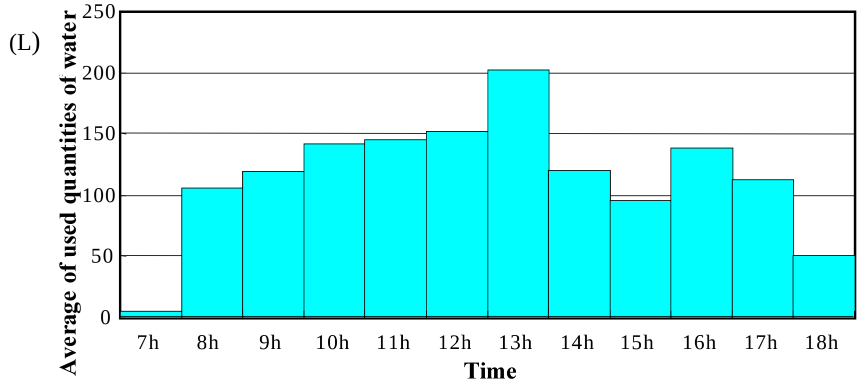


**Figure 5. The average of used quantities of water year-round. (North female's lavatory on 20F)**

**Table 4. The used quantities of water in T-office building.**

| Lavatory | Date | The maximum value of estimation for 1 second: L/min | | | The maximum value for 1 second | The use quantity of water: L | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 95% | 99% | 99.5% | L/min | The maximum value for 1 minute | The maximum value for 1 hour | 10 hours | 24 hours |
| 20F north lavatory (Male) | Winter | 87.196 | 106.988 | 114.492 | 151.696 | 31.336 | 428.868 | 2626.110 | 2954.126 |
| | Summer | 71.376 | 109.323 | 117.720 | 127.595 | 30.286 | 301.634 | 1978.644 | 2183.150 |
| | Year-round | 79.286 | 108.155 | 116.106 | 139.645 | 30.811 | 365.251 | 2302.377 | 2568.638 |
| 20F north lavatory (Female) | Winter | 90.648 | 100.488 | 114.222 | 162.952 | 32.871 | 291.091 | 1658.540 | 1834.928 |
| | Summer | 90.648 | 96.667 | 100.236 | 106.354 | 29.364 | 173.382 | 1015.618 | 1156.230 |
| | Year-round | 90.648 | 98.577 | 107.229 | 134.653 | 31.118 | 232.237 | 1337.079 | 1495.579 |
| 20F south lavatory (Male) | Winter | 66.608 | 87.824 | 97.626 | 122.966 | 25.176 | 255.397 | 1928.659 | 2206.518 |
| | Summer | 60.883 | 81.698 | 88.647 | 98.638 | 21.836 | 272.272 | 1709.978 | 1945.146 |
| | Year-round | 63.746 | 84.761 | 93.136 | 110.802 | 23.506 | 263.834 | 1819.319 | 2075.832 |
| 20F south lavatory (Female) | Winter | 99.930 | 123.188 | 146.552 | 166.012 | 39.437 | 266.040 | 1461.520 | 1621.944 |
| | Summer | 99.213 | 105.041 | 117.697 | 123.212 | 26.677 | 191.642 | 1132.964 | 1326.208 |
| | Year-round | 99.571 | 114.114 | 132.125 | 144.612 | 33.057 | 228.841 | 1297.242 | 1474.076 |
| 36F lavatory (Male) | Winter | 77.108 | 107.060 | 116.958 | 138.086 | 26.894 | 237.849 | 1693.538 | 1866.056 |
| | Summer | 83.937 | 111.560 | 119.912 | 128.690 | 24.537 | 226.162 | 1444.716 | 1620.462 |
| | Year-round | 80.523 | 109.310 | 118.435 | 133.388 | 25.715 | 232.006 | 1569.127 | 1743.259 |
| 36F lavatory (Female) | Winter | 109.916 | 124.192 | 125.120 | 148.978 | 36.761 | 210.636 | 1048.147 | 1101.222 |
| | Summer | 107.064 | 119.912 | 129.904 | 134.496 | 31.686 | 207.552 | 1189.002 | 1248.282 |
| | Year-round | 108.490 | 122.052 | 127.512 | 141.737 | 34.223 | 209.094 | 1118.575 | 1174.752 |

we could not treat as the different data for the investigated data during a year at 0.05- level significance.

The findings to the analysis to all investigated lavatories are shown in Table 8. Almost of the profiles of hourly used water amount belonged to the each population with a few exceptions. In the case of the lavatory for females on the north side of 20th floor, there was difference in seasons.

## 4. The construction of estimation model for the maximum load

Since it costs a great deal to investigate for measuring flow quantities in a second and to analyze the data. We confront the serious problem to execute the projects to investigate more buildings. As the settlement of it, we studied the method to estimate the maximum value in a second by the water amount measured in the longer period.

Firstly, we treated the multi variables regression analysis. The following equations were obtained:

$$Y = 0.778X1 + 0.027X2 + 0.009X3 - 0.013X4 + 68.108 \qquad \text{............ eq. (1)}$$

$R2 = 0.2749$

Y : The estimated maximum values in a second
X1 : The maximum value in a minute
X2 : The maximum value in an hour
X3 : The sum in 10 hours
X4 : The sum in a day
R2 : a multiple correlation coefficient

It is insufficient to apply the estimation model with eq.(1), because a multiple correlation coefficient is lower. Then, we constructed the model by the neural network, which identify the model with the non- linear regression analysis.

We show a neural network model in Figure 6. This model has 3- layers. The first layer is an input layer, which is made formed by 4- units. Those are the maximum value in a minute,
the maximum value in an hour, the sum in 10 hours and the sum in a day. The second layer is a hidden layer, which is made foamed by 9- units. The third layer is a output layer, which has single unit. This is the maximum load in a second to water supply system. A number of units at the hidden layer was decided by the Akaike Information Criteria (AIC). The data of each unit of an input layer and an output layer were standardized from 0.1 to 0.9.

Training such a network involve using the water amount data of every lavatory, which are values for the input and output of the neural network. The data of December 24th and August 8th were excluded, because those data were used for inspection. The neural network would learn by adjusting the weights to minimize the error of the outputs. The error function is the objective of the minimization procedure. The values of error function on the training process are shown in Figure 7.

**Table 5. The maximum quantities of water usage in a second.**

| | Winter | | Summer | | Statistics t-value | t-boundary value |
|---|---|---|---|---|---|---|
| | Average | Variance | Average | Variance | | α=0.05 |
| The maximum in 1 second | 175.1 | 1412.6 | 139.0 | 1066.4 | 7.92 | > 2.0 |
| 99.5% value | 133.4 | 991.2 | 122.3 | 615.7 | 2.56 | > 2.0 |
| 99% value | 117.1 | 419.5 | 110.7 | 266.2 | 2.53 | > 2.0 |
| 95% value | 93.4 | 205.5 | 90.0 | 276.3 | 1.98 | < 2.0 |

**Table 6. The quantities of water usage per one person.**

| | | Winter | | Summer | | Statistics t-value | t-boundary value |
|---|---|---|---|---|---|---|---|
| | | Average | Variance | Average | Variance | | α =0.05 |
| 20F | Male | 27.5 | 1.8 | 24.9 | 2.6 | 2.46 | < 2.8 |
| | Female | 67.3 | 29.3 | 57.1 | 4.7 | 5.12 | > 2.8 |
| 36F | Male | 24.9 | 2.3 | 20.6 | 7.2 | 3.21 | > 2.8 |
| | Female | 68.6 | 101.6 | 65.9 | 51.3 | 1.14 | < 2.8 |

**Table 7. The analysis of variance to the distribution of used quantities of water. (North male's lavatory on 20F)**

| The factor of variation | Variation | Degrees of freedom | Variance | Variance ratio | F-boundary value |
|---|---|---|---|---|---|
| During the groups | 115566 | 9 | 12841 | 1.357 | 1.966 |
| In the groups | 1041170 | 110 | 9465 | | |
| Total | 1156736 | 119 | | | |

**Table 8. The results of analysis of variance.**

| The place of the use | Winter | Summer | Year-round |
|---|---|---|---|
| 20F north lavatory (Male) | O | O | O |
| 20F north lavatory (Female) | O | O | × |
| 20F south lavatory (Male) | O | O | O |
| 20F south lavatory (Female) | O | O | O |
| 20F lavatory (Male) | O | O | O |
| 20F lavatory (Female) | O | O | × |
| 20F lavatory | O | O | O |
| 20F all | O | - | - |
| 36F lavatory (Male) | O | O | O |
| 36F lavatory (Female) | O | O | O |
| 36F lavatory | O | O | O |
| 36F all | O | O | O |

O:The quantities of water usage of each day are belonged to the same group.
×:The quantities of water usage of each day are not belonged to the same group.

A scatter diagram shows the relation between the training data and the estimated data in Figure 8. A multiple correlation coefficient is improved than the case of multi variables regression analysis.

## 5. Findings of estimation

We evaluated the neural network model in the tests with the data of December $24^{th}$ and August $8^{th}$ . The estimated values and the investigated values were compared and shown in Table 9. Close agreement between investigated values and estimated values was obtained. Since a multiple correlation coefficient is 0.824 and results of tests were better than multi variables regression analysis, we think that this method is effective.

## 6. Conclusion

We studied the maximum load of water supply in an office building by the investigation for measuring flow quantities in a second. Since there were difficulties in such investigation, we examined the method to estimate the maximum value in a second by the water amount measured in the longer period. The following results are obtained.

(1) The estimated 95% maximum value in a second is suitable for treating as the maximum load.

(2) In estimation, the method of the neural network modeling were better than it of multi variables regression analysis

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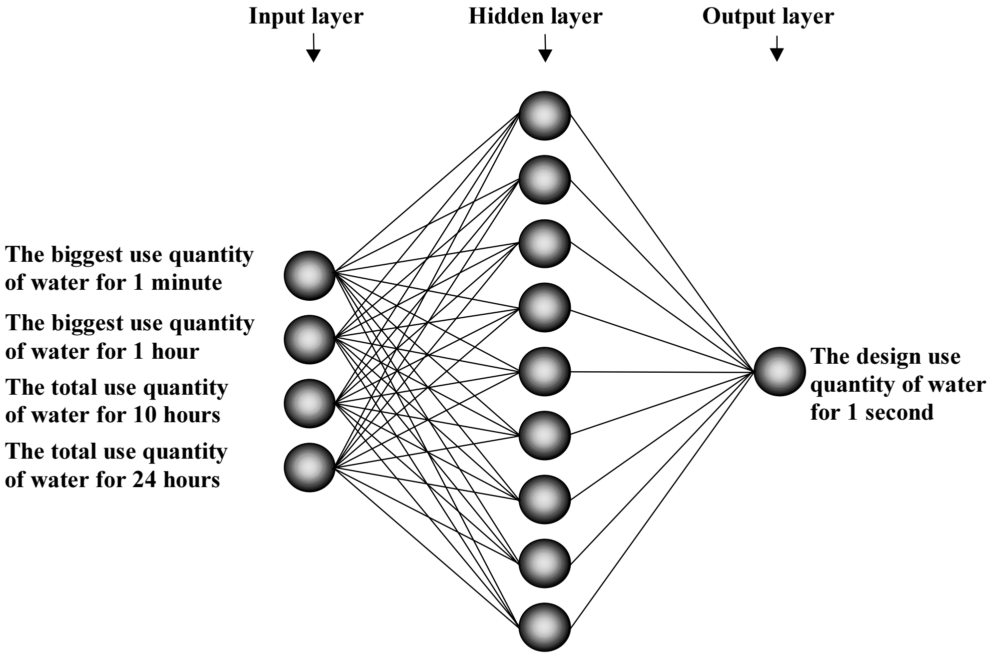


Figure 6. The Neural Network model

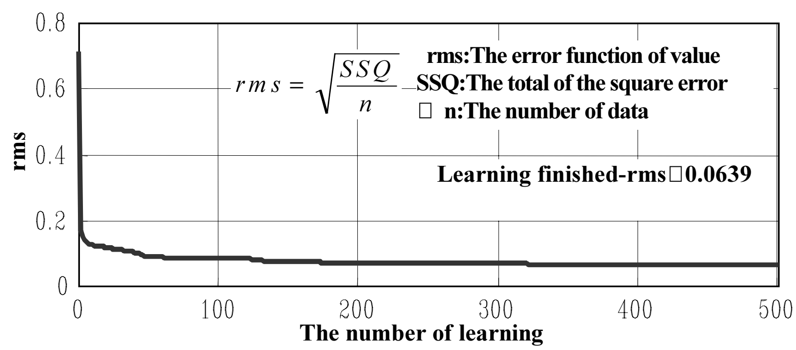


Figure 7. The variation in rms.

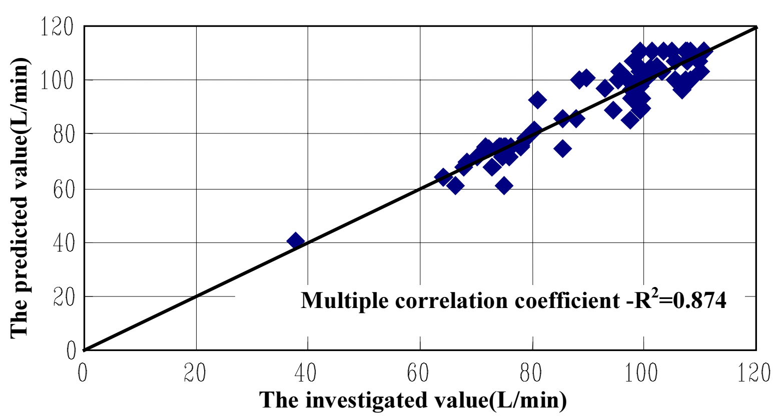


Figure 8. The results of learning.

**Table 9. The results of predicted values.**

| | | Predicted value L/min | Actual value L/min | Predicted value - Actual value. L/min |
|---|---|---|---|---|
| 12/24 | 20F north lavatory (Male) | 102.50 | 96.35 | 6.15 |
| | 20F south lavatory (Male) | 98.76 | 78.48 | 20.28 |
| | 20F south lavatory (Female) | 105.21 | 99.92 | 5.29 |
| | 20F lavatory (Male) | 92.81 | 90.83 | 1.98 |
| | 20F lavatory | 99.21 | 103.50 | -4.28 |
| | 36F lavatory (Male) | 74.24 | 75.01 | -0.78 |
| | 36F lavatory (Female) | 110.27 | 110.63 | -0.37 |
| | 36F lavatory | 101.77 | 107.06 | -5.29 |
| | 36F all | 97.99 | 103.50 | -5.51 |
| 8/29 | 2F north lavatory Male) | 75.26 | 60.67 | 14.59 |
| | 20F south lavatory (Male) | 48.78 | 40.32 | 8.45 |
| | 20F south lavatory (Female) | 109.85 | 96.36 | 13.49 |
| | 20F lavatory (Male) | 73.63 | 71.38 | 2.25 |
| | 20F lavatory | 88.10 | 99.93 | -11.82 |
| | 36F lavatory (Male) | 48.02 | 60.67 | -12.65 |
| | 36F lavatory (Female) | 109.06 | 110.63 | -1.57 |
| | 36F lavatory | 105.71 | 107.06 | -1.36 |
| | 36F all | 107.83 | 110.63 | -2.80 |

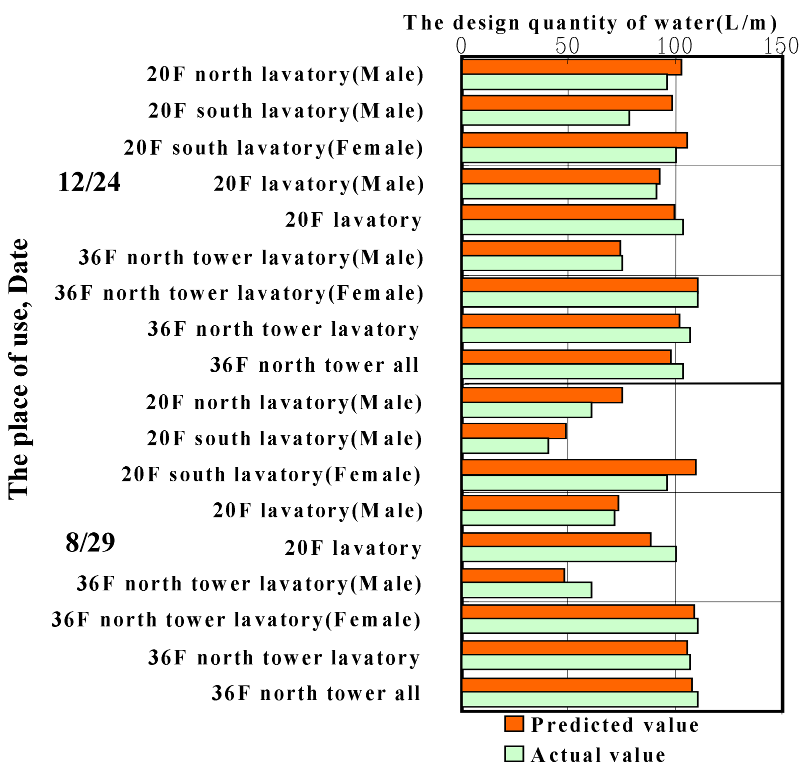


**Figure 9. The result of predicted value.**

# Statistical Method for Estimation of Peak Water Demands in Water Supply Systems for Buildings

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## Abstract

Peak flows are the basic parameters, which are used for estimation the size of the pipe diameters of water supply and drainage installations.

Design demand is water quantity, which reflects the critical load levels of the system during the operational period when it should perform normally. It is obligatory when designing the different elements of the system-pipes, pumps, booster units, tanks, water heaters etc. Depending on the particular design task different time interval is used. The interval can be a day, an hour, a minute, a second. Usually the approaches for calculation of these water quantities are different.

The objective of this paper is to describe a common statistical method for calculation the peak demands in the different branches of water supply systems, which allows taking into account the time interval and confidence coefficient. However it needs additional research and in order to reflect the various factors which influence water demand regime of the different types of buildings. These parameters are specific for every country and type of building. The paper focuses on the stochastic flow rate distribution model in the water supply networks for buildings. Charts for practical application of the method for sizing of the pipes of the plumbing networks are presented.

## Keywords

Flow rate; water demand; stochastic model, design, method;

## 1 Introduction

The stochastic character of the water consumption from the water supply system is reflected very limited from the theory and rarely used in practice. The fact that not only the demand but also the pressure losses are random parameters too is not reflected. There are still questions which are not solved and which need investigation, i.e. how to select the required confidence level, what is the time interval for which the density function will be adequate, what is the duration of the peak demands. Tessendorf [4] suggested 15 second of the duration of the peak demands for the plumbing systems. In fact the different elements of the system can be sized for different time interval duration of the peak demand. The idea of using different duration for the peak demand of the elements of water supply and plumbing systems is very promising. However it needs additional research and in order to reflect the various factors which influence water demand regime of the different types of buildings. These parameters are specific for every country and type of building. This paper focuses on the stochastic flow rate distribution model in the water supply networks for buildings.

## 2 Stochastic water demand model

Stochastic models developed during the last years allow application of the theoretical stochastic methods in the design practice. Stochastic water demand model implementation is discussed in more details in several other papers [1,2,3,4]. The model includes harmonic, centred hourly stochastic, centred stochastic for time interval less then 1 hour components.

The parameters of the model are functions of two major factors, the number of fixtures and the average annual specific water use per fixture and are determined by applying regression analysis. They can be obtained rather quickly for the different types of buildings using recorded consumption and pressure data from normally operating plumbing systems [1,4].

The Cumulative Density Function of the process is described by normal distribution equation:

$$F_t(Q) = \frac{1}{T\sigma_\tau\sqrt{2\pi}}\int_0^Q\int_0^T \exp\left[-\frac{1}{2}\left(\frac{Q_{T(t)}-Q}{\sigma_\tau}\right)^2\right]dtdQ \qquad (1)$$

where

$\sigma_\tau$ is the standard deviation of the stochastic component;

$\tau$ - the time interval;

$Q_{T(t)}$ – the standardised daily profile demands;

$T$ – the duration of the observed period.

## 3 Stochastic water supply network distribution model

Traditional methods of estimating the flow rates assume the same demand at the point of consumption as at the network supply facilities. In fact it is one of many possible values. The criterion for the reliability of the systems is the confidence level which is sufficiently high (0.98-0.99). The possibility of non-coincidence of peak values for various consumers is need additional investigations. The probability of the assumed loading vector for all the consumers, as well as the probability of the water supply system state (pump head and water tank levels etc.) corresponding to the demand values need to be determined.

It is known that the principle of superposition cannot be implemented because of the non-linearity of the water networks. Verbitsky have noticed that there are conditions when this principle is valid [4]. If the nodal demands change in synchrony, then it is possible to use linear operator for the resultant solution. This fact satisfies the prerequisite for estimation the stochastic flow rate distribution.

The flow rate in any water supply network pipe can be estimated by the equation:

$$Q_i = \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij} q_j \ , \qquad (2)$$

where

$c_{ij}$ are coefficients which show the portion of the flow from each pipe in node $j$;

$q_j$ – the flow from pipe $j$;

$m$ – the number of the nodes in the network;

$n$ – the number of the pipes.

If $q_j$ are random values, equation 2 shows that the parameters of the density function of the random flow rates $Q_i$ can be determined by the traditional rules of random value transformation.

Equation 2 does not change if $Q_i$ and $q_j$ are replaced by their mean values and the pipe flow rate variance is determined by:

$$Var(Q_i) = \sum_{j=1}^{m} c_{ij}^2 Var(q_j) + \sum_{j=1,k=1,j\neq k}^{m} Cov(q_j, q_k) \ , \qquad (3)$$

where

$Cov(q_j, q_k)$ is the covariance of the flow rates in nodes $j$ and $k$.

Equations (2) and (3) determine the stochastic flow distribution in a water supply network.

Introducing of matrices of summarised parameters into design process allows application of well-developed procedure for linear networks.

For every node two balanced equations can be written [4]:

$$M(q_j) = M(q_i) + M(q_k) \qquad (4)$$

$$Var(q_j) = M(q_i)^2 V(q_i)^2 + M(q_k)^2 V(q_k)^2 + 2C(q_i, q_k) M(q_i) M(q_k) V(q_i) V(q_k) \qquad (5)$$

where

$M(q_j)$ is the mean flow rate value of pipe $i$ ,

$M(q_i)$ and $M(q_k)$ – the mean flow rate values in pipes $i$ and $k$;

$V(q_i)$ and $V(q_k)$ – the variance coefficients o flow rate values in pipes $i$ and $k$;

$C(q_i, q_k)$ – correlation coefficient.

Equation (4) represents the material balance according Kirchhoff's low and equation (5) represents the statistical balance, which specifies the relationship of random flow rates pipe values and the water flow rate supplied to a certain node.

## 4 Method for estimation the peak second and hourly water demand

The basis of the method is the estimation of the parameters of stochastic model, which allows using one and the same density function to determine the hourly and the shorter time interval water demand (flow rates). The used parameters of the applied model are referred to the public buildings. They are determined on the basis of the recorded flow and pressure data of the existing public buildings in Bulgaria and therefore should be clarified for the conditions in the other countries.

The method comprises the following procedures:

### 4.1 Estimation of the average hourly water demand, $\bar{Q}_h$

The average hourly water demand for a particular building is calculated by the following equation:

$$\bar{Q}_h = \frac{N\bar{q}_d}{t_w}, \tag{6}$$

where

$\bar{q}_d$ is the daily water demand per capita, $dm^3$/c.d;

$N$ – the number of the residents;

$t_w$ – the working period, when shorter than 24 h, h.

### 4.2 Estimation of the average hourly fixture water demand, $\bar{q}$

The average hourly fixture water demand is an important factor, which influences considerably the design flow rates and should be taken into consideration during the pipe sizing procedure. It reflects the fact that the frequency of use of the sanitary fixtures is dependent of the number of the residents of the building. It is determined using the following equation:

$$\bar{q} = \frac{\bar{Q}_h}{\sum n}, \text{ dm}^3\text{/f.h,} \tag{7}$$

where

$\sum n$ is the total fixture units of the building installation.

### 4.3 Estimation of the parameters of the cumulative density function

4.3.1 Variation coefficient

The variation coefficient of the hourly demand process, $V_h$ is estimated according the following mathematical expression:

$$V_h = \frac{\left\{\left(4.95 + 0.1\bar{q} - 0.5\log\sum n\right)^2 + \frac{18.2}{\sqrt{(\sum n)^2 + \left(\frac{\bar{q}}{50}\right)}} .10^{\left[3 - \frac{1.8}{\exp\left(0.08\bar{q}\right)}\right]}\right\}^{0.5}}{\bar{q}} \tag{8}$$

4.3.2 Ratio of the variances of the harmonic and the stochastic hourly demand processes, $M$

The ratio of the variances of the harmonic and the stochastic hourly water demand can be determined by the equation [3]:

$$M = \begin{cases} 0.02(\sum n)^{0.8} & \sum n \le 400 \\ 0.06(\sum n)^{0.6} & \sum n > 401 \end{cases} \tag{9}$$

where

$\sum n$ is the total fixture units supplied by the pipe;

4.3.3 Hourly water demand variance

The variance of the hourly water demand is determined by the following equation:

$$Var(Q_h) = (V_h.\bar{Q}_h)^2, \text{ (dm}^3\text{/h)}^2 \quad (10)$$

4.3.4 Constant water demand process variance

The variance of the constant process is calculated according to the following mathematical expression:

$$Var\left(Q_h^c\right) = \frac{M.Var\left(Q_h\right)}{(M+1)}, \text{ (dm}^3\text{/h)}^2 \quad (11)$$

4.3.5 Variance coefficient of the harmonic demand process

The variation coefficient of the constant (harmonic) demand process is calculated using the equation:

$$V_h^c = \frac{\sqrt{Var(Q_h^c)}}{\bar{Q}_h} \quad (12)$$

4.3.6 Peak hourly water demand coefficient.

The peak hourly water consumption coefficient is estimated by following equation[4]:

$$K = V_h^{c\,2} + V_h^c\sqrt{1+V_h^{c\,2}} + 1. \quad (13)$$

**4.4 Estimation of the is the standard deviation of the stochastic component, $\sigma_\tau$**

The standard deviation of the random water demand process averaged for time interval $\tau$ is estimated according the well-known formula:

$$\sigma_\tau^r = \sqrt{Var\left(Q_\tau^r\right)} = \left(\frac{Var\left(Q_h\right)}{1+M}\right)^{0.5}\sqrt{F_\tau}, \text{ dm}^3/\tau \quad (14)$$

where

$F_\tau$ is determined depending on the time interval $\tau$ by the equation:

$$F_\tau = \frac{Var\left(Q_{300s}^*\right)\left[3.56-\log(\tau)\right]\left(M+1\right)}{1.08Var(Q_h)} + 1 \quad (15)$$

where

$Var(Q^*_{300s})$ is the variance of the recorded water consumption time series (with time interval $\tau = 300\ s$) performed for particular type of building.

$F_\tau$ can also be calculated (after checking the adequacy )using the following mathematical expression (4):

$$F_\tau = 1 + \left[3.56 - \log(\tau)\right]\left\{0.42\left[\left(\frac{\bar{q}}{5.3} - 1\right)^2 + \frac{3.67}{\left[\log\left(n+1\right)\right]^{1.45}}\right]\right\} \quad (16)$$

### 4.5 Estimation of the design flow rates

The design flow rates are estimated depending on the confidence level $P_m$:

$$\frac{\left|F_t(Q) - P_m\right|}{P_m} \leq \varepsilon \qquad (17)$$

where $F_t(Q)$ is the value of the cumulative density function (CDF) (see equation 1).

$\varepsilon$ – the relative allowed error;

$Q$ – the design flow rate for time interval $\tau$, determined as the upper limit of integration of the CDF.

## 5 Results

The design flow rates for the building water supply systems can be determined depending only of two major parameters:

- the total pipe fixture units;
- the annual specific water demand per fixture.

The practical application of the method can easily be done by developing the corresponding tables and charts as well as creating of friendly software.

As the water consumption regime is different for the different types of buildings it is necessary the parameters of the model to be clarified for each type of building. As the sanitary equipment, climatic conditions and culture of the residents are different the parameters of the CDF should be determined and clarified for each country.

The proposed charts (Figures 1 and 2) can be used for estimation of the peak second and peak hourly flow rates for the public buildings. They are created using the established parameters for the country of Bulgaria.

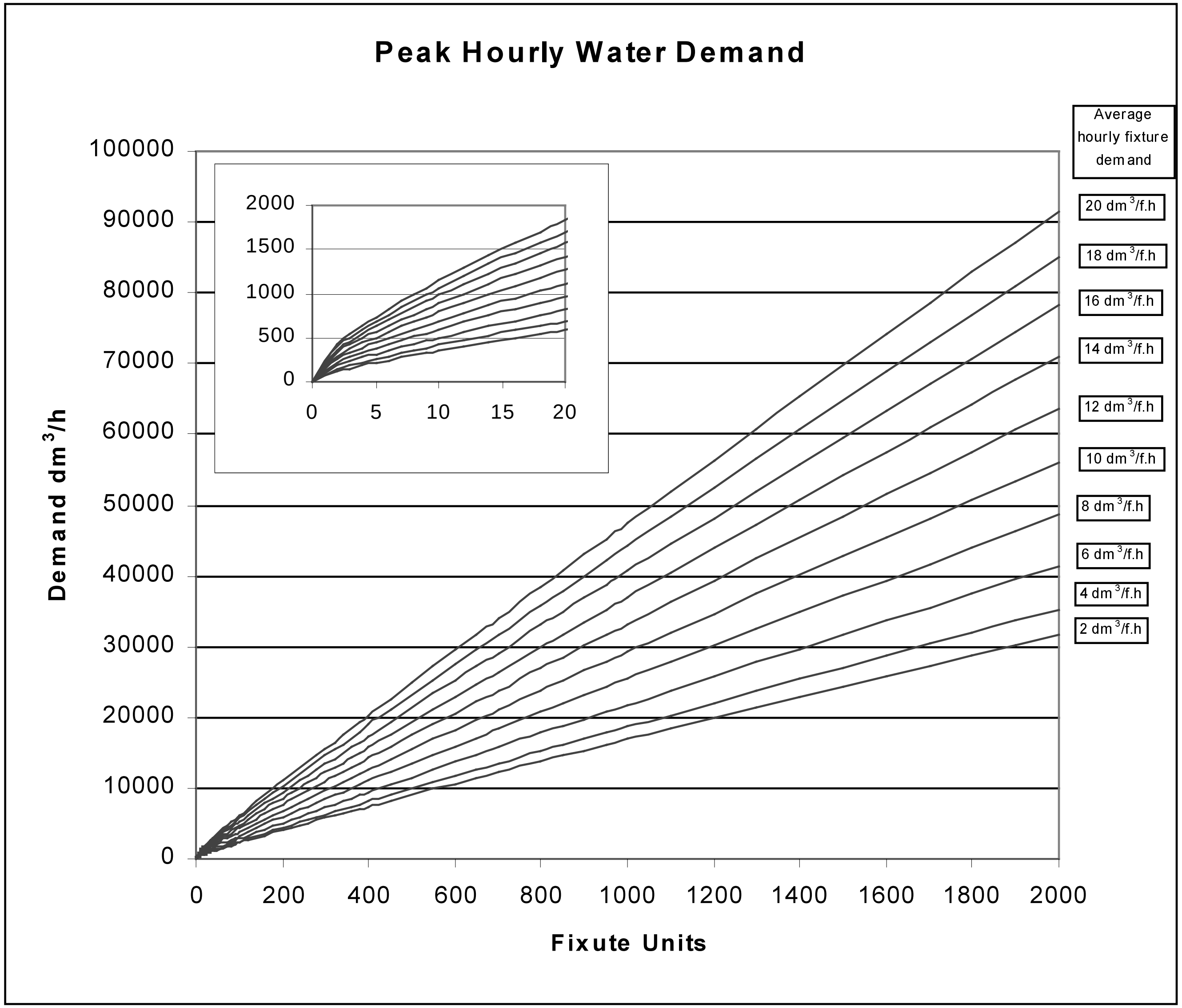


**Figure 1 – Chart for estimation of the peak hourly water demand (Public buildings)**

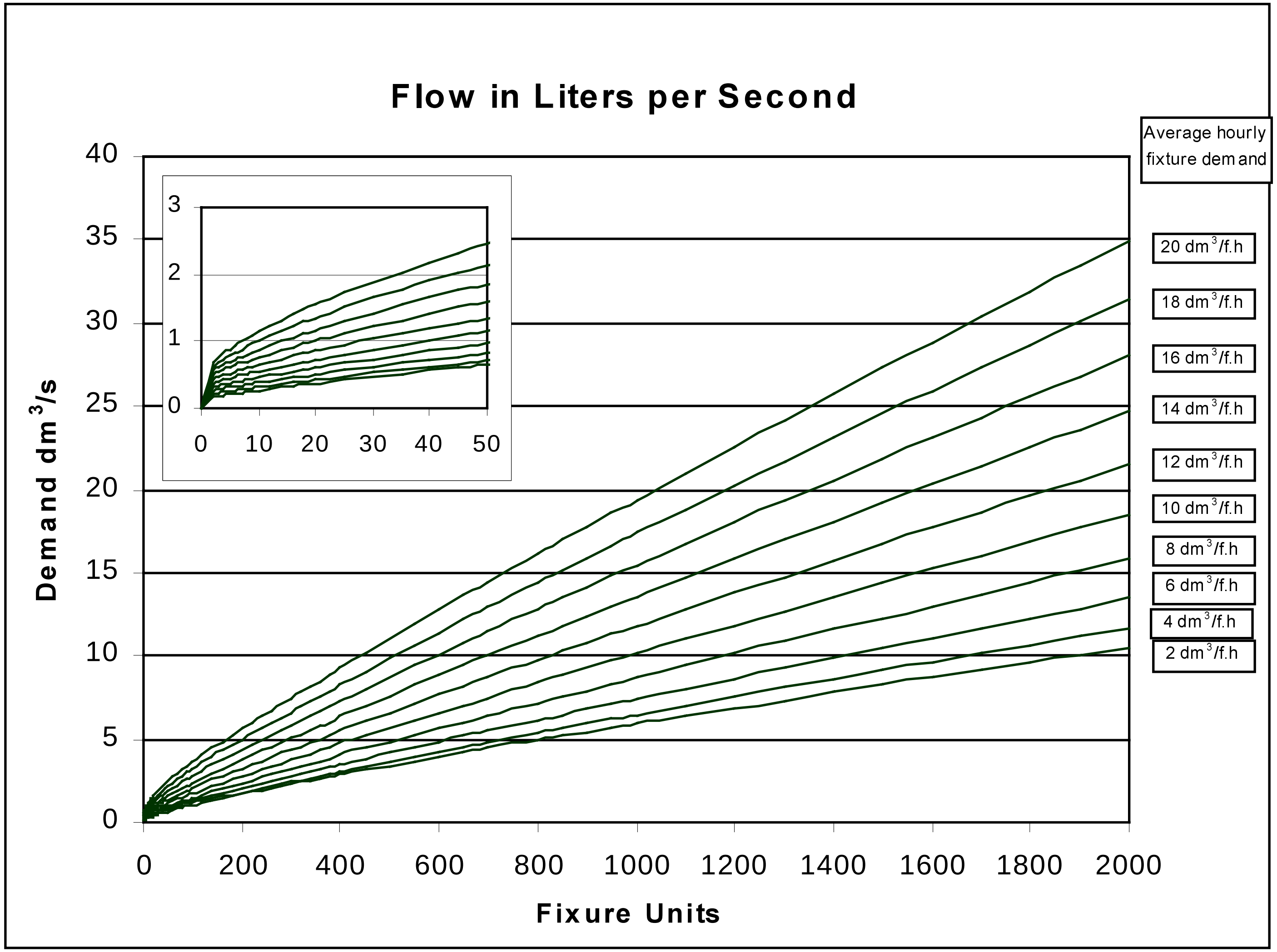


**Figure 2– Chart for estimation of the peak second water demand (Public buildings)**

## 6 Conclisions

1. The proposed statistical method is based on the stochastic water demand model. The parameters of the model are determined operatively for the different types of buildings using recorded flow data from normally operating plumbing systems.
2. The approach gives the possibility, the parameters to be updated periodically with limited financial expenses.
3. The parameters of the model are specific and should be clarified for each country.
4. The method gives the possibilities to reflect the confidence level and the peak flow duration.
5. The proposed charts for sizing the pipe water supply networks of public building illustrate the practical application of the method. The average hourly fixture water demand, which influences considerably the design flow rates and should be taken into consideration during the pipe sizing procedure.

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# Analysis of Toilet Users and their Behaviors in Railway Stations

# A study on the calculating method of fixture requirements for railway stations Part 1

**S. MURAKAWA; K. SAKAUE; Y. KOSHIKAWA; Y. TAKATU; Y.NAKAGAWA**

## Abstract

The purpose of this study is to establish the new calculating method of fixture requirements for railway stations by applying a simulation method based on the characteristic factors of stations. In this paper, as part one of the study, we analyzed the weekday data of toilet users and their behaviors in five stations, Tokyo area.

The main contents are as follows;

At first, we showed the sequential changes of the numbers of passengers and toilet users in each hour through a day. The ratio of toilet users for the passengers has five stages in a day. On the basis of the analysis of the U station including the people of transfer, the number of transfers has to be considered as a factor of the calculating method of fixture requirements for railway stations. We showed the relationships between the passengers included the people of transfer and toilet users in each of four stages needed for the calculation. We clarified the ratios of the number of toilet users in each gender for the estimated numbers of passengers of male and female.

At next, we showed the conditions of fixture usage. We analyzed the relationships between the number of toilet users and that of fixture users in male and female.

Then we showed the numbers of male toilet users are estimated by those of users in urinal, and those of female toilet users are estimated by users in lavatory. On the basis of the estimated numbers, we analyzed the relationships between the number of toilet users and that of lavatory users in each gender. Lastly, we showed the duration time of occupancy in the fixtures.

## Keywords

Toilet of railway station; Fixture requirement; Toilet users; Fixture users; Behavior in toilet; Duration time of fixture occupancy

## Introduction

In East Japan Railway Co., surveys on many stations are carried out with until now various purposes, and the results are accumulated. From those survey results, characteristics of the utilization in the station toilet are clarified, and the proposal of calculating method of fixtures requirements of the new station toilets based on them has be made to be a purpose of this study. Still, present method is based on research value 40 years ago[1].

In this paper, the relationships between passengers getting on and off and users of the station toilet are clarified, and the number of toilet users is calculated according to time zone and male and female from the number of passengers including transfers as a basis of the station toilet utilization. In the after, results of analysis of the toilets in Tokyo 5 stations are shown on frequency and occupancy time of male and female fixtures usage actions after the toilets arrival. The following, East Japan Railway Co. are abbreviated with "JR".

## 1 Outlines of the investigated stations

The outlines of investigated 5 stations is shown at Table 1.

Taking the scale of the toilets in these 5 stations as Table 2, the fixtures layouts are shown in Figure 1. K station is located for the metropolitan suburb line, and there are universities and housing lands near, and there are much utilization of students and housewives in the daytime. S,U stations are together located in the metropolitan loop line. There is S station in the large scale commercial district with many stores for the youth. U station is a terminal station of JR long distance train, and there are art galleries and museums, concert halls, parks, etc. T,J stations are enormous terminal stations of the metropolitan loop line.

**Table 1- The outlines of investigated stations**

| Station name | | K | S | U | T | J |
|---|---|---|---|---|---|---|
| Number of passengers (10000 persons/day) | | 25 | 58 | 48 | 101 | 86 |
| Wicket | New trunk line wicket | | - | 1 | 2 | - |
| | Conventional railway line wicket | 3 | 4 | 4 | 12 | 8 |
| Interconnect line | New trunk line | - | - | 1 | 2 | - |
| | JR line | 1 | 2 | 6 | 8 | 4 |
| | Private railway (except JR) | 1 | 3 | 1 | - | 3 |
| | Subway | - | 2 | 2 | 1 | 2 |

**Table 2- The number of fixtures installed in the investigated toilets**

| Station name | K | S | U | T | J |
|---|---|---|---|---|---|
| Male water closet | 6 | 6 | 4 | 6 | 6 |
| Male urinal | 8 | 11 | 18 | 13 | 12 |
| Male lavatory | 4 | 3 | 4 | 4 | 4 |
| Female water closet | 7 | 6 | 6 | 10 | 7 |
| Female lavatory | 5 | 3 | 6 | 7 | 8 |

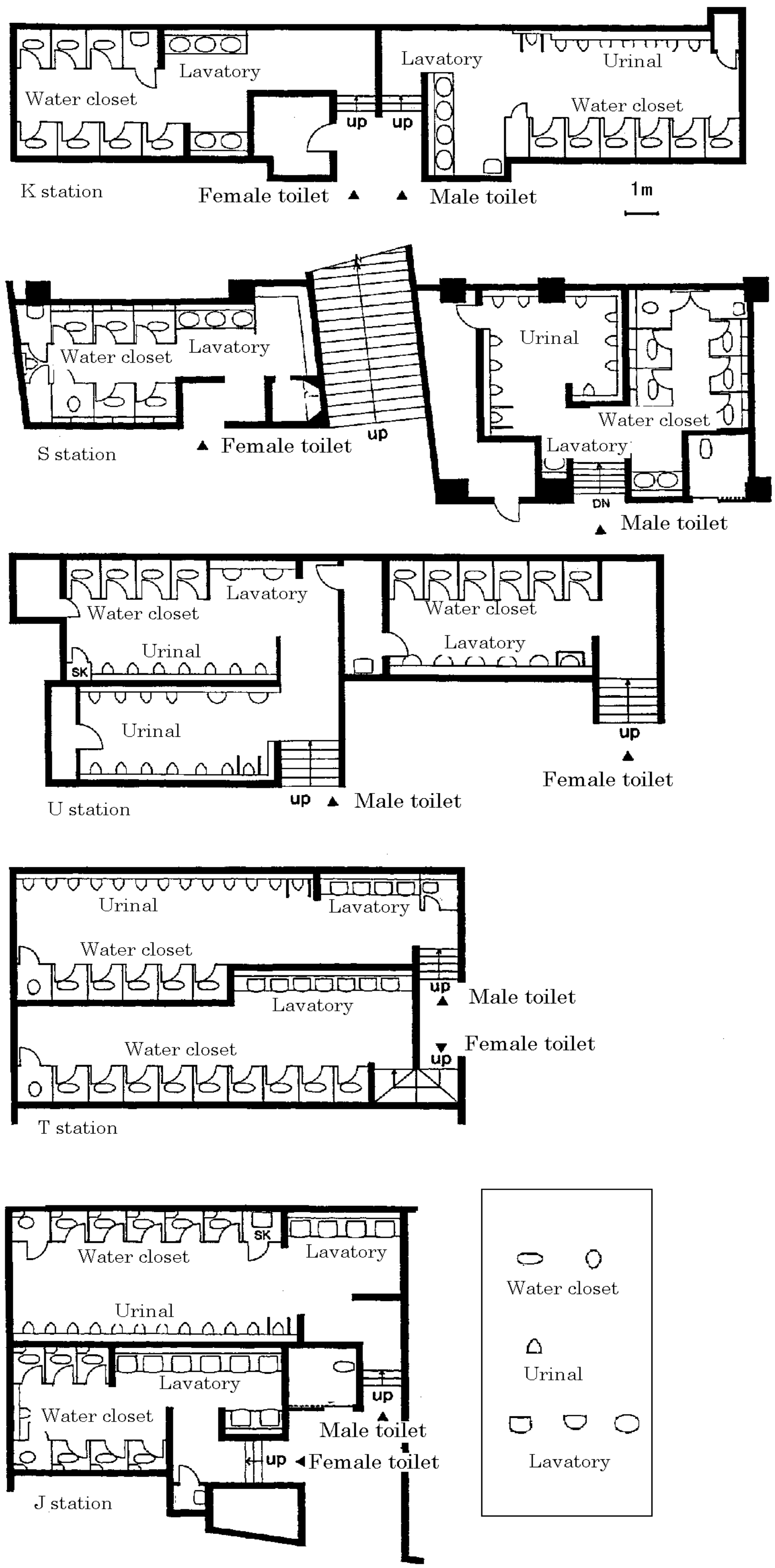



**Figure 1- Layout of the fixtures in the investigated male and female toilets**

## 2 The analysed data

In this paper, next 5 survey results were used.

1). The field study report of toilet utilization in 1993 and 1995.

This report analyzed each situation of toilet utilization, fixture usage and flush valve use to obtain water consumption in the toilets when the water conservation type fixtures are installed. In the following, name is abbreviated with "toilets survey".

2). The investigated report of passengers' flow in U station in 1985.

For the purpose of future planning in U station, this report investigated the passengers' flow on the premises. In the following, name is abbreviated with "flow survey".

3). JR transportation advertising data book, 10000 persons survey data in 1995.

For the purpose of effectiveness verification of the JR transit as advertising medium, this data book was made the inhabitant of urban area. In survey for the utilization of the station, the following are shown for main 28 stations: 1-week utilization ratio, 1-week average utilization frequency of passengers in each station, etc. In the following, name is abbreviated with "10000 persons survey".

4). The hourly change of the number of passengers getting and off in each ticket classification in the automatic wicket of the JR loop line in 1993.

The purpose of this survey is to grasp the time variation patterns of the number of passengers in each wicket every station in JR loop line. In the following, name is abbreviated with "loop line survey".

5). The hourly change of the number of passengers getting on and off in each ticket classification in the automatic wicket of the JR 5 suburb lines in 1993.

The purpose of this survey is equal to 4). In the following, name is abbreviated with "suburb line survey".

## 3 The number of passengers and the number of toilet users

### 3.1 The hourly change of the number of passengers and the number of toilet users

The change of 1 day of the number of passengers from the first train to the last train and the number of toilet users is shown in Figure 2 on weekday (Friday) and holiday (Sunday) in case of K,S,U stations from the data of "toilets survey" . However, the results of "suburb line survey" were used for the insufficient data. Though from the Figure, there are peaks in the fluctuation of the number of weekday passengers in morning and evening, in the holiday such peaks are not recognized. It is proven that the change of toilet users corresponds with the change of passengers in the holiday approximately, though it does not deal with the weekday . In comparison with weekday and holiday, it seems to be the validness to study on the weekday when the congestion of the time zone of toilet utilization is considered.

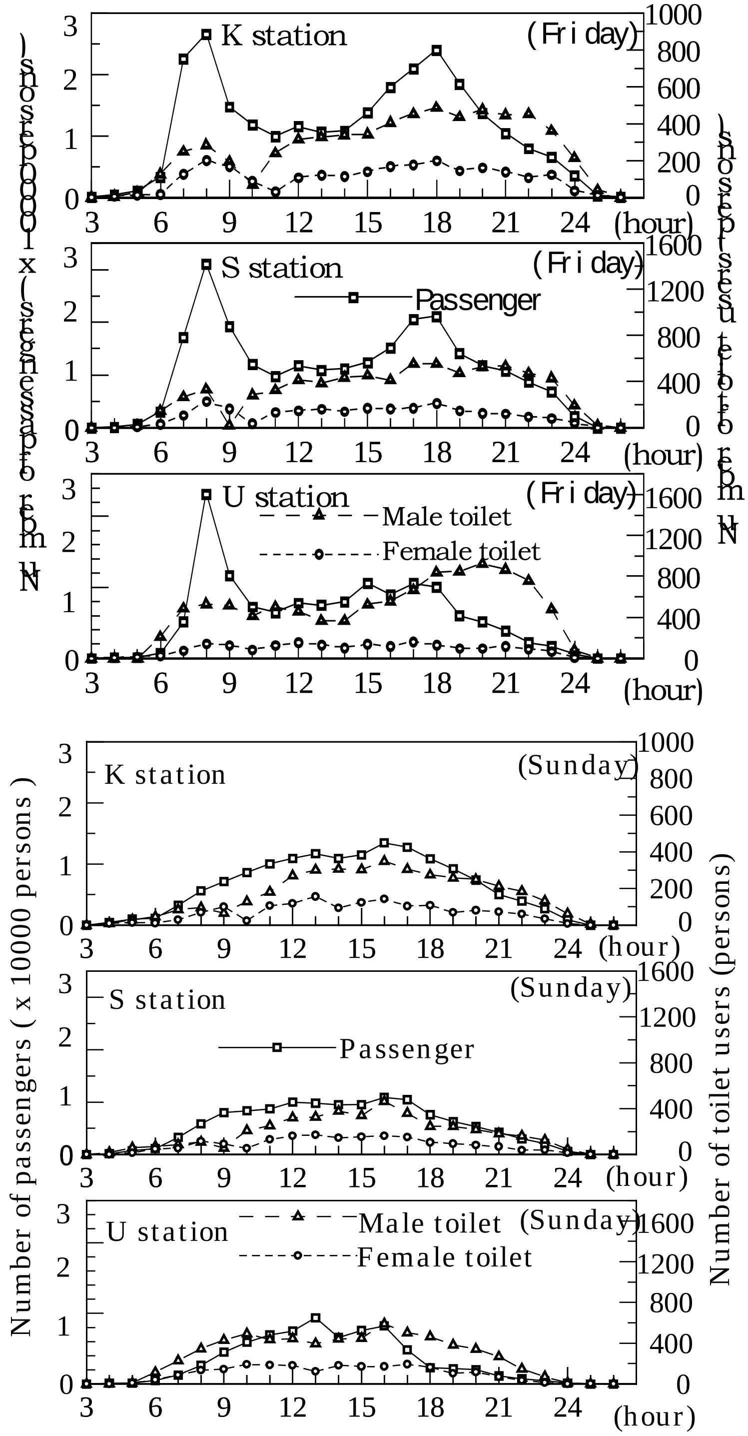



**Figure 2- The number of passengers and the number of toilet users**

### 3.2 The hourly change of toilet utilization ratio

The proportion of the number of toilet users for the number of passengers in any fixed time is made to be toilet utilization ratio (%). The weekday mean values of S,K stations become 3.9% (male : 2.9 % female : 1.0 %) and 3.2% (male : 2.3 % female : 0.9 %) respectively. And, it is proven that every station also shows the proportion which the holiday is higher than that of the weekday. The change of the toilet utilization ratio on Friday in every 1-hour is shown in Figure 3.

Though the value of U station is high, 3 stations also show the similar tendency on the weekday toilet utilization ratio on the hourly change. The toilet utilization ratio is divided into 5 stages like the following, when this tendency and the number of passengers of Figure 2 are considered.

1) To 6 o'clock in the morning in which the part with the big change exists
2) The peak hour in the morning in which toilet utilization ratio is small
3) The time zone in the daytime between peaks morning and evening with small changes
4) The peak hour in the evening in which toilet utilization ratio is bigger than peak hour in the morning
5) After the peak hour in the evening in which male toilet utilization ratio rises

To 6 o'clock in the morning, we also exclude this time zone from the calculation of the number of fixtures, because the number of passengers and the number of toilet users are little, .

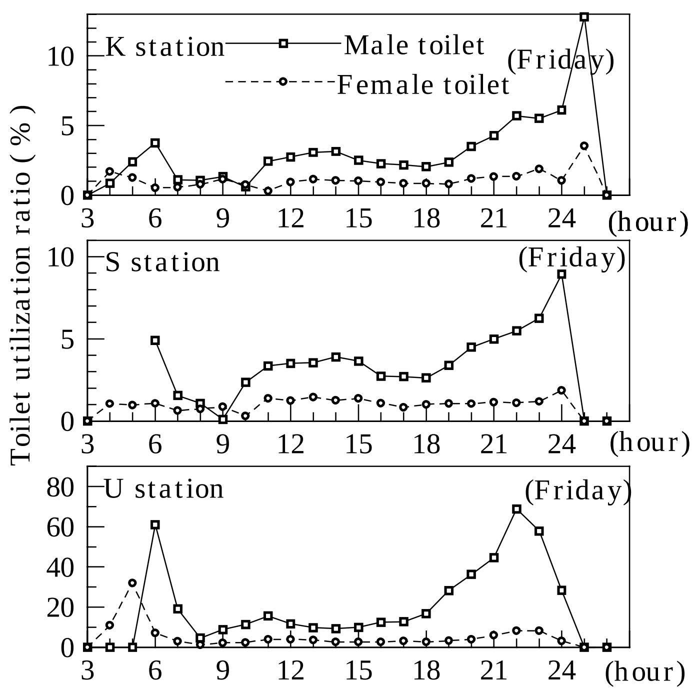



**Figure 3-The change of the toilet utilization ratio**

### 3.3 The analysis of toilet utilization ratio based on U station "flow survey"

The number (removing transfers) of passengers was used for the calculation of fixture requirement in present JR. According to the number, the above mentioned toilet utilization ratio was calculated. However, it is necessary that transfers in premises are analyzed as the object of the number of toilet users, if it is judged from toilet utilization ratios of K,S stations without transfers and U station with many transfers. Therefore the effect of the number of transfers was analyzed using data for investigation of "flow survey" because "toilets survey" was not carried out for the measurement of the number of transfers. The number of passengers, the number of toilet users and the value of toilet utilization ratio from 7 o'clock for 12 hours are shown in Table 3 on 3 stations and U station of "flow survey". The value of U station shows 5.0% (male : 3.9 %, female : 1.1 %), if it is calculated in all passage persons of this area including transfers. It becomes a value of the level which is almost equal to K,S stations. Therefore, the necessity of taking account of transfer as toilet users is proven.

**Table 3- The number of passengers, the number of toilet users and toilet utilization ratios for 12 hours**

| | Item | K station | S station | U station | U station ü a |
|---|---|---|---|---|---|
| | Number of passenger (persons) | 194839 | 192224 | 58480 | 264446 |
| Male | Number of toilet users (persons) | 3693 | 4528 | 6209 | 10268 |
| | Toilet utilization ratio (%) | 1.90 | 2.36 | 10.62 | 3.88 |
| Female | Number of toilet users (persons) | 1628 | 1888 | 1489 | 3032 |
| | Toilet utilization ratio(%) | 0.84 | 0.98 | 2.55 | 1.15 |

ü a(flow survey)

### 3.4 The number of passengers and the number of toilet users

The relationships between the number of passengers and the number of toilet users, they become a basis in calculation of fixtures requirements according to male and female, are shown in Figure 4. Still, U station used the data of "flow survey" (Tuesday). Gradient "a" in the figure shows toilet utilization ratio in each time zone. On the peak hours in the morning and evening, the following differences occur: male (1.64%, 2.88%), female (0.67%, 0.87%). Still, "r" in the figure shows the product moment correlation coefficient of Pearson on the number of passengers and the number of toilet users.

### 3.5 Estimation of the number of passengers and the number of toilet users according to male and female

Ratio of male to female for the number of passengers used until now is uncertain. Then, the number of respondents according to male and female of every station and the proportion of commuter pass and daily ticket utilization were analyzed using "10000 persons survey". Using "loop line survey" and "suburb line survey", the numbers of passengers using commuter pass and daily ticket in each time zone were obtained. Afterwards, by multiplying of these values, the numbers of male and female passengers in each time zone were calculated for every station.

Using the number of male and female passengers in each time zone, Figure 5 shows the relationship between the number of passengers and the numbers of toilet users according to male and female. The peak of utilization ratio in the male toilets is different by the time. In 7 o’clock, 17 o’clock and 20 o’clock, the tendency of the utilization ratio which rises with 2.6, 4.9 and 7.9% can read. In the female toilets, it is proven that the utilization ratio is constant with around 2%.

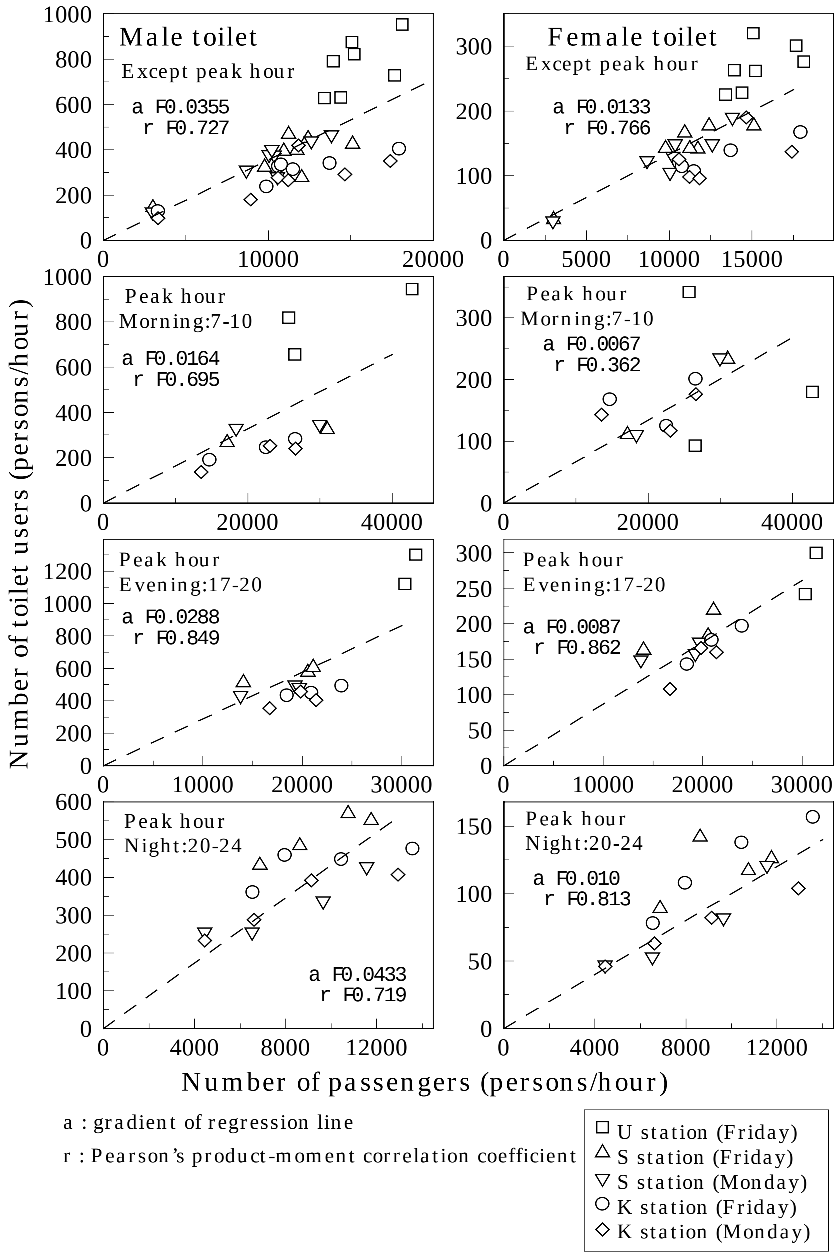



**Figure 4- The number of passengers and the number of toilet users**

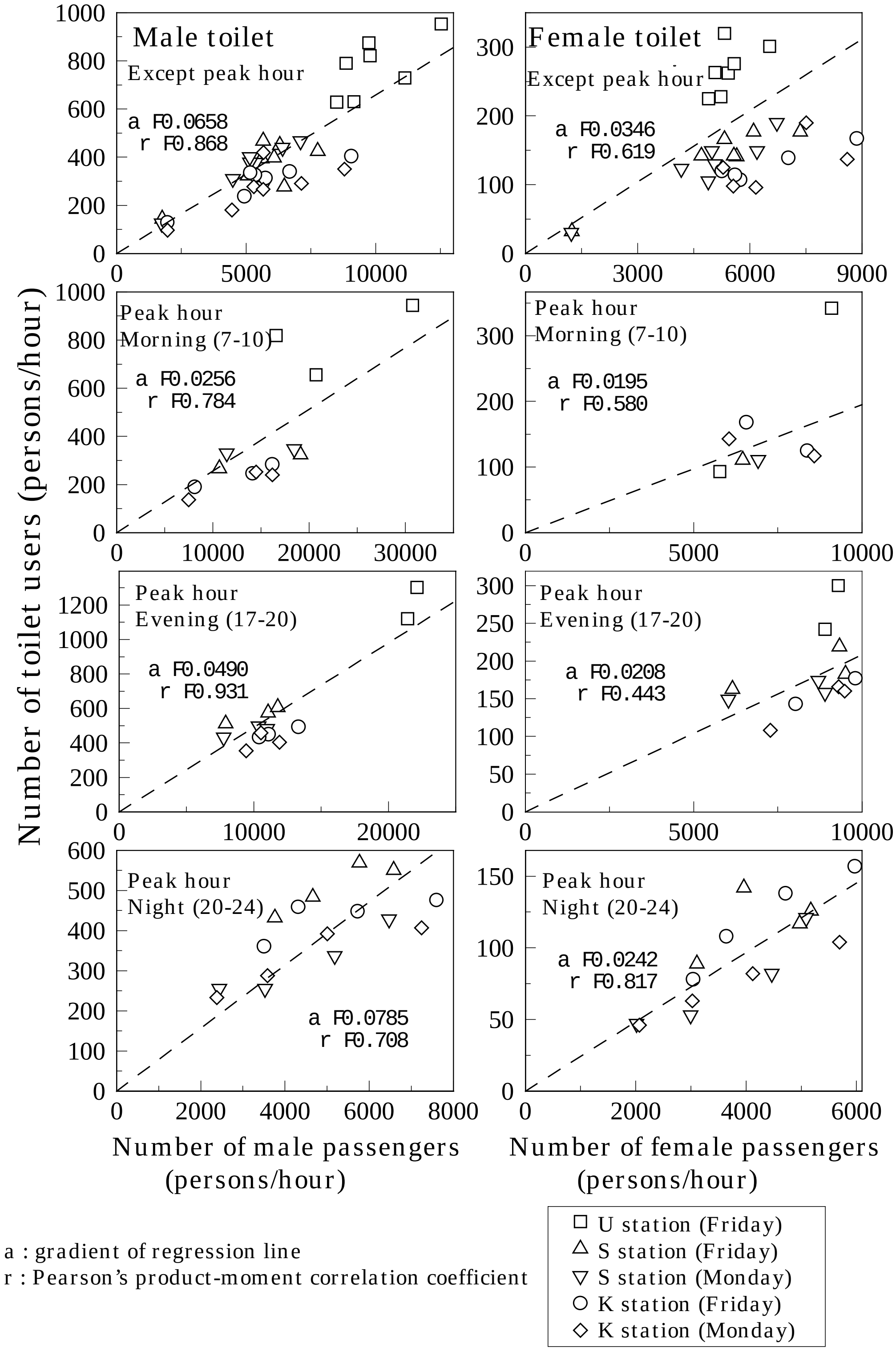



**Figure 5- The number of male and female passengers and the number of toilet users**

## 4 Toilet utilisation and fixtures usage

### 4.1 The number of toilet users and the number of water closet users

By grouping the hourly change of the number of toilet users in the weekday (Friday) of K,S,U stations and the number of water closet users into male toilet and female toilet, it is shown in Figure 6. In the figure, the numbers of fixture users deal with the fluctuations of toilet users. The peak exists on the number of users for male water closet in the morning, and it is proven to decrease with the progress in the time gradually.

The peak of water closet usage in the morning has been recognized in ordinary homes. There is a peak in this morning from the peak of toilet users before 1 hour. The number of male urinal users increases in proportion to that of toilet users, and it increases with the progress in the time. Though the fluctuation of toilet users and water closet users in female are correspondent, some cases are also recognized the difference in the number of toilet users and the number of the water closet users. Though the difference of this toilet users and water closet users is not as female toilets, it exists in male toilets. This difference shows that there are toilet users who use only lavatory. The above matter shows that usage ratio of water closet differs by the time zone. Then, the relationship between the number of toilet users and the number of each water closet users was analyzed. It is Figure 7 that each relation was shown by the number of toilet users and that of each water closet users in peak hour and non-peak hour. From the figure, the male urinal usage ratio increases from the morning to the night, and it is proven that the fluctuations are little. Though the high value of water closet usage ratio is shown in the morning, and it lowers afterwards, the usage ratio fluctuates a little except for the peak hour. From the above fact, it is possible to estimate the number of the users by using these regression coefficients with the number of these urinal users, when the number of male toilet users is uncertain. The lowest regression coefficient of 0.493 in female toilet in the peak hour in the morning is shown, and the usage ratio fluctuates. The usage ratio in the time zone of the others is about 0.7. And, the number of water closet users for the users of female toilet is less than that of male toilet. It seems to be a ratio that the users only using lavatory in female toilet are more than that in male toilet.

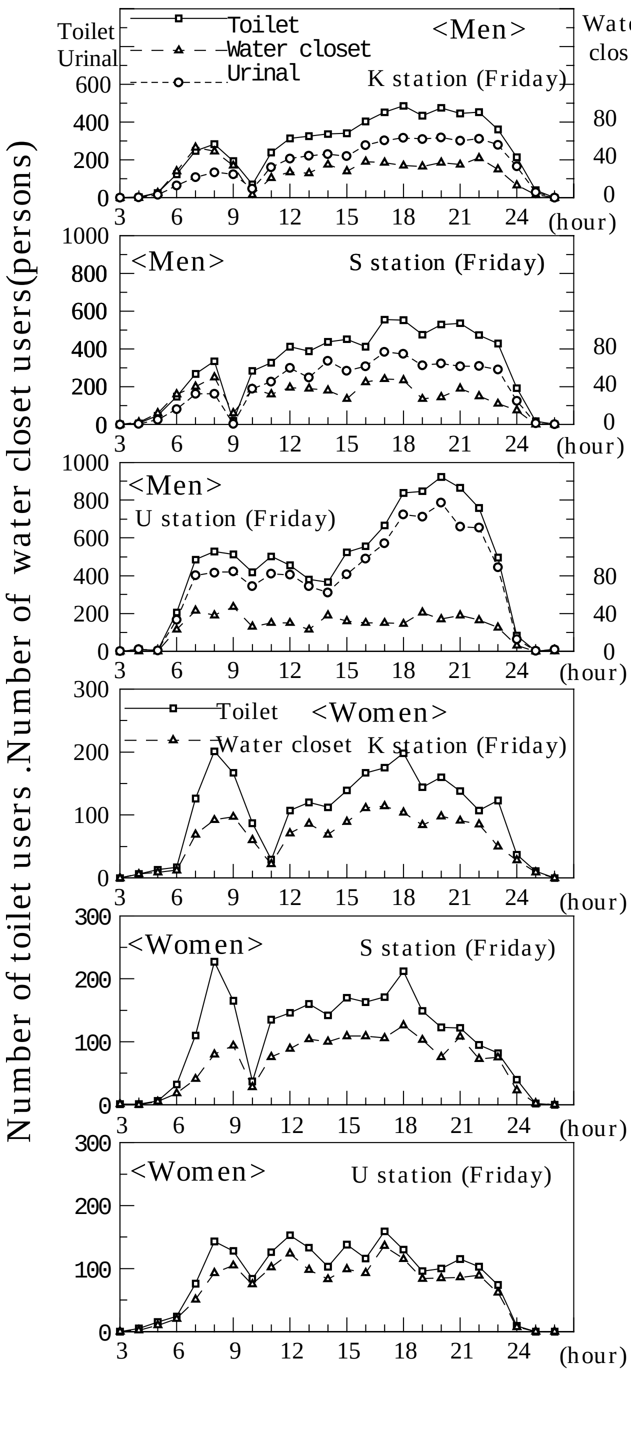
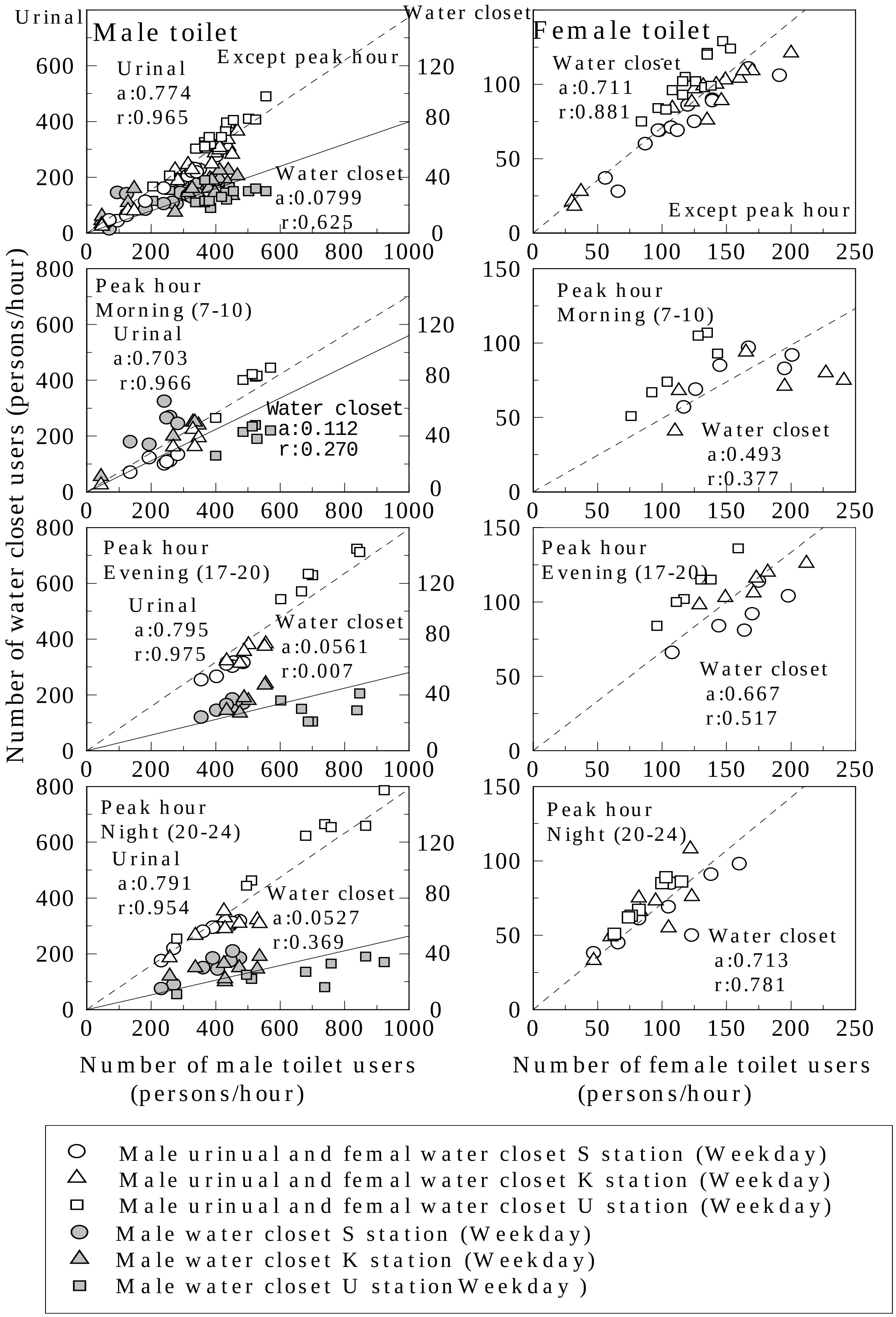



**Figure 6-The number of toilet users and the number of water closet users (weekday)**




a : gradient of regression line

r : Pearson's product-moment correlation coefficient

**Figure 7-The number of male and female toilet users and the number of each water closet users**

**4.2 Lavatory usage.**

The lavatory usage ratio (proportion of the number of lavatory users for the number of toilet users) is decided in order to enable the calculation of the recommended number of the lavatory installed.

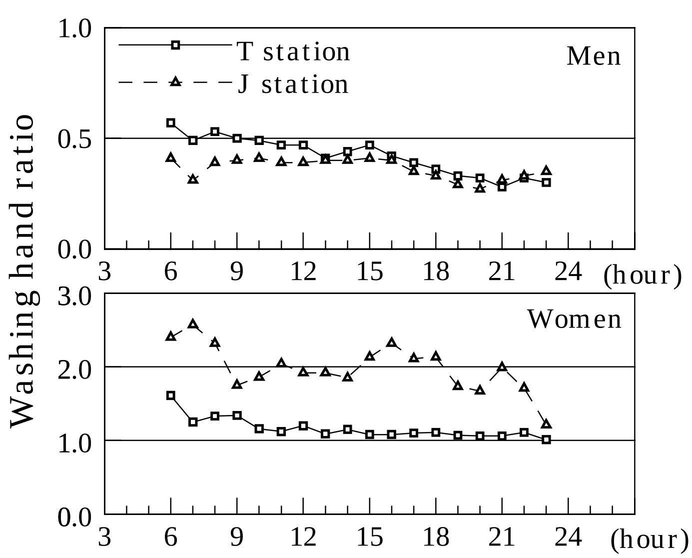
4.2.1 Estimation of the number of toilet users.

It is T,J stations that the number of lavatory users is clarified. However, it is not possible to calculate the lavatory usage ratio because the numbers of toilet users in the stations were not measured. First therefore, the estimation method of the number of toilet users per hour in the 2 stations is analyzed.

It was explained in 5.1 that the estimation of the number of male toilet users was possible using the regression coefficient in Figure 7 in respect of the number of urinal users, when the number of the male toilet users is uncertain. With this, the uncertain numbers of toilet users in the 2 stations were calculated using the number of these male urinal users.

In the female toilets, it was mentioned before that the number of water closet users is less than the number of toilet users because of high ratio using lavatory only. The values of washing hand ratio (the number of lavatory users/ the number of water closet) in T,J stations shown in Figure 8 are confirmed this, because male is around 0.5, female over 1. From the transition of this washing hand ratio, all the members of the female toilet users seem to use almost lavatory. Therefore, it is possible to estimate the number by substitute using the number of lavatory users, when the number of female toilet users is uncertain.

**Figure 8-The washing hand ratio (T, J stations)**




**4.2.2 Lavatory usage ratio.**

Hourly lavatory usage ratios of T,J stations were obtained, after the validity of the estimation method of the number of toilet users was analyzed by using all data of the 5 stations.

In Table 4, calculated values and setting values are respectively shown on each fixture usage ratio of the 5 stations. The setting values are shown in the double line frame, and the calculated values are shown in the bold line frame. At male urinal usage ratio of the table, the value of S station, which was just alike in having the downtown, was used in J station. Since there is no station, which is alike in the number of water closet, etc., it was set at T station referring to “a” value in Figure 7. Then, the usage ratios of male water closet and male lavatory of T,J stations were calculated by the number of toilet users calculated from male urinal usage ratio. On the male lavatory usage ratios of K,S,U stations, the value of the J station was applied to S station and K station with the similarity points a little, and the value of T station was applied to U station because both stations resemble each other in the number of lavatory installed and the conditions around station. The female water closet usage ratios of T,J stations were calculated with the value 1.00 for the female lavatory usage ratio. In Figure 9, the relationships between the number of male toilet users and the number of lavatory users in T,J stations calculated using the regression coefficient of urinal usage ratio in each time zone shown in Figure 7 are clarified. The letters “a” and “r” in the figure are similar to Figure 7. By using this regression coefficient “a”, it becomes the washing hand ratio in each time zone can calculate.

**Table 4-Calculation results of the fixtures usage ratios**

| | | Male water closet | Male urinal | Male lavatory | Female water closet | Female lavatory |
|---|---|---|---|---|---|---|
| K station | Whole | 0.098 | 0.663 | 0.276 | 0.613 | 1.00 |
| | Saturday, Sunday | 0.096 | 0.662 | 0.296 | 0.628 | 1.00 |
| | Monday, Friday | 0.100 | 0.664 | 0.270 | 0.600 | 1.00 |
| S station | Whole | 0.095 | 0.694 | 0.276 | 0.613 | 1.00 |
| | Saturday, Sunday | 0.101 | 0.688 | 0.296 | 0.605 | 1.00 |
| | Monday, Friday | 0.090 | 0.698 | 0.270 | 0.622 | 1.00 |
| U station | Whole | 0.059 | 0.838 | 0.333 | 0.846 | 1.00 |
| | Saturday, Sunday | 0.064 | 0.819 | 0.355 | 0.868 | 1.00 |
| | Monday, Friday | 0.056 | 0.852 | 0.326 | 0.820 | 1.00 |
| T station | Whole | 0.084 | 0.750 | 0.333 | 0.848 | 1.00 |
| | Saturday, Sunday | 0.101 | 0.750 | 0.355 | 0.961 | 1.00 |
| | Monday-Friday | 0.079 | 0.750 | 0.326 | 0.805 | 1.00 |
| J station | whole | 0.102 | 0.694 | 0.276 | 0.603 | 1.00 |
| | Saturday, Sunday | 0.116 | 0.688 | 0.296 | 0.748 | 1.00 |
| | Monday-Friday | 0.097 | 0.698 | 0.270 | 0.545 | 1.00 |
| Maximum value | | 0.116 | 0.852 | 0.355 | 0.961 | 1.00 |
| Minimum value | | 0.056 | 0.662 | 0.270 | 0.545 | 1.00 |

(Double line frame) Setting values; (Bold line frame) Calculated values

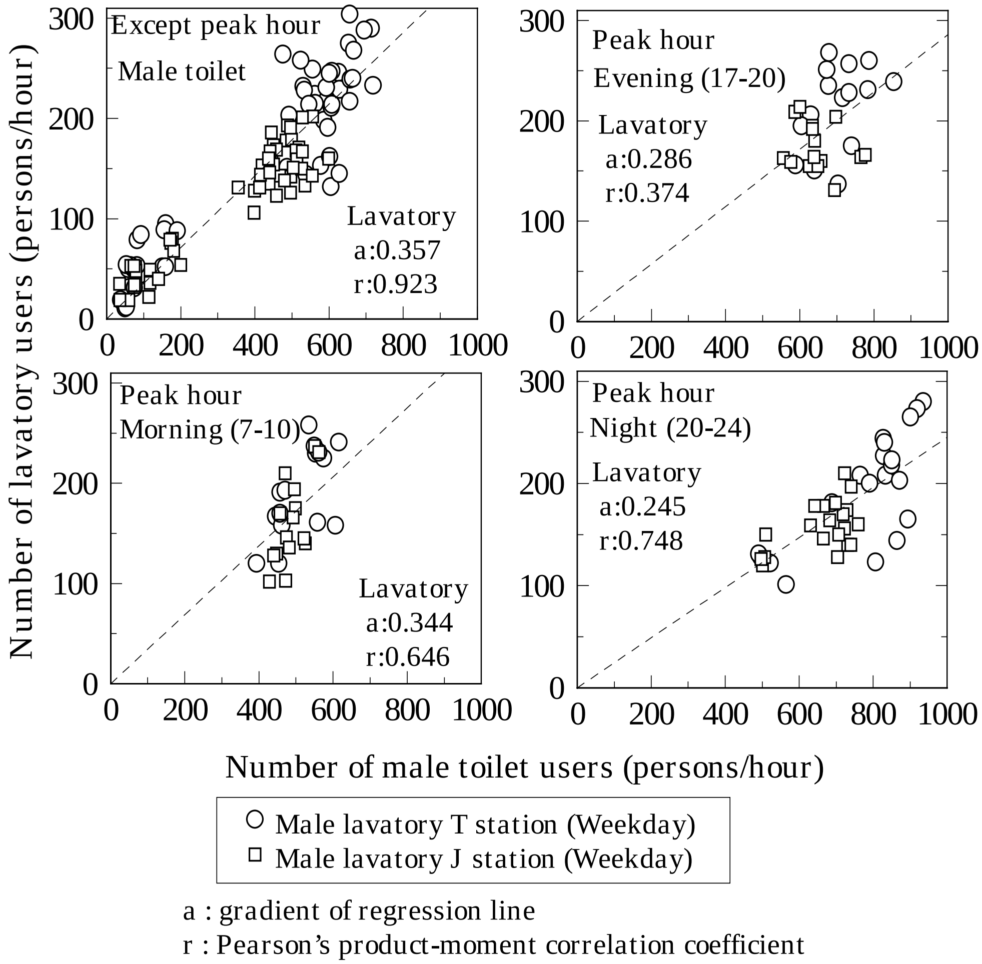
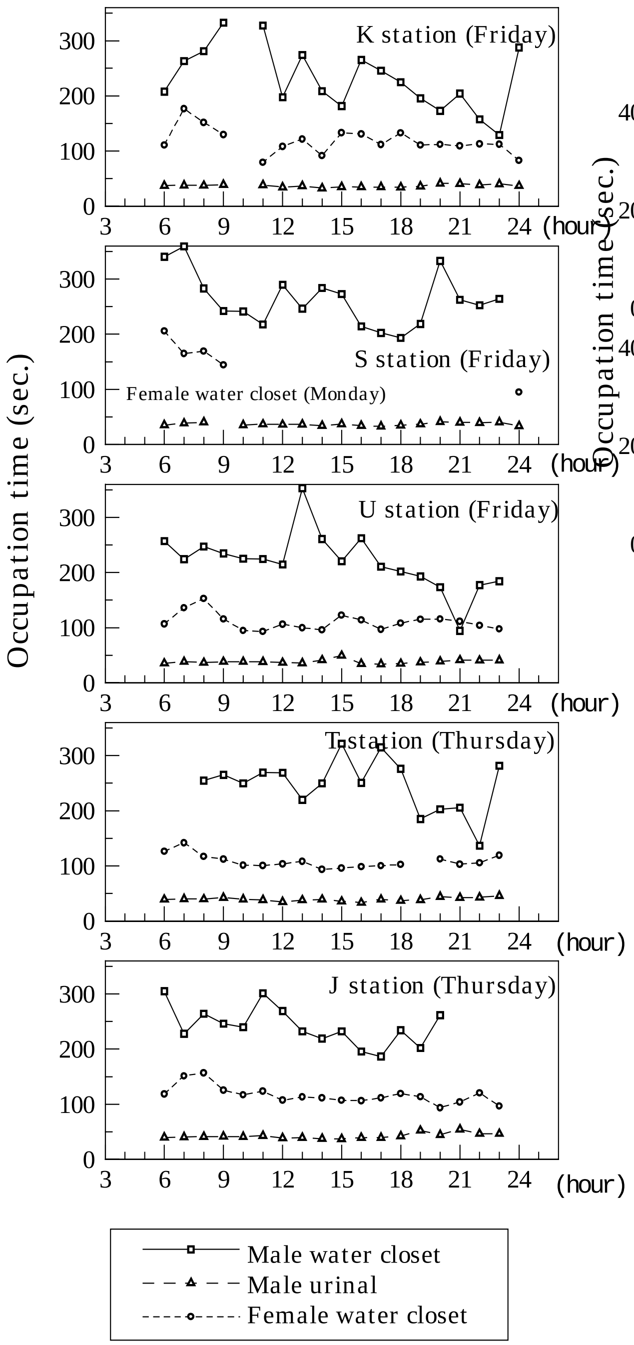



**Figure 9-The number of male toilet users and the number of lavatory users**

# 5 Duration time of occu pancy in fixtures

## 5.1 The change of the occup ancy times in fixtures



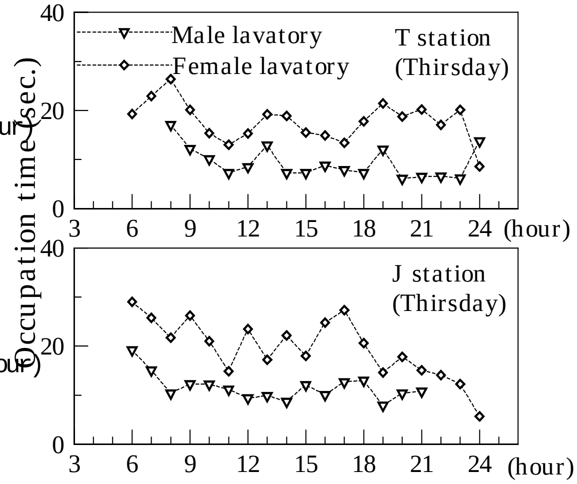




**Figure11-Lavatory occupancy times**

Water closet occupancy times in the 5 stations are shown in Figure 10. Lavatory occupancy times in the 2 stations are shown in Figure11.

Figure10-Water closet occupancy times

In the whole, there is a decline in the occupancy time with the progress in the time, and the tendency of male water closet, female water closet, male and female lavatory becomes small in order. However, in male urinal, there is hardly the change. Still, the occupancy times in Saturday and Sunday had also done the similar change, and large change by day of week could not be recognized. The fluctuation of the mean values in occupancy time is small in male urinal, and is large in male water closet. It seems to be also receiving the effect of the number of users per hour. The statistic of fixture occupancy time in peak hour of every station is shown in Table 5 in order to clarify the tendency of occupancy time in the morning and evening. The lavatory uses only the data of T,J stations.

**Table 5-Duration time of occupancy in fixtures (sec.)**

| Station name | Item | Male water closet | | Male urinal | | Female water closet | | Male lavatory | | Female lavatory | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Morning | Evening | Morning | Evening | Morning | Evening | Morning | Evening | Morning | Evening |
| Whole | Mean value | 271.7 | 213.4 | 39.9 | 38.4 | 148.2 | 113.4 | 14.6 | 10.4 | 24.2 | 20.1 |
| | Standard deviation | 149.4 | 222.6 | 24.2 | 20.6 | 106.1 | 88.1 | 23.9 | 18.3 | 47.5 | 42.6 |
| | Maximum value | 1274 | 1668 | 785 | 293 | 1129 | 1052 | 291 | 225 | 532 | 661 |
| | Minimum value | 10 | 11 | 5 | 5 | 10 | 10 | 1 | 1 | 1 | 1 |
| | Number of users | 455 | 367 | 1885 | 3428 | 980 | 954 | 618 | 618 | 1110 | 857 |
| é j | Mean value | 271.7 | 224.5 | 37.8 | 35.0 | 173.7 | 142.5 | - | - | - | - |
| | Standard deviation | 141.6 | 235.2 | 15.8 | 14.1 | 139.9 | 132.5 | - | - | - | - |
| | Maximum value | 716 | 1314 | 101 | 103 | 1129 | 1052 | - | - | - | - |
| | Minimum value | 65 | 18 | 9 | 5 | 12 | 29 | - | - | - | - |
| | Number of users | 102 | 71 | 242 | 630 | 153 | 170 | - | - | - | - |
| é r | Mean value | 317.4 | 185.3 | 40.2 | 35.4 | 169.7 | - | - | - | - | - |
| | Standard deviation | 162.4 | 171.9 | 44.6 | 16.0 | 106.7 | - | - | - | - | - |
| | Maximum value | 991 | 959 | 785 | 167 | 584 | - | - | - | - | - |
| | Minimum value | 20 | 19 | 6 | 5 | 13 | - | - | - | - | - |
| | Number of users | 90 | 86 | 328 | 744 | 117 | - | - | - | - | - |
| é t | Mean value | 240.3 | 187.7 | 39.0 | 36.5 | 148.3 | 105.7 | - | - | - | - |
| | Standard deviation | 97.5 | 128.1 | 16.0 | 14.8 | 84.5 | 54.0 | - | - | - | - |
| | Maximum value | 524 | 553 | 116 | 135 | 502 | 395 | - | - | - | - |
| | Minimum value | 10 | 21 | 8 | 7 | 12 | 12 | - | - | - | - |
| | Number of users | 64 | 54 | 595 | 825 | 144 | 224 | - | - | - | - |
| é s | Mean value | 269.8 | 305.7 | 40.4 | 39.3 | 129.2 | 101.6 | 17.6 | 7.6 | 24.9 | 16.7 |
| | Standard deviation | 140.7 | 283.1 | 17.0 | 19.3 | 87.7 | 71.6 | 24.3 | 11.7 | 49.1 | 27.4 |
| | Maximum value | 678 | 1477 | 125 | 160 | 649 | 675 | 217 | 102 | 532 | 219 |
| | Minimum value | 17 | 43 | 5 | 5 | 10 | 10 | 3 | 1 | 1 | 1 |
| | Number of users | 63 | 52 | 330 | 635 | 405 | 327 | 259 | 303 | 658 | 403 |
| é i | Mean value | 257.1 | 196.3 | 41.9 | 47.2 | 155.7 | 116.0 | 12.4 | 13.1 | 23.1 | 23.1 |
| | Standard deviation | 162.6 | 241.6 | 18.7 | 33.3 | 117.9 | 90.0 | 23.4 | 22.6 | 45.1 | 52.4 |
| | Maximum value | 1274 | 1668 | 165 | 293 | 902 | 807 | 291 | 225 | 524 | 661 |
| | Minimum value | 28 | 11 | 5 | 5 | 12 | 12 | 1 | 1 | 1 | 1 |
| | Number of users | 136 | 104 | 390 | 594 | 161 | 233 | 359 | 315 | 452 | 454 |

(Morning:7.00ü 9.00ü Evning:17:30-19:30)ü j

## 5.2 The distribution in the occupancy time

In Figure 12, the cumulative frequency distributions of the occupancy time in each fixture are shown. Water closet and lavatory can be approximated to the Erlang distribution and Hyper-exponential distribution respectively. From this, fixture occupancy time can be decided according to the random number in the simulation of toilet utilization. By arranging above cases, the average occupancy times and the distributions of each fixture for the calculation are shown in Table 6. Using the present totaling values, "setting values" shown in upper column of the table were decided for the calculation. The values decided by Uehara and Saito[1] is shown at the lower column.

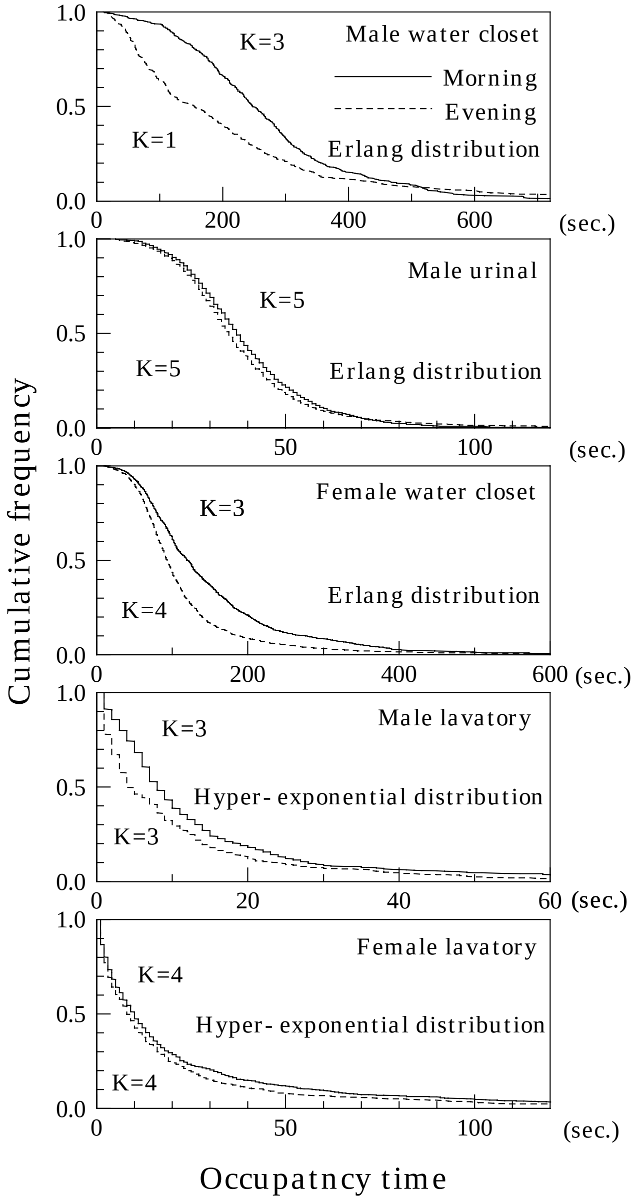



**Figure 12- The cumulative frequency distributions**

**Table 6-The average occupancy time and the distributions of each fixture for the calculation**

| Item | Male water closet | | Male urinal | | Female wash closet | |
|---|---|---|---|---|---|---|
| | Morning | Evening | Morning | Evening | Morning | Evening |
| Setting mean value | 270 | 210 | 40 | | 150 | 110 |
| Approximated distribution | Erlang | | | | | |
| Phase K of distribution | 3 | 1 | 5 | 5 | 3 | 4 |
| Past value [1] | 330 | | 30 | | 90 | |

| Item | Male lavatory | | Female lavatory | |
|---|---|---|---|---|
| | Morning | Evening | Morning | Evening |
| Setting mean value | 12.5 | | 22.4 | |
| Approximated distribution | Hyper-exponential | | | |
| Phase K of distribution | 4 | 3 | 4 | 4 |
| Past value [1] | - | | - | |

## 6 Conclusion

At first, we showed the sequential changes of the numbers of passengers and toilet users in each hour through a day. The ratio of toilet users for the passengers has five stages in a day. On the basis of the analysis of the U station including the people of transfer, the number of transfers has to be considered as a factor of the calculating method of fixture requirements for railway stations. We showed the relationships between the passengers included the people of transfer and toilet users in each of four stages needed for the calculation. We clarified the ratios of the number of toilet users in each gender for the estimated numbers of passengers of male and female.

At next, we showed the conditions of fixture usage. We analyzed the relationships between the number of toilet users and that of fixture users in male and female.

Then we showed the numbers of male toilet users are estimated by those of users in urinal, and those of female toilet users are estimated by users in lavatory. On the basis of the estimated numbers, we analyzed the relationships between the number of toilet users and that of lavatory users in each gender. Lastly, we showed the duration time of occupancy in the fixtures.

This paper was composed the references [2][3].

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# The New Calculating Method of Fixture Requirements for Railway Station Toilet

## A study on the calculating method of fixture requirements for railway stations Part 2

**S. MURAKAWA; K. SAKAUE; Y. KOSHIKAWA; Y. TAKATU; Y.NAKAGAWA**

**Abstract**

In the first paper[1], we showed the results of analyses on the passengers and their behaviors of toilet utilization in the East Japan Railway stations. In this paper, as part two, we showed the new calculating method of fixture requirements for railway stations based on the analyses of fixture usage.

The main contents are as follows;

We showed the calculating method and the calculating conditions by simulation. The arrival patterns to each fixture in the toilet were set up from the investigated values. Also, the duration time of occupancy and the service level of waiting time were shown in each fixture. The maximum permissible waiting time in each fixture was set up from the questionnaire survey [2]on the opinions of toilet utilization in buildings. The Monte Carlo simulation method was applied for the calculation of fixture requirements based on these calculating conditions. The numbers of fixture requirements were shown on the relation of arrival rates in each fixture. The calculating results were compared with the existing fixture numbers of the investigated five stations of the East Japan Railway.

**Keywords**

Toilet of railway station; Fixture requirement; Toilet users; Fixture users; Behavior in toilet; Duration time of fixture occupancy

## 1 Introduction

East Japan Railway Co. has done many researches including the stations toilet until now. From those survey results, the utilization of the station toilet is clarified, and the proposal of the calculating method of the fixture requirements in the station toilet based on them has been made to be a purpose of this study.

In this paper, toilet arrival patterns for each fixture were set by using values clarified in the previous paper. Afterwards, the queuing conditions according to the number of each fixture were calculated by the simulation technique. In addition, the figures to calculate the number of fixtures, which satisfied the permissible queuing time for every arrival rate, were made. The permissible queuing times were set from the past research values. Then, the recommended numbers of fixtures for the arrival rate in the toilets of JR 5 stations were obtained using the calculating figure s. Finally, the validity of calculating method of fixture requirements using the calculating figures was verified in comparison with the existing number of fixtures in the 5 stations.

## 2 New calculation of th e number of fixtures in station toilets

Authors propose the new calculating method of fixture requirements in station toilets evaluated by the permissible queuing times that are simulated with the different queuing conditions. The calculating procedure on each fixture is following. The kinds of fixtures for calculation are the 5 types. They are male water closet, male urinal, male lavatory, female water closet and female lavatory.

1) The calculation of queuing conditions according to each fixture arrival rate and the each number of fixture

2) The calculation of the recommended number of fixtures in each arrival rate using the permissible maximum queuing time as an evaluation index.

3) The analysis of the existing number of fixtures in station toilets using the proposed new calculating figures.

# 3 Calculation of queuing conditions according to each fixture arrival rate and each number of fixtures using the simulation

## 3.1 Calculating conditions

### 3.1.1 Arrival patterns and operation time for simulation

First, arrival characteristics of the toilet users were analyzed, and the arrival patterns were decided for the toilet users in the simulation.

It is considered that the toilet arrival pattern of the users is almost equal to the arrival pattern of users to fixture in the station toilet.

The arrival rate (persons/min.) to the male toilet in peak hour in the morning of K station is shown in Figure 1. It is 1,3,5,10 minutes in order of the totaling time interval in the figure. Other male and female toilets also show the similar changes. The change of the number of arrival persons decreases, if the width in the time interval increases, and the change is smoothed. Though there is the periodicity in the change of the number of arrival persons, the period seems to be around 5 minutes, because it flattens in 10 minutes almost.

The maximum arrival rate in each time interval is shown in Figure 2. This maximum arrival rate converts and obtains the number of the maximum arrival persons in set time into the number of persons of 1 minute. At the maximum arrival rate, the 30 minutes value becomes about 1.05 times of the 60 minutes value. 15 minutes value for the 30 minutes value becomes about 1.2 times, and 5 minutes value becomes about 1.6 times. The almost fixed value over setting interval 5 minutes is shown.

The frequency distributions of arrival rate required in the 1-minute average are shown in Figure 3. The Poisson distributions in the figure were calculated from average arrival rates for 60 minutes. The number of arrival persons is similar to the Poisson distribution, though there is the wavy concentration on the arrival in the short time in about 5 minutes. It is proven that there is the randomness in the number of arrival persons' appearance. By this, it can be said that toilet utilization simulation by the random number generation using the arrival model is possible.

In Figure 4, the change of arrival rate by the random number generation is shown by the same condition with Figure 1. It is proven that the almost same arrival pattern with Figure 1 has been reproduced.

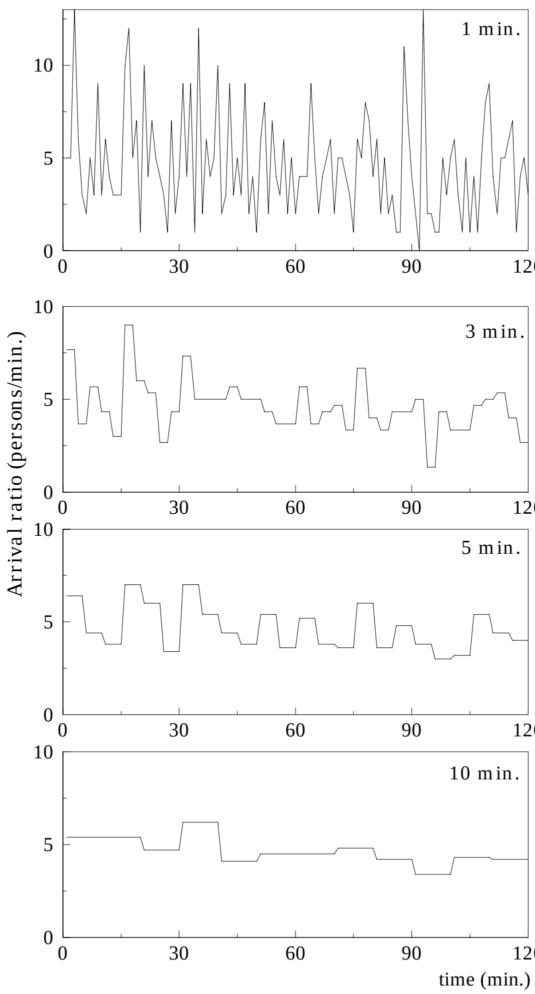


**Figure 1- The arrival rate to the toilet**

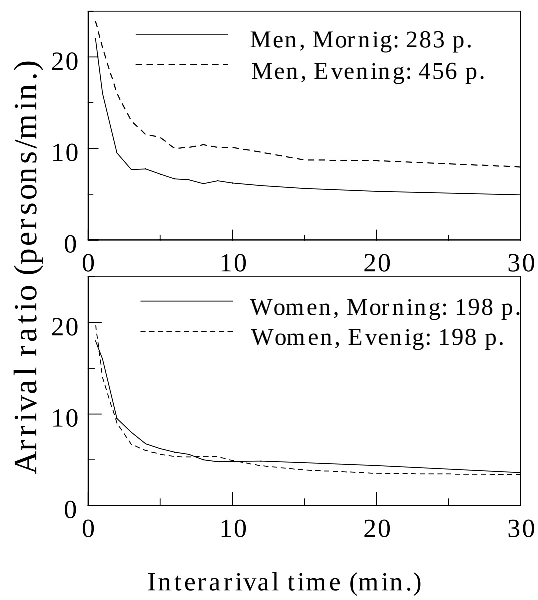


**Figure 2- The maximum arrival rate in each time interval**

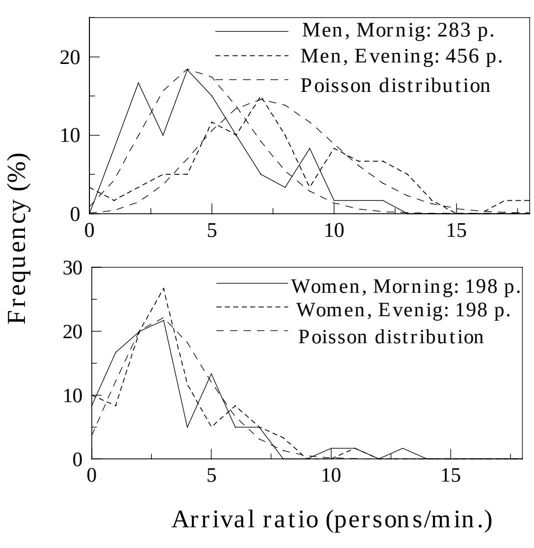


**Figure 3- The frequency distribution of arrival rate**

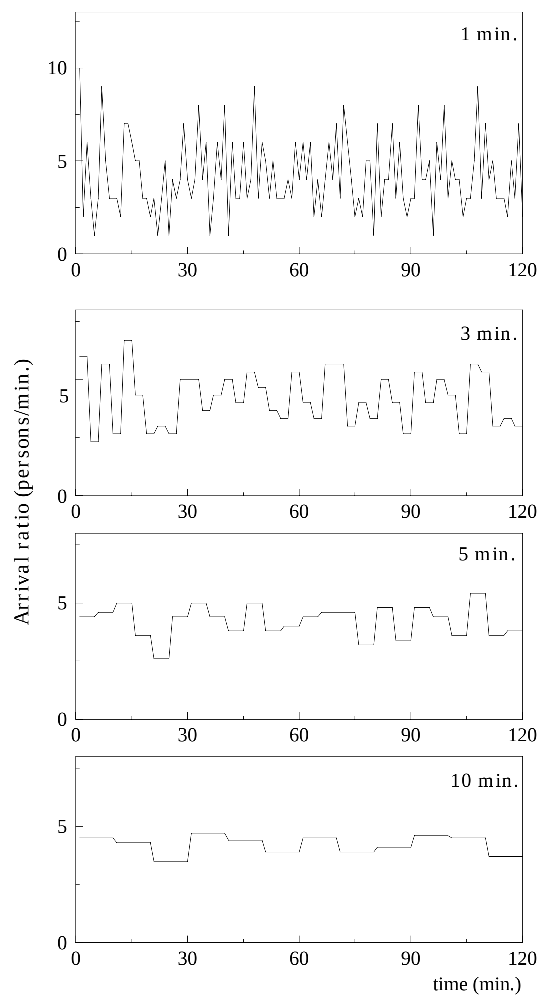


**Figure 4- The arrival rate to the toilet by random number generation**

3.1.2 Fixture arrival rate

The fixture arrival rate is calculated from the number of fixture users, which multiplied the number of toilet users per unit time by the fixture usage ratio.

When the number of toilet users is uncertain, it is calculated by multiplying the numbers of passengers and the toilet utilization ratio shown in Table 1 together. These values are being obtained from Figure 7 "The number of male and female passengers and the numbers of toilet users" in the previous paper.

Peak hour of the toilet utilization is made to be the time zone of the queuing time calculation by the simulation.

Table 2 and Table 3 show the peak hour for the numbers of toilet users and the number of fixture users respectively. From Table 2, the tendency in which it has from the evening to the night for male and from the morning to the evening for female is proven on the peak of the numbers of toilet users. This does not agree with the peak of the number of passengers.

And, from Table 3, it is shifted from the peak of toilet utilization and the peak of the fixture usage, and especially there is difference on the peak of male water closet. Therefore, the peak of fixture usage is not correspondent to the fluctuation of the numbers of passengers and the numbers of toilet users. Then, it fixes as peak hour according to each fixture, and the calculating conditions of the simulation, which can correspond in the time zone are set. The fixture usage ratio is shown in Table 4. The value of Table 4 is being obtained from Figure 7 "The number of male and female toilet users and the number of each water closet users" and Figure 9 "The number of male toilet users and the number of lavatory users" in the previous paper.

Since then, the conditions of the simulation are analyzed for these time zones.

**Table 1-Toilet utilization ratios of male and female passengers**

| Peak hour | Men | Women |
|---|---|---|
| Morning :7-10 | 2.56 | 1.95 |
| Evening :17-20 | 4.90 | 2.08 |
| Night :20-24 | 7.85 | 2.42 |
| Except peak hours | 6.58 | 3.46 |

## Table 2-The numbers of toilet users in the peak hour

| | Date | Number of toilet users | | Peak hour | Peak hour | Peak ratio | Peak time zone |
|---|---|---|---|---|---|---|---|
| | | (persons/day) | (persons/hour) | (persons/hour) | % | | |
| K station | Friday | 6185 | 343,6 | 493 | 7,97 | 1,43 | 18 o'clock |
| Men | Monday | 5195 | 288,6 | 458 | 8,82 | 1,59 | 17 o'clock |
| S station | Friday | 7376 | 409,8 | 607 | 8,23 | 1,48 | 18 o'clock |
| Men | Monday | 6452 | 358,4 | 497 | 7,70 | 1,39 | 17 o'clock |
| U station | Friday | 10346 | 574,8 | 930 | 8,99 | 1,62 | 20 o'clock |
| Men | Monday | 8740 | 485,6 | 739 | 8,46 | 1,52 | 20 o'clock |
| K station | Friday | 2359 | 131,1 | 201 | 8,52 | 1,53 | 08 o'clock |
| Women | Monday | 1975 | 109,7 | 190 | 9,62 | 1,73 | 15 o'clock |
| S station | Friday | 2569 | 142,7 | 233 | 9,07 | 1,63 | 08 o'clock |
| Women | Monday | 2258 | 125,4 | 235 | 10,41 | 1,87 | 08 o'clock |
| U station | Friday | 1963 | 109,1 | 153 | 7,79 | 1,40 | 17 o'clock |
| Women | Monday | 1829 | 101,6 | 149 | 8,15 | 1,47 | 10 o'clock |

**Note:**
**1**) The survey date, K station: 20th - 23rd, Jan., S station: 27th - 30th, Jan., U station: 3rd - 6th, Feb. in 1995
2) (persons/day): the number of users from the first train to the last train in survey day
3) (persons/hour): the number of users per hour. The duration hour is the activity hour (06-24) of the station.
4) Peak hour (%): the proportion of the number in the peak hour for the number of users per day.
5) Peak ratio: the rate of the number in the peak hour for the average number of users per hour

## Table 3-Each fixture usage in the peak hour

| Fixture | Station | Number of fixtures | Date | Number of fixture users | | Peak hour | Peak hour | Peak ratio | Peak time zone | Arrival rate |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (persons/day) | (persons/hour) | (persons/hour) | % | | | (persons/min.) |
| Men | K station | 6 | Mon. | 526 | 29,2 | 65 | 12,36 | 2,22 | 08 o'clock | 1,08 |
| water closet | S station | 6 | Mon. | 683 | 37,9 | 61 | 8,93 | 1,61 | 07 o'clock | 1,02 |
| | U station | 4 | Mon. | 469 | 26,1 | 48 | 10,23 | 1,84 | 07 o'clock | 0,80 |
| | T station | 6 | Fri. | 956 | 53,1 | 74 | 7,74 | 1,39 | 08 o'clock | 1,23 |
| | J station | 6 | Sun. | 944 | 52,4 | 65 | 6,89 | 1,24 | 08 o'clock | 1,08 |
| Men | K station | 8 | Fri. | 3951 | 219,5 | 318 | 8,05 | 1,45 | 20 o'clock | 5,30 |
| urinal | S station | 11 | Fri. | 4500 | 250,0 | 381 | 8,47 | 1,52 | 17 o'clock | 6,35 |
| | U station | 18 | Fri. | 8680 | 482,2 | 786 | 9,06 | 1,63 | 20 o'clock | 13,10 |
| | T station | 13 | tree | 8168 | 453,8 | 740 | 9,06 | 1,63 | 20 o'clock | 12,33 |
| | J station | 12 | Fri. | 7619 | 423,3 | 594 | 7,80 | 1,40 | 19 o'clock | 9,90 |
| Men | T station | 4 | Fri. | 4377 | 243,2 | 311 | 7,11 | 1,28 | 22 o'clock | 5,18 |
| lavatory | J station | 4 | Mon. | 2966 | 164,8 | 224 | 7,55 | 1,36 | 22 o'clock | 3,73 |
| Women | K station | 7 | Fri. | 1387 * | 77,1 | 114 | 8,22 | 1,48 | 17 o'clock | 1,90 |
| water closet | S station | 6 | Fri. | 1686 | 93,7 | 126 | 7,47 | 1,35 | 18 o'clock | 2,10 |
| | U station | 6 | Fri. | 2090 | 116,1 | 136 | 6,51 | 1,17 | 17 o'clock | 2,27 |
| | T station | 10 | Fri. | 4687 | 260,4 | 338 | 7,21 | 1,30 | 10 o'clock | 5,63 |
| | J station | 7 | Mon. | 2409 | 133,8 | 239 | 9,92 | 1,79 | 08 o'clock | 3,98 |
| Women | T station | 7 | Mon. | 5210 | 289,4 | 435 | 8,35 | 1,50 | 10 o'clock | 7,25 |
| lavatory | J station | 8 | Wend. | 4352 | 241,8 | 430 | 9,88 | 1,78 | 16 o'clock | 7,17 |

Note: The research date is same for Table 2

## Table 4-Fixture usage ratio of male and female toilet users (%)

| Peak hour | Male water closet | Male urinal | Male lavatory | Female water closet | Female lavatory |
|---|---|---|---|---|---|
| Morning :7-10 | 11.2 | 70.3 | 34.4 | 49.3 | 100.0 |
| Evening :17-20 | 5.6 | 79.5 | 28.6 | 66.7 | 100.0 |
| Night :20-24 | 5.3 | 79.1 | 24.5 | 71.3 | 100.0 |
| Except peak hours | 8.0 | 77.4 | 35.7 | 71.1 | 100.0 |

3.1.3 Duration time of fixture occupancy

On the basis of previous paper, the average occupancy time and the distribution of each fixture are shown in Table 5. The setting values in the simulation were decided referring to this table.

**Table 5-The setting values of fixture usage for the simulation**

| Item | Male water closet | | Male urinal | | Female water closet | | Male lavatory | | Female lavatory | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Morning | Evening | Morning | Evening | Morning | Evening | Morning | Evening | Morning | Evening |
| Set average value | 270 | 210 | 40 | | 150 | 110 | 12.5 | | 22.4 | |
| Approximated distribution | Erlang distribution | | | | | | Super exponential distribution | | | |
| Phase K of distribution | 3 | 1 | 5 | 5 | 3 | 4 | 4 | 3 | 4 | 4 |

**3.2 Simulation program**

The calculating conditions of the simulation program for toilet fixture usage were decided based on the analyzed results until now.

The analysis of the simulation is on the "queuing". The phenomena of "queuing" occur by the occupation of all fixtures installed. However, the phenomena which "queuing" increases are not for the recommended numbers of fixture. The condition that the phenomena of "queuing" are soon dissolved becomes a condition of the recommended scale calculation. Therefore, the reproduction of dissolving the phenomena of "queuing" is required for the simulation. The arrival pattern to the toilet shows the periodic tendency in some extent duration of peak hour as above-mentioned. In this simulation, it takes 15 minutes as a peak time. This 15 minutes is divided in each 5 minutes interval, and these intervals have the average arrival rates as 1.6, 1.0 and 1.0 times of the 30 minutes value, because the average arrival rate becomes 1.2 times of the 30 minutes value almost. Then, the phenomena of generation and resolution in "queuing" are reproduced in this simulation. By doing pre trial 5 minutes and trial 15 minutes with the 1 trial, the simulation records queuing time of fixture arrival persons in the trial of 15 minutes. The persons are included in the record of "queuing" who enter the toilet in trial hour and starts to use the fixture after trial hour, however the arrival persons in the pre trial are not included. The maximum value of the recorded values is made to be the maximum queuing time after the end of calculation. The arrival patterns were used 100 kinds of files on this trial as the calculated arrival rate of 1 condition. This file was made using simulation random number generation by the mixed congruencial method. The number of fixture was calculated from 1 to 20. The mean value by 100 kinds of arrival person file was obtained on the each number of fixtures at every arrival rate. The list of the calculating conditions is shown at Table 6.

**Table 6-The calculating conditions of the simulation**

| | Male water closet | Male urinal | Female water closet | Male lavatory | Female lavatory |
|---|---|---|---|---|---|
| Arrival model (*) | | | | | |
| Frequency distribution of arrival rate | | | Poisson distribution | | |
| Arrival rate (persons/min.) | 0.025~3.0 | 0.2~20.0 | 0.05~5.0 | 0.3~15.0 | 0.6~30.0 |
| Setting number of fixtures | 1~10 | 1~20 | 1~20 | 1~18 | 1~20 |
| Occupancy time model | | | | | |
| Occupancy time distribution | | Erlang distribution | | Hyper-exponential distribution | |
| Phase K of distribution | 3 | 5 | 3 | 4 | 4 |
| Average occupancy time (sec.) | 300 | 40 | 150 | 15 | 25 |

Note: The following are used as an arrival rate in each 5 minutes; 100%, 160%, 100% and 100% of setting arrival rate. First 5 minutes (100%) is the pre-trial.

### 3.3 Calculated results

In Figure 5, the calculated results are shown. The horizontal axis of the figure is arrival rate, and the vertical line is mean value of the maximum queuing times. The dotted line in the figure shows the number of fixture, and the 5,10, 15 pieces are displayed.

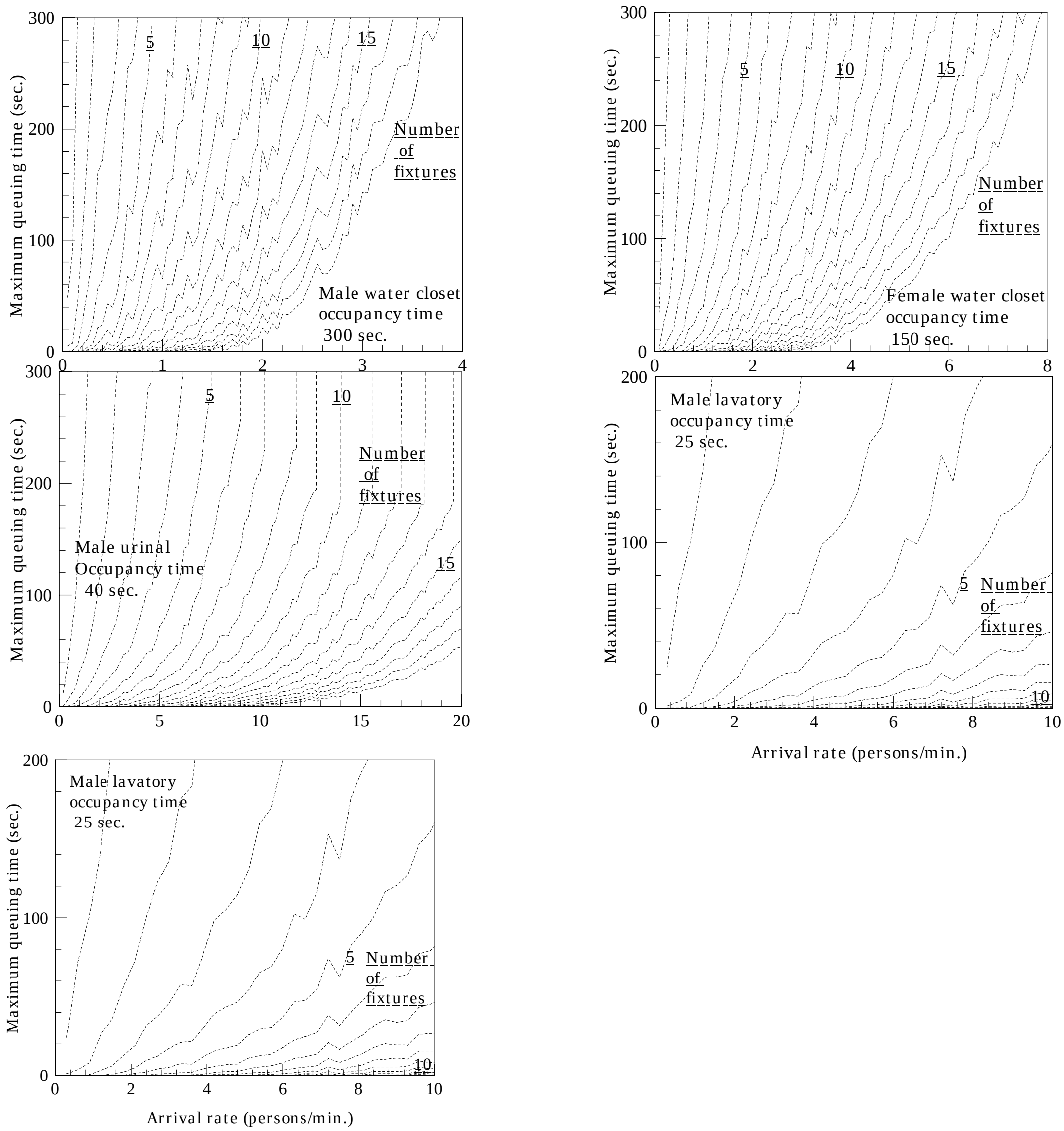


**Figure 5-The calculated results by simulation technique**

## 4 Calculation of the recommended number of fixtures in each arrival rate

Permissible queuing time as a service level is set, since the relationship between arrival rate in each number of fixtures and the maximum queuing time is clarified in the previous chapter, and the calculation of the recommended number of fixtures is analyzed.

### 4.1 Permissible queuing time

Permissible queuing time uses the maximum permissible queuing time for each fixture gotten in the questionnaire survey on the toilet for adults[2]. Replied the maximum permissible queuing time changes from 0 to 1800 seconds. However, it was regarded as a range from 30 seconds to 600 seconds in the time with the judgment of filling up tendency of the respondents, etc. with the reliability. Therefore, only the respondents of this range were totaled. The totaling results are shown at Table 7. In the table, the value of service level 2 is a mean value. The value of service level 1 is pulled standard deviation from mean value and the value of service level 3 is added standard deviation to the mean value.

| Fixture usage | | Number of respondents(persons) | Setting value of permissible queuing time (sec.) | | |
|---|---|---|---|---|---|
| | | | Level 1 | Level 2 | Level 3 |
| Men | Feces | 460 | 78 | 178 | 277 |
| | Urine | 493 | 56 | 153 | 250 |
| | Washing hand | 321 | 28 | 114 | 201 |
| Women | Feces | 238 | 87 | 184 | 280 |
| | Urine | 256 | 100 | 194 | 287 |
| | Washing hand | 228 | 57 | 160 | 263 |

**Table 7-The permissible queuing time according to the questionnaire**

### 4.2 Calculation of the recommended number of fixtures

Calculating result of the number of fixtures as an under queuing time in the every service level are shown in Figure 6. This figure shows that the recommended number of fixture from the arrival rate. Considering the calculating number of fixture in exceeding the range of the figure, the calculating formulas for recommended number of fixtures were decided in applying the nonlinear regression and linear regression style. Those were required by the simplex method, which minimized the error. The calculating results are shown at Table 8. In male and female water closet in which the occupancy time is long, the difference hardly occurs in the significance of both equations; the nonlinearity and linearity. However, the nonlinearity seems to be the usefulness from the linearity in showing the lowering of the required number of fixture according to increase the range. The linear type seems to be the usefulness on the male lavatory in which the occupancy time becomes a minimum.

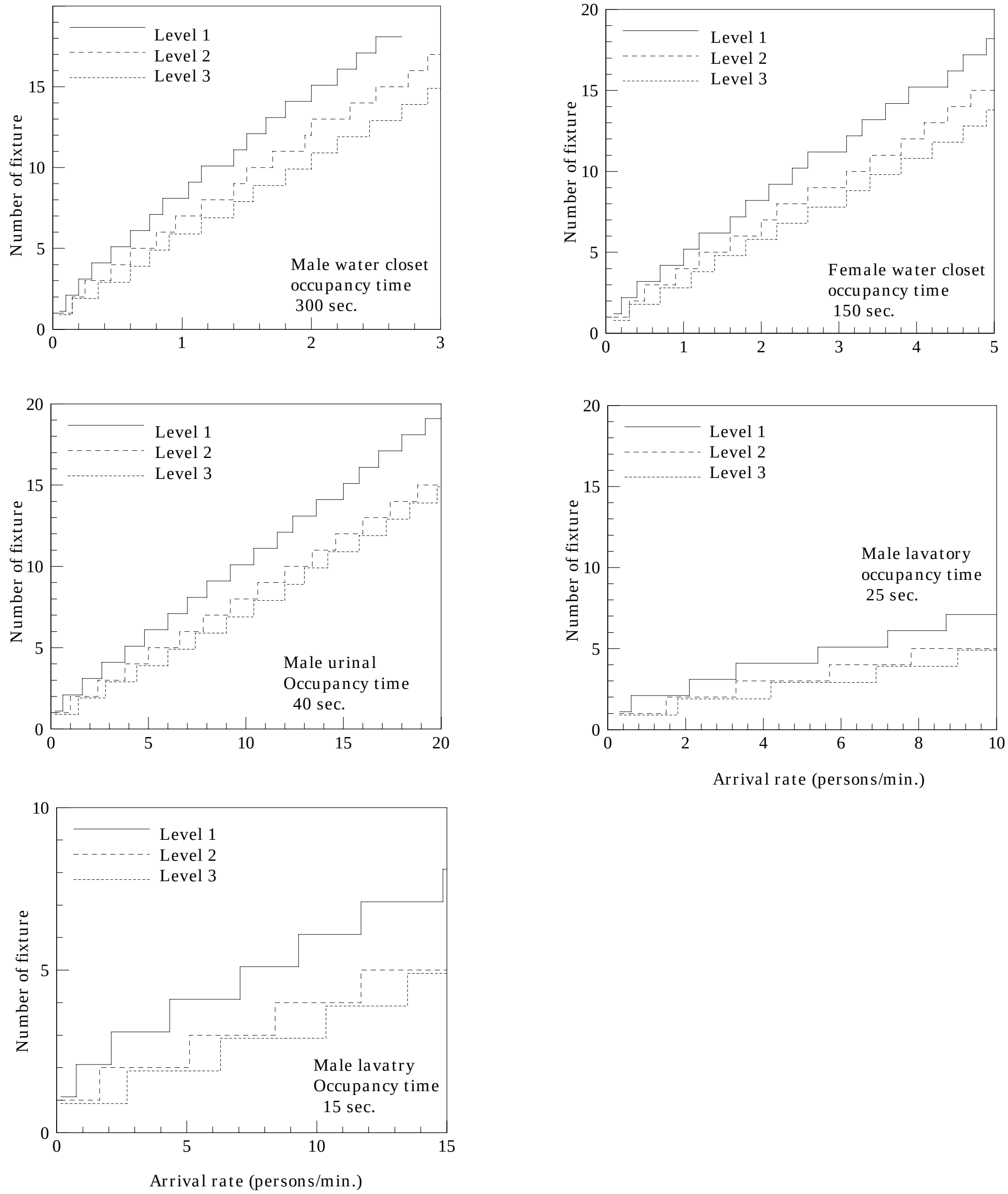


**Figure 6-The recommended number of fixtures in each service level and arrival rate**

**Table 8-The calculation formulas for the recommended number of fixtures**

| Equation | | $Y = aX^{-b}X^{c}$ | | | $Y = aX + b$ | |
|---|---|---|---|---|---|---|
| Fixture | Level | a | b | c | a | b |
| Male water closet | 1 | 4,805 | 3,319 | 0,494 | 6,498 | 1,355 |
| | 2 | 4,471 | 1,998 | 0,482 | 5,347 | 0,964 |
| | 3 | 4,445 | 1,031 | 0,341 | 4,733 | 0,675 |
| Male urinal | 1 | 0,899 | 0,719 | 0,096 | 0,911 | 0,750 |
| | 2 | 0,734 | 0,407 | -0,034 | 0,732 | 0,398 |
| | 3 | 0,705 | 0,247 | -2,051 | 0,707 | -0,030 |
| Male lavatory | 1 | 0,286 | 1,058 | 0,366 | 0,418 | 1,070 |
| | 2 | 0,309 | 0,560 | -0,107 *1 | 0,299 | 0,538 *3 |
| | 3 | 0,285 | 0,398 | -0,378 *2 | 0,274 | 0,293 *4 |
| Female water closet | 1 | 2,977 | 1,360 | 0,323 | 3,246 | 1,032 |
| | 2 | 2,639 | 0,692 | 0,149 | 2,686 | 0,641 |
| | 3 | 2,394 | 0,461 | 0,132 | 2,418 | 0,442 |
| Female lavatory | 1 | 0,560 | 1,004 | 0,071 | 0,569 | 1,055 |
| | 2 | 0,479 | 0,553 | -0,283 | 0,471 | 0,412 |
| | 3 | 0,483 | 0,901 | -2,934 | 0,489 | -0,103 |

Note:* is Level of significance. *1(100%), *2(4.4%), *3(1.0%) and *4(0.1%)

## 5 The recommended number of fixture in the existing station toilets using the calculating figures

In search of the recommended number of fixtures in peak hour, it was compared with the existing number of fixtures in the JR 5 stations. Then, the validity of calculating method of fixture requirements using the new calculating figures was verified.

The existing numbers of each fixture in the 5 stations and calculated values of the every service level are shown at Table 9. In comparing the results, there is an insufficient tendency of the number of male and female water closet. And, there is a superfluous tendency of the number of male urinal and male and female lavatory. Especially, the tendency of the shortage of fixtures is remarkable in female water closet. These show a tendency which reflects present state conditions.

**Table 9-The recommended number of fixtures by calculation**

| Fixture | station | Number of fixtures | Date | Peak time zone | Arrival rate (persons/min.) | Recommended number of fixtures | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Level 1 | Level 2 | Level 3 |
| Male water closet | K station | 6 | Monday | 08 o'clock | 1.08 | 9 | 7 | 6 |
| | S station | 6 | Monday | 07 o'clock | 1.02 | 8 | 7 | 6 |
| | U station | 4 | Monday | 07 o'clock | 0.80 | 7 | 6 | 5 |
| | T station | 6 | Friday | 08 o'clock | 1.23 | 10 | 8 | 7 |
| | J station | 6 | Tuesday | 08 o'clock | 1.08 | 9 | 7 | 6 |
| Male urinal | K station | 8 | Friday | 20 o'clock | 5.30 | 6 | 5 | 4 |
| | S station | 11 | Friday | 17 o'clock | 6.35 | 7 | 5 | 5 |
| | U station | 18 | Friday | 20 o'clock | 13.10 | 13 | 10 | 10 |
| | T station | 13 | Thirsday | 20 o'clock | 12.33 | 12 | 10 | 9 |
| | J station | 12 | Friday | 19 o'clock | 9.90 | 10 | 8 | 7 |
| Male lavatory | T station | 4 | Friday | 22 o'clock | 5.18 | 4 | 3 | 2 |
| | J station | 4 | Monday | 22 o'clock | 3.73 | 3 | 2 | 2 |
| Female water closet | K station | 7 | Friday | 17 o'clock | 1.90 | 8 | 6 | 6 |
| | S station | 6 | Friday | 18 o'clock | 2.10 | 9 | 7 | 6 |
| | U station | 6 | Friday | 17 o'clock | 2.27 | 9 | 8 | 7 |
| | T station | 10 | Friday | 10 o'clock | 5.63 | 20 | 17 | 15 |
| | J station | 7 | Monday | 08 o'clock | 3.98 | 14 | 12 | 10 |
| Female lavatory | T station | 7 | Monday | 10 o'clock | 7.25 | 6 | 4 | 4 |
| | J station | 8 | Wednesday | 16 o'clock | 7.17 | 5 | 4 | 4 |

Note: The research date is same for Table -2.

## 6 Conclusion

In this paper, the following were set; the numbers of toilet users according to time zone and male and female from the number of passengers, fixture usage and occupancy times, toilet arrival patterns and service level by permissible queuing time clarified by previous paper. Then, the figure to calculate the recommended number of fixtures was suggested by the every arrival rate using permissible queuing time as service level, after the queuing time in each number of fixtures is calculated by the simulation.

Finally, the calculated results were compared with the existing number of fixtures in the 5 stations. In the results of comparing, there were superfluous tendency for male urinal, male and female lavatory, and insufficient tendency for male and female water closet.

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# An Analysis on the Loads of Hot Water Consumption in a Company Dormitory for Business Single-handed and Unmarried Persons

**S. MURAKAWA; D. NISHINA; Y. KOSHIKAWA; H. TAKATA**

## Abstract

The purpose of this study is to get the fundamental data applied to planning and design of hot water supply system in dormitory for business single-handed persons taking a post without his family and unmarried persons. We analyzed about the loads of hot water consumption on the basis of data that had been measured for two years in a company dormitory.

First we carried out a questionnaire investigation to clarify the dweller's attitudes and conditions of using cold and hot water. As the results, we showed that there was a distinct difference between the business single-handed persons and the unmarried persons in the point of consciousness of saving water and how to use cold and hot water.

Next we analyzed about cold and hot water consumption by using monthly data of all flats. We showed the volume of cold and hot water consumption changed in each season and water supply temperature. And we clarified the mean values of cold and hot water consumption per flat and per day classified by the business single-handed persons and the unmarried persons based on the number of days stayed out, the style of taking bath or shower as the dweller's behaviors and the consciousness of saving water.

We also studied by using hourly data of 11 houses measured continuously, and showed the changes of the loads of hot water consumption per flat and per day in each season and in each day of the weeks.

## Keywords

Measurement; Hot Water Supply System; Loads of Hot Water Consumption;
Dormitory for Business Single-handed and Unmarried Persons

## 1 Introduction

Recently, the amount of energy consumption of hot water in the residence is increased remarkably. It is caused by the spread of utilization of hot water equipments, the change in user's life style and the enlargement of capacity of hot water equipments according to many functions for our daily life in comfort. The data on the load of hot water is necessary for the optimum design of equipment capacity. In recent years, the useful fundamental data were accumulated by many researches on the consumption of hot water. However, there is little research for the dormitory targeting the business single-handed persons taking a post without his family (Here after, we describe the persons as "the single persons") or unmarried persons. These buildings are recently increased in Japan.

Under these conditions, several investigations of cold and hot water consumption in the dormitories were done by F. Kiya et al. [4] and some researchers [7,8]. In the studies, they had analyzed the trend of hot water consumption. However, the conditions on the loads of hot water are not being cleared enough.

Therefore, it is meaning for equipment design and energy saving plan to grasp the conditions of hot water consumption in these buildings. This study aims at getting the fundamental data applied to planning and design of hot water supply systems on the basis of data that had been measured in a company dormitory. We analyze the relationship between the loads of hot water and the dweller's attributes grasped from the questionnaire investigation.

## 2 Outline of the survey building

The single and the unmarried person's dormitory of the T company was chosen as the survey building. Table 1 shows the outline of the survey building and it's hot water supply system. The dormitory is composed of 30 flats for the single persons, 30 flats for the unmarried persons and one flat for the manager. As the facilities for the convenience of dwellers, there are a dining room with kitchen and a table tennis room on the 1st floor, and a dryness machine room in each floor. The hot water is supplied by the central system equipped a heat pump. The supplied temperature of hot water is about 60 degrees to each flat. But the dining kitchen is covered with another electric water heater.

**Table 1- Outline of survey building and hot water supply system**

| | | |
|---|---|---|
| The building | Building use | Company dormitory |
| | Structure | Reinforced concrete |
| | Scale | 6 stories |
| | Total number of flats | 30 flats for the single persons(1DK:27m$^2$)<br>30 flats for the unmarried persons(1DK:24m$^2$)<br>1 flat for the manager(3LDK:71m$^2$) |
| | Total floor area | 2,968m$^2$ |
| The hot water supply system | Heat source | Air source heat pump |
| | Supply system | Central hot water supply system |
| | Heat pump | Heating power:40.3kW |
| | Storage tank | Structure:Enclosed type<br>Capacity:3000 L × 2 Tanks |

Each flat is composed of a bedroom, dining kitchen and bathroom. The kitchen has a sink with a single-handle mixing faucet, and the bathroom has a bathtub with thermostat mixing shower and faucet, a basin and a water closet. Also, each flat has washing machine, refrigerator, electromagnetic cooking heater and air-conditioner. In the manager flat, there are the same equipments as each flat besides a thermostat shower mixed faucet with the washbowl.

## 3 Outline of the measu rement

Fig.1 shows the hot water supply system and the measurement points. Table 2 shows the measurement outline using the automatic recording devices.

We measured the total consumption of hot water in the building at the pipe of make-up water, point a, by the electromagnetic flow meter, and we measured the hot water consumption per flat for 11 flats by the hot water flow meters. These data are managed and recorded by the head office through the modem and the NTT telephone lines. Furthermore, in addition to the automatic record, we recorded the monthly cold and hot water consumption per flat by reading the meters directly.

We analyze the data through two years from February in 1997 to January in 1999 because personnel transfers are carried out on February 1st in case of the T company.

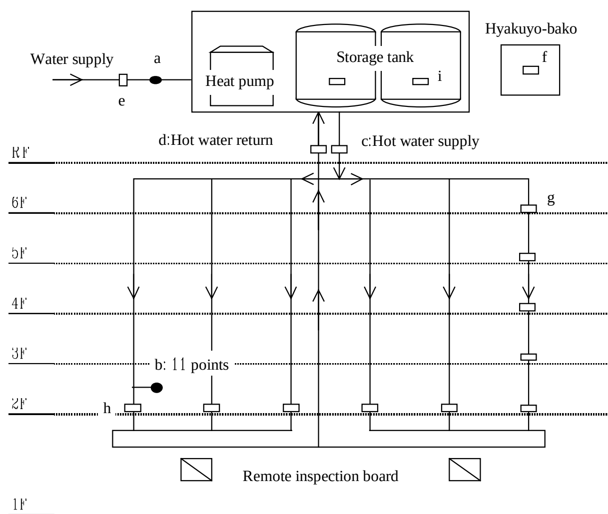



**Figure 1- Hot water supply system and measurement points**

**Table 2- Measurement outline on the hot water supply system**

| Period | February 1, 1997 ~ January 31, 1999 | | | |
|---|---|---|---|---|
| Contents | Data | Item | Instrument | Sign |
| | Volume of flow (L) | Total consumption of hot water | Electromagnetic flow meter | a |
| | | Hot water consumption per flat (11 flats) | Hot water flow meter | b |
| | Temparature (.℃) | Hot water supply temparature | Thermometer | c |
| | | Hot water return temparature | Thermometer | d |
| | | Cold water supply temparature | Thermometer | e |
| | | Outdoor air temparature | Thermometer | f |
| | | Hot water supply temparature (2nd?6th floor) | Thermometer | g |
| | | Hot water supply temparature (the lowest point:6 points) | Thermometer | h |
| | | Storage tank temparature | Thermo-couple | i |
| Interval | Volume of flow | 1 hour | | |
| | Temparature | 5 minutes (*20 minutes:untill March 4, 1997) | | |

Note: The sign "a ? i" show the measurement points on Fig.1.

## 4 Questionnaire investigation

### 4.1 Outline of questionnaire investigation

We carried out a questionnaire investigation in December 1998 to clarify the dweller's behaviors and consciousness of saving water for uses cold and hot water in each flat. The 43 houses moved into at the moment were investigated. We got the information on the number of dwellers in each month from the building management section. We asked the section to distribute the questionnaire, and collected it by mailing from the respondents. The effective number of the respondents was 39 votes, and the collection ratio was 91%. Table 3 shows the contents of questionnaire. We asked dwellers to answer the behaviors of hot water usage in case of summer and winter seasons.

**Table 3- Contents of the questionnaire**

| | |
|---|---|
| Character of the respondents | Sex, Age, Room number, Moving time into the flat |
| Daily behaviors | Holiday, Working hours, Working systems |
| | Number of days stayed out, Consciousness of water usage |
| Kitchen | Frequency of usage, Usage hours, Frequency of hot water usage |
| Washing face and hands | Frequency of washing face and hands, Frequency of hot water usage |
| Bathing | Frequency of bathing, Usage hours<br>Bathing style, Frequency of bathing by other persons |
| Washing clothes | Frequency of washing, How to washing, Use hot water or not |
| Evaluation for hot water system | Flow rate, Temperature, Waiting time for hot water, Smell |

### 4.2 Results of questionnaire investigation

Fig.2 shows the attributes of the respondents. All the dwellers are men, and most of them are 20s or 40s or over 50s age. The ratio of single persons is somewhat high in the all dwellers. In this dormitory, 40% of the dwellers work on the three-shift system per day, and the dwellers that are under 20s age move into the dormitory for the single persons and work on the three-shift system.

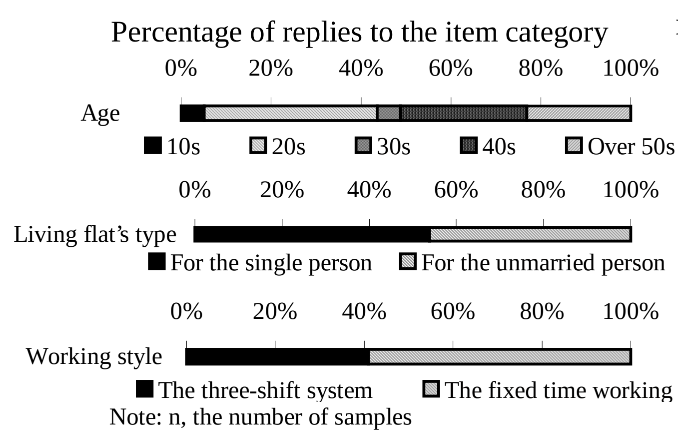



**Figure 2- Attributes of the respondents**

Table 4 shows the results of questionnaire on the life styles and frequency of cold – hot water usage. As for the number of average days of stayed out due to business trip or going home, there is much difference between the single persons; 8.33 days/ month, and the unmarried persons; 2.17 days/ month.

## Table 4- Life styles and frequency of cold - hot water usage

| Contents | | | | | All persons | Single persons | Unmarried persons |
|---|---|---|---|---|---|---|---|
| Daily behaviors | Working system (% ) | Three-shift working system | | | 41,0 | 4,8 | 83,3 |
| | | Fixed time working system | | | 59,0 | 95,2 | 16,7 |
| | Number of days stayed out (days/month) | | | | 5,49 | 8,33 | 2,17 |
| | Consciousness of saving water (% ) | ● | very high | | 12,8 | 23,8 | 0,0 |
| | | ⊙ | high | | 17,9 | 19,0 | 16,7 |
| | | ○ | slightly high | | 23,1 | 28,6 | 16,7 |
| | | ◎ | average | | 43,6 | 28,6 | 61,1 |
| | | × | low | | 2,6 | 0,0 | 5,6 |
| Kitchen | Frequency of usage (times/week) | breakfast | | | 1,87 | 2,24 | 1,44 |
| | | lunch | | | 0,56 | 0,19 | 1,00 |
| | | dinner | | | 1,77 | 1,76 | 1,78 |
| | Frequency of hot water usage (% ) | summer | usually | | 2,6 | 4,8 | 0,0 |
| | | | occasionally | | 23,1 | 19,0 | 27,8 |
| | | | never | | 74,4 | 76,2 | 72,2 |
| | | winter | usually | | 20,5 | 19,0 | 22,2 |
| | | | occasionally | | 48,7 | 42,9 | 55,6 |
| | | | never | | 30,8 | 38,1 | 22,2 |
| Washing face and hands | Frequency of washing face and hands (times/day) | summer | | | 2,10 | 1,95 | 2,28 |
| | | winter | | | 1,74 | 1,67 | 1,83 |
| | Frequency of hot water usage (?) | summer | usually | | 12,8 | 19,0 | 5,6 |
| | | | occasionally | | 15,4 | 19,0 | 11,1 |
| | | | never | | 71,8 | 61,9 | 83,3 |
| | | winter | usually | | 66,7 | 66,7 | 66,7 |
| | | | occasionally | | 20,5 | 19,0 | 22,2 |
| | | | never | | 12,8 | 14,3 | 11,1 |
| Bathing | Frequency of bathing (times/week) | summer | | | 6,68 | 4,60 | 9,00 |
| | | n | | | 35 | 18 | 17 |
| | | winter | | | 6,57 | 5,00 | 8,24 |
| | | n | | | 35 | 18 | 17 |
| | Frequency of bathing and Usage hours (% ) | summer | before going to work | every day | 9,1 | 0,0 | 21,4 |
| | | | | occasionally | 18,2 | 10,5 | 28,6 |
| | | | | never | 72,7 | 89,5 | 50,0 |
| | | | | n | 33 | 19 | 14 |
| | | | immediately after coming home | every day | 30,3 | 31,6 | 28,6 |
| | | | | occasionally | 6,1 | 0,0 | 14,3 |
| | | | | never | 63,6 | 68,4 | 57,1 |
| | | | | n | 33 | 19 | 14 |
| | | | before going to bed | every day | 60,6 | 57,9 | 64,3 |
| | | | | occasionally | 12,1 | 10,5 | 14,3 |
| | | | | never | 27,3 | 31,6 | 21,4 |
| | | | | n | 33 | 19 | 14 |
| | | winter | before going to work | every day | 6,1 | 0,0 | 14,3 |
| | | | | occasionally | 12,1 | 15,8 | 7,1 |
| | | | | never | 81,8 | 84,2 | 78,6 |
| | | | | n | 33 | 19 | 14 |
| | | | immediately after coming home | every day | 30,3 | 31,6 | 28,6 |
| | | | | occasionally | 0,0 | 0,0 | 0,0 |
| | | | | never | 69,7 | 68,4 | 71,4 |
| | | | | n | 33 | 19 | 14 |
| | | | before going to bed | every day | 66,7 | 57,9 | 78,6 |
| | | | | occasionally | 6,1 | 10,5 | 0,0 |
| | | | | never | 27,3 | 31,6 | 21,4 |
| | | | | n | 33 | 19 | 14 |
| | Bathing style (% ) | every day | summer | taking a bath | 6,3 | 12,5 | 0,0 |
| | | | | taking a bath and shower | 21,9 | 18,8 | 25,0 |
| | | | | taking a shower | 71,9 | 68,8 | 75,0 |
| | | | n | | 32 | 16 | 16 |
| | | | winter | taking a bath | 9,1 | 18,8 | 0,0 |
| | | | | taking a bath and shower | 36,4 | 37,5 | 35,3 |
| | | | | taking a shower | 54,5 | 43,8 | 64,7 |
| | | | n | | 33 | 16 | 17 |
| | | occasionally | summer | taking a bath | 13,3 | 33,3 | 0,0 |
| | | | | taking a bath and shower | 20,0 | 16,7 | 22,2 |
| | | | | taking a shower | 66,7 | 50,0 | 77,8 |
| | | | n | | 15 | 6 | 9 |
| | | | winter | taking a bath | 28,6 | 40,0 | 0,0 |
| | | | | taking a bath and shower | 14,3 | 20,0 | 0,0 |
| | | | | taking a shower | 57,1 | 40,0 | 100,0 |
| | | | n | | 7 | 5 | 2 |
| Washing clothes | Frequency of washing (times/week) | summer | | | 2,59 | 1,52 | 3,83 |
| | | winter | | | 2,31 | 1,38 | 3,39 |

Note: As for the percentage of each item, the total become 100% in each content of [All persons], About the consciousness of saving water, there is much difference in the ratio of applying from “very high” to “slightly” between the single persons; about 70%, and the unmarried persons; about 35%. Especially the ratio applying “very high” of the single persons is about 25%.

At the kitchen, although there is a difference among the dwellers, they use hot water a few number of frequency and few use hot water in summer. As for the washing face and hands, the average number of frequency per day increases a few in summer than in winter. The frequency of hot water usage is a little in summer, but over 60% of all dwellers use the hot water in winter. And at the washing face and hands as well as at the kitchen there is no difference between the single persons and the unmarried persons.

As for the bathing, the average number of frequency per week in the unmarried persons is higher than that in the single persons. We could know that the single persons go home on the weekend, supposing from the number of stayed out days. As for the style of taking a bath, there is the tendency that persons who take a shower increase in summer and persons who take a bath or take a bath with shower increase in winter. The number of washing frequency increases in summer, and that of the unmarried persons is twice as much as that of the single persons. There are few persons who use hot water for a washing and reuse the hot water in the bath.

The loads of hot water consumption are a little at the kitchen, and most of the hot water are consumed at the bathroom in each flat.

### 4.3 Dweller’s attributes

We measured the every one-hour for hot water consumption in the 11 houses to clarify the characteristics of the loads of hot water in each house, and we excluded the 3 flats for the analysis because of no dwellers during the measurement. Fig.3 shows the occupied conditions of 8 flats. All flats for the single persons were moved into or left because the personal transfers carried out in February 1998. Therefore, we made a distinction to the houses before and after February in the single person’s flats. Ultimately, we analyzed 11 houses, from T1 to D3, shown in Fig.3.

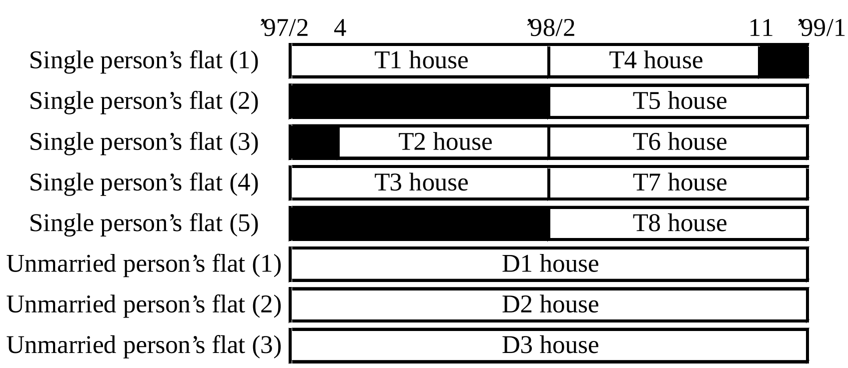



**Figure 3- Occupied conditions of the measurement flats**

Table 5 shows the attributes of the measurement houses. The attributes of 4 houses, from T1 to T4, were unknown because the dwellers of each house had already left at the time carried out the questionnaire investigation.

**Table 5- Attributes of the measurement houses**

| House | Age | Working system | Kitchen | | Washing face and hands | | Bathing style | | Number of days stayed out |
|---|---|---|---|---|---|---|---|---|---|
| | | | summer | winter | summer | winter | summer | winter | (days/month) |
| T5 house | over 50s | Fixed time | ! | ! | × | # | B?S | B?S | 8 |
| T6 house | 40s | Fixed time | ! | ! | ! | ! | B?S | B?S | 6 |
| T7 house | 30s | Fixed time | × | × | # | # | S | B?S | 9 |
| T8 house | 40s | Fixed time | × | # | ! | # | S | B?S | 8 |
| D1 house | 20s | Three-shift | × | × | × | # | S | S | 1 |
| D2 house | 20s | Three-shift | × | × | ! | ! | B?S | B?S | 3 |
| D3 house | 20s | Fixed time | × | ! | × | × | S | B?S | 2 |

Note:As for the frequency of hot water usage at kitchen and washing face and hands

# : usually ! : occasionally x : never

As for the bathing style

B . S: taking a bath and shower S: taking a shower only

## 5 Results of the temperature measurement

Fig.4 shows the change of daily average of each temperature. Hot water supply temperature and return temperature are almost stable, and the average supply and return temperatures are 61.0 degrees (standard deviation 0.8 degrees) and 57.0 degrees (standard deviation 0.7 degrees) respectively. Cold water supply temperature and outdoor air temperature change similarly through the year and have a good relation with the correlation coefficient r=0.971. Therefore, we analyze the data based on cold water supply temperature as from the description. And, we decide the seasonal classification that the winter season is the period from December to March, the summer season is the period from June to September and the middle season is other months based on the changing tendency of each month.

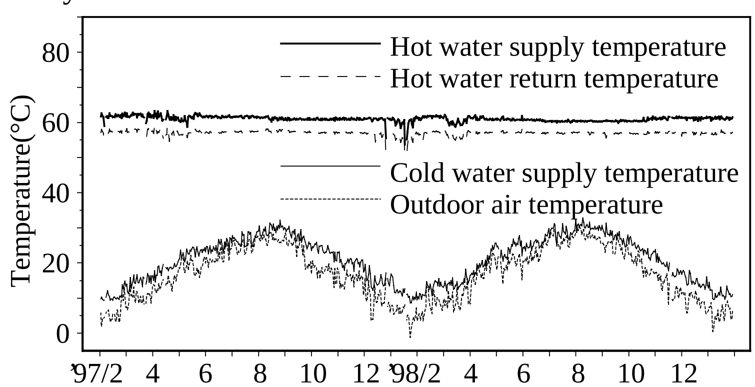



**Figure 4- Results of the temperature measurement**

## 6 Analysis on the monthly cold and hot water consumption

In this chapter, we analyze the cold and hot water consumption measured from all flats of the dormitory in every month. We calculated the energy consumption by the following equation (1). Each numerical value adopted the mean value for the month.

[Monthly energy consumption] = [Monthly hot water consumption] x [Hot water temperature at each floor - Cold water temperature] x [Specific heat] . . .(1)

As for analysis, we showed about the average case that the single persons and the unmarried persons were put together and the classified case because the two groups had difference in the point of the consciousness of saving water and how to use cold and hot water as shown in the chapter 3. And, one sample (800L/ person/ day) of the single persons was excluded as the abnormal consumption.

### 6.1 Loads on all of the composed flats

We analyze the data measured from all of the composed flats. Fig.5 shows the average water consumption and the average hot water consumption per flat per day in each month of the single persons and the unmarried persons. We calculated the mean values by dividing the monthly consumption by the number of days in each month. According to Fig.5, the unmarried persons consume the nearly double volume in comparison with the single persons in both cold and hot water consumption. The cold water consumption reversely fluctuates to the hot water consumption. The cold water consumption increase in summer and the hot water consumption increase in winter, and the pattern of change appears remarkably in the hot water consumption. The cold and hot water consumption per flat per day of each month have relations with the correlation coefficient r=0.617 by calculating for all flats.

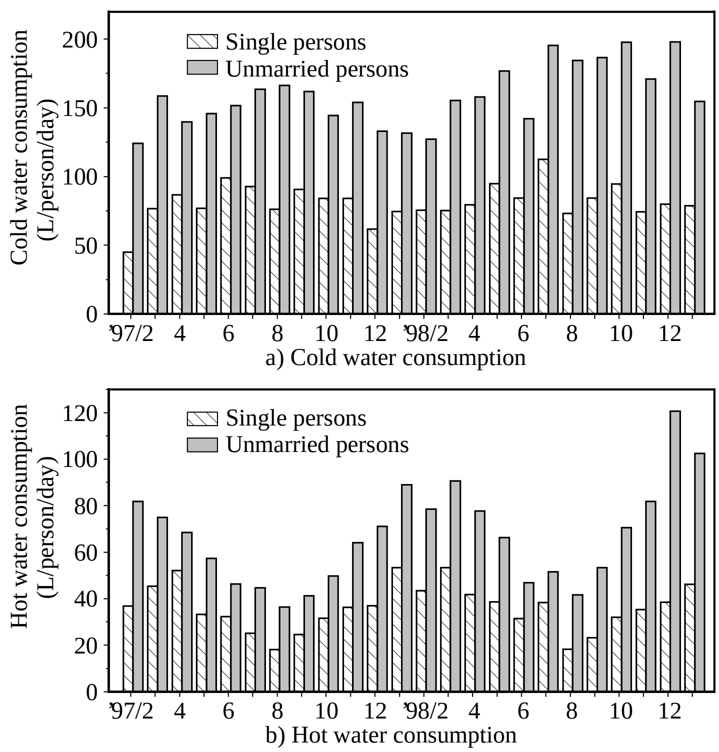
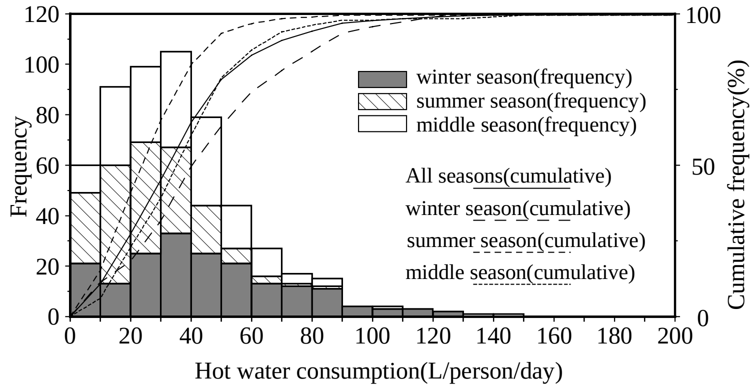
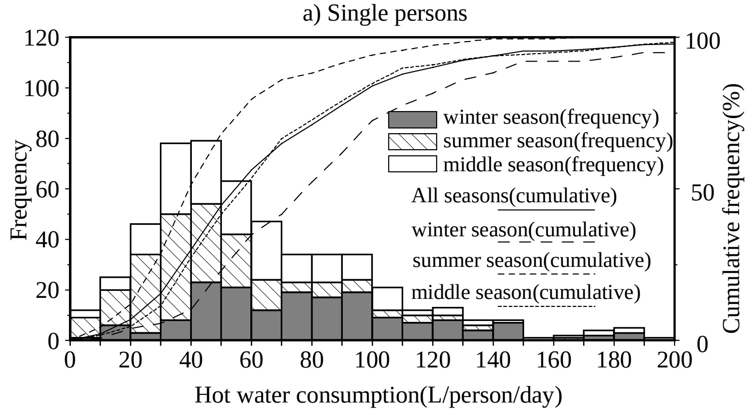



**Figure 5- Cold and hot water consumption**

Next, we analyze the loads by using the seasonal classification mentioned in chapter 5. Fig.6 shows the frequency distributions and the cumulative frequency distributions of the single and unmarried person's average hot water consumption per flat per day in each month. The unmarried person's distributions spread out widely and have a gentle ascent in comparison with the single person's distributions. However, as the distribution of each season, the two groups have the same tendency.




a) Single persons




b) Unmarried persons

**Figure 6- Frequency distributions and cumulative frequency distributions of hot water consumption per flat per day in each month**

Table 6 shows the values of cold and hot water consumption, and energy consumption in each season. In "All seasons" at "All persons", the cold and hot water consumption are 121.3L/ person/ day and 51.7L/ person/ day respectively. The total consumption shows the value between 130L/ person/ day in the single person's dormitory and 220L/ person/day in the unmarried person's dormitory that were investigated in the past researches. The hot water consumption is a few little in comparison with the values that the authors measured in the detached houses before; 63.5L/ person/ day of the A house and 70.1L/ person/day of the E house converted to 60 degrees of supply hot water temperature.

**Table 6- Values of cold and hot water consumption and energy consumption in each season**

| House | Season | Cold water consumption | | | | n | Hot water consumption | | | | n | Energy consumption | | | | n |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Average | 95% value | Maximum | Standard deviation | | Average | 95% value | Maximum | Standard deviation | | Average | 95% value | Maximum | Standard deviation | |
| | | (L/person/day) | | | | | (L/person/day) | | | | | (MJ/person/day) | | | | |
| All persons | All | 121.3 | 257.7 | 545.0 | 71.2 | 1092 | 51.7 | 122.3 | 398.4 | 41.4 | 1093 | 8.27 | 21.17 | 70.61 | 7.29 | 1093 |
| | winter | 109.4 | 247.4 | 400.0 | 66.5 | 363 | 66.4 | 141.9 | 398.4 | 49.5 | 364 | 12.29 | 26.42 | 70.61 | 9.11 | 364 |
| | summer | 131.4 | 271.5 | 545.0 | 76.8 | 369 | 36.5 | 88.1 | 305.2 | 28.3 | 369 | 4.60 | 11.33 | 36.42 | 3.53 | 369 |
| | middle | 123.1 | 253.2 | 451.3 | 68.2 | 360 | 52.5 | 122.6 | 279.0 | 38.0 | 360 | 7.97 | 19.07 | 48.34 | 5.89 | 360 |
| Single persons | all | 83.1 | 155.2 | 545.0 | 48.4 | 554 | 36.9 | 83.1 | 305.2 | 28.0 | 554 | 5.90 | 15.03 | 48.34 | 4.83 | 554 |
| | winter | 72.2 | 153.0 | 254.5 | 41.3 | 186 | 45.1 | 97.8 | 129.4 | 27.8 | 186 | 8.38 | 18.65 | 23.06 | 5.20 | 186 |
| | summer | 91.0 | 160.4 | 545.0 | 58.1 | 184 | 27.0 | 52.8 | 305.2 | 25.4 | 184 | 3.42 | 6.76 | 36.42 | 3.14 | 184 |
| | middle | 86.1 | 167.1 | 292.0 | 42.4 | 184 | 38.4 | 76.9 | 279.0 | 27.8 | 184 | 5.87 | 11.61 | 48.34 | 4.57 | 184 |
| Unmarried persons | all | 160.7 | 283.9 | 451.3 | 69.4 | 538 | 66.9 | 145.8 | 398.4 | 47.0 | 539 | 10.71 | 25.84 | 70.61 | 8.50 | 539 |
| | winter | 148.5 | 276.8 | 400.0 | 65.6 | 177 | 88.6 | 207.2 | 398.4 | 57.1 | 178 | 16.38 | 39.26 | 70.61 | 10.44 | 178 |
| | summer | 171.5 | 311.3 | 431.0 | 72.1 | 185 | 45.9 | 108.1 | 162.7 | 27.9 | 185 | 5.77 | 13.74 | 19.89 | 3.51 | 185 |
| | middle | 161.7 | 293.6 | 451.3 | 68.7 | 176 | 67.2 | 166.4 | 228.1 | 41.6 | 176 | 10.16 | 24.22 | 35.18 | 6.32 | 176 |

## 6.2 Loads based on the dweller's attributes

In the previous paragraph, we analyzed to grasp a general tendency without taking the differences such as the number of days stayed out or how to use cold and hot water into consideration. Therefore, we advance the analysis on the basis of the dweller's attributes that were answered about the questionnaire. Moreover, we examine the influence on the hot water consumption by classified with the style of taking a bath or shower as the dweller's behaviors and further classified the each style to the consciousness level of saving water. As for the persons who replied it "Taking a bath every day", we classified into two groups that take a bath or a shower with the bathing style. And in each style, we classified into a group that replied "very high" - "slightly high" and a group that replied "average" or "low" in the consciousness of saving water. Table 7 shows the cold and the hot water consumption in each classified group.

**Table 7- Cold and hot water consumption in each classified group**

| Season | contents | | All persons | | | | Single persons | | | | Unmarried persons | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | bating style | | bath | | shower | | bath | | shower | | bath | | shower | |
| | consciousness of saving water | | □ | × | □ | × | □ | × | □ | × | □ | × | □ | × |
| summer | cold water consumption | style | 177,8 | | 164,0 | | 112,4 | | 127,9 | | 259,6 | | 203,8 | |
| | | consciousness | 113,6 | 258,2 | 155,7 | 173,2 | 105,9 | 138,5 | 133,6 | 112,6 | 144,1 | 298,1 | 214,6 | 199,1 |
| | hot water consumption | style | 64,6 | | 37,0 | | 44,6 | | 29,3 | | 89,7 | | 45,5 | |
| | | consciousness | 45,0 | 89,1 | 35,1 | 39,2 | 43,3 | 49,9 | 29,4 | 29,0 | 52,0 | 102,2 | 50,2 | 43,5 |
| | Number of flats (flats) | | 5 | 4 | 11 | 10 | 4 | 1 | 8 | 3 | 1 | 3 | 3 | 7 |
| winter | cold water consumption | style | 138,0 | | 146,4 | | 105,6 | | 93,4 | | 196,2 | | 187,6 | |
| | | consciousness | 103,8 | 199,5 | 112,1 | 173,0 | 99,5 | 127,0 | 81,9 | 122,0 | 118,7 | 247,8 | 187,5 | 187,6 |
| | hot water consumption | style | 104,6 | | 72,9 | | 78,8 | | 46,8 | | 150,9 | | 93,2 | |
| | | consciousness | 79,8 | 149,1 | 61,2 | 82,1 | 81,7 | 69,0 | 38,9 | 66,7 | 73,5 | 202,5 | 116,8 | 86,5 |
| | Number of flats (flats) | | 9 | 5 | 7 | 9 | 7 | 2 | 5 | 2 | 2 | 3 | 2 | 7 |

Note: The unit is (L/person/day)

As for the consciousness of saving water, □ :[very high] ~ [slightly high], ×:[average] or [low]

On the cold water consumption, the differences in the single persons and the unmarried persons are influenced by the difference on the washing days as one of the factors. So far as seeing "All persons", there are no differences between taking a bath and taking a shower. Moreover, the group with the high consciousness of saving water decreases the consumption as for as seeing "All persons".

On the hot water consumption, the difference between taking a bath and taking a shower is clear in each season. The group of taking a bath increases the volume of consumption. Moreover, on the consciousness of saving water in each style, the tendency is same with the cold water consumption, and the difference appears remarkably in the group of taking a bath.

Assuming that dwellers use the most of hot water for the bathing behavior in summer, the following content can be said about the taking a shower in summer. When we convert the volume of hot water consumption at hot water supply temperature 57.5 degrees, taking a shower temperature 41.0 degrees and cold water supply temperature 27.6 degrees, the volume of consumption in the single and unmarried persons becomes 65.4 L and 101.5 L respectively. This value is a little small in comparison with the experimental results that the authors carried out by using the general shower head (G-3; Number of holes 60, Hole size 1.0mm); 75.94 L in the saving type A (Stopping to use hot water when washing the body or hair) and 142.61 L in the wasting type C (No stopping to use hot water during the bathing behavior).

# 7 Analysis on the hourly loads of hot water

In this chapter, we judge the number of days stayed out by using every one-hour hot water data that we measured automatically at 11 flats. We analyze the loads of hot water per flat by excluding the number of days stayed out.

And, the energy consumption per flat per day was calculated by using the hourly mean value in the following equation (2).

[Energy consumption per flat] = [Hot water consumption per flat] x
[Each floor hot water temperature - Cold water temperature] x [Specific heat] . . . (2)

Still, the unusual data such as the maintenance days were excluded.

## 7.1 Daily loads of hot water

Fig.7 shows the example of fluctuation of daily hot water consumption per flat. Differences of hot water consumption in summer and winter appear clearly through a year.

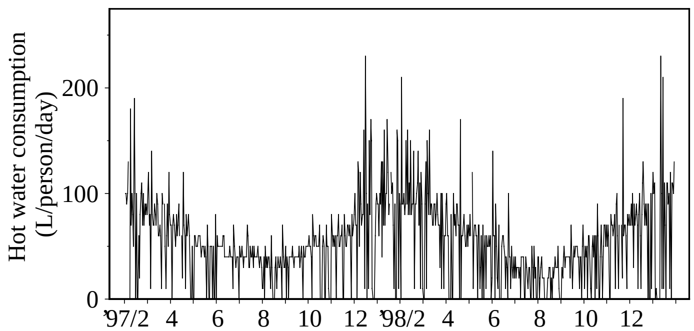
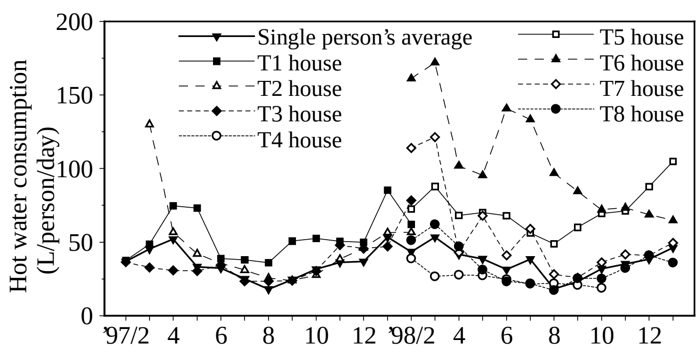
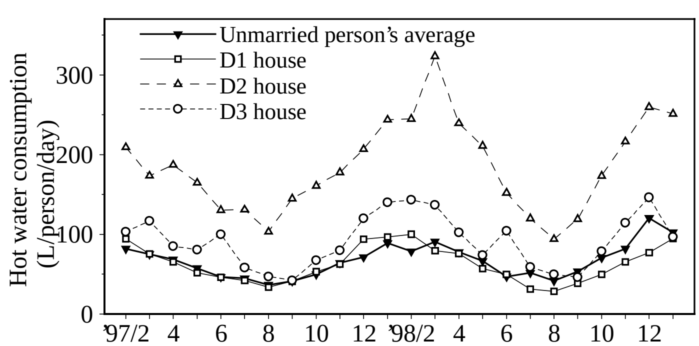



**Figure 7- Fluctuation of daily hot water consumption per flat (Example of D1 house)**




a) Single persons




b) Unmarried persons

**Figure 8- Hot water consumption per flat in each month**

Fig.8 shows the hot water consumption per flat in each month for the single person's flat and the unmarried person's flat. The values of each month are shown as the daily average hot water consumption in the month. The seasonal fluctuations are seen remarkably on the unmarried person's flats. Comparing with the unmarried person's average value shown in the chapter 6, it is clear that the D2 house uses extremely much volume of hot water.

Fig.9 shows the frequency distributions and the cumulative frequency distributions of the daily hot water consumption in each season as examples of D1 and D3 house. In the D1 house, the distributions in each season show the normal distribution type as the frequency of the central value is large. At the order in winter, middle and summer, the range in each season spreads out widely. In the D3 house, the range of the distribution is wide in each season and the frequency beyond 100L/ person/ day increases especially in winter. According to Table 5, the D1 house does not change the bathing style of taking a shower by the season though it changes the frequency of washing face and hands. Therefore, the change of the hot water consumption in each season is influenced by the seasonal change of cold water supply temperature. On the other hand, the D3 house changes behavior at the kitchen and the bathing style by the season. The dweller takes a shower in summer, and takes a bath and shower in winter. The differences on the life style of the D1 and D3 house appear on the distribution patterns.

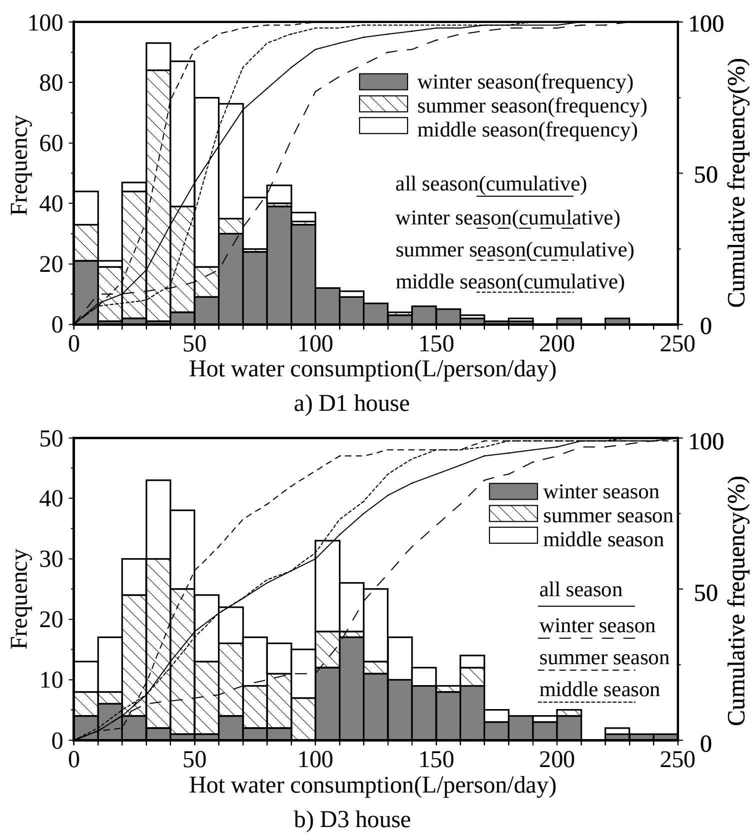



**Figure 9- Frequency distributions and cumulative frequency distributions of the daily hot water consumption in each season as example of D1 and D3 house**

Table 8 shows the mean value, maximum value, standard deviation and the non-excess probability 95% value as a daily loads of hot water per flat in each season.

The mean values of winter are bigger than the mean values of summer except for the T6 house, and the majority of the values of middle season become the values between summer and winter. In “All seasons”, the mean values per flat show large dispersion from 25 L/ person/ day to 185L/ person/ day. The mean values of hot water consumption of the single persons (8 houses) and the unmarried persons (3 houses) are 52.4L/ person/ day and 112.2L/ person/ day respectively. From the viewpoint of the consciousness of saving water level, the D2 house with low level is a waste type of water uses, and the loads of hot water correspond clearly to the consciousness of saving water.

**Table 8- Daily loads of hot water per flat in each season**

| House | Season | Hot water consumption | | | | Energy consumption | | | | Number of days used hot water | Reference column | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Average | 95% value | Maximum | S.d. | Average | 95% value | Maximum | S.d. | | Kitchen | Washing face and hands | Bathing |
| | | (L/person/day) | | | | (MJ/person/day) | | | | | | | |
| T1 house | All | 51,5 | 130,0 | 250,0 | 43,7 | 8,14 | 23,70 | 47,72 | 7,72 | 220 | | | |
| | winter | 54,6 | 149,5 | 250,0 | 54,6 | 10,19 | 28,52 | 47,72 | 10,26 | 80 | | | |
| | summer | 40,1 | 80,0 | 100,0 | 22,2 | 5,12 | 10,86 | 12,77 | 2,88 | 73 | As for the hot water usage | | |
| | middle | 60,1 | 142,0 | 160,0 | 44,7 | 8,99 | 21,34 | 27,09 | 6,84 | 67 | at the kitchen and | | |
| T2 house | All | 39,0 | 80,0 | 130,0 | 21,9 | 5,99 | 13,31 | 23,20 | 3,99 | 197 | washing face and hands | | |
| | winter | 53,8 | 90,0 | 130,0 | 26,2 | 9,80 | 16,38 | 23,20 | 4,83 | 42 | # : usually | | |
| | summer | 29,4 | 50,0 | 70,0 | 12,9 | 3,79 | 6,89 | 9,61 | 1,80 | 78 | ! : occasionally | | |
| | middle | 40,6 | 80,0 | 90,0 | 21,8 | 6,14 | 12,24 | 15,12 | 3,49 | 77 | x: never | | |
| T3 house | All | 34,5 | 70,0 | 160,0 | 22,1 | 5,50 | 12,93 | 31,81 | 4,06 | 320 | | | |
| | winter | 42,7 | 90,0 | 160,0 | 26,0 | 7,97 | 17,49 | 31,81 | 4,96 | 107 | As for the bathing style | | |
| | summer | 26,4 | 50,0 | 130,0 | 15,9 | 3,36 | 7,06 | 16,76 | 2,09 | 107 | B.S : taking a | | |
| | middle | 34,4 | 66,5 | 120,0 | 20,1 | 5,16 | 11,32 | 19,29 | 3,13 | 106 | bath and shower | | |
| T4 house | All | 24,6 | 90,0 | 120,0 | 22,2 | 3,55 | 14,67 | 21,75 | 3,73 | 119 | S : taking a shower | | |
| | winter | 31,9 | 109,0 | 110,0 | 32,2 | 5,82 | 20,21 | 20,35 | 5,98 | 21 | | | |
| | summer | 22,5 | 70,0 | 90,0 | 16,4 | 2,72 | 8,71 | 11,42 | 2,02 | 57 | | | |
| | middle | 23,9 | 111,0 | 120,0 | 22,8 | 3,54 | 15,14 | 21,75 | 3,71 | 41 | | | |
| T5 house | All | 72,5 | 130,0 | 190,0 | 35,4 | 11,27 | 23,25 | 35,15 | 6,82 | 249 | | | |
| ● | winter | 89,3 | 150,0 | 190,0 | 43,0 | 16,35 | 28,56 | 35,15 | 8,07 | 84 | ! | # | B.S |
| (fixed) | summer | 59,1 | 90,0 | 140,0 | 25,8 | 7,23 | 12,16 | 17,87 | 3,38 | 88 | ! | × | B.S |
| | middle | 69,6 | 110,0 | 110,0 | 28,1 | 10,35 | 16,31 | 18,10 | 4,36 | 77 | | | |
| T6 house | All | 105,9 | 251,0 | 340,0 | 81,2 | 16,15 | 42,59 | 58,43 | 13,42 | 177 | | | |
| ○ | winter | 114,4 | 325,0 | 340,0 | 96,0 | 20,74 | 56,70 | 58,43 | 17,05 | 64 | ! | ? | B.S |
| (fixed) | summer | 116,7 | 250,0 | 290,0 | 71,5 | 14,17 | 33,28 | 39,21 | 9,13 | 54 | ! | ? | B.S |
| | middle | 86,8 | 220,0 | 270,0 | 68,8 | 12,99 | 35,18 | 48,94 | 10,86 | 59 | | | |
| T7 house | All | 56,0 | 160,0 | 370,0 | 54,7 | 8,83 | 28,98 | 64,43 | 9,43 | 231 | | | |
| ◎ | winter | 81,9 | 206,0 | 370,0 | 70,8 | 14,85 | 37,47 | 64,43 | 12,64 | 77 | × | # | B.S |
| (fixed) | summer | 39,4 | 63,0 | 250,0 | 33,6 | 4,77 | 8,51 | 28,57 | 4,03 | 78 | × | # | S |
| | middle | 46,8 | 120,0 | 280,0 | 43,2 | 6,92 | 20,90 | 36,45 | 6,00 | 76 | | | |
| T8 house | All | 35,0 | 79,0 | 110,0 | 20,7 | 5,60 | 13,60 | 19,89 | 3,98 | 221 | | | |
| ○ | winter | 47,6 | 80,0 | 110,0 | 23,5 | 8,66 | 14,31 | 19,89 | 4,24 | 75 | # | # | B.S |
| (fixed) | summer | 22,3 | 30,0 | 70,0 | 8,6 | 2,73 | 4,27 | 8,67 | 1,13 | 69 | × | ! | S |
| | middle | 34,0 | 80,0 | 80,0 | 18,2 | 5,19 | 13,68 | 14,50 | 3,21 | 77 | | | |
| D1 house | All | 62,8 | 130,0 | 230,0 | 35,2 | 10,12 | 22,49 | 44,87 | 7,08 | 620 | | | |
| ○ | winter | 88,4 | 160,0 | 230,0 | 41,0 | 16,29 | 29,91 | 44,87 | 7,83 | 214 | × | ? | S |
| (3-shift) | summer | 39,1 | 60,0 | 140,0 | 15,8 | 4,90 | 8,30 | 19,16 | 2,19 | 209 | × | × | S |
| | middle | 60,0 | 90,0 | 190,0 | 22,5 | 8,97 | 14,25 | 32,37 | 3,81 | 197 | | | |
| D2 house | All | 185,1 | 379,5 | 540,0 | 96,9 | 29,46 | 67,35 | 96,71 | 18,69 | 680 | | | |
| × | winter | 240,3 | 430,0 | 540,0 | 106,9 | 44,20 | 80,03 | 96,71 | 19,89 | 230 | × | ! | B.S |
| (3-shift) | summer | 122,9 | 236,0 | 390,0 | 57,9 | 15,33 | 30,95 | 52,73 | 7,89 | 227 | × | ! | B.S |
| | middle | 191,6 | 330,0 | 460,0 | 79,7 | 28,64 | 52,81 | 81,57 | 12,94 | 223 | | | |
| D3 house | All | 88,8 | 180,0 | 260,0 | 52,6 | 14,02 | 33,13 | 44,37 | 9,76 | 394 | | | |
| ⊙ | winter | 125,2 | 210,0 | 250,0 | 54,4 | 22,96 | 38,18 | 44,37 | 9,84 | 119 | ! | × | B.S |
| (fixed) | summer | 62,9 | 130,0 | 260,0 | 38,3 | 7,89 | 18,05 | 35,37 | 5,26 | 140 | × | × | S |
| | middle | 83,6 | 154,0 | 230,0 | 45,8 | 12,49 | 24,00 | 35,91 | 7,27 | 135 | | | |

Note: The dweller’s attributes of T1 ~T4 house are unknown because these flats had no dwellers at the time of the questionnaire investigation carried out.

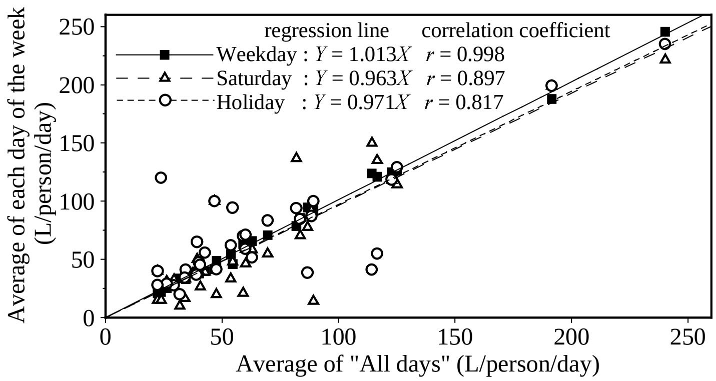
The sign of ● ⊙ ○ ◎ ↑ at the House show the conscious of saving water in Fig.4.

(3-shift) and (fixed) show the working systems.

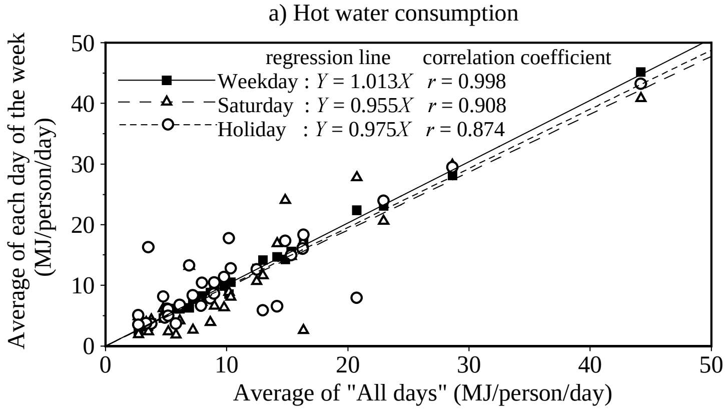
### 7.2 Loads of hot water in each day of the week

We defined the days from Monday to Friday as “Weekday”, Sunday and a national holiday as “Holiday” to analyze the change by the day of the week.

Fig.10 shows the relation of the average loads of hot water per day and the “Weekday”, “Saturday” and “Holiday” mean values in each season. Table 9 shows the values of the hot water consumption and the energy consumption per flat in each season and in each day of the week.




a) Hot water consumption




b) Energy consumption

**Figure 10- Relation of the mean loads of hot water per day and the Weekday, Saturday and Holiday mean values in each season**

According to Fig.10, “Saturday” values and “Holiday” values decrease less than “Weekday” values with the ratio of 0.95 - 0.96 on the hot water consumption, and with the ratio of 0.94 - 0.96 on the energy consumption. Though “Weekday” values are almost on the regression line, “Saturday” and “Holiday” values show large dispersion. Referring to Table 9, the unmarried persons, especially three-shift working persons, use almost the same volume of hot water by the day of the week because their holidays are not fixed. On the other hand, the single persons sometimes do not use hot water in the weekend by going home or staying out. The weekend values are varied by decreasing the number of days of using hot water.

**Table 9- Values of the hot water consumption and the energy consumption per flat in each season and in each day of the week**

a) Hot water consumption per flat (L/person/day)

| Season | Day of the week | T1 house | T2 house | T3 house | T4 house | T5 house | T6 house | T7 house | T8 house | D1 house | D2 house | D3 house |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All seasons | All days | 51.5 | 39.0 | 34.5 | 24.6 | 72.5 | 105.9 | 56.0 | 35.0 | 62.8 | 185.1 | 88.8 |
| | Weekday | 47.7 | 39.2 | 32.6 | 23.4 | 75.4 | 113.6 | 52.5 | 35.5 | 62.5 | 186.1 | 90.2 |
| | Saturday | 45.9 | 31.0 | 34.8 | 26.7 | 31.8 | 110.0 | 91.0 | 16.7 | 65.4 | 178.9 | 79.0 |
| | Holiday | 69.8 | 40.6 | 42.2 | (55.0) | 91.3 | 43.2 | 90.9 | 35.3 | 62.0 | 186.3 | 90.2 |
| winter season | All days | 54.6 | 53.8 | 42.7 | 31.9 | 89.3 | 114.4 | 81.9 | 47.6 | 88.4 | 240.3 | 125.2 |
| | Weekday | 45.9 | 54.4 | 40.0 | 33.7 | 93.2 | 123.9 | 78.7 | 48.7 | 88.0 | 245.5 | 126.0 |
| | Sunday | 48.0 | (33.3) | 39.2 | (10.0) | (14.0) | (150.0) | (136.7) | (20.0) | 92.0 | 221.3 | 114.3 |
| | Holiday | 94.3 | (62.0) | 55.8 | (20.0) | 100.0 | 41.3 | (94.0) | 41.4 | 87.1 | 235.0 | 129.1 |
| summer Season | All days | 40.1 | 29.4 | 26.4 | 22.5 | 59.1 | 116.7 | 39.4 | 22.3 | 39.1 | 122.9 | 62.9 |
| | Weekday | 37.9 | 29.5 | 25.3 | 20.8 | 63.2 | 121.0 | 38.1 | 22.1 | 39.9 | 125.0 | 65.8 |
| | Monday | (40.0) | (32.5) | 31.1 | (40.0) | 21.1 | (135.0) | (50.0) | (15.0) | 38.1 | 118.1 | 58.2 |
| | Holiday | 47.5 | 27.7 | 28.9 | (40.0) | (70.0) | (55.0) | (65.0) | (28.0) | 36.8 | 118.5 | 51.6 |
| middle season | All days | 60.1 | 40.6 | 34.4 | 23.9 | 69.6 | 86.8 | 46.8 | 34.0 | 60.0 | 191.6 | 83.6 |
| | Weekday | 60.2 | 40.3 | 33.0 | 21.8 | 70.8 | 94.6 | 41.4 | 34.8 | 60.0 | 187.8 | 85.6 |
| | Tuesday | 46.3 | (26.7) | 33.3 | (15.0) | 55.0 | (77.5) | (100.0) | (16.7) | 61.7 | 198.8 | 70.6 |
| | Holiday | 71.0 | 45.4 | 41.1 | (120.0) | (83.3) | 38.6 | (100.0) | 34.3 | 59.0 | 199.1 | 84.5 |

b) Energy consumption per flat (MJ/person/day)

| Season | Day of the week | T1 house | T2 house | T3 house | T4 house | T5 house | T6 house | T7 house | T8 house | D1 house | D2 house | D3 house |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All seasons | All days | 8.14 | 5.99 | 5.50 | 3.55 | 11.27 | 16.15 | 8.83 | 5.60 | 10.12 | 29.46 | 14.02 |
| | Weekday | 7.46 | 6.03 | 5.18 | 3.41 | 11.65 | 17.28 | 8.33 | 5.69 | 10.04 | 29.64 | 14.14 |
| | Saturday | 7.37 | 4.87 | 5.59 | 3.53 | 4.59 | 16.96 | 13.62 | 2.44 | 10.79 | 28.35 | 12.35 |
| | Holiday | 11.27 | 6.17 | 6.79 | (7.51) | 15.40 | 6.86 | 14.16 | 5.62 | 9.98 | 29.65 | 14.75 |
| winter season | All days | 10.19 | 9.80 | 7.97 | 5.82 | 16.35 | 20.74 | 14.85 | 8.66 | 16.29 | 44.20 | 22.96 |
| | Weekday | 8.54 | 9.88 | 7.47 | 6.14 | 17.06 | 22.38 | 14.28 | 8.82 | 16.21 | 45.15 | 23.10 |
| | Sunday | 8.85 | (6.33) | 7.22 | (1.84) | (2.57) | (27.76) | (24.01) | (3.89) | 17.05 | 40.83 | 20.60 |
| | Holiday | 17.74 | (11.36) | 10.42 | (3.66) | 18.30 | 7.92 | (17.30) | 7.82 | 16.04 | 43.21 | 23.93 |
| summer Season | All days | 5.12 | 3.79 | 3.36 | 2.72 | 7.23 | 14.17 | 4.77 | 2.73 | 4.90 | 15.33 | 7.89 |
| | Weekday | 4.81 | 3.80 | 3.22 | 2.51 | 7.73 | 14.70 | 4.59 | 2.70 | 4.98 | 15.55 | 8.23 |
| | Monday | (5.19) | (4.30) | 3.90 | (4.86) | 2.61 | (16.88) | (6.16) | (1.86) | 4.81 | 14.77 | 7.26 |
| | Holiday | 6.12 | 3.63 | 3.71 | (5.04) | (8.33) | (6.51) | (8.13) | (3.47) | 4.65 | 14.96 | 6.61 |
| middle season | All days | 8.99 | 6.14 | 5.16 | 3.54 | 10.35 | 12.99 | 6.92 | 5.19 | 8.97 | 28.64 | 12.49 |
| | Weekday | 9.09 | 6.11 | 4.94 | 3.27 | 10.51 | 14.14 | 6.28 | 5.34 | 9.02 | 28.14 | 12.78 |
| | Tuesday | 6.59 | (4.18) | 5.22 | (2.38) | 8.07 | (11.60) | (13.16) | (2.35) | 9.37 | 29.84 | 10.64 |
| | Holiday | 10.44 | 6.73 | 6.04 | (16.28) | (12.77) | 5.85 | (13.26) | 4.97 | 8.61 | 29.47 | 12.61 |

Note: The values that the number of samples are five or less show within ( ) as the reference.

# 8 Conclusion

In this paper, we analyzed the loads of hot water per flat per day in each season and each day of the week at the point of difference of person's attributes and how to use cold and hot water based on the data that were measured and recorded for two years in a company dormitory. The main contents are as follows;

According to the questionnaire investigation, the dwellers were hardly using hot water in the kitchen, and were almost using hot water by bathing and washing face and hands in each house. And the single persons and unmarried persons showed each other the difference in consciousness of saving water and how to use cold and hot water.

The cold water consumption and the hot water consumption showed each other a reverse pattern of seasonal fluctuation. Relating with the results of the questionnaire investigation, the unmarried persons showed more high consumption of the cold and hot water than the single persons. And it was influenced by the bathing style and the number of frequencies of washing face and hands.

We clarified the average cold and hot water consumption in case of summer and winter seasons based on each person's attributes. As for the hot water consumption, we showed the dwellers taking a bath used more volume of hot water than the dwellers taking a shower in both case of summer and winter, and the consciousness of saving water corresponded to the volume of consumption at the "All persons" average.

Next, we clarified the hot water consumption and the energy consumption per flat per day based on the hourly data that were measured from the 11 houses. And we showed that though the hot water consumption in each flat was dispersed by the life style or how to use cold and hot water, the values of hot water consumption classified with the bathing style became near by the values calculated with monthly data. Finally as for the loads of hot water in each day of the week, we showed that the Saturday and Holiday values were about 5% smaller than the Weekday values.

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# GUIDELINES FOR WASTE OF WATER CONTROL IN BUILDINGS

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## Abstract

Results of some Brazilian Rational Water Use Program in buildings have appointed more values of reduction impact of water consumption for the action of detection and correction of leaks. Thus, this paper presents guidelines for waste of water control in buildings, with emphasis for wastes caused by leaks. This action is one of the most important for the reduction and stabilization of water consumption in lower levels.

## Keywords

Leak detection; water loss control; water conservation

## 1 Introduction

Brazil is one of the countries with largest water resources, but spite of that it suffers water scarcity in some regions. This problem occurs in function of several factors such as: physicals, climatic, social, economics, politics and cultural as well as due to the reduction of the quality of surface water resulting from throwing of domestic and industrials effluents, without treatment or insufficient treatment, verified in great urban centers.

Observing this scenery, the Brazilian government is implementing since 1997 the PNCDA – National Program of Combat of Waste of Water with the aims to reduce demand and water consumption, through adequation of users' procedures and the development of technologies that promote rational water use in public and building systems.

Thus, "Programa de Uso Racional da Água – PURA" - Rational Water Use Program – PURA has been implemented in buildings of different typologies in order to reduce the water consumption, besides offering better performance conditions of water use: operation and maintenance. Analysing the impacts of reduction of water consumption resultants from these programs it has been verified that the most important action is the detection and correction of leaks.

According to OLIVEIRA et al. (1999), the impact of reduction of water consumption verified in a building school and hospital after leak correction was 94% and 28,4% respectively and the impact of reduction obtained after substituting conventional components to water savers was 8% and 15,3% respectively. According to TESIS (1998), the impact of reduction reached in an industrial kitchen after leak correction was 12,4% and after water saver components was 12,2%.

Figure 1 shows results of that PURAs, highlighting the reduction impact values of consumption indicator of water obtained after the correction of leaks (CI1) and also the replacement of conventional components for water savers (CI2), related to the consumption indicator in the background history (ICh).

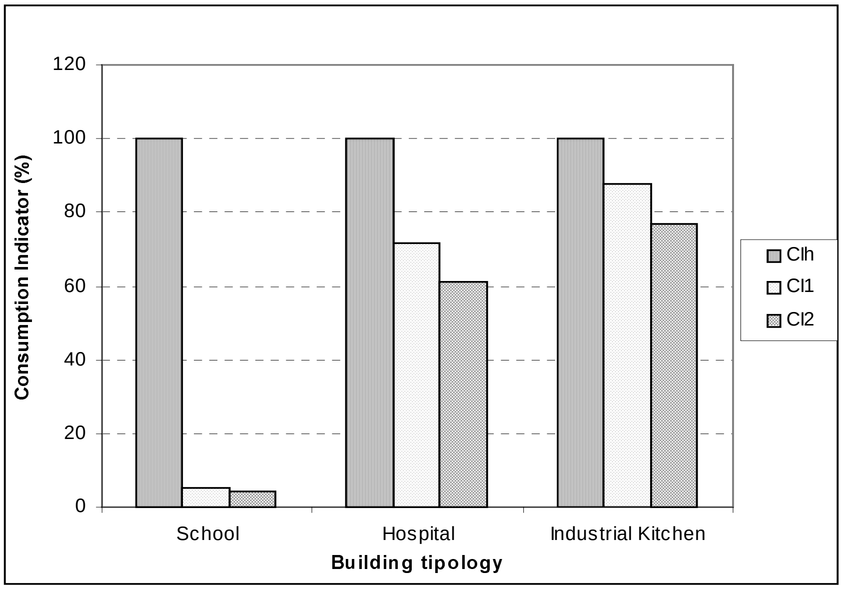


**Figure 1 – Reduction impact of water consumption in three building typologies after the correction of leaks and substitution of conventional components for water savers.**

## 2 Rational water use and waste of water

Rational water use in buildings is the optimization of its use considering two operational actions in the system:

- act – action that promotes the reduction of water consumption;
- control – action that helps the stabilization of water consumption at minimum levels reached.

### 2.1 Water consumption

In general, the wastes of water in buildings are due to: leaks in pipes; storage tanks and components of use; inadequate concepts of water supply systems and neglecting of users. These factors tend to increase the volumes of water used and wasted in the system. The concept of consumption considers the quantity of water used to attend the necessity of users, including the wastes in the system, according to equation 1:

$$\text{Consumption} = \text{used water} + \text{wasted water} \quad (1)$$

Thus, the values of daily water consumption indicator, obtained in systems of different typologies, include the volume of water used in activities and the volume of water wasted, both excessive use or water loss.

### 2.2 Waste of water

Waste of water is that water that has being disposable in a water supply building system and it is lost before using for an activity or, when it is used in an excessive way. The concept of waste of water is presented in equation 2:

$$\text{Waste} = \text{loss} + \text{excessive use} \quad (2)$$

Water loss is the water that escapes from the system before being used to a final activity. In general, the water losses occur due to the follow factors:

- leak – flow out of water from a water supply system, from pipes and fixtures, components of use, storage tanks and pumps and others equipment;
- bad performance of the system – an example is a recycling system of hot water operating as an inadequate manner, it means, with a long time of hope and therefore, producing water loss before being used by user;
- neglecting of user – exemplified by a faucet not closed correctly after its using.

Excessive use is understood as an utilization of water to a final activity in a wasteful manner, it means, in an inadequate procedure or by a bad performance of the system. Some examples of excessive use:

- inadequate procedures – long time bath, washing of sidewalk with a hose instead using a broom;
- bad performance of the system – a system which outlets are designed to flowrate higher than it necessaries to develop the activities related to the use of water, such as faucets with high flowrate, that besides waste of water, causes discomfort to the users with splashing of water.

### 2.3 Leaks in water supply systems of buildings

In a brazilian systems it is considered that the higher incidence of leaks in these systems are in the outlets, but it can be observed that the water losses can be higher if leaks occur in water supply pipe, in general, required by high values of hydraulic pressure from water supply public system. We can highlights two groups of leaks: the visible and the non-visible, according as following.

2.3.1 Visible leaks and non-visible leaks

Visible leaks are those that manifest by direct way, it means, through flow or dripping of water and, therefore, are rapidly detected by users. They occur mainly in outlets. Non-visible leaks are those manifest by indirect manner, in general, by means of the following manners:

- humidity spots;
- sound of water flowing when none of outlet is open;
- appearance of vegetation between tiles in external floor areas;
- continuous inflow of water in storage tanks.

## 3 Guidelines for waste of water control in buildings

The waste of water in building can reach the minimum levels through the following manners of actuation in the system: detection and correction of leaks; install of water savers components; pressure water control and adequacy of procedures related to the water use.

According to OLIVEIRA et al. (1999), leak correction is one of most effective actions to reduce water consumption in the system. The implementation of this action before substituting conventional components for water savers is very important because it is the way of avoiding false results in the reduction of consumption resulting of the saver components. Furthermore the permanent water loss control in the system tends to bring it closer to its full performance condition.

Installing water saver component, such as a metering or electronic faucet, it helps the user at the same time to:

- reducing the water consumption in function of the shorter turning off time of the faucet;
- avoiding the waste of water, through the automatic turning off, because it is common improper closing of conventional faucets.

It is important to stress that these components require an efficient maintenance service, because they are calibrated to a flowrate of use nearly 0,15 ℓ/s. Thus, a “running” faucet, it means, with a problem of closing can waste 12960 ℓ/day, if the problem is not rapidly detected rapidly.

About the adequacy of procedures related to the water use, it has been known that it is also of great value to the reduction of water consumption. But, the users must be aware to the problem of scarcity of water in order to achieve that goal, according to MURAKAWA et al. (1992), in a research developed at Fukuoka City, in Japan.

### 3.1 Pressure control

The knowledge of this parameter is very important, because the flowrate in outlets and leaks are influenced by it. The hydraulic pressure can contribute to the increasing waste of water through more frequency of bursts of pipes.

Although the brazilian water supply building systems, in general, are required for small pressure values, it is highlighted that the water supply pipes are always required by high pressure values, mainly during the night, because they are connected to the street mains. Thus, the pressure reduction in these systems as in distribution system of high rise buildings, is an important contribution to the reduction of waste of water.

According to the Brazilian Standard NBR 5626/98, the water supply building system must be dimensioned for maximum static pressure of 400 KPa and minimum dynamic pressure of 5 KPa, whereas in outlets this value is 10 KPa, with exception of the outlet of WC cistern that can achieve the minimum of 5 KPa and the outlet of WC flush valve that can not be above to 15 KPa. Although these recommendations, a lot of water supply systems are required by pressure values upper, contributing for water loss through of bursts in pipes and flexible hose of WC cisterns and lavatories’ faucets.

Thus, the pressure control is recommended in the water supply building systems, for example in the water supply pipe and outlets with high values of pressure. This work can be executed through the connection of a pressure gauge or a data logger in outlets.

### 3.2 Detection and correction of leaks

Detection of leaks is considered as the process to verify and locate leaks in water supply systems. There are several factors that influence the occurrence and detection of leaks in water supply systems, such as: hydraulic pressure, conditions of pipe, materials, components and execution process, maintenance, age of system and type of soil.

3.2.1 Beginning of leaks

The beginning of leaks in the water supply building systems is the increase of values of consumption indicator of water according to equation 3.

$$IC = \frac{Cm}{AC \cdot ND} \times 1000 \qquad (3)$$

where:

IC = consumption indicator - ℓ/person/day, ℓ/student/day, etc.;
Cm = monthly consumption of water, $m^3$.
AC = total of consumer agents – persons, students, etc.;
ND = total of days relative to the month of the water consumption.

When the evaluation of consumption indicator of background history period shows the increase of water consumption, proceed as following:

- verify from what month there was an increase of water consumption and work together with the users making an evaluation of retroactive facts, that can justify that increasing, such as:
  - burst of some water pipe;
  - leak in some equipment or component of use;
  - drain of storage tank for cleanliness;
  - beginning of operation of an equipment or a new activity in the system;
  - changing of procedures in some activity related to the water use;
  - remodeling, enlarge, painting services and others.

If did not occur any event that justify an increase of water consumption indicator, probably there is a leak in the system. In some cases leak occurs in so high proportions that is not possible get a background history, because they are detected as soon as they rise.

3.2.2 Detection of visible leaks

The visible leaks, in general, occur in pipes, valves, tanks and components of use.

a1. Leak detection in faucets

The water loss in these components ranges in function of the leak such as: dripping, small continuous flow, type of tip of faucet, roughness of its walls and also of their hydraulic pressure. Thus, one faucet will can lose more water at night than during the day, due to the possibility of higher values of hydraulic pressure of the water supply system in that period.

a2. Leak detection in valves

One way to detect leaks in valves is through observing the existence of yellow spots on surface of walls, mainly in walls covered with tiles of light colors.

According to the Brazilian Standard NBR 5626/98, the leaks in these fixtures can be accepted until the value near 0,01 mℓ/s.

a3. Leak detection in water closets

Usually, leaks in water closets are non-visible, but when the water loss is high they become easily visible through the flow of water on the internal wall bowl or the formation of small waves on the surface inlet water. This leak can occur in WC cisterns and in WC flush valve. Another local of visible leak is in flexible hose of WC cistern, always, due to the high pressure values or inadequate sealing.

a4. Leak detection in storage tanks

The visible leaks in tanks can occur due to:

- damage float operated ball valve – water is loss through the overflow pipe;
- damage fixtures – the inlet and outlet fixtures of storage tanks can be damaged or not be adjusted causing leaks on surface of walls and bottom of storage tanks.
- valves not completely closed – in general, gate valves are installed in net work pipe of storage tanks and they can be with sealing problem, possibiliting the water flow, for example, in drain pipe, which can permit the flow through the rainwater drainage systems, postponing the leak detection.

3.2.3 Non-visible leak detection

The non-visible leak detection can be conducted by simple tests, which consist in simple procedures at the interest points of the system or by special tests with acoustics equipment. The special tests are conducted when is not possible to detect a leak with simple test or to check a process of detection. An example is a detection of leak at water supply pipe that, in general, through special tests it is located.

3.2.3.1 Simple tests

These tests are used in leak detection of water supply pipe, storage tanks and water closets, following this manner:

- Leak detection in water supply pipe
    - water meter test;
    - suction test.
- Leak detection in storage tanks
    - test for leak detection in underground tanks;
    - test for leak detection in roof tank.
- Leak detection in water closets
    - dye test.

The procedures to realize these tests are presented by OLIVEIRA (1999).

3.2.3.2 Special tests

The most difficulty of the leak detection in underground pipes is, many times, because leaks are manifested in different local that is supposed to. For these cases some processes of non-visible leak detection are presented with the utilization of the following acoustics equipment: listening stick, electronics geophone and leak noise correlator. In these processes the work is executed without destruction of the floors or walls covers. That is their advantages.

It is important to stress that in order to the leak detection be well succeed the value of water pressure in net work of pipe must be upper to 120 KPa. Therefore, in some cases it is better conduct this work during the night, when, in general, we can find pressure values upper and less background noise.

a. Listening stick process

Listening stick is the instrument more simple used in leak detection. Nevertheless, so as to this work can be well succeed, the operator must be very prepared to distinguish the sound of a leak and background noise. This instrument consists of a metal stick of 1500 mm with an acoustics amplifier at one of its tip, that identifies the occurrence of the leak near the researched points, according shows figure 2.

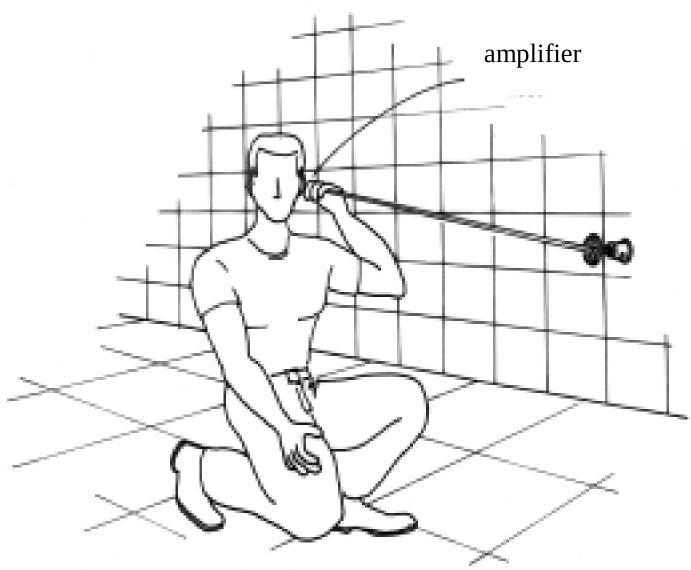


**Figure 2 – Leak detection with listening stick.**

The listening stick is utilized in valves, water meters, hydrants or whatever link point to the underground water pipes or in the walls. The procedures to conduct the leak detection using the listening stick are presented by OLIVEIRA (1999).

b. Electronic geophone process

This process uses the electronics geophone that detects and amplifies the sound of a leak but removes some of unwanted extraneous noise by the frequency filters. There are two types of geophone: one for small values of flowrate of water loss, which is utilized to detect leak on vertical surfaces; and other to higher water loss flowrate, utilized on horizontal surfaces, according shows figure 3.

This process utilizes the electronic geophone that is capable of detecting the leak noise through of a sensor placed the nearest of a underground pipe, amplifying and filtering it, eliminating the range of frequencies not related with the installation.

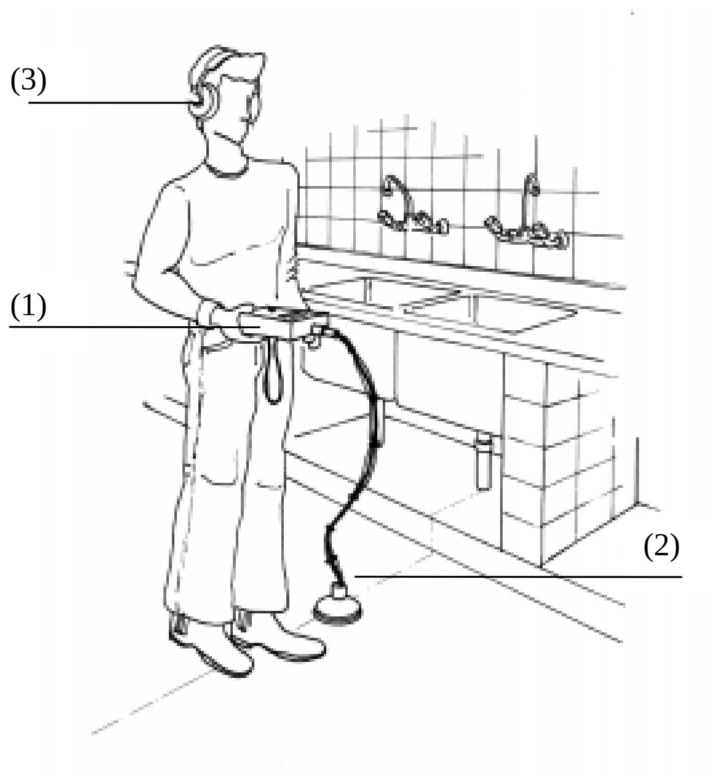


**Figure 3 – Leak detection on floor with electronic geophone.**

The components of this equipment are:

(1) amplifier with six filters, being three of low frequency (100 Hz a 400 Hz) and three of high frequency (600 Hz a 1200 Hz), through to that combination gives nine range of frequency;

(2) sensor of high sensibility which is connected to the amplifier;

(3) phones to listen the leak noise, also connected to the amplifier.

The beginning of leak detection occurs after the location of the underground network of pipe. The procedures for leak detection with this equipment are presented by OLIVEIRA (1999).

c. Leak noise correlator process

This process consists in locate the leak point through using an equipment called leak noise correlator, which is presented in figure 4. It is compounded of two acoustics sensors, being that each one of them has one amplifier (radio transmitter). These sensors detect the noises on the pipe and transmit them to the correlator, which processes the signals of the noises and determines the leak position in relation to the two sensors, showing the distances at the screen of the correlator.

The sensors are connected directly at the pipe or they are installed in points such as valves, hydrants or in position that can be imagined leak stays between two sensors. The operator gives to the correlator the follows information of the length of pipe researched: distance between two sensors, diameter and material of pipe.

In the beginning of the operation great range of sounds is detected, it means, noises of leaks, noises of turbulences and noises of flowing that feed another sources. All of these noises are transmitted, via radio, from amplifiers to the correlator.

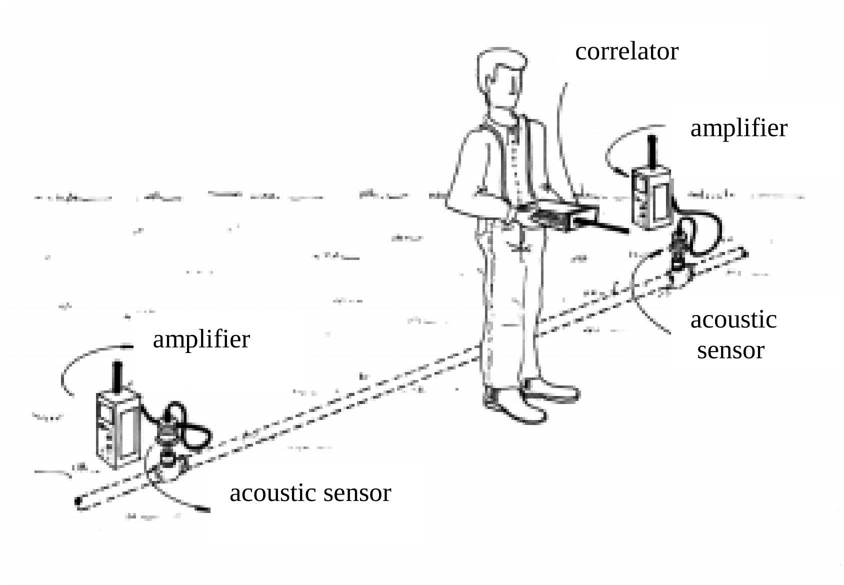


**Figure 4 – Leak detection with leak noise correlator.**

The correlator analises the signals received and identifies what of them is common to both sensors, that, in general, corresponds to a noise of leak. From one sensor, used as reference, the correlator measures the time that the same noise takes to reach the second sensor. This time is called delay time – Td. This delay is directly related to the difference between a noise source – leak, and the two sensors, according to figure 5.

Such determination is obtained to any length of pipe, material and diameter. Thus, when the leak noise reaches sensor 2, it will have also reached point C and, therefore, run to go through the same distance “L”. Then, when the leak noise reaches sensor 2, the correlator measures the time that the same noise takes to reach the sensor 1 (Td), it means, to run to go through the distance “R”.

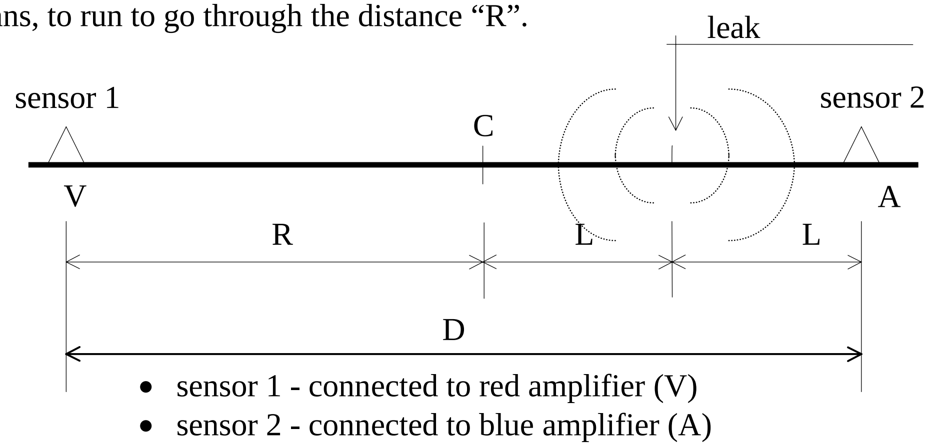


**Figure 5 - Determination of leak point in a length of pipe. FUJI TECOM (s.d.).**

Knowing the distance “D” and the sound velocity “V” in pipe between two sensors, the position of leak can be determined by measuring the difference in time taken for the noise to reach the two sensors. The velocity of sound ranges in function of several factors, but particularly with the material and diameter of the pipe. The leak noise correlator has in its memory the velocity to more commons materials and diameter of pipes. From figure 5 the distance “L” can be determined as following:

$$D = R + L + L \quad (4)$$
$$L = (D - R)/2 \quad (5)$$
$$R = V \cdot Td \quad (6)$$

Substituting (5) in (4), we have:

$$L = [D - (V \cdot Td)]/2 \quad (7)$$

where:

L = distance of leak to the nearest sensor, m;
D = distance between the two sensors, m;
V = velocity of sound to respective material and diameter, m/ms;
Td = delay time, ms;
R = distance reached by leak noise during the delay time, it means, after reaches the sensor 2, m.

The screen of the correlator shows the reference from what the delay time is measured – blue amplifier (A) or red amplifier (V). It also gives a graphics with the indication of the leak peak. The procedures to conduct tests with the utilization of leak noise correlator are presented by OLIVEIRA (1999).

## 5. Final considerations

The guidelines presented for waste of water control in buildings promote a reduction of water consumption in minimum levels.

About equipment used in special tests, we consider that the electronic geophone and the listening stick are more indicated to any water supply system of buildings: small, medium and large. About the leak noise correlator, it is more indicated to high horizontal systems, in function of a large number of access points such as valves, hydrants and long lengths of water supply pipe.

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# Examination on the effective way of water use in the area by the use of land use map of present condition

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## Abstract

In this paper, the author have developed the method to compute site area and building area classified into building type by the image processing of land use map of present condition those have scanned in a computer. Moreover, water consumption and water conservation rates have quantitatively computed in the objective area and examined effective way of water use in the area.

## Keywords

water conservation; image processing; reclaimed water; storm water; simulation

## 1 Introduction

In Japan, a lot of wastewater recycling system and storm water treatment system has installed in buildings or areas. From up to the present, installation of these facilities has promoted in Tokyo and Fukuoka City. But in recent days, they are installed in various parts of the country and small buildings such as residences and apartment houses. Based on such backgrounds, this paper aims to get water consumption in the objective area to compute area measurement classified into building type by image processing of land use map of present condition. These data would be basic data about future trends of water demand and supply in the area and to examine the effective way of water use.

## 2. Summary of analysis

### 2.1 Selection of the objective area

To compute the possibility of reclaimed and storm water supply, 3 areas are selected in Itabashi Ward of Tokyo Metropolitan because land use maps of present condition have been published in October 1996. Each area has 1 $km^2$ and named Area A, Area B and Area C. Land use maps of present condition classified into site and building type or building story of each area are following (Figure 1).

**Classified into site and building type** | **Classified into building story**


**Area A (many lowrise residences and apartent houses)**


**Area B (many highrise apartment houses)**

**Figure 1 - Land use map of present condition (Area A and Area B)**


**Figure 1 - Land use map of present condition (Area C, from previous page)**

## 2.2 Flowchart of analysis

Flowchart of analysis indicates figure 2. In the first place, building area and total floor area are computed on each building type by image processing from land use map of present condition. Next, water consumption, possibility of reclaimed water demand, possibility of recyclable water supply, possibility of storm water supply, city water consumption in case using reclaimed water and water conservation rates are computed in the objective area from estimated water consumption unit and water consumption rate for each specific use.

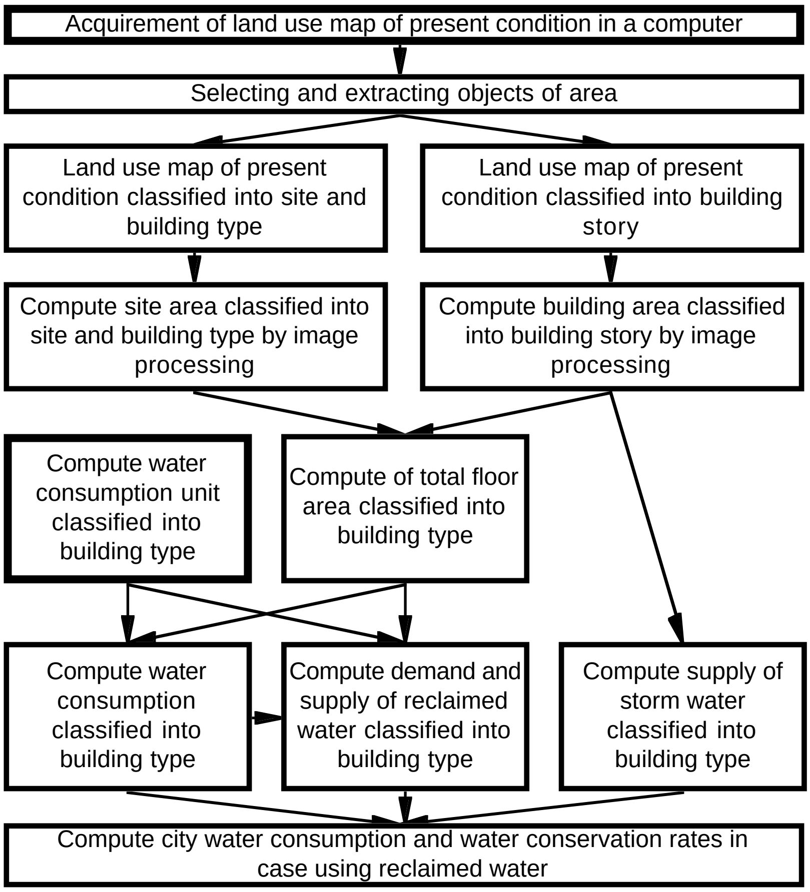


**Figure 2 - Flowchart of analysis**

# 3 Compute area and water consumption for each building type

## 3.1 Compute of area for each building type

Process for computing area indicates Figure 3. To compute site area, building area and total floor area in the objective area, present state maps of land using are changed digital data and acquired in a computer by a scanner. These maps have too many colors to discriminate from each building type or story by image processing. Therefore in the first place, color is reduced to discriminate from them. From the image at land use map of present condition classified into site and building type, site area can be computed for each building type. Further, building area and story can be computed for each building type by same process. Last, total floor area for each building type can be computed to multiply building area by average of building story.

## 3.2 Compute of water consumption for each building type

On Reference 1, it lists water consumption unit and water consumption rates for each specific use for each building type excluded housing and factory sites. These data is used the land use map of present condition of land using classified into site and building type.

And water consumption unit (Table 1), rates of reclaimed water demand in whole water consumption (Table 2) and rates of recyclable water supply in whole water consumption (Table 3) are computed according to the flowchart of water use for specific use (Figure 4).

In the housing site, average water consumption unit is computed as occupancy area 25 m$^2$/person from the results of measurement and estimate on Reference 2. Water consumption rates for each specific use is adopted data of Reference 2 intact (Table 5).

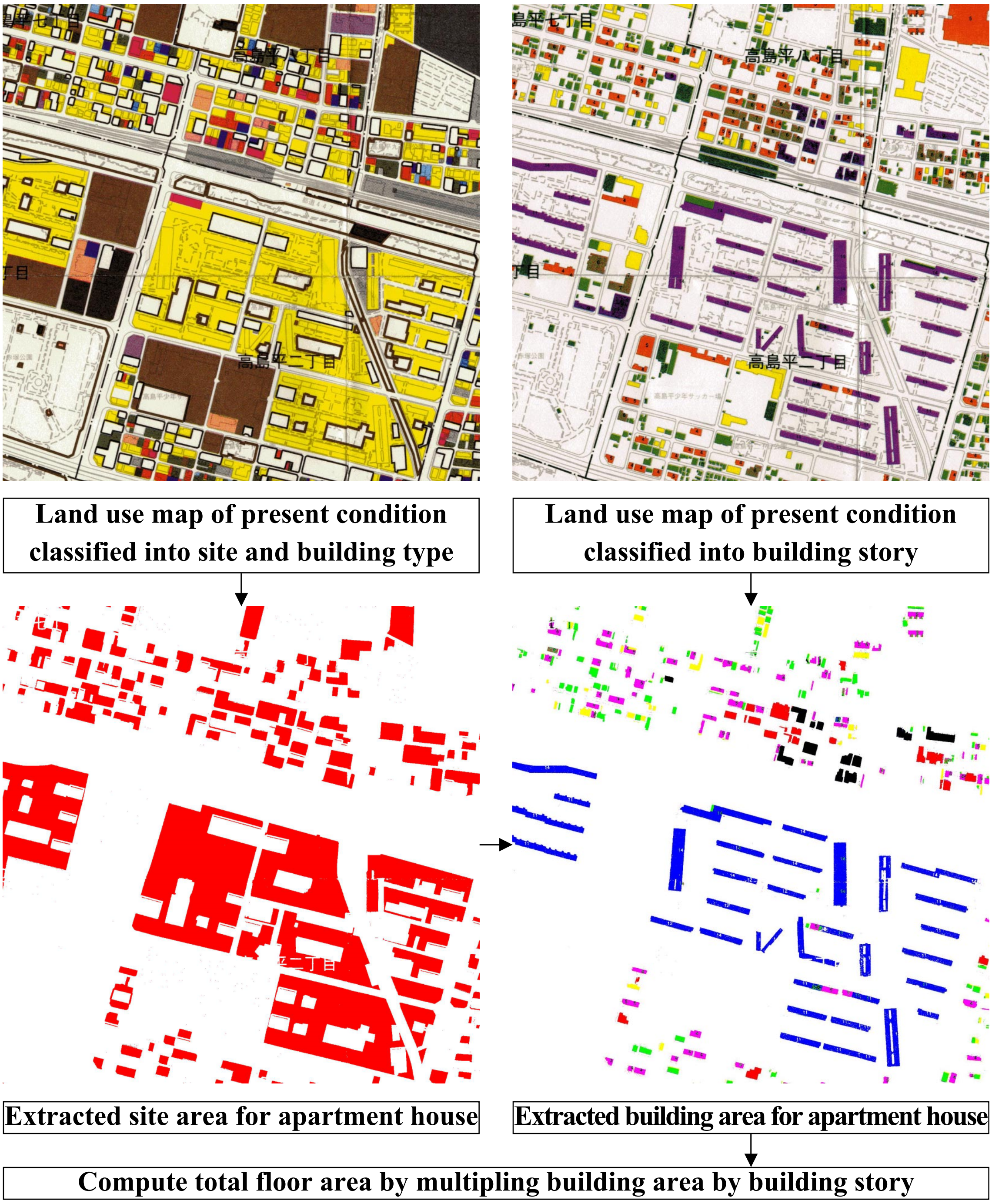


**Figure 3 - Process to compute area (Area B and apartment house)**

**Table 1 - Average water consumption unit of building in the public and commercial site**

| Site | Building type | Average water consumption unit [l /m²day] | Compute from Reference 1) [l/m²day] |
|---|---|---|---|
| Public Site | Education | 10.70 | Average of Elementary school : 13.7, Junior High School : 11.6 and High School : 6.8 |
| | Welfare | 26.35 | Average of Hospital : 27.2 and Clinic : 25.5 |
| | Others | 8.65 | Public and Supply institution : based on Office |
| Commercial Site | Office | 8.65 | Average of Large scale building : 8.8 , Small and medium scale building : 8.5 |
| | Department Store | 21.70 | Department Store : 21.7 |
| | Hotel | 25.55 | Average of Hotel : 21.1 and Inn : 30.0 |
| | Leisure | 20.75 | Average of Theater : 23.0 and Movie house : 18.5 |
| | Shop | 13.59 | 30% of Department : 21.7 and 70% of House: 10.12 (from Table 2) |

**Table 2 - Rates of reclaimed water demand from whole water consumption of building in the public and commercial site**

| Site | Building type | Rates of reclaimed water demand from whole water consumption [%] | Compute from Reference 1) (Rates of flushing water from whole water consumption) [%] |
|---|---|---|---|
| Public Site | Education | 62.3 | Average of Elementary school : 58, Junior High School : 63 and High School : 66 |
| | Welfare | 35.0 | Average of Hospital : 36 and Clinic : 34 |
| | Others | 35.5 | Public and Supply institution : based on Office |
| Commercial Site | Office | 35.5 | Average of Large scale building : 33 , Small scale building : 38 |
| | Department Store | 41.0 | Department Store : 41 |
| | Hotel | 23.0 | Hotel : 23 |
| | Leisure | 52.0 | Average of Theater : 37 and Movie house : 67 |
| | Shop | 26.3 | 30% of Department : 41 and 70% of House: 20 (from Table 2) |

**Table 3 - Rates of recyclable water supply from whole water consumption of building in the public and commercial site**

| Site | Building type | Rates of recyclable water supply from whole water consumption [%] | Compute from Reference 1) (Rates of kitchen and washbasin water from whole water consumption) [%] |
|---|---|---|---|
| Public Site | Education | 25.7 | Average of Elementary school : 38, Junior High School : 33 and High School : 28 (add pool water) |
| | Welfare | 19.5 | Average of Hospital : 14 and Clinic : 25 |
| | Others | 33.0 | Public and Supply institution : based on Office |
| Commercial Site | Office | 33.0 | Average of Large scale building : 37 , Small scale building : 29 |
| | Department Store | 51.0 | Department Store : 51 |
| | Hotel | 66.0 | Hotel : 66 (add bath and laundry water) |
| | Leisure | 31.0 | Average of Theater : 46 and Movie house : 16 |
| | Shop | 71.3 | 30% of Department : 51 and 70% of House: 80 (from Table 2) |

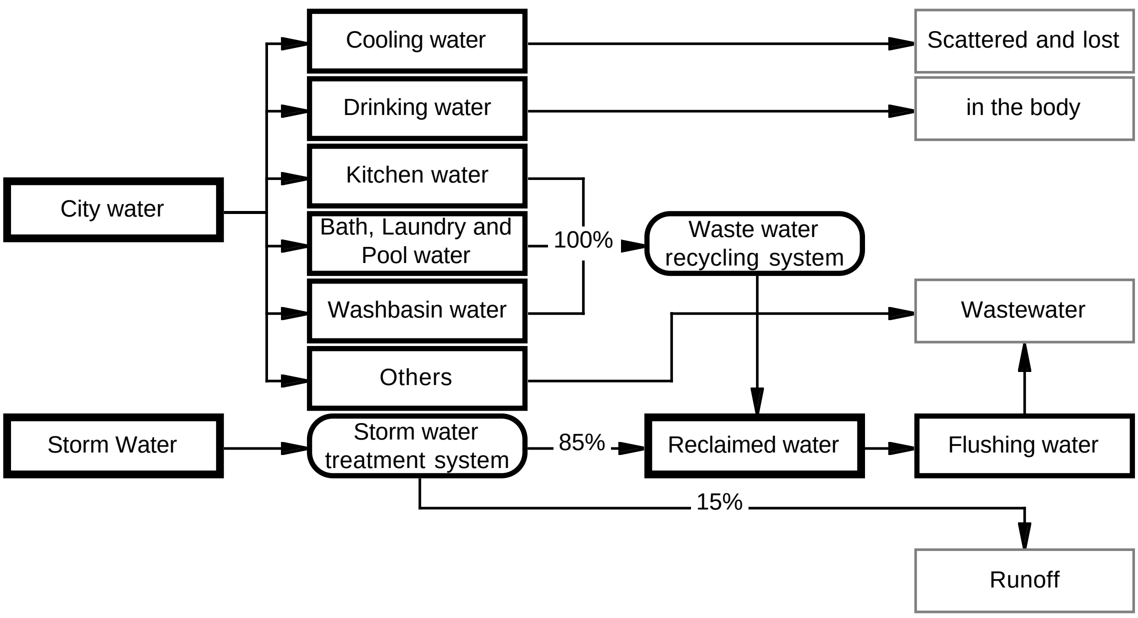


**Figure 4 - Flowchart of water use for specific use**

**Table 4 - Average water consumption unit and water consumption rates for each specific use of building in the housing site**

| Water use | Water consumption [l /person day] | Rates |
|---|---|---|
| Bath | 85.3 | 34% |
| Kitchen | 49.0 | 19% |
| Laundry | 60.0 | 24% |
| Washbasin | 7.9 | 3% |
| WC | 50.7 | 20% |
| Total | 252.9 | |

Compute as occupancy area : 25 [$m^2$/person] (common Residence and Apartment House)
252.9 [l /person day] / 25 [$m^2$/person] = 10.12 [l /$m^2$ day]

**Table 5 - Rates of office floor area in total floor area in the industrial site**

| Factory | Total floor area [$m^2$] | Office floor area [$m^2$] | Rate of office floor area from total floor area |
|---|---|---|---|
| A | 19,390 | 13,340 | 68.8% |
| B | 1,920 | 150 | 7.8% |
| C | 5,046 | 2,620 | 51.9% |
| D | 14,279 | 2,712 | 19.0% |
| E | 10,135 | 570 | 5.6% |
| F | 19,570 | 540 | 2.8% |
| G | 8,200 | 1,700 | 20.7% |
| H | 5,050 | 540 | 10.7% |
| I | 3,100 | 800 | 25.8% |
| J | 10,516 | 1,504 | 14.3% |
| K | 3,413 | 410 | 12.0% |
| L | 1,597 | 438 | 27.4% |
| M | 4,484 | 1,594 | 35.5% |
| N | 2,353 | 267 | 11.3% |
| O | 14,385 | 2,673 | 18.6% |
| P | 3,275 | 1,202 | 36.7% |
| Q | 1,320 | 255 | 19.3% |
| R | 32,800 | 750 | 2.3% |
| S | 21,972 | 725 | 3.3% |
| T | 31,370 | 571 | 1.8% |
| U | 9,989 | 780 | 7.8% |
| V | 4,280 | 522 | 12.2% |
| W | 14,369 | 334 | 2.3% |
| X | 18,173 | 1,900 | 10.5% |
| Y | 13,362 | 904 | 6.8% |
| Z | 4,772 | 495 | 10.4% |
| AA | 8,100 | 750 | 9.3% |
| Total | 287,220 | 39,046 | 13.59% |

In the industrial site, 27 buildings is extracted from 592 buildings that appear about plumbing system on Reference 3 and rates of office floor area from total floor area (13.59%). From this numerical value, office floor area is computed as compared with total floor area and then the numerical value at office on Table 1,2,3 are applied as using city water at office area only in the industrial site.

## 4 Computed results of area and water consumption

### 4.1 Characteristics of land use in each area

Site area, building area and total floor area has computed on the process of Section 3.1. On a computer, images have 1,572*1,572 pixels, and actual area is 998*998 m that is approximately equal to 996,000 $m^2$. Consequently area per pixel have 0.403 $m^2$. Area A is housing area that has residences mainly, accordingly the building coverage ratio is high and the floor area ratio is low. Area B is housing area that has high-rise apartment houses mainly, accordingly the building coverage ratio is low and the floor area ratio is high. Area C has both commercial and housing area, accordingly both the building coverage ratio and the floor area ratio are high. In the next section it considers how these tendencies affect water consumption in areas.

### 4.2 Characteristics of water use at each area

Computed results indicate on Table 6. Rates of reclaimed water demand in whole water consumption is higher in Area C then Area that has a lot of office and department store where is high rate of flushing water in whole water consumption. It indicates that reclaimed water is of utility value where urbanization is proceeding. The other way, rates of recyclable water supply in whole water consumption is higher in Area A than Area C. The reason of it is that rates of residences and apartment houses in whole land use.

Possibility of storm water supply is lower in Area B than Area A because the building coverage ratio is lower in Area B than Area A. Storm water utilization is more effective in housing site of low-rise building.

In case that wastewater recycling system and storm water treatment system are applied at all buildings in area, city water conservation rates are highest in Area C (25.8%) that have much reclaimed water demand. In Area A, city water conservation rates are 22.8% and in Area B, city water conservation rates are 22.9%. Those results are estimated individual system in each building. But it is more effective that reclaimed water which is supplied from residences and apartment houses because possibility of recyclable and storm water supply is more little than reclaimed water demand at education, welfare and leisure. At an office building, the installation of storm water treatment system is desirable with the installation of wastewater recycling system because reclaimed water is insufficient only wastewater.

# Table 6 - Computed results of water consumption and water conservation (Area A and Area B)

| | | A | B | C | D | E=C*(Average water consumption unit)* $10^{-3}$ | F=E*(Rates of flushing water usage) | G=E*(Rates of recyclable water supply) | H=B*(Normal amount of precipitation)*(Runoff coefficient)* $10^{-3}/365$ | I=E-F [F<G+H] or I=E-(G+H) [F>=G+H] | J=(G+H)/F * 100 | K=(1-I/E) * 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

Area A

| Site | Building type | Site area [$m^2$] | Building area [$m^2$] | Total floor area [$m^2$] | Rates of each building floor area from all building floor area | Average water Consumption [$m^3$/day] | Reclaimed water demand [$m^3$/day] | Possibility of recyclable water supply [$m^3$/day] | Possibility of storm water supply*4) [$m^3$/day] | City water consumption in case using reclaimed water [$m^3$]*3) | Rates of possibility reclaimed water supply | Water conservation rates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Public Site | Education | 42,549 | 14,647 | 32,001 | 5.2% | 342.41 | 213.32 | 87.88 | 47.94 | 206.59 | 63.7% | 39.7% |
| | Welfare | 3,426 | 1,898 | 4,384 | 0.7% | 115.52 | 40.43 | 22.53 | 6.21 | 86.78 | 71.1% | 24.9% |
| | Others | 4,891 | 2,263 | 5,962 | 1.0% | 51.57 | 18.31 | 17.02 | 7.41 | 33.26 | 133.4% | 35.5% |
| Commercial Site | Office | 6,351 | 3,180 | 8,247 | 1.3% | 71.34 | 25.33 | 23.54 | 10.41 | 46.01 | 134.0% | 35.5% |
| | Department Store | 5,313 | 2,224 | 5,586 | 0.9% | 121.22 | 49.70 | 61.82 | 7.28 | 71.52 | 139.0% | 41.0% |
| | Hotel | 0 | 0 | 0 | 0.0% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0% | 0.0% |
| | Leisure | 7,215 | 1,887 | 4,851 | 0.8% | 100.66 | 52.34 | 31.20 | 6.17 | 63.28 | 71.4% | 37.1% |
| | Shop | 44,807 | 25,593 | 55,482 | 9.0% | 754.01 | 198.30 | 537.61 | 83.76 | 555.70 | 313.3% | 26.3% |
| Housing Site | Residence | 292,096 | 130,899 | 259,592 | 42.2% | 2,626.03 | 525.21 | 2,100.83 | 428.38 | 2,100.83 | 481.6% | 20.0% |
| | Apartment House | 160,441 | 85,733 | 235,524 | 38.3% | 2,382.56 | 476.51 | 1,906.05 | 280.57 | 1,906.05 | 458.9% | 20.0% |
| Industrial Site | Factory*1) | 28,776 | 15,047 | 3,822 | 0.6% | 33.06 | 11.74 | 10.91 | 49.24 | 21.33 | 512.5% | 35.5% |
| Total | | 595,864 | 283,370 | 615,452 | | 6,598.38 | 1,611.19 | 4,799.39 | 927.36 | 5,091.35 | 355.4% | 22.8% |
| Rate*2) | | 59.8% | 28.5% | 61.8% | | | 24.4% | 72.7% | 14.1% | 77.2% | | |

Area B

| Site | Building type | Site area [$m^2$] | Building area [$m^2$] | Total floor area [$m^2$] | Rates of each building floor area from all building floor area | Average water Consumption [$m^3$/day] | Reclaimed water demand [$m^3$/day] | Possibility of recyclable water supply [$m^3$/day] | Possibility of storm water supply*4) [$m^3$/day] | City water consumption in case using reclaimed water [$m^3$]*3) | Rates of possibility reclaimed water supply | Water conservation rates |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Public Site | Education | 89,888 | 21,047 | 60,664 | 6.3% | 649.10 | 404.39 | 166.60 | 68.88 | 413.62 | 58.2% | 36.3% |
| | Welfare | 9,836 | 5,268 | 19,800 | 2.1% | 521.72 | 182.60 | 101.74 | 17.24 | 402.75 | 65.2% | 22.8% |
| | Others | 50,146 | 19,636 | 59,994 | 6.2% | 518.95 | 184.23 | 171.25 | 64.26 | 334.72 | 127.8% | 35.5% |
| Commercial Site | Office | 5,613 | 2,452 | 6,511 | 0.7% | 56.32 | 19.99 | 18.58 | 8.02 | 36.32 | 133.1% | 35.5% |
| | Department Store | 5,256 | 3,209 | 6,677 | 0.7% | 144.89 | 59.40 | 73.89 | 10.50 | 85.48 | 142.1% | 41.0% |
| | Hotel | 0 | 0 | 0 | 0.0% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0% | 0.0% |
| | Leisure | 5,177 | 3,467 | 8,555 | 0.9% | 177.52 | 92.31 | 55.03 | 11.35 | 111.14 | 71.9% | 37.4% |
| | Shop | 14,279 | 8,188 | 24,714 | 2.6% | 335.86 | 88.33 | 239.47 | 26.80 | 247.53 | 301.4% | 26.3% |
| Housing Site | Residence | 0 | 0 | 0 | 0.0% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0% | 0.0% |
| | Apartment House | 253,332 | 86,656 | 775,627 | 80.5% | 7,846.25 | 1,569.25 | 6,277.00 | 283.59 | 6,277.00 | 418.1% | 20.0% |
| Industrial Site | Factory*1) | 2,664 | 1,501 | 374 | 0.0% | 3.24 | 1.15 | 1.07 | 4.91 | 2.09 | 520.4% | 35.5% |
| Total | | 436,192 | 151,425 | 962,915 | | 10,253.83 | 2,601.65 | 7,104.63 | 495.55 | 7,910.65 | 292.1% | 22.9% |
| Rate*2) | | 43.8% | 15.2% | 96.7% | | | 25.4% | 69.3% | 4.8% | 77.1% | | |

*1) In a factory, total floor area and water consumption are computed only office area.
*2) About "Area", Rates are ratio in total area : 996,000[$m^2$], about "water consumption", Rates are ratio in whole water consumption in the area
*3) "Total" is in case of individual reclaimed system. In case of using area reclaimed system, water consumption is a little reduced.
*4) "Normal amount of precipitation" is used 1,405.3[mm] in Tokyo, and "Runoff coefficient" is used 0.85.

## Table 7 - Computed results of water consumption (Area C, from previous page)

| Area C | | A | B | C | D | E=C* (Average water consumption unit)* $10^{-3}$ | F=E* (Rates of flushing water usage) | G=E* (Rates of recyclable water supply) | H=B* (Normal amount of precipitation)* (Runoff coefficient)* $10^{-3}$/365 | I=E-F [F<G+H] or I=E-(G+H) [F>=G+H] | J=(G+H)/F * 100 | K=(1-I/E) * 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Building type | Site area [$m^2$] | Building area [$m^2$] | Total floor area [$m^2$] | Rates of each building floor area from all building floor area | Average water Consumption [$m^3$/day] | Reclaimed water demand [$m^3$/day] | Possibility of recyclable water supply [$m^3$/day] | Possibility of storm water supply[4)] [$m^3$/day] | City water consumption in case using reclaimed water [$m^3$][3)] | Rates of possibility reclaimed water supply | Water conservation rates |
| Public Site | Education | 86,165 | 31,449 | 86,292 | 7.6% | 923.32 | 575.23 | 236.99 | 102.92 | 583.42 | 59.1% | 36.8% |
| | Welfare | 13,463 | 7,266 | 25,196 | 2.2% | 663.92 | 232.37 | 129.46 | 23.78 | 510.68 | 65.9% | 23.1% |
| | Others | 15,661 | 7,017 | 28,360 | 2.5% | 245.31 | 87.08 | 80.95 | 22.96 | 158.22 | 119.3% | 35.5% |
| Commercial Site | Office | 23,615 | 16,098 | 88,666 | 7.8% | 766.96 | 272.27 | 253.10 | 52.68 | 494.69 | 112.3% | 35.5% |
| | Department Store | 21,315 | 17,902 | 60,148 | 5.3% | 1,305.22 | 535.14 | 665.66 | 58.59 | 770.08 | 135.3% | 41.0% |
| | Hotel | 0 | 0 | 0 | 0.0% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0% | 0.0% |
| | Leisure | 0 | 0 | 0 | 0.0% | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.0% | 0.0% |
| | Shop | 84,043 | 54,538 | 153,673 | 13.5% | 2,088.42 | 549.25 | 1,489.04 | 178.48 | 1,539.16 | 303.6% | 26.3% |
| Housing Site | Residence | 180,977 | 118,175 | 236,685 | 20.8% | 2,394.31 | 478.86 | 1,915.44 | 386.74 | 1,915.44 | 480.8% | 20.0% |
| | Apartment House | 178,144 | 109,857 | 447,514 | 39.3% | 4,527.06 | 905.41 | 3,621.64 | 359.52 | 3,621.64 | 439.7% | 20.0% |
| Industrial Site | Factory[1)] | 57,981 | 37,356 | 12,257 | 1.1% | 106.03 | 37.64 | 34.99 | 122.25 | 68.39 | 417.8% | 35.5% |
| Total | | 661,363 | 399,658 | 1,138,792 | | 13,020.54 | 3,673.26 | 8,427.28 | 1,307.93 | 9,661.73 | 265.0% | 25.8% |
| Rate[2)] | | 66.4% | 40.1% | 114.3% | | | 28.2% | 64.7% | 10.0% | 74.2% | | |

*1) In a factory, total floor area and water consumption are computed only office area.
*2) About "Area", Rates are ratio in total area : 996,000[$m^2$], about "water consumption", Rates are ratio in whole water consumption in the area
*3) "Total" is in case of individual reclaimed system. In case of using area reclaimed system, water consumption is a little reduced.
*4) "Normal amount of precipitation" is used 1,405.3[mm] in Tokyo, and "Runoff coefficient" is used 0.85.

# 5 Conclusion

In this paper, the author has developed to compute estimated water consumption using land use map of present condition and got basic data about future trends of water demand and supply in the area and the effective way of water use. In this paper, basic data of water consumption is quoted mainly from Reference 1, but those data is old. It is desirable to update those data.

In this paper, area is limited and flowchart of water usage is simple and static. Water consumption would be computed changing area and water usage, and the effective way of water use is necessary taking into consideration of water quality and the cost in the future.

## 6 Acknowledgement

This paper war realized by the great help of Kentaro Manabe who was formerly on the register of Toyo University as a student.

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# Vortex applications in steep energy gradient

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## Abstract

Vortex applications in steep energy gradient will be presented. This issue is discussed by following the separate characteristics of fluid flow, as they occur through the problem description. These characteristics are related to the conditions for fluid flow, potential vortex flow, helical flow and the problem of steep energy gradient. The characteristic conditions consist of the theoretical treatment, the results obtained on the experimental hydraulic model as well as with practical solutions for the energy line drop of 1126 m. Related existing examples used in Central Europe (Switzerland, Italy, Germany and Austria) are compared and discussed. In addition the description of certain shafts, having in mind A-241 (ATV- Abwasser Technische Vereinigung, Deutschland), will be presented and the suggestions for improvements will be given. In relation to the transition from small to steep energy gradients further elaboration of the existing formulae for velocity computation after Torricelli, is also presented.

## Keywords

Vortex, vorticity, horizontal vortex, vertical vortex, helical flow, shaft drainage, water jump.

# 1 Conditions for fluid flow

**Differential Equations**

1. Continuity

$$\frac{\partial p}{\partial t} + \nabla(\rho v) = 0$$

for incompressible flow $\nabla \cdot v = 0$

2. Momentum

$$\rho\left(\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j}\right) = -\frac{\partial p}{\partial x_i} + B_i + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k}\right)\right] + \frac{\partial}{\partial x_i}\left(\zeta \frac{\partial u_k}{\partial x_k}\right)$$

For constant density and viscosity the momentum equation is

$$\rho \frac{Dv}{Dt} = -\nabla p + B_i + \mu \nabla^2 v$$

3. Energy equation

$$\rho c_v \frac{DT}{Dt} = -p\nabla \cdot v + \kappa \nabla^2 T - \nabla q_r + \Phi + q^m$$

**Symbols**

| | |
|---|---|
| p – pressure | ρ - density |
| Bi– body force vector per unit volume | $q_r$ - radiation heat flux vector |
| $\kappa$ - thermal conductivity | $q^m$ - interval heat generation rate per unit volume |
| v – velocity vector | $\Phi$ - dissipation function |
| $\mu$ -viscosity | $c_v$ - specific heat |
| T – absolute temperature | $x_i$ - position |
| T – time | $\frac{D}{Dt}$ - substantial or material derivative |

# 2 Potential vortex flow

Assuming that for vortex the following equations for angular velocity are valid

$$\dot{\varphi} = \frac{C}{r^2} = const \quad . \tag{1}$$

$$\dot{\varphi} = \frac{d\varphi}{dt}; \tag{2}$$

where $\varphi$ is rotation angle, r a distance between surface and vertical axis of outflow. Inflow velocity can be written as $v_i = a\dot{\varphi}$ where a is distance between axis of inflow and vertical axis of outflow

$$C = a.v_i \tag{3}$$

$$\dot{r} = -r \ln(k) \text{ ; k - unit vector} \tag{4}$$

$$\ddot{r} = -\dot{r} \ln(k) - r \frac{1}{k} \dot{k} = r \ln^2(k) \text{ ;} \tag{5}$$

$$\ddot{\varphi} = \frac{d^2\varphi}{dt^2} = -\frac{2av_i\dot{r}}{r^3} \text{;} \tag{6}$$

$$t = \sqrt{\frac{2z}{\mu^2 g}} \text{ ; t - time} \tag{7}$$

Velocity vector may be written as

$$\vec{v} = \frac{d\vec{r}}{dt} = \dot{r}\vec{e}_r + r\dot{\varphi}\vec{e}_\varphi - z\vec{k} = \dot{r}\vec{e}_r - r\dot{\varphi}\vec{e}_\varphi - \omega\vec{k} \text{ ;} \tag{8}$$

$$\frac{d\vec{v}}{dt} = \vec{K} - \frac{1}{\rho}\vec{\nabla} p \text{ ;} \tag{9}$$

where $\vec{\nabla}$ is vector differential operator in cylindrical coordinates, $\rho$ stand for density, p represent a pressure and $\vec{K}$ is space vector. Therefore the velocity is

$$|\vec{v}| = \sqrt{\dot{r}^2 + r^2\dot{\varphi}^2 + \omega^2} \text{ ;} \tag{10}$$

and after substitution we obtain the velocity for potential vortex flow as

$$|\vec{v}| = \sqrt{r^2 \ln^2(k) k^{-2\sqrt{\frac{2z}{\mu^2 g}}} + \frac{a^2 v_i^2}{r^2 k^{-2\sqrt{\frac{2z}{\mu^2 g}}}} + \mu^2 2gz} \text{ ;} \tag{11}$$

and computing a force per unit mass ( $\vec{K}$ - space vector), we recover

$$\left|\vec{K}_r\right| = r \ln^2(k) k^{-\sqrt{\frac{2z}{\mu^2 g}}} - \frac{a^2 v_i^2 k^{3\sqrt{\frac{2z}{\mu 2g}}}}{r^3} + \frac{\mu^2 g^2 \sqrt{\frac{2z}{\mu^2 g}} \cdot k^{-\sqrt{\frac{2z}{\mu^2 g}}}}{r^2 \ln^2(k)} \tag{12}$$

$$\left|\vec{K}_\varphi\right| = -\frac{\mu^2 g^2 trk^{-t}}{av_i} = -\frac{\mu^2 g^2 \sqrt{\frac{2z}{\mu^2 g}} \cdot k^{-\sqrt{\frac{2z}{\mu^2 g}}}}{av_i} \tag{13}$$

$$\left|\vec{K}_z\right| = -g(1 + \mu^2) \tag{14}$$

## 3 Helical flow in pipelines

### 3.1 Ideal fluid

We discus the flow of incompressible fluid which represents a stationary regime. The velocity of fluid particles in a pipeline at arbitrary position in time can be expressed with velocity field $\vec{v}(\vec{r})$. Velocity field may be described with the streamlines. The tangent at an arbitrary point on the streamline represents the velocity vector. For incompressible fluid flow in pipeline the following equation is valid

$$div\ \vec{v} = 0 \tag{15}$$

In such a case the streamlines are connected lines and the particles flow depends on the vorticity in fluid. Velocity field $\vec{v}(\vec{r})$ is continuous so the vorticity vector $\vec{\omega}(\vec{r})$ may be determined as

$$\vec{\omega}(\vec{r}) = rot\vec{v}(\vec{r}) = \nabla \times \vec{v}(\vec{r}); \tag{16}$$

Suppose that we know the vorticity vector $\vec{\omega}(\vec{r})$ in certain cross section in time, then the velocity vector $\vec{v}(\vec{r})$ on the distance of pipeline radius $\vec{r}$ is the sum of total vorticity field

$$\vec{v}(\vec{r}) = \frac{1}{4\pi}\iiint \frac{\vec{\omega}(\vec{r}\,') \times (\vec{r} - \vec{r}\,')}{|\vec{r} - \vec{r}\,'|^3} dV'; \tag{17}$$

This equation can be defined with the use of the velocity field vector potential $\vec{H}$:

$$\vec{v} = rot\ \vec{H}\ ; \tag{18}$$

and we obtain

$$\vec{\omega}(\vec{r}) = rot\vec{v} = rot(rot\vec{H}) = grad\,(div\vec{H}) - \nabla^2\vec{H}\ . \tag{19}$$

When we request that for vector field the equation $div\ \vec{H} = 0$ is valid, we obtain

$$\nabla^2\vec{H} = -\vec{\omega}(\vec{r}) \tag{20}$$

The solution of this equation with boundary condition $\vec{H} = 0$ gives

$$\vec{H}(\vec{r}) = \frac{1}{4\pi}\iiint \frac{\vec{\omega}(\vec{r}\,')dV'}{|\vec{r} - \vec{r}\,'|}\ . \tag{21}$$

After integrating over the domain where vorticity vector $\vec{\omega}(\vec{r}) \neq 0$ yielding result

$$\vec{v}(\vec{r}) = rot\,\vec{H}(\vec{r}) = \frac{1}{4\pi}\iiint rot\left[\frac{\vec{\omega}(\vec{r}\,')}{|\vec{r}-\vec{r}\,'|}\right]dV'\,; \tag{22}$$

which is the same as already above-mentioned solution.

Vorticity field $\vec{\omega}(\vec{r})$ can be described with vorticity lines that connect the points in a way that the vorticity vector represent the tangent on the vorticity line in every point. Several vorticity lines together form a vorticity pipe (similar as streamline pipe or solenoid). Vorticity pipe with small cross section is vorticity thread. As for the streamline pipe, also for the vorticity pipe the mass conservation law is valid.

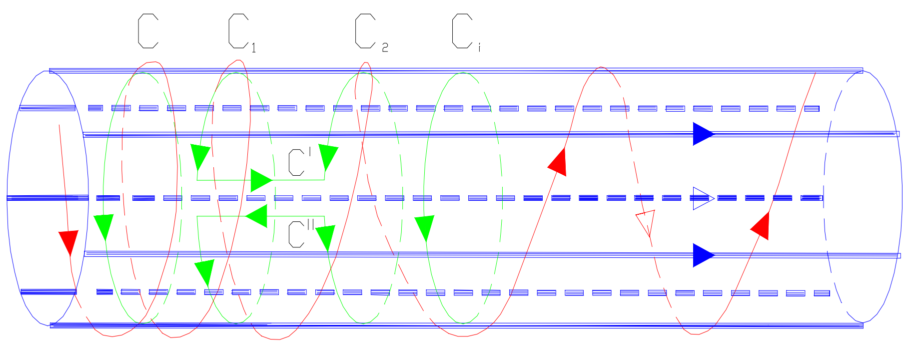



Figure 1: Helical flow for ideal and real fluid

With the velocity integral, the velocity circulation is obtained

$$\oint \vec{v}\cdot d\vec{S} = \Gamma \tag{23}$$

where $d\vec{S}$ is a curve element. The curves C,$C_1$,$C_2$ and also C' and C" lies on the vorticity pipe. Circulation at the concluded way is

$$\oint_{C_1+C_2+C'+C''} \vec{v}\cdot d\vec{S} = \iint \vec{\omega}\cdot d\vec{S} = 0\,; \tag{24}$$

because the vorticity vector $\vec{\omega}$ is rectangular to the area $d\vec{S}$. Integrals at C' and C" are exterminated and we obtain

$$\oint_{C_1} \vec{v}\cdot d\vec{S} = \oint_{C_2} \vec{v}\cdot d\vec{S}\,; \tag{25}$$

The circulation $\Gamma$ is always the same for one vorticity pipe

$$\Gamma = \oint \vec{v}\cdot d\vec{S} = \iint rot\,\vec{v}\cdot d\vec{S} = \iint \vec{\omega}\cdot d\vec{S}\,; \tag{26}$$

where we have

$$\omega = \frac{d\Gamma}{dS} \tag{27}$$

which means that the vorticity movement is more intensive by smaller cross section. We can also conclude that the following relations are valid

$$dV' = dr' \cdot dS'; \tag{28}$$

where dr' is element on the vorticity thread and dS' threads cross section. Also

$$\vec{\omega}(\vec{r})dV' = \vec{\omega}(\vec{r}')d\vec{r}' \cdot d\vec{S}' = dr' \omega(\vec{r}')d\vec{S}' = d\vec{r}' \cdot d\Gamma'; \tag{29}$$

Vectors $\vec{\omega}$ and $d\vec{r}'$ are collinear which gives

$$\vec{v}(\vec{r}) = \frac{1}{4\pi}\iiint \frac{\vec{\omega}(\vec{r}') \cdot dV' \times (\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3} = \frac{1}{4\pi}\iint d\Gamma' \int \frac{d\vec{r}' \times (\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3}; \tag{30}$$

### 3.2 Real fluid

In this case the velocity of fluid particles in a pipeline at arbitrary position in time can be expressed with

$$\vec{v}(x,y,z) = \left( \frac{-\omega_0 y}{\sqrt{x^2+y^2}}, \frac{\omega_0 x}{\sqrt{x^2+y^2}}, v_0 \right); \tag{31}$$

$$\vec{v}(0) = (x_0, y_0, 0) \tag{32}$$

$$z(t) = v_0 t \tag{33}$$

$y^2 + x^2 = const. \Rightarrow$ regime is on the circle $\sqrt{x_0^2 + y_0^2}$

$$x(t) = R\cos f(t) \quad \Rightarrow \quad \dot{x} = -R\sin f \cdot \dot{f} \tag{34}$$

$$y(t) = R\sin f(t) \quad \Rightarrow \quad \dot{y} = R\cos f \cdot \dot{f} \tag{35}$$

The streamline function can be written as

$$\vec{v}(t) = \left( R\cos\frac{\omega t}{R}, R\sin\frac{\omega t}{R}, v_0 t \right) \tag{36}$$

$$\vec{v} = \left( \frac{-y}{\rho g(z)}, \frac{x}{\rho g(z)}, v_0 \right) \tag{37}$$

with the corresponding solutions

$$\vec{v}_1 = \left( \frac{-\omega y}{Rz^2}, \frac{\omega x}{Rz^2}, v_0 \right),\ \vec{v}_2 = \left( \frac{-\omega y}{\mathrm{Re}^z}, \frac{\omega x}{\mathrm{Re}^z}, v_0 \right),\ \vec{v}_3 = \left( \frac{-\omega y(1-\beta z)}{R}, \frac{\omega x(1-\beta z)}{R}, v_0 \right)$$

$$\vec{v}(t) = \left( R\cos\left( C_0 - \frac{\omega_0 R}{v_0^2 t} \right), R\sin\left( C_0 - \frac{\omega_0 R}{v_0^2 t} \right), v_0 t \right) \tag{38}$$

$$|\vec{v}| = \sqrt{R_i^2 \cdot \ln^2(k) k^{-2\sqrt{\frac{2z}{\mu^2 g}}} + \frac{a^2 v_e^2}{R_i^2 \cdot k^{-2\sqrt{\frac{2z}{\mu^2 g}}}} + \mu^2 2gz} \tag{39}$$

and further for the unit mass we obtain the force

$$\left|\vec{K}_R\right| = R_i \cdot (\ln^2 k) k^{-\sqrt{\frac{2z}{\mu^2 g}}} - \frac{a^2 v_e^2 k^{3\sqrt{\frac{2z}{\mu^2 g}}}}{Ri^3} + \frac{\mu^2 g^2 \sqrt{\frac{2z}{\mu^2 g}} k^{-\sqrt{\frac{2z}{\mu^2 g}}}}{R_i \ln^2 k} \tag{40}$$

$$\left|\vec{K}_\varphi\right| = -\frac{\mu^2 g^2 t R_i \cdot k^{-t}}{a v_e} - \frac{\mu^2 g^2 \sqrt{\frac{2z}{\mu^2 g}} k^{-\sqrt{\frac{2z}{\mu^2 g}}}}{a v_e} \tag{41}$$

$$\left|\vec{K}_z\right| = -g(1+\mu^2) \tag{42}$$

$$rot\vec{v} = \left( 0,0, \frac{2\omega_0 R - \omega_0 R}{R^2} \right) = \left( 0,0, \frac{\omega_0}{R} \right) = \left( 0,0, \frac{\omega_0}{\sqrt{x^2+y^2}} \right) \tag{43}$$

$$\vec{r}(t) = \left( R\cos(\omega(t)\cdot t), R\sin(\omega(t)\cdot t), v(t)\cdot t \right) \tag{44}$$

*Uniform flow* R =const.
v = const.

*Nonuniform flow*

$$\vec{v} = \left( -R\omega \sin\omega t, R\omega\cos\omega t, v \right) + t(R\omega' \sin\omega t, R\omega' \cos\omega t, v') \tag{45}$$

What is $\vec{v}(\vec{r})$ in this case? At constant value we have $\vec{v}(x,y,z) = \left( -\omega(z)y, \omega(z)x, v(z) \right)$
When this velocity has divergence equal to zero? Possibilities are

1. when $v'(z) = 0$ it follows $\vec{v}(x,y,z) = \left( -\omega(z)y, \omega(z)x, v_0 \right)$; $v(z) = const$
2. when $R = \sqrt{x^2+y^2}$ then $\vec{v}(x,y,z) = \left( -\omega(z, \sqrt{x^2+y^2}) y, \omega(z, \sqrt{x^2+y^2}) x, v(z) \right)$ and $div\vec{v} = -\frac{\partial\omega}{\partial\rho} \cdot \frac{x}{\rho} y + \frac{\partial\omega}{\partial\rho} \cdot \frac{y}{\rho} x + v'(z) = v'(z)$

In stationary conditions $v(z) = v_0$ is valid. If the velocity is a function then we must write $v(z)$. If we want that $div\vec{v} = 0$, means that also v(z) must be a constant. Let say that v(z)=$v_0$. In this the velocity is $\sqrt{v_0^2 + R^2(\omega' t + \omega)^2}$
The velocity will be a constant when

$$\frac{\partial^2 \omega}{\partial t^2} \cdot t + 2\frac{\partial \omega}{\partial t} = 0 \tag{46}$$

with the solution

$$\omega = \frac{f(R)}{t} \qquad \omega = \frac{C}{tR^2} \tag{47}$$

The streamline function can be written as

$$\vec{v} = \left(\omega \sin\frac{\omega t}{R}, \omega \cos\frac{\omega t}{R}, v\right) = \left(-R\sin\omega t(\omega' t + \omega), R\cos\omega t(\omega' t + \omega), v_0\right) \tag{48}$$

$$v = |\vec{v}| = \sqrt{\omega^2 + v^2} \tag{49}$$

and the acceleration is

$$\vec{a} = \left(-\frac{\omega^2}{R}\cos\frac{\omega t}{R}, -\frac{\omega^2}{R}\sin\frac{\omega t}{R}, 0\right) = -R(\omega' t + \omega)^2(\cos\omega t, \sin\omega t, 0) + \\ + R(\omega'' t + 2\omega')(-\sin\omega t, \cos\omega t, 0) = \vec{a}_r + \vec{a}_t \tag{50}$$

Therefore we obtain the accelerations:
- radial acceleration is $a_r = |\vec{a}_r| = R(\omega' t + \omega)^2$ (51)
- tangential acceleration is $a_t = |\vec{a}_t| = R(\omega'' t + 2\omega')$ (52)

The next question is when helical or circular – tangential (spiral) acceleration lose the influence?

$$t\ddot{\omega} + 2\dot{\omega} = 0 \tag{53}$$

1.) $\alpha = \dot{\omega} = 0 \Rightarrow \omega = const.$
2.) if we mark $\dot{\omega} = \alpha$ tangential acceleration is negligible if the function $\omega$ takes the form $\omega(t) = \frac{C}{t} + k$, which mean that the tangential acceleration has no more influence. As long as the helical flow exists there is no interrupt of the fluid flow.

## 4 Steep energy gradient

Some solutions for steep gradient sewage used in the Central Europe are presented on Figure 2.

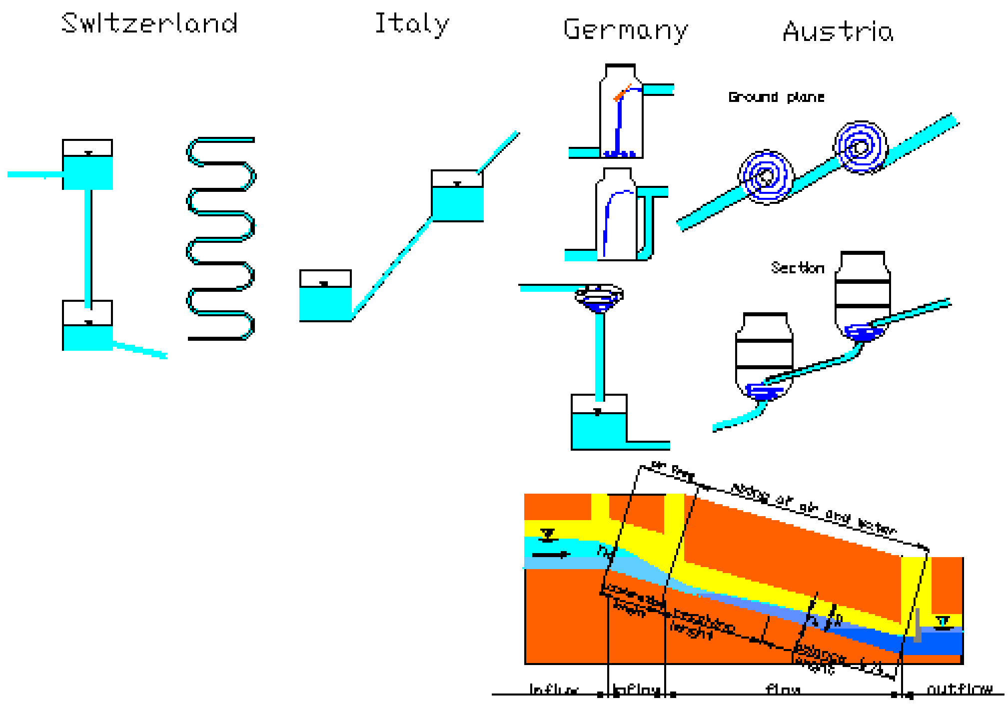



Figure 2: Some existing examples for steep energy gradients used in Central Europe

In Switzerland we can found the solutions on a steep side of a hill in a form of vertical connection between two shafts as well as serpentine shape solutions. In both cases in the lower shaft the minimal water height is assured with the special way of outflow. In the alpine part of nordern Italy the solution with the inflow possibility above the surface and also at the bottom of the shaft, can be found. In Bayern (Germany) a few solutions are possible following the ATV 241 instructions. These are shafts with or without inflow pipe and reflection board. For higher gradients we can found the examples with the upper shaft for the fluid vorticity and classical lower shaft. In Austria the solution with shafts enabling the horizontal vortex formation dominated. Such solutions in Schladming (ski world cup center), Kaprun, Sonnenkopf, Malnitz, etc., are used.

On a hydraulic model (Figure 3.) the characteristic water outflow are presented where on one side the vortex is implemented and on the other side not.

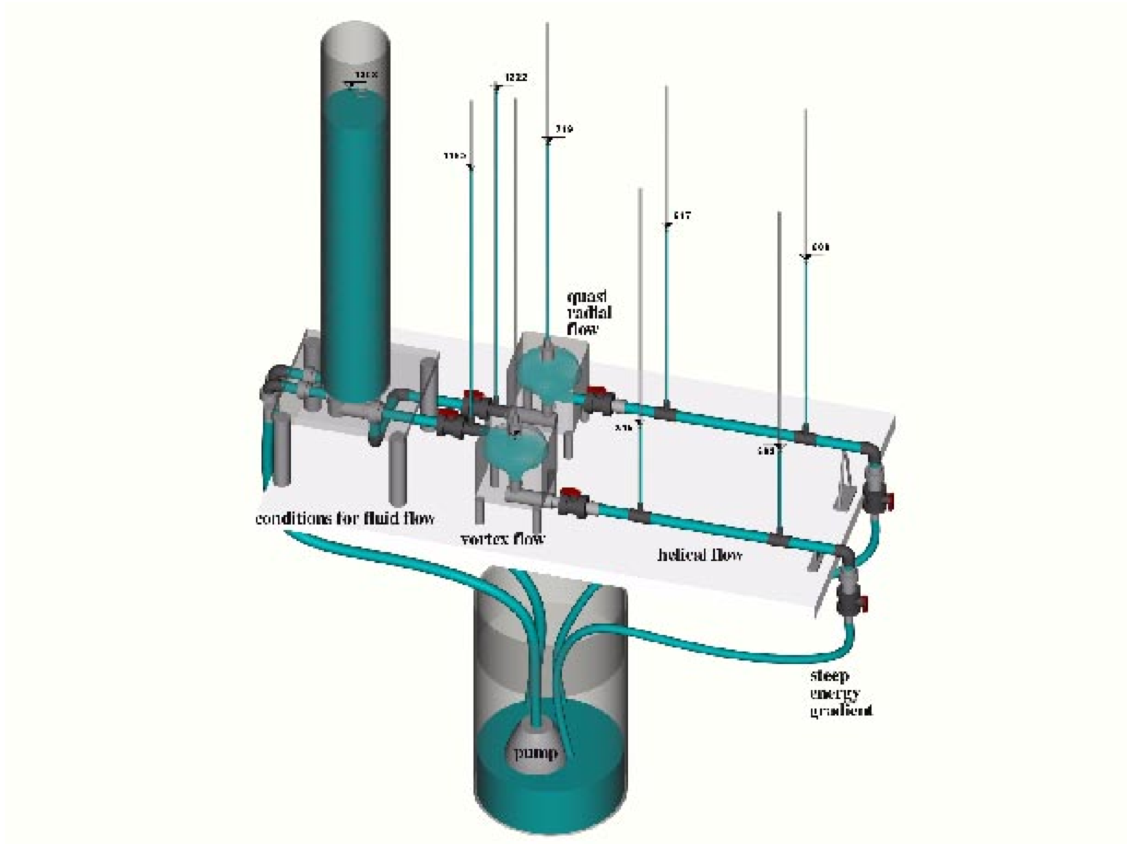
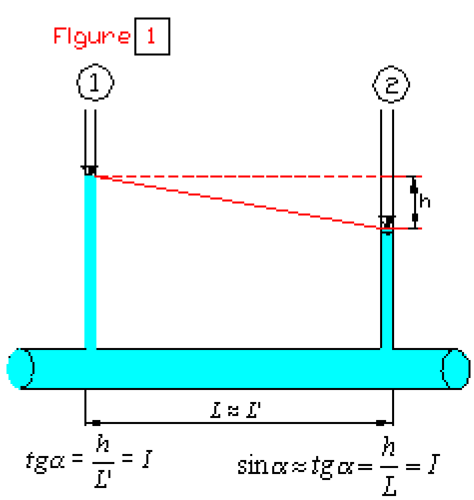



Figure 3: Hydraulic model

In transition from small to steep gradients $\alpha > 20^\circ$ - Figure 4. (figures 1. - 12) on the basis of the model research we can conclude that it is suitable to use additional water vorticity and not only horizontal.

On the basis of Figure 4., we can observe the meaning of hydraulic gradient $I$ and comparison between $\sin\alpha$ and $tg\alpha$. Also today we often find an exchange of those two terms in the literature.



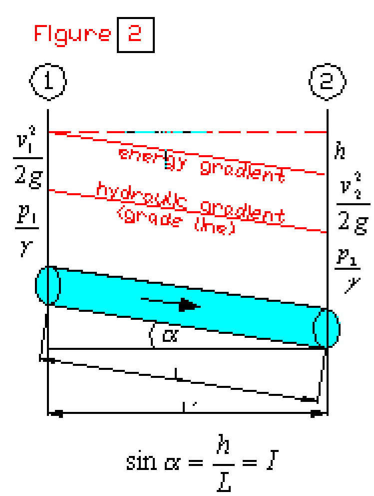
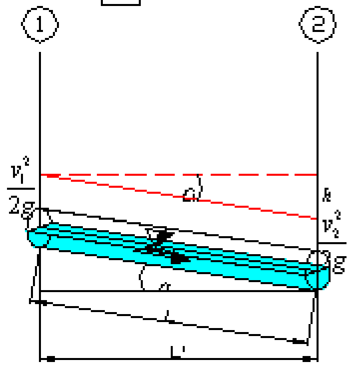
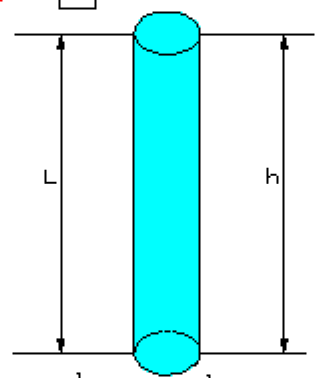



Figure 3




$$\sin\alpha = \frac{h}{L} = I$$

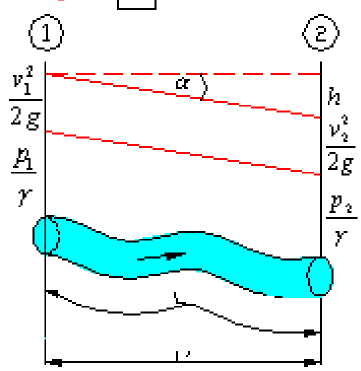
Figure 4




$$I = \frac{h}{L} = 1 \qquad \frac{h}{L} = 1 = 100\%$$

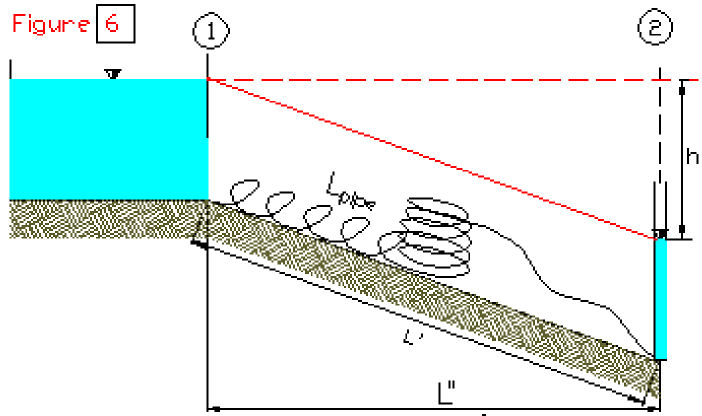
$$\alpha = 90^0 \quad \sin 90^\circ = 1\ ;\ tg\frac{\Pi}{2} = \infty$$

Figure 5



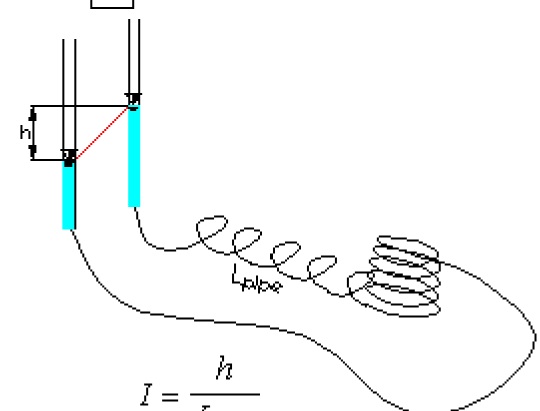

$$\sin\alpha = \frac{h}{L} = I$$

Figure 6



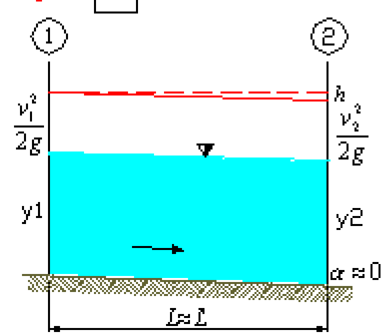

$$I = \frac{h}{L_{PIPE}}$$

Figure 7




$$I = \frac{h}{L_{PIPE}}$$

Figure 8




$$\sin\ \alpha \approx tg\ \alpha = \frac{h}{L} = I$$

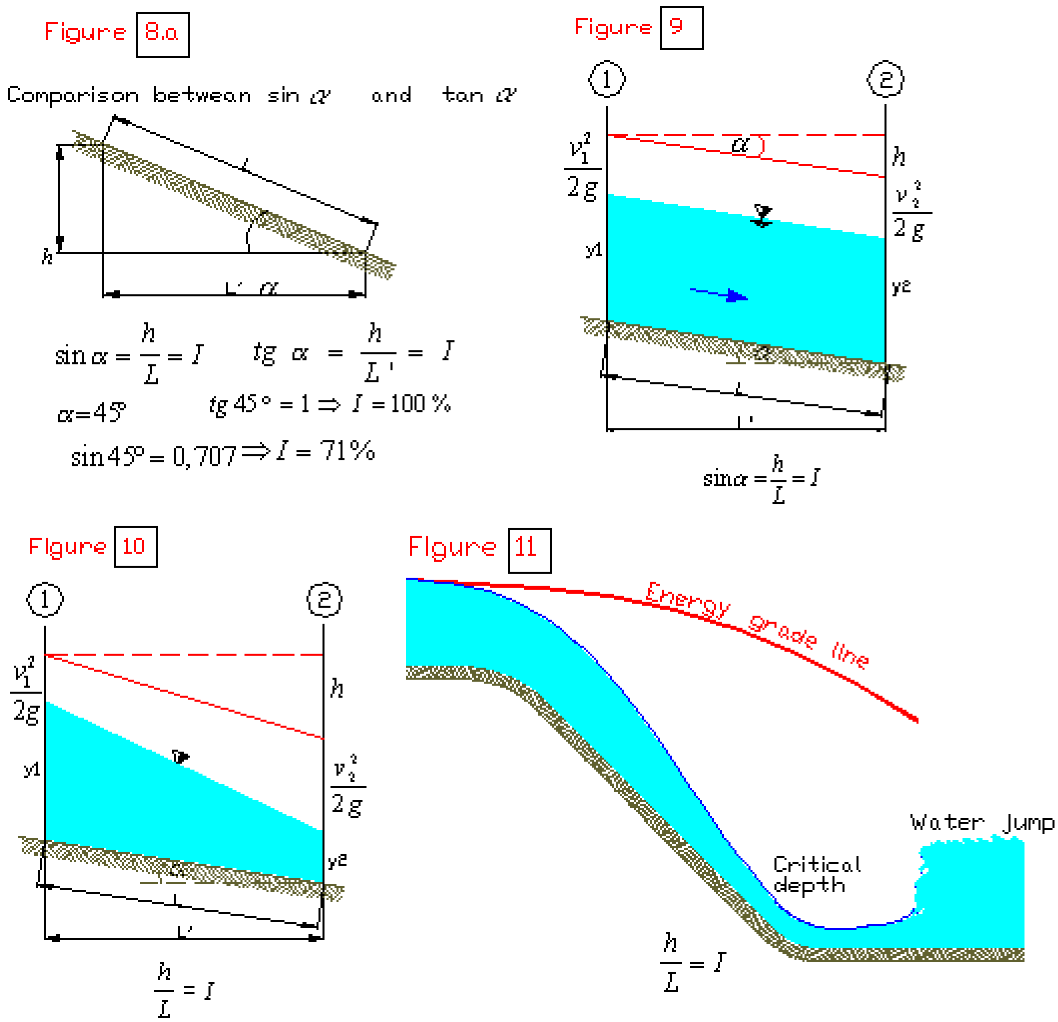



Figure 4: Characteristic parameters of hydraulic gradient

## 4.1 Influence area of hydraulic gradient

On the basis of the Table 1. the influence area of hydraulic gradient $I$ is presented on the Figure 5. in the form $I = \sin\alpha$ and $I^{1/2} = I^{0.5} = (\sin\alpha)^{0.5}$. We are dealing with the inclination in interval $0° \le \alpha \le 90°$ and therefore conclude that $I_{\min} = 0\,(0\ \%) \Rightarrow \alpha = 0°$ for minimal inclination and $I_{\max} = 1\ (100\ \%) \Rightarrow \alpha = 90°$ for maximal inclination. Consequently hydraulic gradient lies in interval $0 \le I \le 1$.

From Table 1. which is accompanied with the Figure 5. we can observe that $\sin\alpha$ and $\mathrm{tg}\,\alpha$ are almost the same until the inclination is less than $\alpha \cong 15°$. Neglecting small deviations this limit is around $\alpha \approx 20°$. When the inclination $\alpha > 20°$ it is obviously clear that any comparison between $I = \sin\alpha$, $I^{\frac{1}{2}} = (\sin\alpha)^{\frac{1}{2}}$ and $I = tg\alpha$, $I^{\frac{1}{2}} = tg\alpha^{\frac{1}{2}}$ is unlogical. On the basis of this observations we may divide the influence area as

- small values for $\alpha < 20°$,
- high values when $\alpha > 20°$.

Conclusion of the above explanation, that definition of hydraulic gradient as $I = tg\alpha$ is unlogical and without any sense, can be expressed. Hydraulic gradient $I$ represents the ratio $I = \frac{h}{L}$, where the length L means the real length of the pipeline transporting the fluid and not the projection of this length on a horizont.

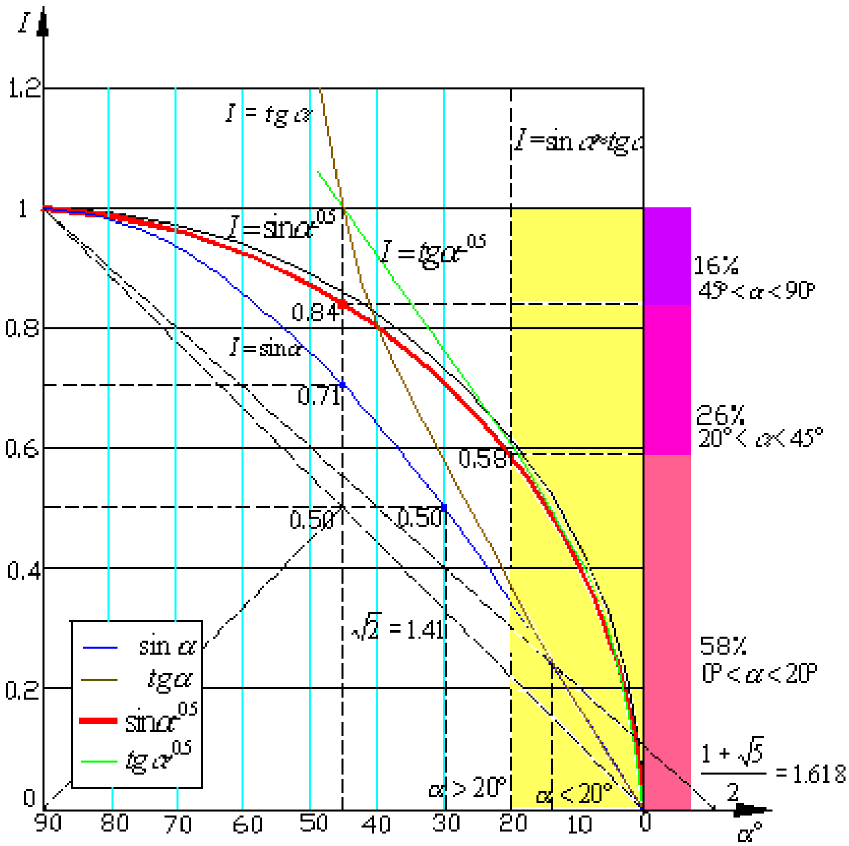



Figure 5. The influence of hydraulic gradient and the terrain inclination

Also we can conclude that different tables for calculating pipe diameters according to the hydraulic gradient in the form of $I = tg\alpha = tg45° = 1$(that represent 100% inclination) are matchless. In such a case we need to ask ourselves where is the control between the fluid velocity as calculated in those tables and the fluid velocity in pipeline at real operating conditions. From Figure 5. we can also observe that the influence of hydraulic gradient is nonuniform. Until $\alpha \leq 20°$ there is 58% of the whole problem on hand, for $20° \leq \alpha \leq 45°$ we have already 84% and for the interval $45° \leq \alpha \leq 90°$ there is only 16% of the whole problems left. It is normal to anticipate that the fluid velocity is higher with larger inclination. For that reason in the interval $45° \leq \alpha \leq 90°$ there are, gentle said, some unlogical constellations. This unlogicality derive from the ratio $I = \frac{h}{L}$. It is also a question of correctness of expression for velocity in the case of vertical and horizontal pipe or the pipe with a small inclination. In the expressions for the fluid velocity in most cases the hydraulic gradient is presented in the form $I^{\frac{1}{2}} = I^{0.5}$.

On the Figure 5. we attend how the function is going on and we can see that there is a very little difference between this function and a circle. Also we can observe the function $\sqrt{2}=1.41$ and gold section $\frac{1+\sqrt{5}}{2}=1.618$ and finally conclude that gold section is very well suited for representing the hydraulic gradients for small and high angles $\alpha$.

| $\alpha°$ | I | I | I^(1/2) | I^(1/2) |
|---|---|---|---|---|
| | Sin($\alpha$) | Tg($\alpha$) | Sin($\alpha$)^(1/2) | Tg($\alpha$)^(1/2) |
| 0 | 0 | 0 | 0 | 0 |
| 2 | 0.034899 | 0.034921 | 0.1868141 | 0.186871 |
| 5 | 0.087156 | 0.087489 | 0.2952215 | 0.2957848 |
| 7 | 0.121869 | 0.122785 | 0.3490979 | 0.3504063 |
| 10 | 0.173648 | 0.176327 | 0.4167111 | 0.4199131 |
| 15 | 0.258819 | 0.267949 | 0.5087426 | 0.5176381 |
| 17 | 0.292372 | 0.305731 | 0.5407141 | 0.5529292 |
| 20 | 0.34202 | 0.36397 | 0.5848249 | 0.6032995 |
| 25 | 0.422618 | 0.466308 | 0.650091 | 0.6828672 |
| 30 | 0.5 | 0.57735 | 0.7071068 | 0.7598357 |
| 35 | 0.573576 | 0.700208 | 0.7573483 | 0.836784 |
| 40 | 0.642788 | 0.8391 | 0.8017404 | 0.9160238 |
| 45 | 0.707107 | 1 | 0.8408964 | 1 |
| 50 | 0.766044 | 1.191754 | 0.8752396 | 1.0916747 |
| 55 | 0.819152 | | 0.9050702 | |
| 60 | 0.866025 | | 0.9306049 | |
| 70 | 0.939693 | | 0.9693774 | |
| 80 | 0.984808 | | 0.9923748 | |
| 90 | 1 | | 1 | |

Table 1. Values of characteristic parameters.

### 4.2 Comparison between characteristic expressions for velocity and suggestion for addition

• Evangelista Torricelli (1608-1647) was a student of Galileo Galilei (1564-1642). In the literature today the Torricelli expression [5], [6] for the flow velocity can be found

$$v=\sqrt{2gh} \tag{54}$$

where the regime of flow is not mentioned, or in the additional form as

$$v=\mu\sqrt{2gh} \tag{55}$$

with the coefficient of contraction $\mu$ ($\mu<1$) included.

• Specific energy and critical depth [3] are written as $E_s=y+\frac{v^2}{2g};q=vy$. The depth for minimum energy $y_c$ is called critical depth and the velocity of flow at critical depth where Froud number $F_r = \frac{v}{\sqrt{g y_c}}$ [8] is equal to unity ( $F_r = 1$) is

$$v_c = \sqrt{g y_c}\ , \qquad (56)$$

where $y_c$ = h and the flow regime is included in Froud number.

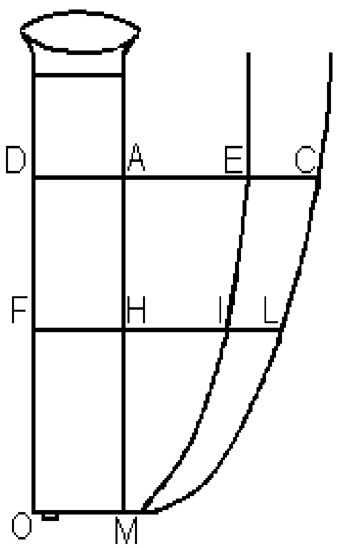
• For hydraulic jump [8] we can write

$$v = \sqrt{gh} \qquad (57)$$

• Outflow of the fluid from the reservoir [9]

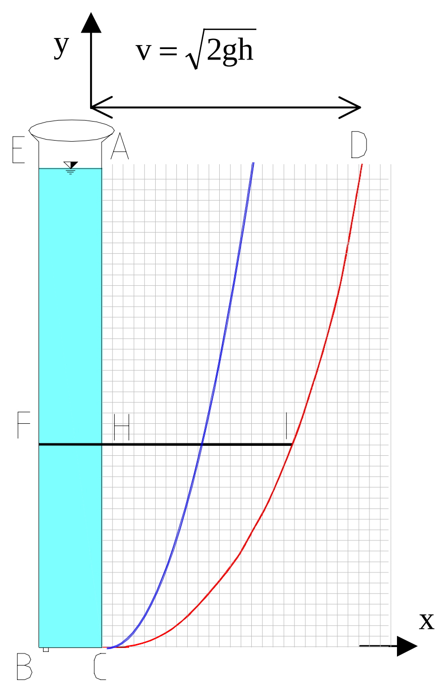
$$v = \sqrt{2gh} \qquad v = \mu\sqrt{2gh} \qquad \mu \le 1 \qquad (58)$$

After mentioned expressions, following the work of Torricelli, the graphical presentation of a velocity function is given on Figure 6.




Torricelli

| v | H |
|---|---|
| 0 | 0 |
| 4,99 | 0 |
| 9,96 | 0,12 |
| 14,98 | 0,94 |
| 19,95 | 2,11 |
| 24,97 | 4,31 |
| 29,97 | 6,86 |
| 34,95 | 10,53 |
| 39,98 | 14,89 |
| 44,96 | 19,81 |
| 49,97 | 25,56 |
| 54,97 | 31,31 |
| 59,99 | 38 |
| 64,97 | 45,21 |
| 69,95 | 54,11 |
| 74,98 | 63,22 |
| 79,95 | 73,55 |
| 84,97 | 85,7 |
| 89,99 | 98,62 |
| 94,99 | 113,03 |
| 99,97 | 128,8 |
| 104,99 | 145,94 |
| 109,96 | 165,82 |
| 114,98 | 190,71 |
| 119,95 | 219,56 |




Loria, G., Vassura, G., (1919):
Opere di Evangelista Torricelli
(De Motu Aquarum, Page 185)

$$y = 0.0001 \cdot x^3 - 0.0006 \cdot x^2 + 0.2832 \cdot x - 2.31$$

Figure 6. Velocity calculation

The coordinate values for the curve on the scheme are taken from ’’Opera di Evangelista Torricelli) [5]. Coordinate y represents the height and x coordinate represent velocity. Expression beyond the right scheme is the third order polynomial. Because of different basic expressions for the velocity the suggestion for the further improvement of the formulae, is given as

$$v = \sqrt{\frac{2gh}{K}} \qquad (59)$$

where K is a flow characteristics that can be divided for:

K = 1 propagation wave
K = 1 for uniform distribution of velocity
K = 1,02 – 1,15 for turbulent flow ( G. de Marchi )
K = 2 for laminar flow

### 4.3 Vortex in water outflow instalation

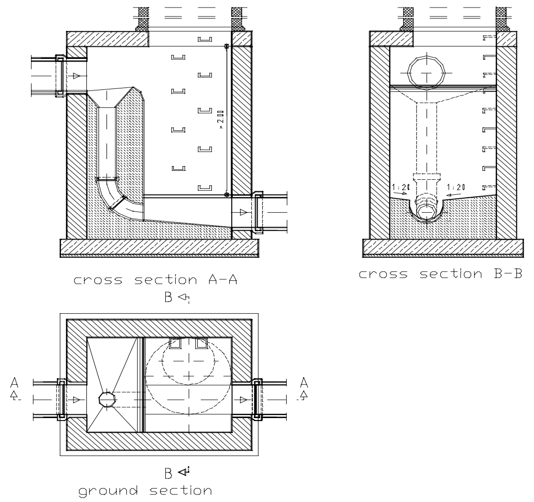
Figure 7. Water outflow instalation in house

On the right picture of the Figure 7. the classical solution of water outflow instalation is presented, while on the left hand side there is a solution with the use of vortex or solution with rotation. The advantage of the later lies in reduction of outflow water velocity and also a considerable reduction of noise. Measured results are 73 - 75 dB noise with the classical and 52 - 53 dB with the vortex solution.

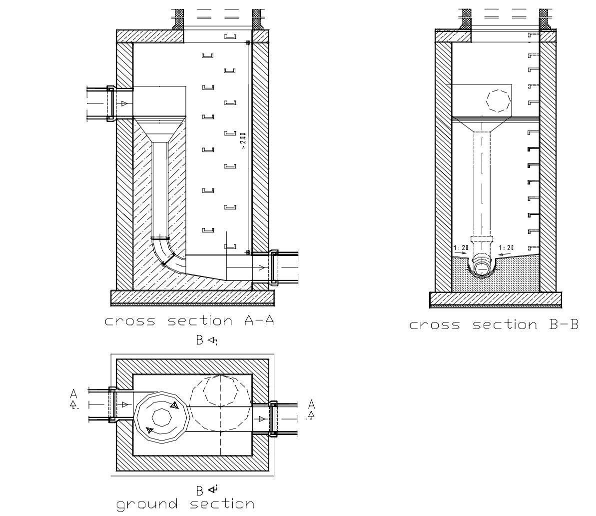
## 5. Suggestions for ATV A-241 solutions

Suggestions for improvement of some technical solutions given in ATV A-241 (Abwasser Technische Vereinigung, Deutschland), are presented in Figure 8., where the numbers that mark the single solutions are according to the cited regulations.

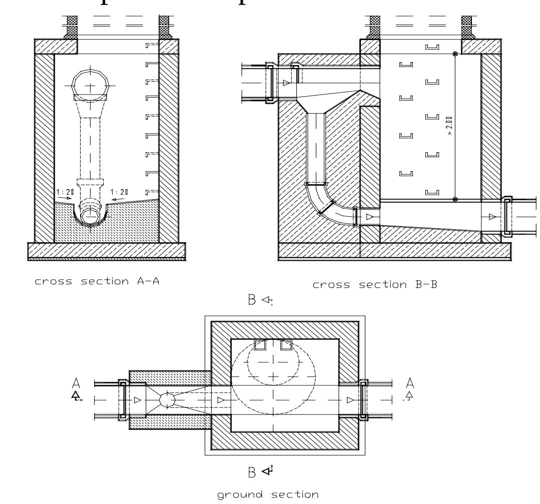
8.2.1 Input shaft – present solution



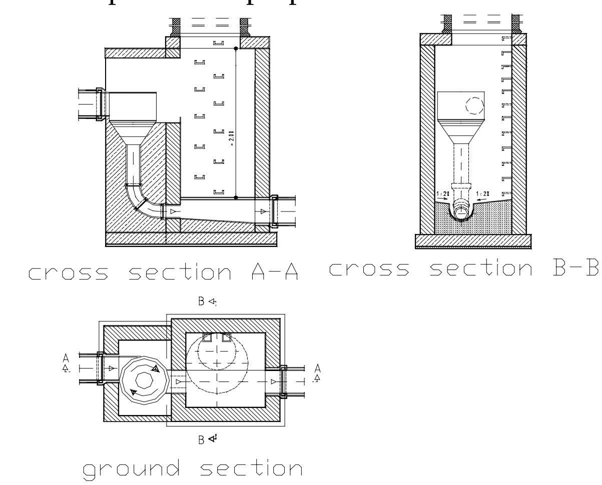

8.2.1 Input shaft - proposal of the new solution



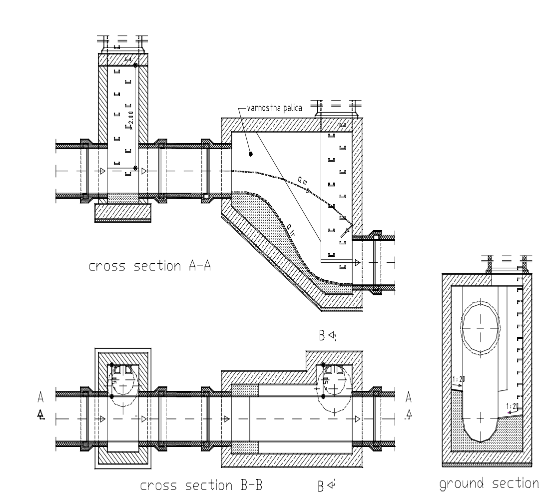

8.2.2 Input shaft - present solution



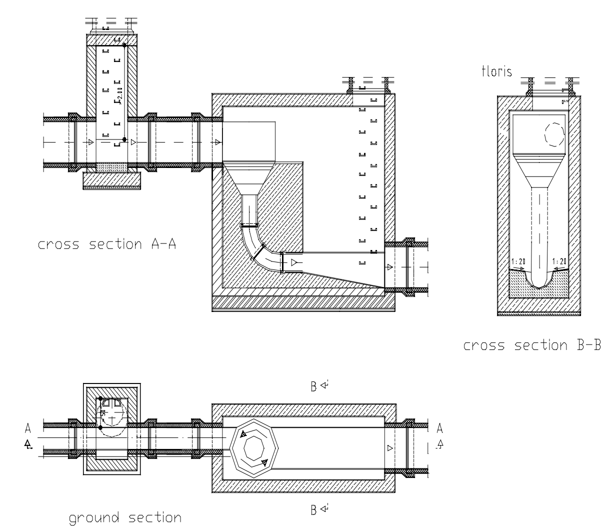

8.2.2 Input shaft - proposal of the new solution



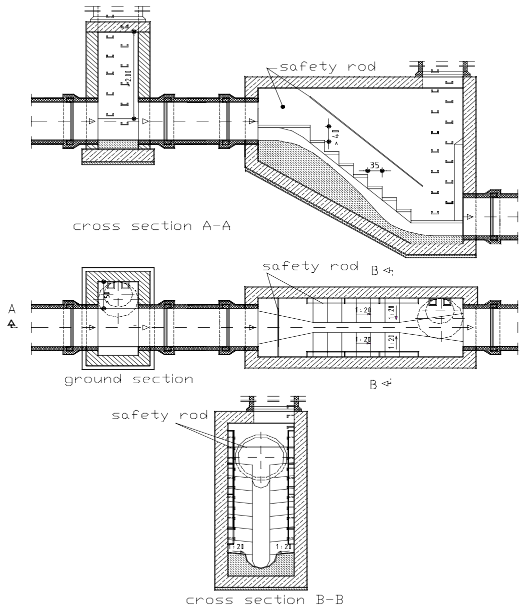

8.2.3 Input shaft – present solution



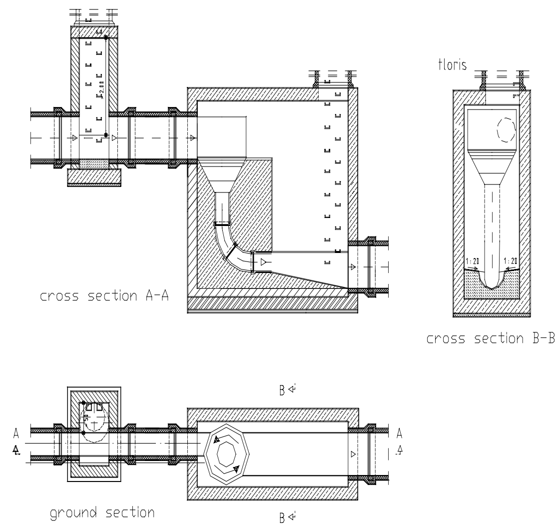

8.2.3 Input shaft – proposal of the new solution



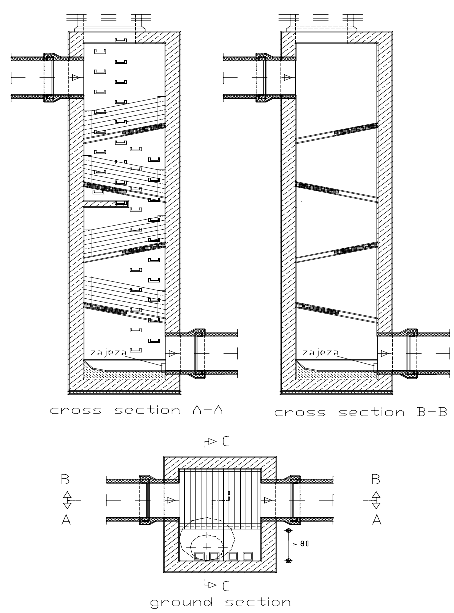
8.2.4 Input shaft with cascades – present solution



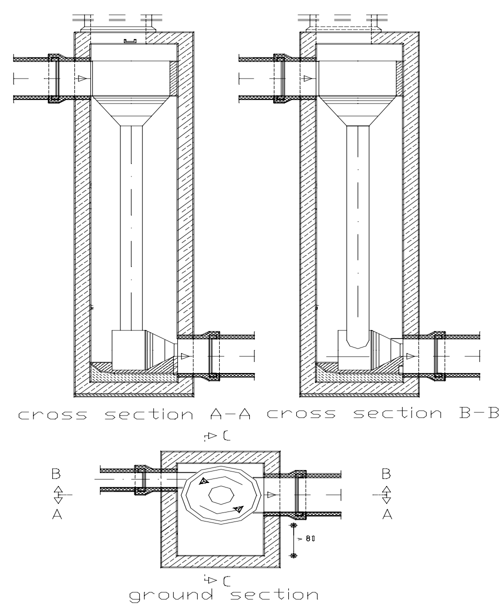

8.2.4 Input shaft with cascades - proposal of the new solution




8.2.5 Input shaft with powerful change of energy level - present solution




8.2.5 Input shaft with powerful change of energy level - proposal of the new solution



## 6 **Conclusion**

1. As long as the helical flow exists there is no interrupt of the fluid flow.
2. Break points in a vertical plane of the cross section are dangerous for interrupting of the helical flow. On such a places the use of vortex is suitable.
3. As long as the proper rotation with indicated center of the rotation and afterwards helical flow in vertical or inclined pipe is present, there is no need to limit the length between vortex shafts. In this case, the length between vortex shafts may be longer than 100 m, which is also valid for the vertical difference between shafts.
4. A properly modeled vortex reduces the noise in the pipe.
5. Vortex enables easier realization of the canalization objects.
6. In the canalization, the horizontal and vertical vortex must be taken into account.

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# Self Acting – Automatic Downstream-Upstream Pressure Control Valves - Matlab Simulations

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## Abstract

Leakage losses in a water distribution network increase significantly for higher pressures and an obvious way of reducing losses is by reducing network pressures. The origin of these difficulties is, among other causes, the feeding pressure. An efficient solution, but less used in present, is the promotion of the self acting – automatic pressure control valves. This paper presents technical details that we considered necessary for a better knowledge of the functional principle of these devices, giving possibilities to find specifically applications of these. The self-operated controller is a self-contained regulating device, which includes the set-value adjuster, transducer, control point element, controller. For simulating in MATLAB the downstream-upstream pressure controlling, we use the diagram of fluid circuit on which control valve is mounted and we obtained the dynamic results of the simulation.

## Keywords

Pressure control; dynamic simulation

## 1 Introduction

Leakage losses in a water distribution network increase significantly for higher pressures and an obvious way of reducing losses is by reducing network pressures.

Pressure variations are generated by:

- uncontrollable flows absorbed by the customers;
- uncontrollable transient flows;
- insufficient pressure service at source;
- pressure peaks over and under normal pressure, inducted by uneven hydraulics phenomenon;
- excessive or accidental leakage losses.

The origin of these difficulties is, among other causes, the feeding pressure. An efficient solution, but less used in present, is the promotion of the self acting – automatic pressure control valves. This paper presents technical details that we considered necessary for a better knowledge of the functional principle of these devices, giving possibilities to find specifically applications of these.

Any project for realization or/and modernization of the water distribution systems must have theoretical support. Self-acting control valves must be included in the general methodology for pressure management in a water distribution network, using a computational program. The hypotheses that must be considered are:

- water demand – determined by the nature of using and the customer's activities;
- water property – imposed by consumer exigency and regulations;
- water energy – to provide water transportation and normal pressure for customer;
- safe exploitation – expressing through continuously in providing quantitative and qualitative parameters.

Of course, hypotheses are relative and each of these four categories is interdependent and all of these have economics consequences.

## 2 The pressure service

The pressure service imposed in distribution network depend by:

- the geographical position of the customer;
- the minimum pressure impose in point of the receiving;
- the loss pressure in interior installation of the customer;
- the loss pressure on branch pipe.

The minimum value accepted for pressure service is between 1 bar and 2,5 bar, these pressures allowed the utilization of sanitary objects and electrical device by buildings with height till to P+3E.

The geographical delimitation for distribution network is conditioned by these values. In many real situations, the relief and configuration of the distribution networks conduct to the exceeding of this interval, with unfavorable consequence in determining the pressure.

To establish service pressure necessary to be assured in each situation, a number of functions must take in account: specific relief, height of the region, geometrical and hydraulic characteristics interior installation and utilization pressure to consumers.

With informative title, accepted like admissible value to branch pipe, in function by the number of levels *n*, service pressure is:

$$P = \frac{1 + 4n}{10} [bar]$$

The maximum admissible statically pressure must be 6 bars, imposed by the nominal pressure of the fittings.

In the case of high buildings and very high, it is possible to exceed the admissible maximum pressure and in these cases it is justify to function with different distribution network, at specific pressure.

Pressure growth in distribution network is equivalent, near always, with the increase of the power consumption. Simultaneous, it raises the volume of the leakage losses in a water distribution network and the initial consumption quantity in interior installations.

Independently of the variations of the pressure at source, it is important for these variations on the branch pipe to be as small as possible, all around of the minimum value of service.

In this way we ensure:

- increasing the comfort degree of the customers;

- increasing the efficiency and extension the life time of the fittings and devices;
- leakage losses diminution through no-tightness;
- diminution of the cracking risk or of the tearing of the pipes.

Keeping up the service pressure in determinate limits, in certain section, can be landing in two distinct manners, as follows:

- satisfying conditions in permanent mode, or
- accepting, in outstanding limits conditions; just like diminution of the service pressure in case of huge simultaneous flows.

For the first method it is usually to use self-acting control systems.

## 3 Self-acting automatic pressure control valves

The modification of the hydraulic cross-section of a fluid through a pipe or duct can carried out by means of two classes of control devices: valves and damper plates or flaps. The term self-acting (self-operated or direct action) regulators apply to those control devices in which the transducer actuates on the final control element by a system of mechanical transmission, without amplification of the signal. In consequence, the energy required to displace the final control element is wholly supplied by the sensor, which takes it over the controlled medium. The self-operated controller is a self-contained regulating device, which includes the set-value adjuster, transducer, control point element, controller.

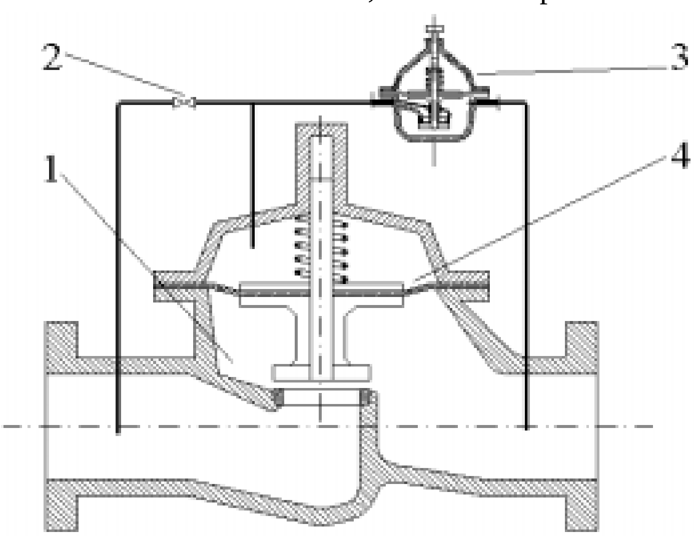


**Figure 1 – Working principle: 1 – main valve; 2 – hydraulic resistance; 3 – pilot; 4 – membrane.**

The working principle for a pressure-reducing valve is presented in fig.1. When the down-stream pressure rises, the pilot valve 3 closes. Pressure in the upper chamber rises also and forces the membrane to close the main valve 1 witch reproduces the movement of the pilot. When the downstream pressure is to low, no pressure is acting on the membrane and the pilot opens, pressure in the upper chamber is released and the main valve 1 opens reproducing the movement of the pilot. For controlling, the pilot is set at a given downstream pressure to be maintained. If the pressure downstream is higher than the setting pressure, the main valve works in closing phase until the setting pressure is reached. When the down pressure is below the setting pressure, the valve works in opening phase until the setting pressure is reached downstream. The upstream pressure must be fairly higher than the setting pressure.

The role of control valves in their many functions is to restore the balance by regulating water distribution according to pre-determinate priorities: controlling downstream pressure, controlling upstream pressure, differential pressure control, controlling downstream/ upstream pressure.

## 4 MATLAB simulation for self-acting automatic pressure control valves

The peculiarity of the simulation diagram in Fig. 2 consists in using those two references:

- the upstream reference pressure
- the downstream reference pressure

The priority of the control loop in which the regulating valve is included is assured by changing the reference through a switch driven (Relay) by the state of the upstream pressure. Provided that the upstream area pressure is protected when the lower area requires increased flows. Thus is achieved the dynamic coupling of some areas with different conditions of static pressure.

In the MATLAB model diagram, the applied input data are the pressure variations of the upstream pressure source, as well as various variation hypotheses for the upstream and downstream hydraulic resistances (simulating the upstream fluctuations or the variable requirements of flows in the downstream area).

By the moments of time at which the variations of these measures are set, we can identify and monitor the way in which the systems responds.

The main condition that can be thus assured is the exploitation of the water source (underground collecting) from the upper area at the maximum capable flow, by undertaking a part from the lower area, which under normal conditions is supplied by surface sources.

The integration of the self acting pressure controllers is achieved by mounting these controllers on level curves. A special issue is to determine the height at which these devices should be mounted in order to minimize their number. In case the concrete position on vertical plane is different than the established medium height, the difference will be set, with its corresponding mark, as reference value for that controller.

For modeling the self acting pressure controllers, the authors used the following MATLAB original functions:

- debb - calculates the flow in the network sector, described by the upstream pressure, the upstream and downstream hydraulic resistances, as well as by the kv parameter of the regulating valve;
- pressamo - calculates the pressure drop upstream the pressure controller;
- press - calculates the upstream pressure drop, including the pressure controller;
- kv = f(H) - interpolation table for the hydraulic characteristic of the valve. Its shape was adopted arbitrarily, with values from the usual range.

The validation of working principle of the simulation diagram was achieved by applying it for downstream control valves and also upstream control valves.

### 4.1 Downstream pressure controlling – MATLAB simulation

This self-acting control system maintains a constant preset reduced downstream pressure regardless of variations in downstream demand or upstream pressure. These valves reduce:

- distribution pressure when the supply comes from a source situated at a relatively high level;

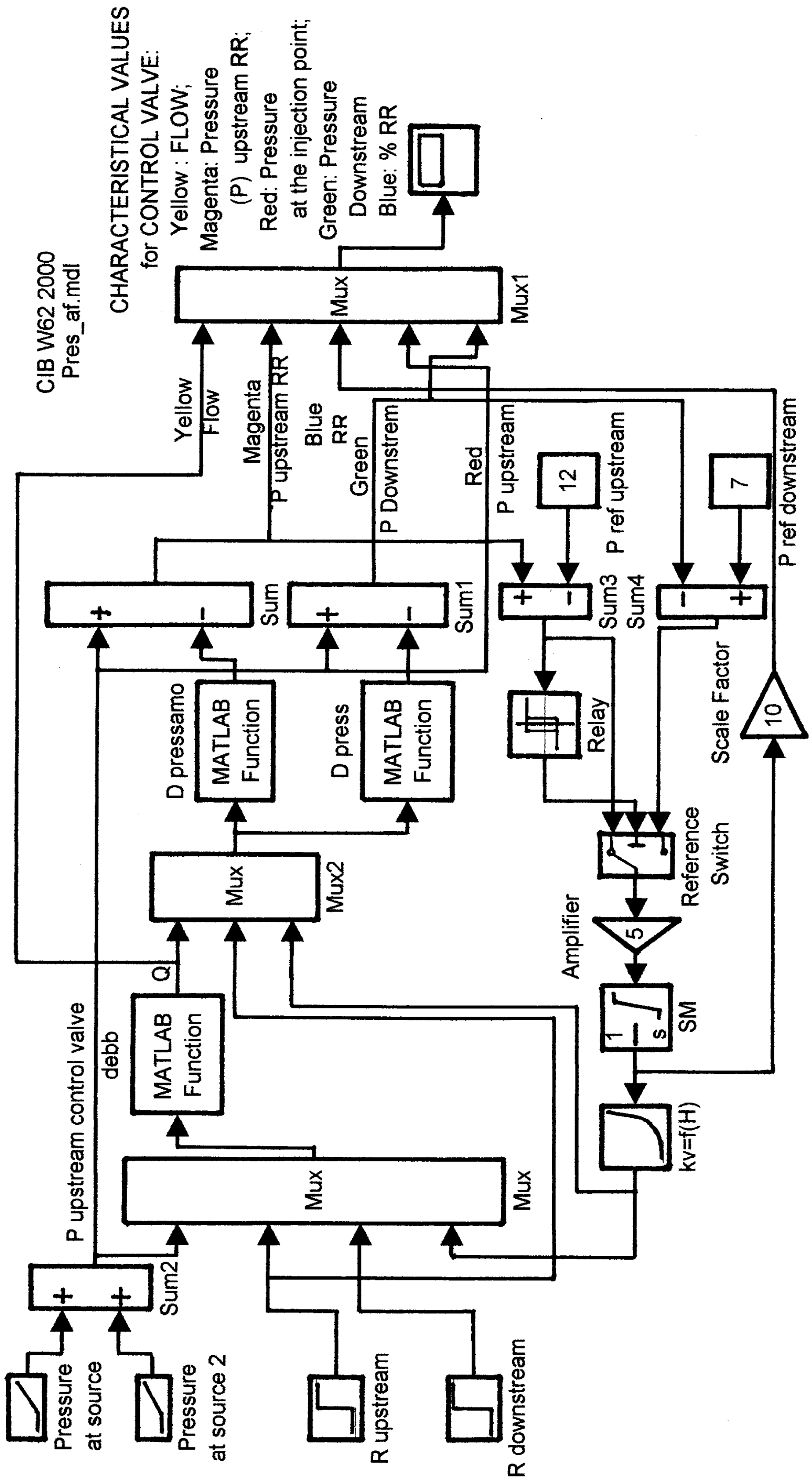


**Figure 2 – Diagram (MATLAB with SIMULINK) for downstream-upstream control valves simulation**

- distribution pressure to a working level for a given zone;
- the pressure at the discharge side of a pump when it is too high;
- pressure in an irrigation system.

Equipped with non-return valves (check valves), it closes automatically in case of a return of water or it opens automatically to reverse the direction of flow if the upstream pressure becomes less than the downstream pressure.

For simulating in MATLAB the downstream pressure controlling, we use the diagram of fluid circuit on which control valve is mounted (Fig.3). Fig. 4 must be inspected, with the dynamic results of the simulation.

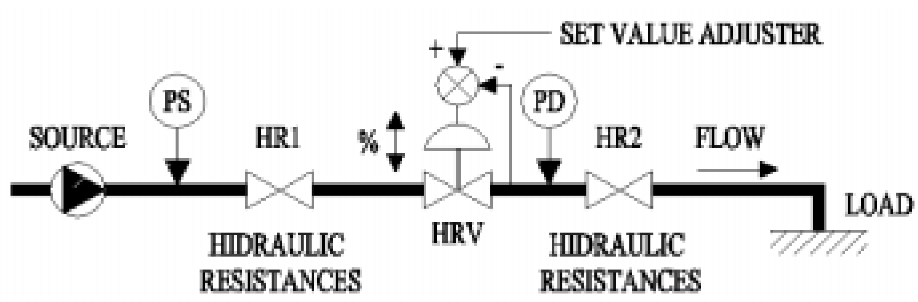


**Figure 3 - Diagram of fluid circuit for downstream pressure controlling**

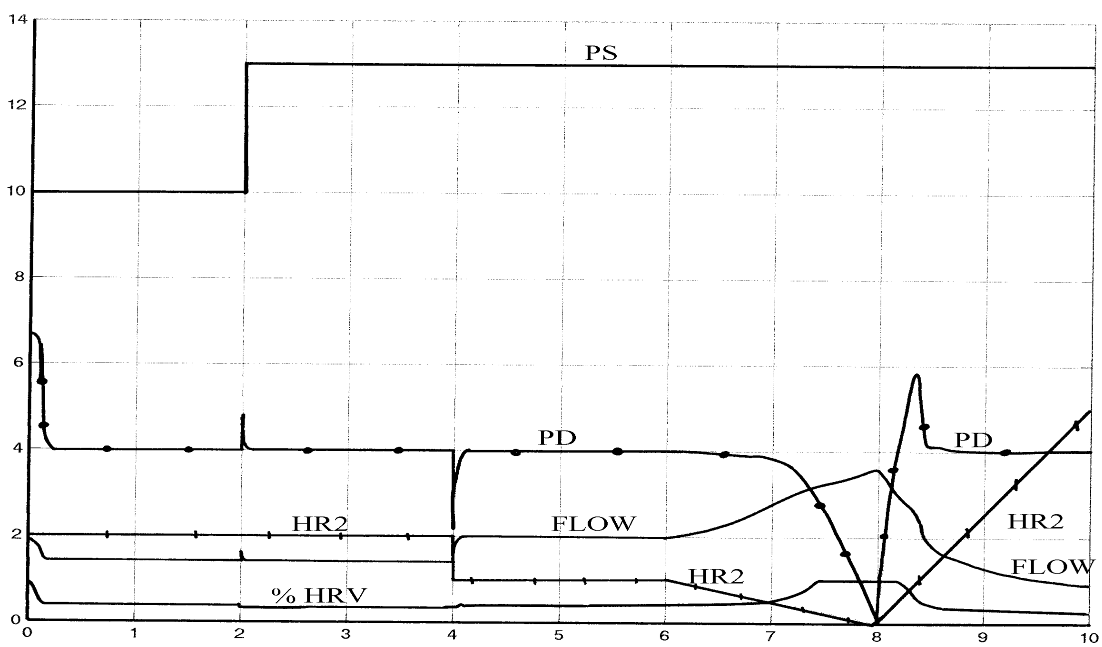


**Figure 4 – Downstream pressure controlling simulation: PS = variable input; HR1= constant; HR2 = variable.**

**4.2 Upstream pressure controlling–MATLAB simulation**

This self-acting control system maintains a constant preset upstream pressure whatever the variations in downstream demand. This valve guarantees the maintenance of pressure upstream. It can also prevent the flow rate intake in a pump from falling bellow a safe minimum. It prevents overstretching of pumping capacity when the demand is too great. Equipped with non-return valves, it closes automatically in the event of a return of water, or it opens automatically to reverse water flow if the upstream pressure becomes less than the downstream pressure.

For simulating in MATLAB the upstream pressure controlling, we use the diagram of fluid circuit on which control valve is mounted (Fig.5). Fig.6 must be inspected, with the dynamic results of the simulation.

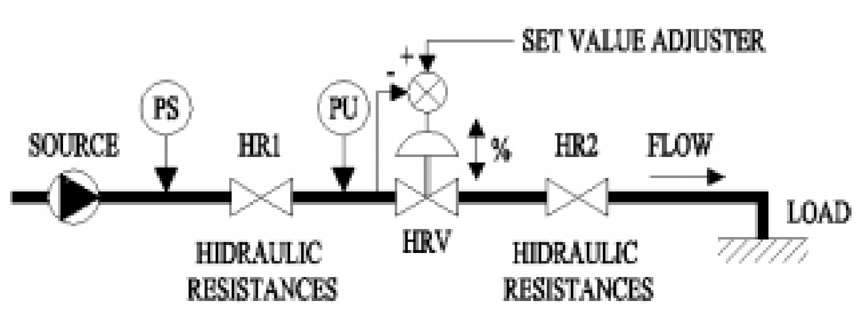


**Fig. 5 - Diagram of fluid circuit for upstream pressure  controlling**

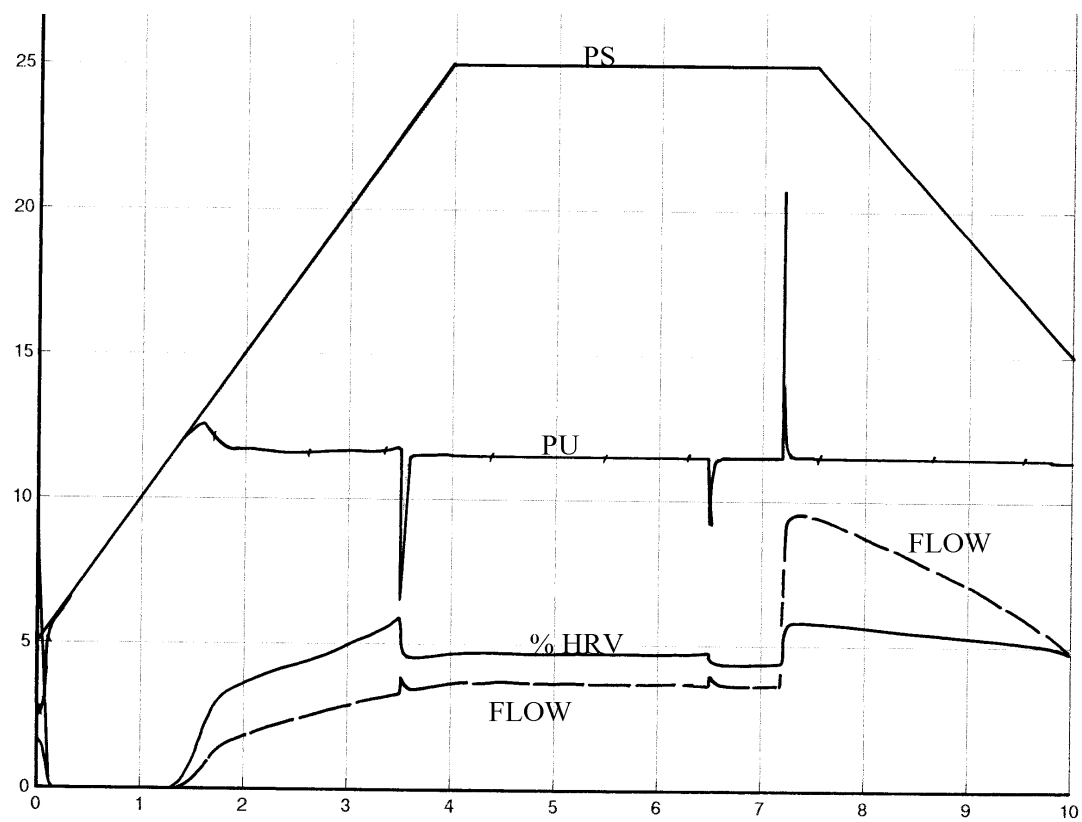


**Figure 6 – Upstream pressure controlling simulation: PS = variable input; HR1= variable; HR2 = variable.**

## 5 MATLAB simulation for self-acting automatic upstream-downstream pressure control valves

This self-acting control system maintains a constant preset reduced downstream pressure regardless of variations in downstream demand or upstream pressure. This valve guarantees the maintenance of pressure upstream, after the downstream demand become higher and the downstream pressure is impossible to maintained.

For simulating in MATLAB the downstream-upstream pressure controlling, we use the diagram of fluid circuit on which control valve is mounted (Fig.7). Fig. 8 must be inspected, with the dynamic results of the simulation.

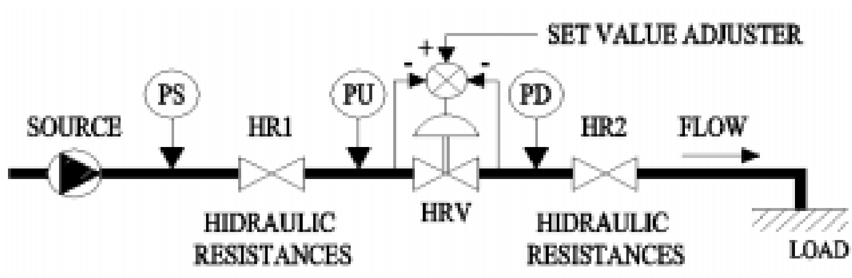


**Figure 7 – Diagram of fluid circuit for upstream pressure controlling**

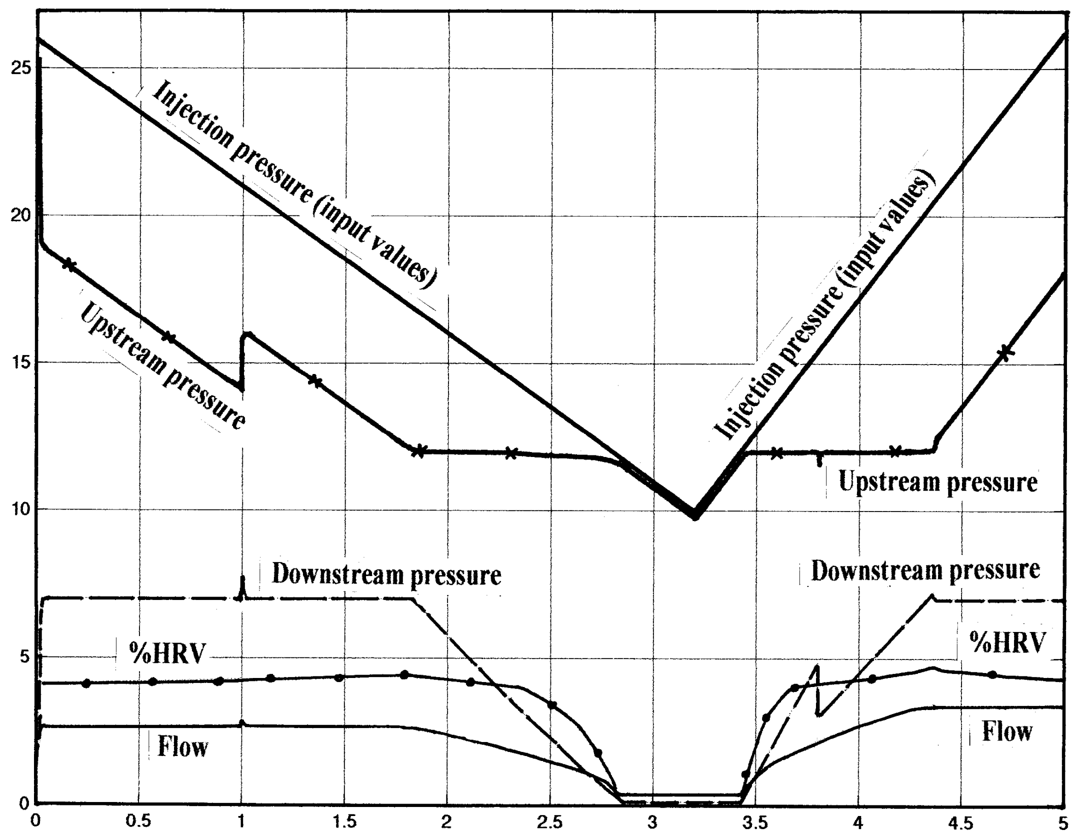


**Figure 8 – Downstream-Upstream pressure controlling simulation.**

The simulation presented in fig.8 has the next parameters:

- Injection pressure = a) initial input = 16; slope= -5; start time = 0.
  b) initial input = 10; slope= 14; start time = 3.2.
- RH1 = 1 if time = (0 to 1); RH1 = 0.7 if t>1;
- RH2 = 1 if time = (0 to 3.8); RH2 = 0.6 if t>3.8;

These hypothesis cover all the possibilities for the pressure evolution.

## 5 Conclusions

Simulating in MATLAB, achieved by the authors, is a powerful instrument for a better understanding and for efficiently integration in water systems. Self-acting pressure regulators are comparatively simple instruments from a constructional point of view. They are reliable and cheap, which explains their applications in water distribution network.

The work demonstrates the importance of the unitary analyses of the self acting pressure controllers, by simulating their functioning on a network sector.

We can thus outline limitations of the utilization possibilities and more than this we can determine the pressure variation limits, including by considering the controller specific response time.

The simulation offers to the experts from the water distribution networks exploitation the possibility to observe and to know the interactions between the pressure controllers and the network, decreasing thus the number of manual maneuvers.

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# APPROPRIATE TECHNOLOGY FOR WATER SUPPLY IN TROPICAL AFRICAN COUNTRIES

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## Abstract

Water is critical for sustaining development in tropical Africa. Population growth must be met while maintaining the standard of service. Discussions in this paper are concentrated on rural areas water supply that forms 60% of total demand. It should be emphasised that sustainable development can only be achieved through the decentralisation and privatisation of water supply services and the creation of local industries based on local artisan and professional skill development. The technologies adopted should be simple, durable with low maintenance and repair demands and suitable for rural community management. In this connection application of renewable energy technologies like hand pumps, wind pumps, soar pumps are discussed with related cost analysis. To reduce government expenditures and water resources, water services should be paid for or contribution in kind made by users in one way or the other. Regular evaluations of the state of art should be made and clear specifications on the range of technologies appropriate for the job provided, in order to identify the best options for providing sustainable yields that meet the community needs. Policies suggested in this paper can be communicated throughout the government system and also made available to both local communities and private sector.

## Keywords

Technologies; cost comparison; suggestions

## 1 Introduction

Botswana water resource is scarce and the annual demand projected to increase from 135 to 350 million cubic meter in 25 years period. Permanent water shortage, higher amounts of evaporation than precipitation, regular droughts, groundwater mining due to limited recharge are all related to natural climatic conditions for which the water supply systems must be designed to cope up. Majority of people lives in rural villages and depends mainly with groundwater. A tripartite settlement pattern between village lands area and cattle-post living is still maintained. People and livestock are mutually inter-dependant and hence drinking water is directly linked to watering of livestock also. Livestock raising is becoming principle source of rural income for majority of population. Water position in Botswana involves a mixed approach, where central and local Government shares responsibilities for services. The programme to provide all villages with reasonable access to safe water has been a tremendous task. The objectives of water provision for village households with access to water points within 200m, and the ongoing evaluation of land area, water provision is a worth goal in a developing country context, but need to be economically realistic! Water supply provision is officially limited to villages at least 5 years old, with a minimum of 100 households or 500 inhabitants and having been under the control of Local District Councils. But these conditions are not always being met with and many smaller villages and settlements are still under waiting list for the provision of satisfactory water supply. [1, 2]

## 2 Water Technologies – The State of Art

### 2.1 Pumps and Diesel engines

Over several decades 'Mono' screw pumps and 'Lister' diesel engines have been widely

Used for extracting ground water in Botswana. This has been a successful approach since a constant production and operation quality and reliability has been achieved. This has mainly emerged from the establishment of a government policy, which allowed the creation of a private supply and maintenance market. This concept has proven to be adequate for the large range of users at present. A support structure including the design/ installation/ repair/ maintenance and training of local staff and caretakers has been established. The great versatile of diesel engines makes it difficult to find a better power resource. The major disadvantage of this system has been its operation and Maintenance cost - somebody has to be trained to take care of pump and the engine together with fuel cost represent the reason for the total recurrent costs. High transport requirements/ costs due to the level of service and monitoring needed also do not favour this option for application in rural areas. Furthermore, the overall efficiency of this system is only 6 – 10%

### 2.2 Renewable Energy Systems

Renewable energy systems include hand, solar and wind pumping applications. A project has been undertaken during 1986 – 1990 aimed at establishing the future potential of renewable energy systems on a technical and economical basis. Although the project was complemented for unknown reasons its recommendations were not implemented. No follow-up from the government has been observed.

## 3 Renewable Energy Technologies – The State of Art

Major achievements in renewable energy technologies include the following

### 3.1 Wind mil pumps

Rotary pumps are at present able to pump from 200 – 300 m depth, however yields at this depth are limited to 5 – 8 $m^3$/day in average wind speeds of 3 m/s. In the range from 10 – 100 m depths several options are available, which provides a discharge between 10 – 30$m^3$/day again based on average conditions. Wind pumps are designed to most reliable requiring least maintenance and attention. They are expected to run unattended with only minor service once annually and major service or replacement only after 80 000 operational hours which is 6 to 10 times the span of a small diesel engine. Inevitably they are expensive in relation to their power output because of the robust nature of their construction. However the minimum recurrent costs make them a highly viable option especially in the coastal territories of Africa. In other places the major constraint remains with the available wind speeds. Botswana being an interior land locked country with less wind speed potential this method is less significant. The available power from a wind pump is given by

$P = K V^3$, where P = average available power from wind mil and V = wind velocity in m/s obtained from wind pattern density function and K = constant of proportionality.

It is found from few experimental wind mil stations in tropical African countries that the overall system efficiency which varies with the design concept and available wind speeds, ranges between 5 – 15 %.

### 3.2 Hand pumps

The hand pumps option is found to be the lowest cost option for the low yields in rural areas. The need for standardisation of handpumps for covering various applications has been already acknowledged and implemented by ministries and organisations. Henceforth the major objectives to be followed are the dissemination, reduce confusion and to create a supply network. However the standardisation is not always adhered to at all levels. Pumping equipment today, offers a range of operational modes i.e. traditional direct lift and lever action which are able to pump at a total head up to 110m of forced lift beyond the pump and transport through pipes to water reservoirs all of which are highly reliable and low maintenance systems. Still hand pumps are operated by hand which will reticulate village water supply for an individual household with an operator, as water has to be pumped in to an overhead tank. The overall efficiency of the system is 50 – 60%.

### 3.3 Solar Pumps

Solar pumping system is found to very expensive and cannot be used if total pumping head exceeds 150m or the power required is more than 1 to 1.5 kW as the number of panels needed are too expensive compared to other systems. DC and AC systems are available. DC systems tend to be more expensive on the pump side, however they have a higher total efficiency, demand smaller PV (Photo Voltaic) arrays and have lower recurrent costs than AC systems. AC pumps utilise conventional electric motors which are of lower price but have higher maintenance demands. Battery systems are inefficient and expensive too. In addition local arid climatic conditions may adversely affect their life and efficiency. Using inverters to change DC to AC voltage also demands batteries for power storage (often inverters cannot operate without a continuous supply of power). Inverters (maximum efficiency about 80%) are one of the vulnerable systems components when converting power from DC to AC. These units are rated for the start up surge, which normally will be 4 to 6 times the systems operational demand. Investments in reliable units are critical for developing arid countries since both power rating and operational reliability are linked with highly expensive units. Employing power conditioning to convert voltage places emphasis on regular maintenance by qualified technicians. Coupling a hybrid system with a standby generator require the system to be regularly serviced. An important factor is maintenance of the array, being mainly the cleaning of the solar panels to maintain panel efficiency. Overall system efficiency varies with the design and the components used. Options, which require less maintenance and use less power conditioning equipment, are the better long-term solution. Table 1 indicates costs for a 1 kW system operating at 50m depth and figure 1 shows the comparison of different technologies.

**Table 1. Technology cost comparison in US $**

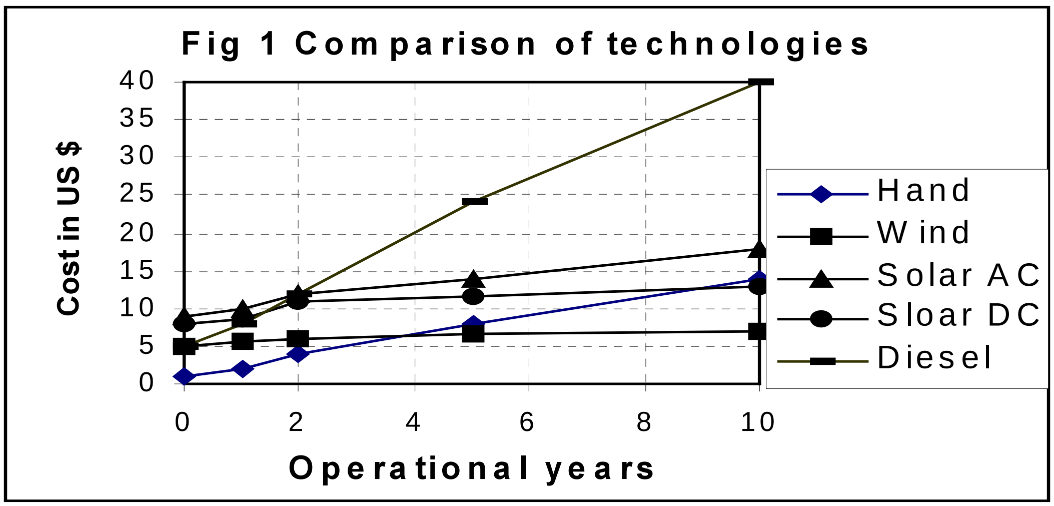
| Technologies | Investment cost | Annual recurrent cost | Yield $M^3$/hour Expected yield Maintenance |
|---|---|---|---|
| **Engine powered** | | | |
| Engine | 2200 | 700 | 3 - 10 |
| Pump | 1900 | 140 | |
| Ancillaries | 1200 | 3160 | high |
| Installation | 1200 | | |
| **Total** | **6500** | **4000** | high |
| **Wind mill pumps** | | | |
| Above ground level | 3950 | 140 | 0 - 8 |
| Pump | 1200 | 140 | |
| Ancillaries | 1750 | 140 (labour) | low - medium |
| Installation | 1000 | | |
| **Total** | **7900** | **420** | low |
| **Solar powered AC** | | | |
| PV arrays | 6500 | 60 | 0 - 10 |
| Inverters | 1250 | 200 | |
| Pump | 2950 | 140 | medium/high |
| Ancillaries | 1000 | 650 (labour) | |
| (batty/cabl/pipe) | | | medium/high |
| Installation | 1200 | | |
| **Total** | **12900** | **1050** | |
| **Solar powered DC** | | | |
| PV arrays | 6500 | 30 | 0 - 10 |
| Pump | 4000 | 140 | |
| Ancillaries | 650 | 420 (labour) | medium/high |
| Installation | 650 | | |
| **Total** | **11800** | **590** | low |
| **Hand pumps** | | | |
| Pump | 1200 | 30 | 1 - 2 |
| Ancillaries | 140 | 1670 (labour) | |
| Installation | 280 | | low |
| **Total** | **1620** | **1700** | low |

A wind generator is being tested at Botswana. It suited to the country's arid conditions and will be the cheapest and most effective alternative power source available. Wind generators are more cost effective than PV. If limitations concerning the availability of wind all round the year exists then a solar/wind hybrid could be very easily installed. This harnesses energy from both wind and sun to provide power, making it very reliable and efficient source for remote village water pumping.

## 4 Other Technologies

### 4.1 Water Treatment Systems

Where saline groundwater is found supply systems are often limited to desalination. Passive distillation with solar stills at our laboratory is providing pure water at very limited yield of 4 to 10 litres per unit per day and requires regular maintenance. Forced desalination has been tested through two different technologies; low pressure reverse osmosis plants - which has produced encouraging results and electro-dialysis, which has not been successful. High-pressure reverse osmosis has been recently constructed in South Africa, which has produced successful results in the process of saline water from




sea but ofcourse, with exorbitant cost for rural applications. The introduction of these technologies has given special consideration towards repairs and maintenance demands , which still have to be quantified. Various technologies for desalination have been tried and have been proven to be cable of supplying potable water.

Reeds beds have been investigated as biological systems for treatment of municipal, industrial and private wastewater. Water quality acceptable for horticulture watering is successfully achieved. A project is at present conducted by the author at Rural Industries Innovation Centre (RIIC) in Maun, Botswana.[2]

### 4.2 Rainwater harvesting

In many rural areas in Botswana, Tanzania and Kenya rainwater catchment from roofs and paved surface floors are in use. This system has, however, never been fully operational especially for the supply of potable water because of contamination with organic impurities.[3]

### 4.3 Sand rivers

Since sand river water storage capacities are substantial in parts of eastern Botswana and in many parts of Zimbabwe, several abstraction systems like filter beds and infiltration galleries have been developed from low yield domestic applications to high yield commercial farming systems. The limiting factor is the local river conditions.

## 5 Problems involved

Awareness of technical options in the water sector and general knowledge on appropriate solutions is very much needed in many arid African countries. In most cases evaluations are being undertaken by external consultants on contract basis at high cost. Alternate solutions are not in general being widely researched since existing systems are presently found to be affordable and meet expected service levels. The rural communities, which have government officials as their major source of information, are not always well informed or current technical developments. Limited participation in the water supply systems reduces the community responsibilities and involvement to a minimum. Government is expected to cater for all aspects from technology choice and initial investment, to the operation and maintenance costs.

## 6 Suggestions

1 Clean water is a pre-requisite for health and development and an economic product, which has to be valued. In order to save resources and maintain sustainable development water services have to be paid for or contributions in kind should be made by the users in one way or other.

2 Low yield technologies are at present followed in many areas. The evaluation of technologies should be based on the appropriateness for the job, for the community and for the resources available. The choice of technology should be *needs driven and not technology driven.* This basically boils out to selecting options available which will satisfy the need, based on available resources and a overall economic judgement both involving investment /recurring charges.

3 The lack of awareness and knowledge of appropriate technology options within the government as well as on a community level must be addressed. Community involvement will have to be increased and information channels strengthened and formalised. Information channels must be made two ways to cater for dissemination of knowledge and feedback to policy/decision makers to enable continuous reviews of standards and procedures to be implemented.

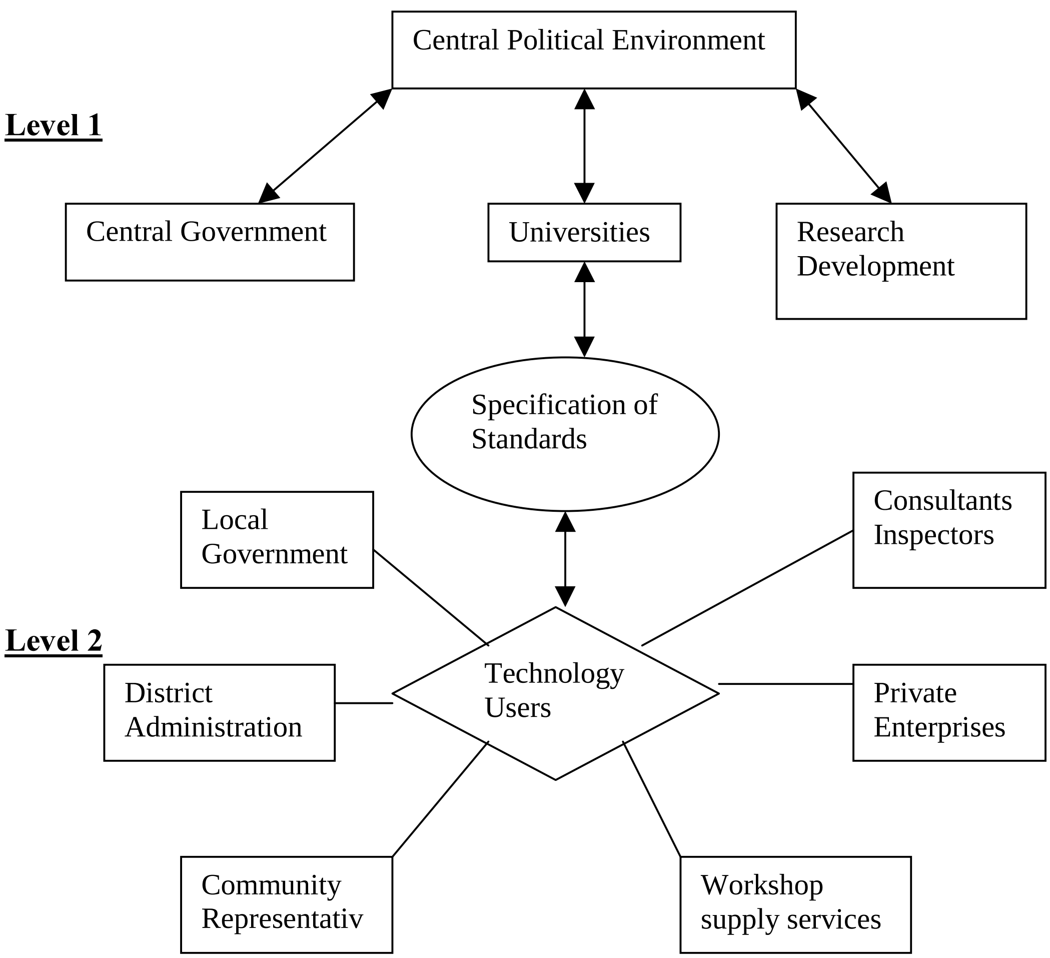
4 In establishing the recommended technology ranges. Policy makers and technical advisors both from within and outside government must be involved.

5 The co-ordination of private sector activities is a crucial factor in the success of low yield technology implementation. The balance between providing a high level of technical assistance and not interfering in the supply demand pattern must be found.

6 Local industries need to be organised and operated in a clearly defined regulated framework. Standardisation and stable policy are essential conditions. Public sector t of Public sector will specially require quality control and quality assurance. Certification will affirm that the specifications are adhered to and this may be achieved by involving independent inspection agencies. Established workshops should be identified for certification of water supply technology manufacture. To enable immediate quality performance highly skilled staff should be appointed both at the administration and manufacturing levels for the initial period. Specifications towards production resources, machinery and skills must be available to ensure development of a competitive industry.

7 In a limited market such as Botswana, local manufacture and services can only succeed if all parties direct orders towards their home industries. Channelled order volumes based on rural water supply will ensure economic viability for small-scale industries, which will also be an incentive for income diversification.[4]

**Fig. 2 Proposed Institutional Structure for Water Supply Programme**



8 A structure defining all relevant players in appropriate water supply programmes is hereby proposed.

9 The desalination programme can be extended and expanded to those areas where no other viable option for water supply exists.

10 Rehabilitation and improvements of traditional water resources and the introduction of rainwater catchment systems should be promoted.

11 Recurrent cost existing water supply schemes are major constraint. Existing rural village water supplies should be evaluated in light of the existing range of appropriate technologies in order to reduce recurrent costs and increase community participation.

12 In the introduction new technologies information channels must be created and strengthened to cater for dissemination of knowledge and feedback to policy/decision makers to enable continuous reviews of standards and procedures.

13 In a city such as Gaborone 18000 $m^3$ of wastewater is produced everyday. Smaller, although still significant amounts of waste water is produced by villages and even by individual households. A clear, policy, backed by the necessary legislation, is formed for wastewater management.

14 A local, regional and if necessary an international study be conducted by every African arid countries so that suitable appropriate technology can be decided as adaptable, available and ultimately transferable.

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# The Prediction Method of Water Temperature in Distribution Pipes

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## Abstract

Hot water supply system accounts for more than 30% of all energy consumption in buildings such as hotel, residential houses and hospitals. In considering energy conservation in buildings, therefore, reduction of energy consumption in hot water supply system poses an important issue. The first step to grapple with this problem is to predict water supply temperatures.

In this report we measured water temperatures at purification facilities in 9 major cities in Japan, conducted correlation analysis in relation to air temperature, and established regressive equations to predict water temperature from air temperature. A prediction method of water temperature is indicated based on the calculation models for two separate water passages: one from the source of rivers to purification facilities, the other from purification facilities to distribution pipes.

## Keywords

Hot water supply system, Water distribution pipes, Water temperature, Prediction method

## 1 Introduction

The percentages of energy consumption accounted for by hot water supply system in various types of buildings in Japan are: approximately 3% in office buildings, over 40% in hospitals, roughly 35% in residential houses and about 30% in hotels (Figure 1). In considering energy conservation in buildings, reduction of energy consumption in hot water supply system plays an important role. To measure efficiency of energy conservation, we used coefficient of energy consumption for hot water supply (CEC/HW). In this method Japan is divided into 9 climatic regions and hot water supply loads are estimated for each region based on monthly water supply temperatures. Energy control of water supply system, therefore, necessitates prediction of water temperatures.

In Japan approximately 30% of water used for water works is derived from underground and 70% from rivers (Figure 2). The temperatures of river water when passing through purification facilities and distribution pipes are affected by weather conditions, particularly by air temperatures, and they can be estimated by calculation.

In this present study we measured water temperatures at purification facilities in 9 cities on the basis of climatic regions in Japan (Figure 3), analyzed their relationship to air temperature and proposed regression equations to predict water temperature from air temperature data. Furthermore, methods for predicting water temperature were developed for two separate water passages; one from the source of rivers to purification facilities, the other from purification facilities to distribution pipes.

## 2 Correlation between Water and Air Temperatures

### 2.1 Outline of Survey and Analysis

Water temperatures at 9 major purification facilities (Sapporo, Sendai, Niigata, Nagoya, Tokyo, Osaka, Fukuoka, Kagoshima, and Kochi) over the period of 1991-1994 were measured. The climatic data of AMeDAS (Automated Meteorological Data Acquisition System) were used for air temperatures.

In order to find annual and seasonal changes in the relationship between water and air temperatures at the purification facilities in Tokyo, we conducted correlation analysis both annually (from January through December) and seasonally (spring: April and May, summer: June to September, fall: October and November, winter: December to March). Since it is highly likely that previous air temperatures have any effect on the water temperature at purification facilities, we checked air temperatures of 3 days prior to the measurement of water temperatures and moving average temperatures of up to 10 days prior against water temperatures for correlation. In the following text, tables, and figures, the day air temperature was measured is designated as DAY-0, 1 day before DAY-1, 2 days before DAY-2, and 3 days before DAY-3 on the basis of the day measured water temperature, respectively.

### 2.2 Results

As the first step we will outline correlation analyses conducted for 4 days (on DAY-0, DAY-1, DAY-2, DAY-3) and moving average temperatures for up to 10 days before DAY-0 taking purification facilities in Tokyo for example. Next, the result of correlation analysis based on annual data of 9 cities and effect of low air temperatures are discussed.

#### (1) Result of analysis in Tokyo

Figure 4 shows the fluctuations of air and water temperatures in Tokyo. Water and air temperatures changed concomitantly, but air temperatures were typically higher than water temperatures in summer and the tendency was reversed in winter.

**a) Analysis based on air temperatures**

Correlation coefficient between water and air temperatures on each measurement day (DAY-0, DAY-1, DAY-2, DAY-3) based on annual data is shown in Figure 5, and that based on seasonal data is shown in Figure 6. Correlation coefficient tended higher for both annual and seasonal data on DAY-1 and DAY-2. The highest correlation coefficient was 0.89 in spring and fall followed by 0.80 in summer and 0.70 in winter.

**b) Analysis based on moving average temperatures**

Correlation coefficient between water temperatures and moving average air temperatures based on annual data is shown in Figure 7, and that based on seasonal data in 1993 is shown in Figure 8. Correlation was the highest with 6 days moving average temperatures in annual analysis while seasonally correlation was high with 4 days moving average temperatures in spring and fall, with 6 days in summer, and 7 days in winter. In all seasons correlation with one day average was the lowest. Seasonally the highest correlation coefficient was 0.92 in spring and fall, and 0.81 in summer, then 0.76 in winter. This agrees with the result of analysis based on air temperatures measured on each measurement day.

**(2) Results of analysis in 9 cities**

**a) Analysis based on air temperatures**

Table 1 shows the days on which air temperatures were measured, highest and lowest values of correlation coefficient based on annual data for 8 cities in 1993. Here the analysis is based on purified water. However, the temperatures of river water were used for the cities where no data was obtained on purified water. Kagoshima is not included in the analysis since water temperature was measured only once a month in the city.

Correlation coefficient was highest on DAY-3 in Sendai and Nagoya, DAY-2 in Osaka and DAY-1 in the other cities. The lowest correlation coefficient was seen on DAY-3 or DAY-0 except for Nagoya. In Sapporo and Sendai correlation coefficient was lower than the other cities. It is probable that low temperatures in these cities in winter lowered the correlative values between water temperatures and air temperatures.

**b) Relationship between water temperature and low air temperature**

As mentioned above correlation coefficient in Sapporo and Sendai was lower than the other cities. It is assumed that in winter the water temperature does not change concomitantly with the air temperature in these cold regions because of a large number of days with average air temperatures below freezing point. Therefore we then analyzed the relationship between low air temperature and temperature of purified water taking Sapporo as an example.

Figure 9 shows the changes in water temperatures and air temperatures from April 1991 through March 1994. It can be clearly seen that the temperature of purified water leveled off when air temperature is below 5 ºC, and the overall correlation is extremely low. In view of this fact two separate regression equations were created; one for the air temperatures where the correlation coefficient with water temperatures begin to increase and the other for the air temperatures below that point. The point where this shift in correlation occurred is called the shifting temperature point. As a result the air temperature at the shifting point was found to be 4 degrees centigrade, and the regression model is shown in Figure 10.

### 2.3 Calculation of Tap Water Temperature in each region

Based on the analyses described above, the highest correlation coefficient can be obtained when moving average temperatures of several days prior to DAY-0 are used. This procedure, however, requires complex calculation. On the other hand correlation coefficient derived from actual air temperatures is only a little lower than that obtained from moving average temperatures. When correlation coefficients on each air temperature measurement days are compared, the differences are insignificant, but coefficient is lowest on DAY-0. Taking this fact into consideration, we adopted regression equations, which are based on air temperatures on DAY-0. Table 2 shows highest and lowest values of both water and air temperatures, regression coefficient and regression constant. The temperatures obtained from these regression equations are water temperature at purification facilities, and not necessarily identical to the temperature of tap water. Here, however, the two are considered as the same for the sake of convenience.

## 3 Prediction of Tap Water Temperature

Temperatures at two different water passages; one from rivers to purification facilities and the other from purification facilities to water taps were measured, and a prediction method was postulated. To test the accuracy of the method, temperatures were measured at Kanamachi purification facilities in Tokyo for both river water and purified water, and data were also collected from 13 thermometers installed throughout the distribution pipes. The climatic data of AMeDAS were used for air temperatures and solar radiation.

### 3.1 Prediction of Inlet Water Temperature

The temperature of river water rises or drops as a result of heat exchange with atmosphere or riverbed as the river travels along. The temperatures predicted by Kondo's equations[3)] were checked against the actual temperatures of inlet water (water temperatures at the inlets of purification facilities), and examined if the equations can be used as a prediction model. The actual inlet water temperatures were taken from 1993 data. In Kanamachi purification facilities, temperature at the water intake was considered identical to inlet water temperature since the water intake is only 10m away from the purification facilities.

**(1) Outline of calculation model and methods**

The temperature of river water is affected by atmospheric conditions (solar radiation, air temperature) and other factors such as water temperature at the source, water depth, flow speed, and thermal capacity and thermal conductivity at the riverbed.

To begin with temperature at the river source ($T_0$) was calculated, and then temperature at the water intake ($T_{WM}$) was figured out from $T_o$ and equilibrium temperature ($T^*$). The equations are shown in Tables 3~5.

Temperature at the river source was considered the same as that of raindrops when there is precipitation, and as an average of the soil temperatures at the depth of $Z_1$ (1.5m) and $Z_2$ (0.1m) when there is no precipitation. River conditions were analyzed by changing water depth ($d_w$) and the time ($\tau$) that takes water to move from the river source to the purification facilities ($l_x$).

**(2) Results**

The predicted temperatures matched most closely with actual temperatures when 11 hours elapsed, on condition of water depth : $d_w$ = 0.5m, elapsed time: $\tau$ = 1~20 hours with an increment of 1 hour (Figure 11). Table 6 shows mean deviation between predicted and actual temperatures of inlet water when water depth ($d_w$) was changed from 0.2m to 1.0m with an increment of 0.1m. As a result inlet water temperatures are found to be predicted with an accuracy of ±1.5~2.0 ºC

### 3.2 Prediction of Tap Water Temperature

The temperature of water carried from purification facilities to water taps changes as a result of heat exchange with the soil around distribution pipes. Taking heat balance into consideration, we created equations to obtain tap water temperature from the length of distribution pipes, compared predicted water temperatures with actual water temperatures.

**(1) Outline of Calculation Model and Calculation Method**

A simplified model of a distribution pipe is shown in Figure 12, an actual model including diameter and length in Figure 13, and a schematic representation of cross section of a pipe in Figure 14. Tables 7~9 show equations to obtain underground soil temperatures, over-all heat transfer coefficient, and temperatures at water tap. Mean deviations (Σ| y' - y|/n) between predicted temperatures (y') and actual temperatures (y) were obtained with depth of pipes and over-all heat transfer coefficient below as parameters, and the validity of the prediction equations was analyzed. Pipe diameters shown in Table 7 are those of the main pipes.

① depth of pipes ($Z$): constant at 1.2m and variable between 0.5m and 1.5m with an increment of 0.1m

② over-all heat transfer coefficient ($K_L$): variable in the range of 0~4190 kJ/($m^2$ . h . ºC) with an increment of 209.5.

**(2) Calculation results**

Mean deviations were calculated under the conditions shown in Table 7 with the depth of pipes as constant at 1.2m. As a result water tap A showed the largest mean deviation and water tap M the smallest. Figure 12 and 13 show the changes of predicted temperatures and actual temperatures over time between the two water taps. When the depth of pipes were varied, mean deviation was the smallest at the depth of 0.7~0.9m, but the difference from the result at the depth of 1.2m was small (0.5). The calculation results with variable over-all heat transfer coefficient showed small mean deviations when over-all heat transfer coefficient values are lower than those shown in Table 7. This was due to the fact that over-all heat transfer coefficients in Table 7 were calculated with a constant pipe diameter (diameter of main pipes).

Mean deviations of over-all heat transfer coefficients and temperatures derived from a simplified model (with constant pipe diameter) and actual model (with variable diameters) on water tap A and water tap M are shown in Table 11. Over-all heat transfer coefficients are smaller in an actual model than in a simplified model. Mean deviations of tap water temperatures calculated with an actual model were approximately 1.9 (water tap A) and 0.5 (water tap M). Therefore we can conclude that the equations achieved a high degree of prediction accuracy.

## 4 Conclusion

In this report we have examined the method to predict tap water temperatures based on air temperatures. The results can be summarized as follows:

(1) Comparison of water temperatures with air temperatures on DAY-0, DAY-1, DAY-2, and DAY-3 at purification facilities in 9 major cities showed the highest correlation coefficient on DAY-1 in 7 cities.

(2) When compared with moving average air temperatures, correlation coefficient was highest with 6 days moving average.

(3) Seasonally correlation coefficient was highest in spring and fall followed by summer and winter.

(4) Correlation between air and water temperatures was extremely low when air temperature was below 4ºC.

(5) We proposed regression equations (regression coefficient, regression constant) for each of the nine cities based on annual data with air temperatures as a variable.

(6) We predicted inlet water temperatures using prediction equations, and found the equations have an accuracy of ±1~2ºC.

(7) We created prediction equations for water temperatures in distribution pipes and predicted the temperatures at 13 water taps. Comparison with actual data showed that the equations are accurate within a tolerance of 2ºC.

As a next step we intend to develop a method to predict water temperatures in water and hot water supply systems in buildings, and establish an overall water temperature prediction system which covers the whole process of water supply from rivers to buildings.

Note: Though we did not mention in the text, we measured the temperatures of inlet and outlet water at the purification facilities and found that the temperature of outlet water is approximately 0.5~1.5ºC higher than that of inlet water.

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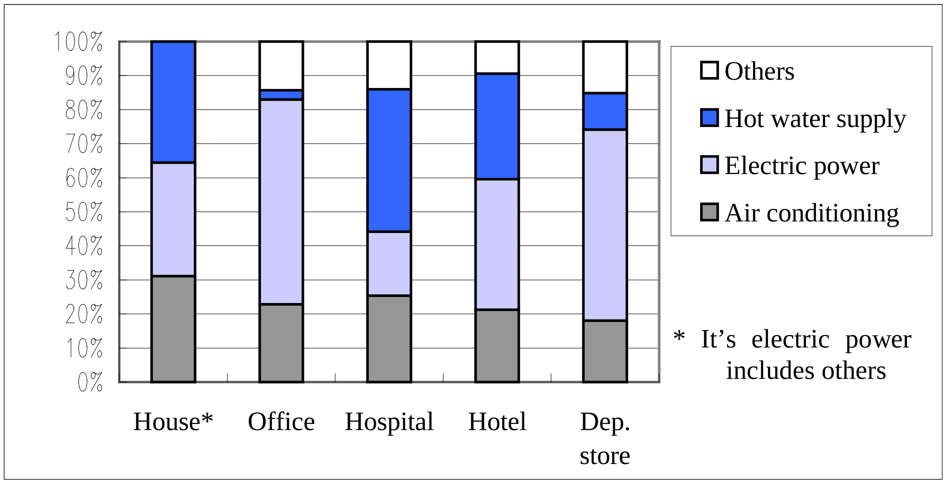



**Figure 1 Ratio of energy consumption for various uses in various types of buildings[1)]**

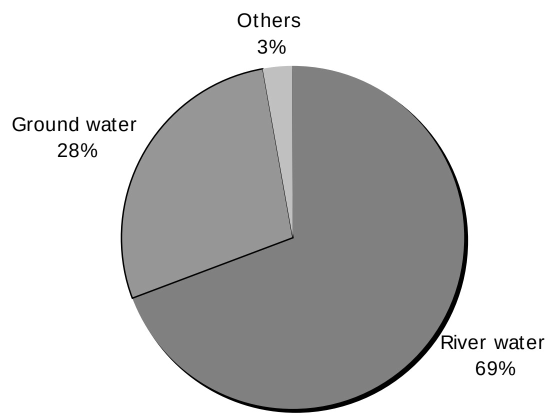



**Figure 2 Ratio of various types of water sources for water works (1995)[2)]**

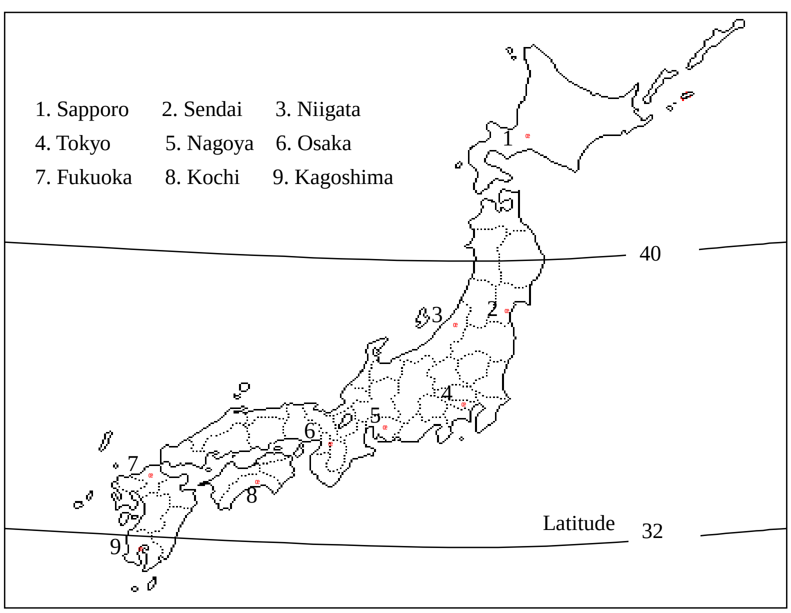



**Figure 3 9 cities on the basis of climatic regions in Japan**

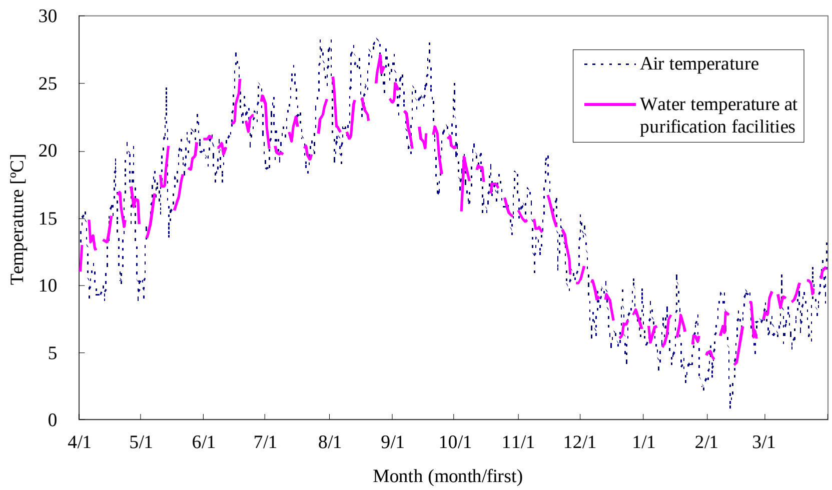



**Figure 4 Changes in relationship between water temperature at purification facilities and air temperature (Tokyo)**

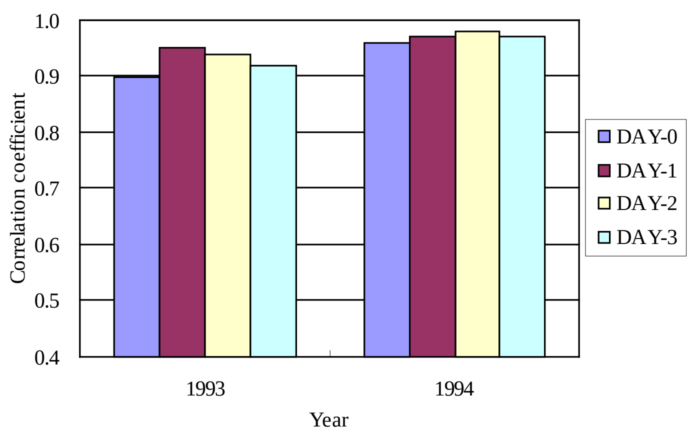



**Figure 5 Correlation coefficient between water and air temperature on each measurement days based on annual data**

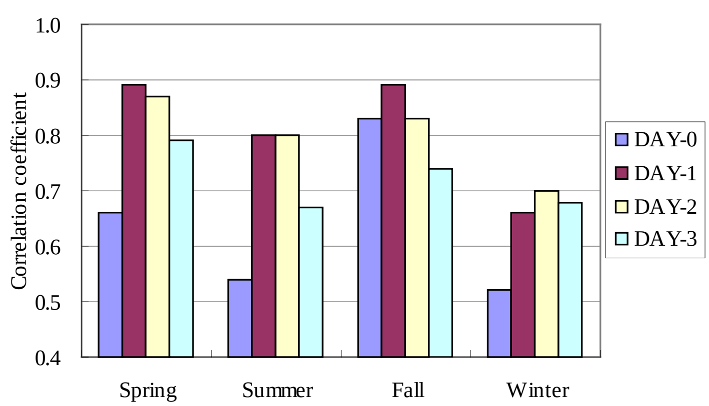



**Figure 6 Correlation coefficient between water and air temperature on each measurement days based on seasonal data in 1993**

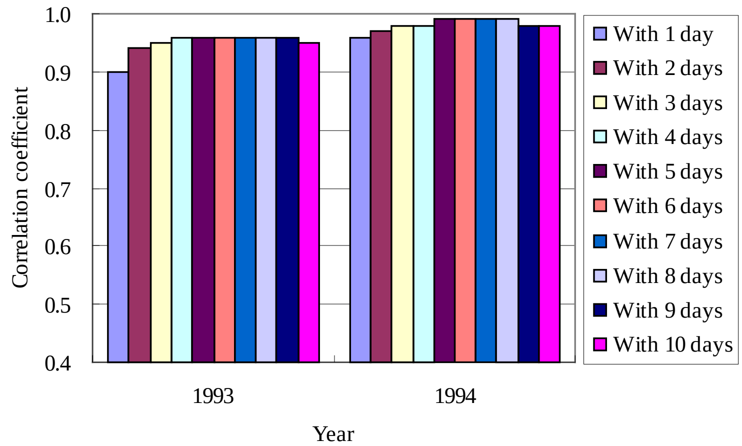



**Figure 7 Correlation coefficient between water temperature and moving average air temperature with each 1 ~ 10 days based on annual data**

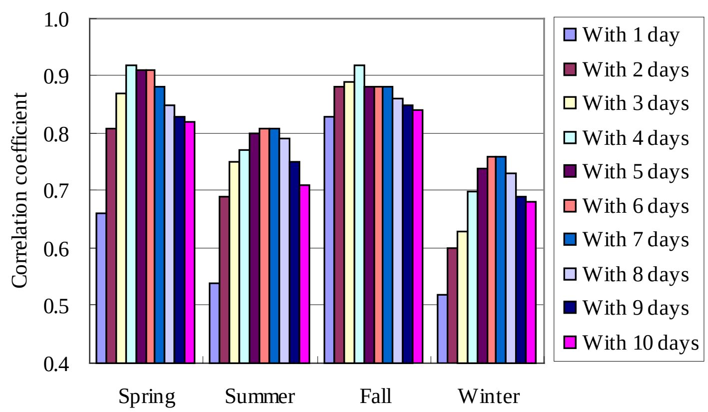



**Figure 8 Correlation coefficient between water and moving average air temperature with each 1 ~ 10 days based on seasonal data in 1993**

**Table 1 Max. and min. of correlation coefficient between water and air temperature on each measurement day based annual data (1993) in 8 cities**

| City | Max. | | Min. | |
|---|---|---|---|---|
| | Correlation coefficient | Measurement day of air temperature | Correlation coefficient | Measurement day of air temperature |
| Sapporo | 0.91 | DAY-1 | 0.90 | DAY-3 |
| Sendai | 0.93 | DAY-3 | 0.92 | DAY-0 |
| Niigata | 0.98 | DAY-1 | 0.96 | DAY-3 |
| Nagoya | 0.95 | DAY-3 | 0.94 | DAY-2 |
| Tokyo | 0.95 | DAY-1 | 0.90 | DAY-0 |
| Osaka | 0.99 | DAY-2 | 0.98 | DAY-0 |
| Fukuoka | 0.95 | DAY-1 | 0.92 | DAY-0 |
| Kochi | 0.96 | DAY-1 | 0.95 | DAY-3 |

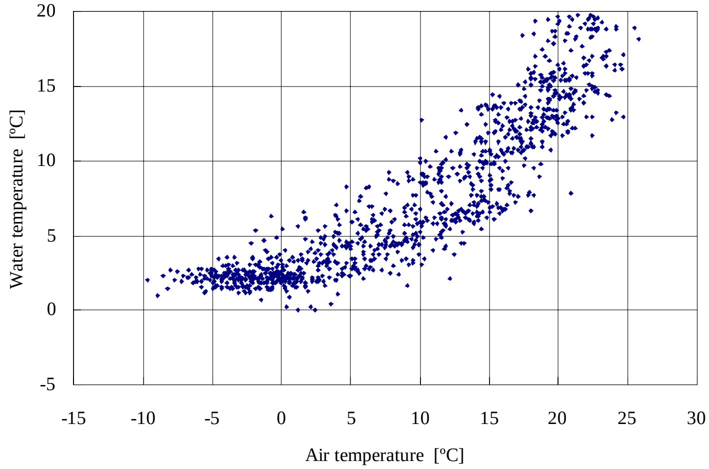



**Figure 9 Relationship between water and air temperature (DAY-0), April 1991 ~ March 1994, in Sapporo**

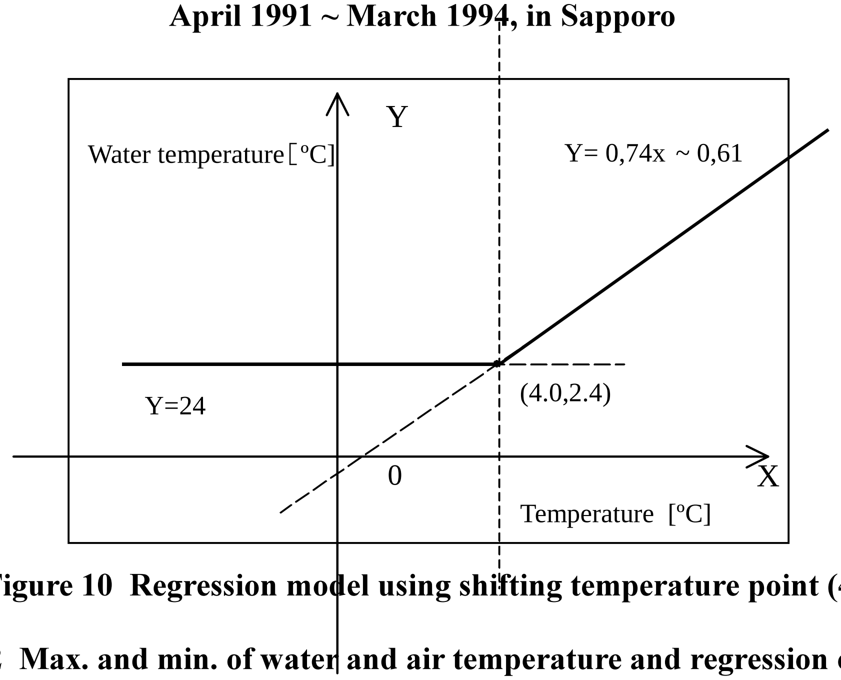



**Figure 10 Regression model using shifting temperature point (4ºC)**

**Table 2 Max. and min. of water and air temperature and regression coefficient and constant in 9 cities**

| City | Air temperature [ºC] | | Water temperature[ºC] | | Regression coefficient | Regression constant |
|---|---|---|---|---|---|---|
| | Max. | Min. | Max. | Min. | | |
| Sapporo | 25.8 | -9.7 | 19.7 | 0.0 | 0.53 | 2.62 |
| Sendai | 29.8 | -2.0 | 24.5 | 3.0 | 0.72 | 3.42 |
| Niigata | 29.7 | 0.0 | 27.0 | 0.0 | 0.84 | 1.88 |
| Nagoya | 33.3 | -0.7 | 28.0 | 4.4 | 0.72 | 3.36 |
| Tokyo | 32.4 | 0.9 | 31.6 | 4.1 | 0.89 | 2.23 |
| Osaka | 32.9 | 1.6 | 31.3 | 5.6 | 0.86 | 2.09 |
| Fukuoka | 32.1 | 0.2 | 25.9 | 8.2 | 0.52 | 7.89 |
| Kagoshima | 30.6 | 6.3 | 26.4 | 11.6 | 0.62 | 6.07 |
| Kochi | 30.8 | 0.8 | 28.3 | 5.4 | 0.73 | 3.14 |

**Table 3 Equations for temperature of river source**

$$T_0 = \frac{T(z_1)+T(z_2)}{2} \tag{1}$$

$$T(z) = \sum_{n=1}^{12} F_n \cos(n\omega_Y t - \phi_{YN} - \varepsilon_{Yn}) \tag{2}$$

$$T_s = \sum_{n=1}^{12} f_n \cos(n\omega_Y t - \phi_{YN}) \tag{3}$$

$$F_n = f_n \exp\left[-z\left(\frac{\omega_Y}{2a}\right)^{\frac{1}{2}}\right],\ \varepsilon_{Yn} = z\left(\frac{\omega_Y}{2a}\right)^{\frac{1}{2}} \tag{4}$$

$T_0$: Temperature of river source [ºC], $T(z)$: Underground soil temperature [ºC],
$T□_S$: Ground surface temperature [ºC], $\omega$: Frequency in a day(2π/86400[S$^{-1}$]), $\phi$: Phase difference, : Emissivity of water long wave, $a$: Temperature diffusion coefficient (0.7×10$^6$[m$^2$S$^{-1}$])
[Affix]
M: Average value in a day, Y: Seasonal variation, W: Water volume

**Table 4 Equations for equilibrium temperature**

**Erro! Vínculo não válido.** (5)

$$R_M^{\downarrow} = (1 - ref_W) S_M^{\downarrow} + \varepsilon L_M^{\downarrow} \tag{6}$$

$$\chi = \iota \rho C_H U_M [q_{SAT}(T_M) - q_M] \tag{7}$$

$$\mu = 4\varepsilon\sigma T_M^3 + c_P \rho C_H U_M + \iota\rho C_H U_M \Delta \tag{8}$$

$$C_H U_M = (C_H U_M)_{U=0} + 0.00566(U^{0.8} / X^{0.2}),\ (C_H U_M)_{U=0} = 0.001 \tag{9}$$

$$\Delta = \frac{6.1078(2500 - 2.4T)}{0.4615(273.15+T)^2} \times 10^{7.5T/(237.3+T)} \times \frac{0.622p}{(p - 0.378e_{SAT})}$$

$T^*$: Equilibrium temperature [ºC], $T_M$: Air temperature (=23[ºC]),
$R_M$: Input solar radiation,
$X$: Transport volume of latent heat [Wm-$^2$],
$\mu$: Coefficient on infrared radiant, sensible heat and latent heat for condition of saturation humidity

**Table 5 Equations for predicted water temperature**

$$T_{WM} = T_0 + (T^* - T_0)\left[1 - \exp\left(-\frac{\tau}{\tau_0}\right)\right] \tag{10}$$

$$\tau_0 = \frac{c_W \rho_W d_W}{\mu} \tag{11}$$

$T_0$: Temperature of river source [ºC], $\tau$: Elapsed time from river source to water intake [s],
$\tau_0$: Response time for water temperature [s]

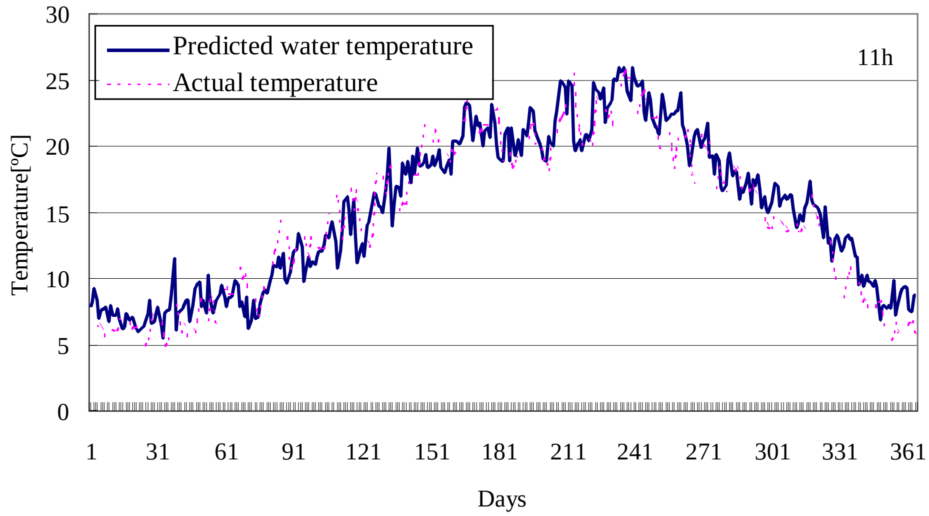



**Figure 11 Comparison of predicted water temperature with actual water temperature at inlet of purification facilities**

**Table 6 Mean deviation between predicted and actual temperature of inlet water changing elapsed time and water depth (*dw*)**

| Elapsed time (τ) ) [h] | Water depth (*dw* ) [m] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
| 0 | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 | 2.10 |
| 1 | 1.81 | 1.90 | 1.95 | 1.97 | 1.99 | 2.01 | 2.02 | 2.03 | 2.03 |
| 2 | 1.62 | 1.74 | 1.81 | 1.86 | 1.90 | 1.93 | 1.95 | 1.96 | 1.97 |
| 3 | 1.50 | 1.62 | 1.71 | 1.77 | 1.81 | 1.85 | 1.88 | 1.90 | 1.92 |
| 4 | 1.44 | 1.53 | 1.62 | 1.69 | 1.74 | 1.78 | 1.81 | 1.84 | 1.86 |
| 5 | 1.44 | 1.48 | 1.55 | 1.62 | 1.67 | 1.72 | 1.76 | 1.79 | 1.81 |
| 6 | 1.47 | 1.44 | 1.50 | 1.56 | 1.62 | 1.67 | 1.71 | 1.74 | 1.77 |
| 7 | 1.51 | 1.44 | 1.47 | 1.52 | 1.57 | 1.62 | 1.66 | 1.70 | 1.72 |
| 8 | 1.56 | 1.45 | 1.44 | 1.49 | 1.53 | 1.57 | 1.62 | 1.66 | 1.69 |
| 9 | 1.61 | 1.47 | 1.44 | 1.46 | 1.50 | 1.54 | 1.58 | 1.62 | 1.65 |
| 10 | 1.67 | 1.50 | 1.44 | 1.44 | 1.48 | 1.51 | 1.55 | 1.58 | 1.62 |
| 11 | 1.72 | 1.53 | 1.45 | 1.44 | 1.46 | 1.49 | 1.52 | 1.55 | 1.59 |
| 12 | 1.78 | 1.56 | 1.46 | 1.44 | 1.44 | 1.47 | 1.50 | 1.53 | 1.56 |
| 13 | 1.83 | 1.60 | 1.49 | 1.45 | 1.44 | 1.46 | 1.48 | 1.51 | 1.54 |
| 14 | 1.88 | 1.63 | 1.51 | 1.46 | 1.44 | 1.44 | 1.47 | 1.49 | 1.52 |
| 15 | 1.93 | 1.67 | 1.54 | 1.47 | 1.44 | 1.44 | 1.46 | 1.48 | 1.50 |
| 16 | 1.97 | 1.71 | 1.56 | 1.49 | 1.45 | 1.44 | 1.44 | 1.47 | 1.49 |
| 17 | 2.01 | 1.74 | 1.59 | 1.50 | 1.46 | 1.44 | 1.44 | 1.45 | 1.47 |
| 18 | 2.04 | 1.78 | 1.61 | 1.52 | 1.47 | 1.45 | 1.44 | 1.44 | 1.46 |
| 19 | 2.07 | 1.81 | 1.64 | 1.54 | 1.48 | 1.45 | 1.44 | 1.44 | 1.45 |
| 20 | 2.10 | 1.85 | 1.67 | 1.56 | 1.50 | 1.46 | 1.44 | 1.44 | 1.44 |

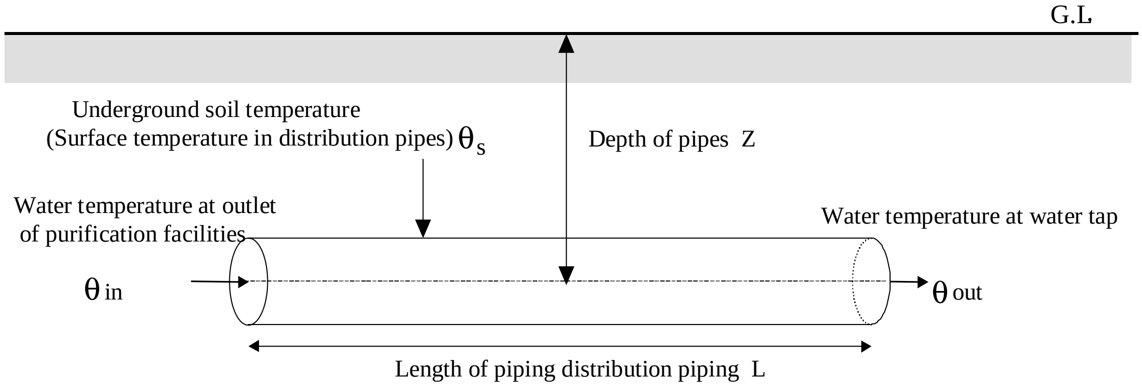
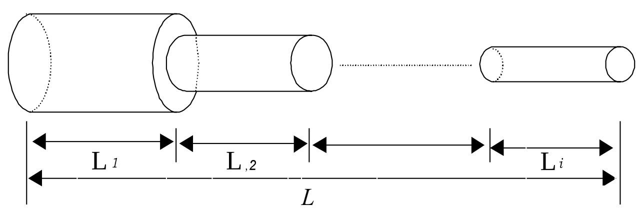



**Figure 12 Simplified model of distribution piping**




$$\overline{K} = \frac{\sum K_i L_i}{L} = \frac{K_1 L_1 + K_2 L_2 + \cdots + K_i L_i}{L}$$

**Figure 13 Actual model of distribution piping**

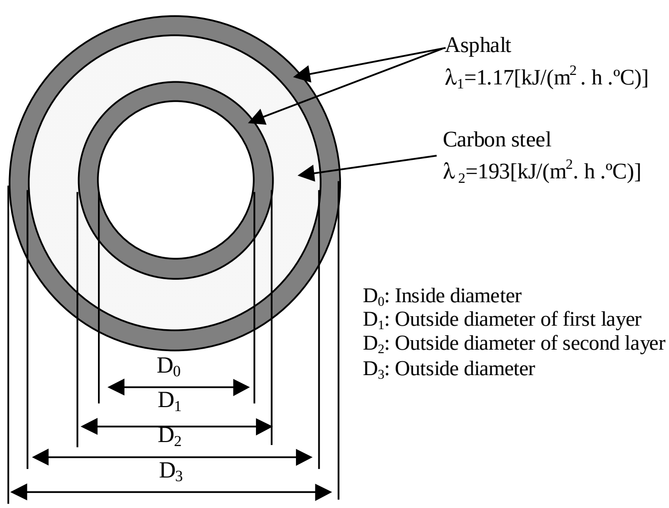



**Figure 14 Cross section of distribution piping**

**Table 7 Conditions of distribution piping with water taps**

| Water tap | Distribution line | Nominal diameter [mm] | Outside diameter [mm] | Internal diameter [mm] | Length of piping [m] | Over-all heat transfer coefficient [kJ/(m$^2$. h . ºC)] |
|---|---|---|---|---|---|---|
| A | Touzai line | 2200 | 2235.2 | 2195.2 | 14596 | 1453.5 |
| B | Yotugi line | 1500 | 1524.0 | 1496.0 | 16963 | 997.6 |
| C | Terashima line | 1800 | 1828.8 | 1796.8 | 13226 | 1194.9 |
| D | Touzai line | 2200 | 2235.2 | 2195.2 | 12723 | 1453.5 |
| E | Terashima line | 1800 | 1828.8 | 1796.8 | 18961 | 1194.9 |
| F | Mizue line | 700 | 711.2 | 697.2 | 8957 | 468.8 |
| G | Terashima line | 1800 | 1828.8 | 1796.8 | 8062 | 1194.9 |
| H | Senjyu line | 1200 | 1219.2 | 1197.2 | 3129 | 800.7 |
| I | Senjyu line | 1200 | 1219.2 | 1197.2 | 7032 | 800.7 |
| J | Kahama line | 2400 | 2438.4 | 2394.4 | 16315 | 1582.1 |
| K | Kahama line | 2400 | 2438.4 | 2394.4 | 19470 | 1582.1 |
| L | Kahama line | 2400 | 2438.4 | 2394.4 | 19061 | 1582.1 |
| M | Kahama line | 2400 | 2438.4 | 2394.4 | 17158 | 1582.1 |

**Table 8 Equation for earth temperature**

$$T_{GRZ} = T_{GRO} + \frac{1}{2}\Delta T_{GRS} e^{-0.526Z} \cos\{0.017214(n - 213 - 30.556Z)\} \quad (12)$$

$T_{GRZ}$: Underground soil temperature [ºC], $T_{GRO}$: Average temperature of a year [ºC],
$Z$: Depth of pipes [m], $\Delta T_{GRS}$: Difference of ground surface temperature in a year [ºC], n: Days

**Table 9 Equation for over-all heat transfer coefficient**

$$\frac{1}{K_L} = \frac{1}{\pi}\left\{\frac{1}{\alpha_0 D_0} + \frac{1}{2}\sum_{i=1}^{N}\frac{1}{\lambda}\log\left(\frac{D_i}{D_{i-1}}\right) + \frac{1}{\alpha_N D_N}\right\} \quad (13)$$

$K_L$: Over-all heat transfer coefficient [kJ/(m$^2$ .h . ºC)], $D_0$: Inside diameter [m], $D_N$: Outside diameter [m],
$D_I$: Outside diameter of $i$ layer [m], $\lambda_I$: Thermal conduction rate of $i$ layer [kJ/( m$^2$ .h . ºC )],
$\alpha_0$, $\alpha_N$: Heat transfer rate of inside surface and outside surface [kJ/(m$^2$ .h . ºC)],

**Table 10 Equation for predicted water temperature**

$$\theta_{out} = \theta_s + (\theta_{in} - \theta_s)\exp\left(-\frac{K.L}{c_w.G}\right) \quad (14)$$

$\theta_{out}$ : Water temperature at outlet of piping (tap water temperature) [ºC],

$\theta_{in}$ : Water temperature at inlet of piping (water temperature at outlet of purification facilities) [ºC],

$\theta_S$ : Underground soil temperature [ºC], $K$: Over-all heat transfer coefficient [kJ/(m$^2$ . h . ºC)],

$Z$: Depth of pipes [m], $L$: Length of piping [m], $C_w$: Specific heat of water (=4.19[kJ/(kg . ºC)]),
$G$: Flow rate [kg/h]

**Table 11 Mean deviation of predicted water temperature at water tap by actual model and simplified model**

| Water tap | Model of distribution piping | Over-all heat transfer coefficient [kJ/(m$^2$ . h . ºC)] | Mean deviation of tap water temperature ºC |
|---|---|---|---|
| A | Actual model (Z=1.2m) | 1453.5 | 2.05 |
| | Simplified model (Z=1.0 m) | 1165.2 | 1.87 |
| M | Actual model (Z=1.2m) | 1582.1 | 0.54 |
| | Simplified model (Z=1.0 m) | 1379.3 | 0.48 |

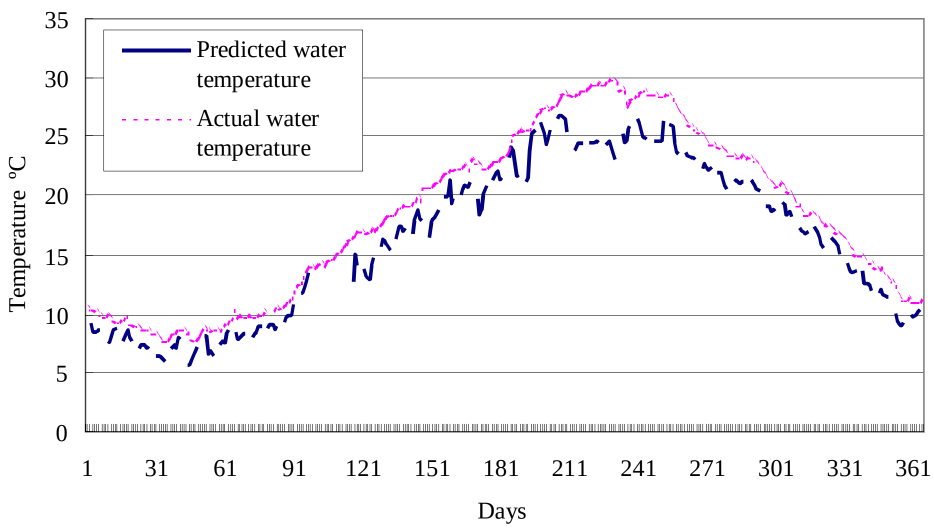



**Figure 15 Comparison of predicted water temperature with actual water temperature at water tap A (1994)**

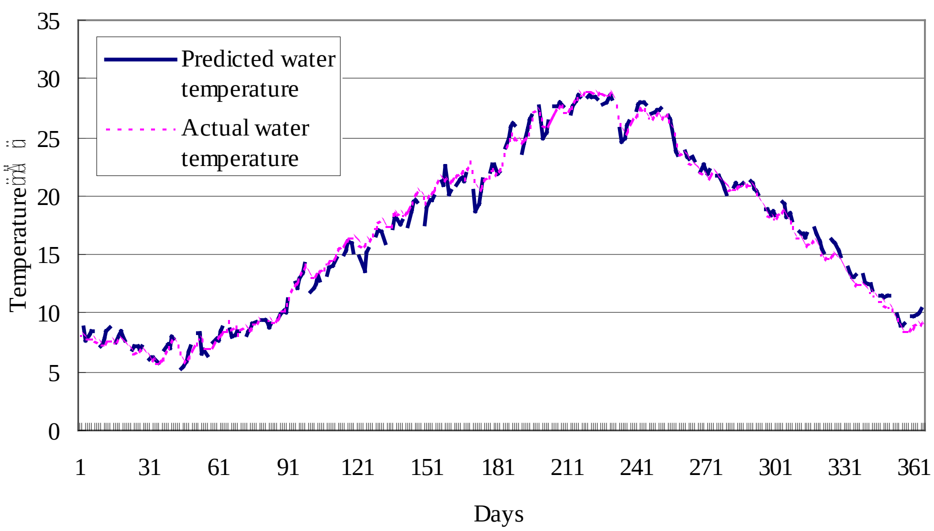



**Figure 16 Comparison of predicted water temperature with actual water temperature at water tap M (1994)**

# International pipe sizing regulations. Analysis of differing methods for friction head loss calculation.

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## Abstract

Pipe sizing of water supply systems for buildings is done in each country according to its respective regulations, standards or codes that may however differ significantly, in criteria and methodology, from one country to another. One of the subjects that has different approaches in the design of these systems is the calculation of the friction head loss that occurs through the pipes. On this particular matter, this paper intends to analyse the most usual procedures and to seek any eventual differences that may result from their application.

## Keywords

Water supply systems; pipe sizing; friction head loss

## 1 Introduction

In the last Symposium of CIB/W62 it was presented an extensive description of several “official” methods concerning the pipe sizing of water supply systems [1]. The referred work has listed the main criteria and procedures of each of those methods. In the brief comparison that was done, there were focused different aspects such as peak flow rate calculation, velocity limits, residual pressures and head loss estimation.

In this paper it will be studied, more detailedly, this last subject. Considering that, in the methods mentioned above, we may find different equations or graphs to compute the friction head loss, the basic question is to know how close are their results. To make this comparison there were taken some reference methods that will be described in the next section. The analysis was done over two kinds of pipes, representing each one a certain type of interior roughness – copper as smooth surface pipes and galvanised steel as rough surface pipes.

In each case it was studied a broad interval of different pipe diameters. Their characterization is presented in tables 1 and 2, being ED and ID, respectively, the external and internal diameters. From the second table, where it is expressed a diameter tolerance for galvanised steel, it was used the less favourable value, the lower one, in the following calculations.

For each diameter there were also analysed several conditions of flow, having been established certain values of the flow velocity. The values adopted are between 0,5 and 3,0 m/s, according to the limits defined in many of the methods used in here.

**Table 1 - Copper pipes (BS 2871 table X)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ED (mm) | 15,0 | 18,0 | 22,0 | 28,0 | 35,0 | 42,0 | 54,0 | 67,0 | 76,1 | 108,0 | 133,0 | 159,0 |
| Thickness (mm) | 0,7 | 0,8 | 0,9 | 0,9 | 1,2 | 1,2 | 1,2 | 1,2 | 1,5 | 1,5 | 1,5 | 2,0 |
| ID (mm) | 13,6 | 16,4 | 20,2 | 26,2 | 32,6 | 39,6 | 51,6 | 64,6 | 73,1 | 105,0 | 130,0 | 155,0 |

**Table 2 - Galvanised steel pipes (DIN 2440, BS 1387)**

| ED (in) | EDmax (mm) | EDmin (mm) | Thickness (mm) | IDmax (mm) | IDmin (mm) |
|---|---|---|---|---|---|
| 1/2 | 21,8 | 21,0 | 2,65 | 16,50 | 15,70 |
| 3/4 | 27,3 | 26,5 | 2,65 | 22,00 | 21,20 |
| 1 | 34,2 | 33,3 | 3,25 | 27,70 | 26,80 |
| 1 1/4 | 42,9 | 42,0 | 3,25 | 36,40 | 35,50 |
| 1 1/2 | 48,8 | 47,9 | 3,25 | 42,30 | 41,40 |
| 2 | 60,8 | 59,7 | 3,65 | 53,50 | 52,40 |
| 2 1/2 | 76,6 | 75,3 | 3,65 | 69,30 | 68,00 |
| 3 | 89,5 | 88,0 | 4,05 | 81,40 | 79,90 |
| 4 | 115,0 | 113,1 | 4,50 | 106,00 | 104,10 |
| 5 | 140,8 | 138,5 | 4,85 | 131,10 | 128,80 |
| 6 | 166,5 | 163,9 | 4,85 | 156,80 | 154,20 |

## 2 Friction head loss calculation

For this study it was considered a theoretical, straight pipe system, of 100 m length. Over this system there were admitted several hypothesis of pipe materials, diameter sizes and flow velocities as previously described. In the friction head loss calculation, for the purpose of comparison, there were chosen five methods that are listed in table 3. The corresponding equations and their respective parameters are further described.

**Table 3 - Methods used for friction head loss calculation**

| country | method |
|---|---|
| Germany, Switzerland, South Africa | Colebrook-White |
| Brazil | Fair-Whipple-Hsiao |
| France, Portugal | Flamant |
| United Kingdom | Lamont |
| United States | Harris |

## 2.1 Method of Colebrook-White [2, 3]

Formula of Darcy-Weisbach (general expression for friction head loss in pipes of circular section):

$$J = \frac{\lambda}{D} \cdot \frac{U^2}{2g} \qquad (1)$$

J, friction head loss (m/m)
λ, friction head loss coefficient (non dimensional parameter)
D, internal diameter (m)
U, flow velocity (m/s)
g, gravitational acceleration (9,81 m/s$^2$)

Formula of Colebrook-White:

$$\frac{1}{\sqrt{\lambda}} = -2\log_{10}\left( \frac{\frac{k}{D}}{3,7} + \frac{2,51}{\mathrm{Re}\sqrt{\lambda}} \right) \qquad (2)$$

Re, Reynolds number (non dimensional parameter)
k, equivalent rugosity of pipe (m):

| | |
|---|---|
| copper | 0,0015x10$^{-3}$ m |
| galvanized steel | 0,15x10$^{-3}$ m |

$$\mathrm{Re} = \frac{UD}{\upsilon} \qquad (3)$$

υ, kinematic viscosity of water (1,31x10$^{-6}$ m$^2$/s at 10 ºC)

The formula of Colebrook-White was solved by iteration, using an initial λ of 0,02 and requiring that $|\lambda_{i+1}-\lambda_i|<0{,}0001$.

**2.2 Method of Fair-Whipple-Hsiao** [4]

Formula of Fair-Whipple-Hsiao for smooth pipes:

$$J = 8{,}69 \cdot 10^6 \cdot Q^{1{,}75} \cdot D^{-4{,}75} \quad (4)$$

Formula of Fair-Whipple-Hsiao for rough pipes:

$$J = 20{,}2 \cdot 10^6 \cdot Q^{1{,}88} \cdot D^{-4{,}88} \quad (5)$$

J, friction head loss (KPa/m)
Q, estimated peak flow rate (l/s)
D, internal diameter (mm)

**2.3 Method of Flamant** [5, 6, 7]

Formula of Flamant for smooth pipes:

$$j = 0{,}00056 \cdot U^{1{,}75} \cdot D^{-1{,}25} \quad (6)$$

Formula of Flamant for rough pipes:

$$j = 0{,}00092 \cdot U^{1{,}75} \cdot D^{-1{,}25} \quad (7)$$

j, friction head loss (m/m)
U, flow velocity (m/s)
D, internal diameter (m)

**2.4 Method of Lamont** [8]

Formula of Lamont for smooth pipes:

$$V = 0{,}552 \cdot D^{0{,}6935} \cdot i^{0{,}5645} \quad (8)$$

V, flow velocity (m/s)
D, internal diameter (mm)
i, hydraulic gradient (m/m)

The BS 6700, which defines Lamont's formula for smooth pipes, does not present any similar equation for rough pipes. In this case, the friction head loss for galvanized steel pipes was calculated through the graph of figure 1, obtained from the Institute of Plumbing [9].

**2.5 Method of Harris** [10]

The methodology studied is the one defined in the Uniform Plumbing Code [11]. The formulas used in here are presented by Cyril Harris and they correspond to the graphs included in the UPC for friction head loss calculation.

Formula of Harris for copper pipes (fairly smooth surface):

$$q = 4{,}57 \cdot p^{0{,}546} \cdot d^{2{,}64} \tag{9}$$

Formula of Harris for galvanised steel pipes (fairly rough surface):

$$q = 4{,}29 \cdot p^{0{,}521} \cdot d^{2{,}562} \tag{10}$$

q, flow rate (gpm)
p, pressure loss due to friction (psi/100 ft)
d, internal diameter (in)

## 3 Results

The study that was carried on and the results that were achieved are summarized in the tables and figures included in the appendices. Tables 4 and 6 express the main data necessary to this analysis, concerning respectively copper pipes and galvanized steel pipes. For a clear understanding, some data, such as internal diameters and flow rates, required in the stages of intermediary calculation, has been purposely omitted in here.

A graphical comparison between the different methods considered, based directly on the absolute values achieved, would lead us to several curves almost juxtaposed. Being so, the comparison was done in a relative way, quantifying the difference between the result of each method and a certain reference. The method that was taken as reference was Colebrook-White's because it is considered the most accurate of all. With this criteria there were built tables 5 and 7.

Figures 2 and 3 were done through the reference method. The first is for copper and the second is for galvanized steel pipes. Through these two figures it can be analyzed the behaviour of each material and inferred the differences between smooth and rough pipes. Figures 4 and 5 were obtained from the tables 5 and 7. To be more expressive and to serve as an example they were built for a flow velocity of 2 m/s. These curves give us an idea of how spread are the results and a view of the diameters' influence on the amplitude of those differences.

The last table presents a brief analysis of the friction head loss achieved for different materials, which nominal diameters could be eventually considered, in practice, as hydraulically equivalents.

## 4 Conclusions

The results obtained allow us to take a few conclusions. The first comment that can be made is that it is obvious, from figures 2 and 3, that friction head loss increases with the flow velocity and decreases with the pipe diameter. In detail, it can be pointed that the influence of the flow velocity over the friction head loss is not significant for large diameters but for the small ones, very common inside buildings, it is enormous. For example, in the range of small diameters, if a velocity limit of 3 m/s is assumed, for instance, rather than 1m/s, the friction head loss in copper pipes gets an increase of about 0,20 to 0,65 m/m (for $\phi$42 and for $\phi$15 mm, respectively). These values become even greater if we take galvanized steel pipes. Being though, it looks that it would be wise, in the design of water supply systems, to establish different limits of velocity according to the range of pipe diameters.

From figures 4 and 5 we can get some differences between the methods studied. These figures were drawn for a flow velocity of 2 m/s, which is inside the common limits adopted almost everywhere. Through the first figure we can conclude that these methods are very close from each other. The only exception is the american method, which appears to be far away from the others – a further analysis of it would be advisable to confirm the results here presented. Apart the exception that was mentioned, it can be said that, for smooth pipes, there are meaningless differences between the studied methods for friction head loss calculation.

For galvanized steel pipes and for rough pipes in general, it is clear that these methods are not equivalent. Even though, some comments can be made about their particularities. In here, almost all the curves cross the reference line of Colebrook-White, existing some values below and some others far above that line. The brazilian method and the american method present a significant deviation from the Colebrook-White method for pipe diameters above 1 ¼”. Despite this difference, its impact is reduced because it occurs in the range of large diameters where the friction head loss is low. Another line that deserves special attention is Flamant’s curve which course is quite parallel to the reference curve. A closer look to table 7 show us, however, that these two curves have different distances according to the velocity being considered. Compared to Colebrook-White’s, the results from Flamant represent an increase of about 40% for a flow velocity of 0,5 m/s and of approximately 15% for a flow velocity of 2,0 m/s.

At last, a view on table 8. This table includes three parts, corresponding each one to a certain common pipe diameter. In each of these parts it was considered a specific flow rate and several pipe materials that are normally accepted by plumbing trade as having the same pipe size. As we can see, despite this similarity of nominal diameters, there are in fact great differences in their internal diameters, that gives rise to greatly varying velocities and, consequently, to very different friction head losses. In the pipe sizing design it is though quite important to specify both nominal and internal pipe diameters in order to avoid any mistake in the construction phase that may later affect the pipe system behaviour and the residual pressures available.

## 5 References


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## Appendices

Included further are the remainder tables and figures mentioned in the text.

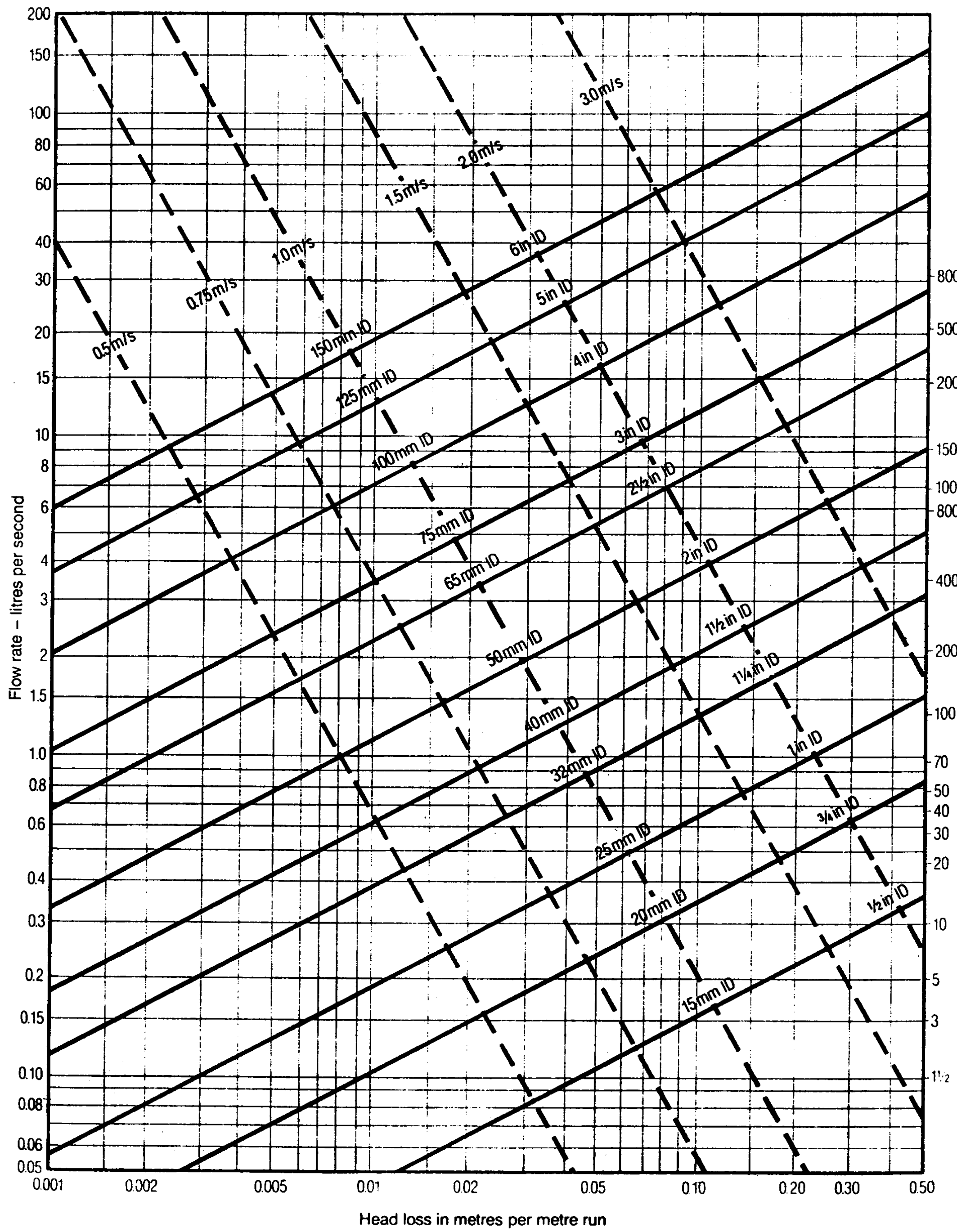


**Figure 1 – Friction head loss for galvanized steel pipes** [9]
**(according to the Institute of Plumbing)**

**Table 4 - Friction head loss for copper pipes**

| ED (mm) | Velocity (m/s) | Colebrook-White (m/100m) | Fair-Whipple-Hsiao (m/100m) | Flamant (m/100m) | Lamont (m/100m) | Harris (m/100m) |
|---|---|---|---|---|---|---|
| 15,0 | 0,5 | 3,48 | 3,65 | 3,58 | 3,40 | 3,71 |
| 18,0 | 0,5 | 2,73 | 2,88 | 2,84 | 2,70 | 2,98 |
| 22,0 | 0,5 | 2,10 | 2,22 | 2,19 | 2,09 | 2,33 |
| 28,0 | 0,5 | 1,51 | 1,61 | 1,58 | 1,52 | 1,72 |
| 35,0 | 0,5 | 1,14 | 1,22 | 1,20 | 1,16 | 1,33 |
| 42,0 | 0,5 | 0,90 | 0,96 | 0,94 | 0,91 | 1,06 |
| 54,0 | 0,5 | 0,64 | 0,69 | 0,68 | 0,66 | 0,78 |
| 67,0 | 0,5 | 0,49 | 0,52 | 0,51 | 0,50 | 0,60 |
| 76,1 | 0,5 | 0,42 | 0,45 | 0,44 | 0,43 | 0,52 |
| 108,0 | 0,5 | 0,27 | 0,28 | 0,28 | 0,28 | 0,34 |
| 133,0 | 0,5 | 0,21 | 0,22 | 0,21 | 0,21 | 0,26 |
| 159,0 | 0,5 | 0,17 | 0,17 | 0,17 | 0,17 | 0,21 |
| 15,0 | 1,0 | 11,53 | 12,26 | 12,06 | 11,60 | 13,21 |
| 18,0 | 1,0 | 9,10 | 9,70 | 9,54 | 9,22 | 10,61 |
| 22,0 | 1,0 | 7,00 | 7,48 | 7,35 | 7,14 | 8,31 |
| 28,0 | 1,0 | 5,06 | 5,40 | 5,31 | 5,18 | 6,13 |
| 35,0 | 1,0 | 3,86 | 4,11 | 4,04 | 3,96 | 4,74 |
| 42,0 | 1,0 | 3,03 | 3,22 | 3,17 | 3,12 | 3,78 |
| 54,0 | 1,0 | 2,19 | 2,32 | 2,28 | 2,25 | 2,77 |
| 67,0 | 1,0 | 1,66 | 1,75 | 1,72 | 1,71 | 2,13 |
| 76,1 | 1,0 | 1,43 | 1,50 | 1,47 | 1,47 | 1,84 |
| 108,0 | 1,0 | 0,92 | 0,95 | 0,94 | 0,94 | 1,20 |
| 133,0 | 1,0 | 0,71 | 0,73 | 0,72 | 0,72 | 0,94 |
| 159,0 | 1,0 | 0,57 | 0,59 | 0,58 | 0,58 | 0,76 |
| 15,0 | 1,5 | 23,41 | 24,93 | 24,51 | 23,80 | 27,77 |
| 18,0 | 1,5 | 18,52 | 19,73 | 19,40 | 18,91 | 22,30 |
| 22,0 | 1,5 | 14,29 | 15,20 | 14,95 | 14,64 | 17,46 |
| 28,0 | 1,5 | 10,35 | 10,98 | 10,80 | 10,63 | 12,87 |
| 35,0 | 1,5 | 7,91 | 8,36 | 8,22 | 8,13 | 9,97 |
| 42,0 | 1,5 | 6,22 | 6,55 | 6,45 | 6,40 | 7,93 |
| 54,0 | 1,5 | 4,50 | 4,71 | 4,63 | 4,62 | 5,82 |
| 67,0 | 1,5 | 3,43 | 3,55 | 3,50 | 3,51 | 4,47 |
| 76,1 | 1,5 | 2,95 | 3,05 | 3,00 | 3,01 | 3,87 |
| 108,0 | 1,5 | 1,90 | 1,94 | 1,90 | 1,93 | 2,53 |
| 133,0 | 1,5 | 1,47 | 1,48 | 1,46 | 1,49 | 1,97 |
| 159,0 | 1,5 | 1,19 | 1,19 | 1,17 | 1,20 | 1,60 |
| 15,0 | 2,0 | 38,82 | 41,24 | 40,56 | 39,61 | 47,03 |
| 18,0 | 2,0 | 30,76 | 32,63 | 32,09 | 31,47 | 37,76 |
| 22,0 | 2,0 | 23,77 | 25,15 | 24,73 | 24,37 | 29,58 |
| 28,0 | 2,0 | 17,25 | 18,17 | 17,87 | 17,70 | 21,81 |
| 35,0 | 2,0 | 13,19 | 13,83 | 13,60 | 13,53 | 16,88 |
| 42,0 | 2,0 | 10,39 | 10,84 | 10,66 | 10,66 | 13,44 |
| 54,0 | 2,0 | 7,53 | 7,79 | 7,66 | 7,70 | 9,85 |
| 67,0 | 2,0 | 5,73 | 5,88 | 5,78 | 5,84 | 7,57 |
| 76,1 | 2,0 | 4,94 | 5,04 | 4,96 | 5,02 | 6,55 |
| 108,0 | 2,0 | 3,19 | 3,20 | 3,15 | 3,22 | 4,28 |
| 133,0 | 2,0 | 2,47 | 2,45 | 2,41 | 2,47 | 3,34 |
| 159,0 | 2,0 | 2,00 | 1,97 | 1,94 | 1,99 | 2,71 |

**Table 5 - Comparison between values of table 4 and Colebrook-White's estimation**

| ED (mm) | Velocity (m/s) | Colebrook-White (m/100m) | Fair-Whipple-Hsiao (m/100m) | Flamant (m/100m) | Lamont (m/100m) | Harris (m/100m) |
|---|---|---|---|---|---|---|
| 15,0 | 0,5 | 1,00 | 1,05 | 1,03 | 0,98 | 1,07 |
| 18,0 | 0,5 | 1,00 | 1,05 | 1,04 | 0,99 | 1,09 |
| 22,0 | 0,5 | 1,00 | 1,06 | 1,04 | 1,00 | 1,11 |
| 28,0 | 0,5 | 1,00 | 1,07 | 1,05 | 1,01 | 1,14 |
| 35,0 | 0,5 | 1,00 | 1,07 | 1,05 | 1,02 | 1,17 |
| 42,0 | 0,5 | 1,00 | 1,07 | 1,05 | 1,02 | 1,18 |
| 54,0 | 0,5 | 1,00 | 1,07 | 1,05 | 1,03 | 1,21 |
| 67,0 | 0,5 | 1,00 | 1,07 | 1,05 | 1,03 | 1,23 |
| 76,1 | 0,5 | 1,00 | 1,07 | 1,05 | 1,03 | 1,24 |
| 108,0 | 0,5 | 1,00 | 1,06 | 1,04 | 1,03 | 1,27 |
| 133,0 | 0,5 | 1,00 | 1,05 | 1,04 | 1,03 | 1,28 |
| 159,0 | 0,5 | 1,00 | 1,05 | 1,03 | 1,03 | 1,29 |
| 15,0 | 1,0 | 1,00 | 1,06 | 1,05 | 1,01 | 1,15 |
| 18,0 | 1,0 | 1,00 | 1,07 | 1,05 | 1,01 | 1,17 |
| 22,0 | 1,0 | 1,00 | 1,07 | 1,05 | 1,02 | 1,19 |
| 28,0 | 1,0 | 1,00 | 1,07 | 1,05 | 1,02 | 1,21 |
| 35,0 | 1,0 | 1,00 | 1,07 | 1,05 | 1,03 | 1,23 |
| 42,0 | 1,0 | 1,00 | 1,06 | 1,05 | 1,03 | 1,24 |
| 54,0 | 1,0 | 1,00 | 1,06 | 1,04 | 1,03 | 1,27 |
| 67,0 | 1,0 | 1,00 | 1,05 | 1,04 | 1,03 | 1,28 |
| 76,1 | 1,0 | 1,00 | 1,05 | 1,03 | 1,03 | 1,29 |
| 108,0 | 1,0 | 1,00 | 1,04 | 1,02 | 1,03 | 1,31 |
| 133,0 | 1,0 | 1,00 | 1,03 | 1,01 | 1,02 | 1,32 |
| 159,0 | 1,0 | 1,00 | 1,02 | 1,00 | 1,02 | 1,33 |
| 15,0 | 1,5 | 1,00 | 1,06 | 1,05 | 1,02 | 1,19 |
| 18,0 | 1,5 | 1,00 | 1,07 | 1,05 | 1,02 | 1,20 |
| 22,0 | 1,5 | 1,00 | 1,06 | 1,05 | 1,02 | 1,22 |
| 28,0 | 1,5 | 1,00 | 1,06 | 1,04 | 1,03 | 1,24 |
| 35,0 | 1,5 | 1,00 | 1,06 | 1,04 | 1,03 | 1,26 |
| 42,0 | 1,5 | 1,00 | 1,05 | 1,04 | 1,03 | 1,27 |
| 54,0 | 1,5 | 1,00 | 1,05 | 1,03 | 1,03 | 1,29 |
| 67,0 | 1,5 | 1,00 | 1,04 | 1,02 | 1,02 | 1,30 |
| 76,1 | 1,5 | 1,00 | 1,03 | 1,02 | 1,02 | 1,31 |
| 108,0 | 1,5 | 1,00 | 1,02 | 1,00 | 1,02 | 1,33 |
| 133,0 | 1,5 | 1,00 | 1,01 | 0,99 | 1,01 | 1,34 |
| 159,0 | 1,5 | 1,00 | 1,00 | 0,98 | 1,01 | 1,35 |
| 15,0 | 2,0 | 1,00 | 1,06 | 1,04 | 1,02 | 1,21 |
| 18,0 | 2,0 | 1,00 | 1,06 | 1,04 | 1,02 | 1,23 |
| 22,0 | 2,0 | 1,00 | 1,06 | 1,04 | 1,03 | 1,24 |
| 28,0 | 2,0 | 1,00 | 1,05 | 1,04 | 1,03 | 1,26 |
| 35,0 | 2,0 | 1,00 | 1,05 | 1,03 | 1,03 | 1,28 |
| 42,0 | 2,0 | 1,00 | 1,04 | 1,03 | 1,03 | 1,29 |
| 54,0 | 2,0 | 1,00 | 1,03 | 1,02 | 1,02 | 1,31 |
| 67,0 | 2,0 | 1,00 | 1,03 | 1,01 | 1,02 | 1,32 |
| 76,1 | 2,0 | 1,00 | 1,02 | 1,00 | 1,02 | 1,33 |
| 108,0 | 2,0 | 1,00 | 1,00 | 0,99 | 1,01 | 1,34 |
| 133,0 | 2,0 | 1,00 | 0,99 | 0,98 | 1,00 | 1,35 |
| 159,0 | 2,0 | 1,00 | 0,98 | 0,97 | 1,00 | 1,36 |

**Table 6 - Friction head loss for galvanised steel pipes**

| ED (in) | Velocity (m/s) | Colebrook-White (m/100m) | Fair-Whipple-Hsiao (m/100m) | Flamant (m/100m) | IoP (m/100m) | Harris (m/100m) |
|---|---|---|---|---|---|---|
| 1/2 | 0,5 | 3,70 | 3,65 | 4,92 | 3,27 | 3,35 |
| 3/4 | 0,5 | 2,48 | 2,61 | 3,38 | 2,29 | 2,42 |
| 1 | 0,5 | 1,82 | 2,01 | 2,52 | 1,71 | 1,88 |
| 1 1/4 | 0,5 | 1,26 | 1,47 | 1,78 | 1,27 | 1,39 |
| 1 1/2 | 0,5 | 1,03 | 1,23 | 1,46 | 1,05 | 1,18 |
| 2 | 0,5 | 0,76 | 0,95 | 1,09 | 0,81 | 0,91 |
| 2 1/2 | 0,5 | 0,54 | 0,71 | 0,79 | 0,58 | 0,69 |
| 3 | 0,5 | 0,44 | 0,59 | 0,64 | 0,50 | 0,58 |
| 4 | 0,5 | 0,32 | 0,44 | 0,46 | 0,36 | 0,44 |
| 5 | 0,5 | 0,24 | 0,35 | 0,35 | 0,29 | 0,35 |
| 6 | 0,5 | 0,19 | 0,28 | 0,28 | 0,24 | 0,28 |
| 1/2 | 1,0 | 13,60 | 13,45 | 16,55 | 11,75 | 12,67 |
| 3/4 | 1,0 | 9,12 | 9,61 | 11,37 | 8,29 | 9,16 |
| 1 | 1,0 | 6,70 | 7,39 | 8,48 | 6,22 | 7,11 |
| 1 1/4 | 1,0 | 4,64 | 5,39 | 5,97 | 4,58 | 5,25 |
| 1 1/2 | 1,0 | 3,81 | 4,54 | 4,93 | 3,75 | 4,45 |
| 2 | 1,0 | 2,81 | 3,49 | 3,67 | 2,86 | 3,45 |
| 2 1/2 | 1,0 | 2,02 | 2,60 | 2,65 | 2,14 | 2,61 |
| 3 | 1,0 | 1,64 | 2,17 | 2,17 | 1,75 | 2,19 |
| 4 | 1,0 | 1,18 | 1,62 | 1,56 | 1,32 | 1,65 |
| 5 | 1,0 | 0,90 | 1,27 | 1,19 | 1,02 | 1,31 |
| 6 | 1,0 | 0,72 | 1,04 | 0,95 | 0,86 | 1,08 |
| 1/2 | 1,5 | 29,59 | 28,82 | 33,66 | 25,24 | 27,58 |
| 3/4 | 1,5 | 19,85 | 20,59 | 23,12 | 18,13 | 19,95 |
| 1 | 1,5 | 14,59 | 15,84 | 17,25 | 14,00 | 15,49 |
| 1 1/4 | 1,5 | 10,11 | 11,56 | 12,14 | 10,00 | 11,44 |
| 1 1/2 | 1,5 | 8,29 | 9,73 | 10,02 | 8,43 | 9,69 |
| 2 | 1,5 | 6,12 | 7,47 | 7,46 | 6,44 | 7,52 |
| 2 1/2 | 1,5 | 4,39 | 5,58 | 5,39 | 4,64 | 5,67 |
| 3 | 1,5 | 3,58 | 4,66 | 4,40 | 4,00 | 4,77 |
| 4 | 1,5 | 2,56 | 3,46 | 3,16 | 2,91 | 3,58 |
| 5 | 1,5 | 1,96 | 2,73 | 2,42 | 2,27 | 2,85 |
| 6 | 1,5 | 1,57 | 2,23 | 1,94 | 1,90 | 2,35 |
| 1/2 | 2,0 | 51,65 | 49,51 | 55,68 | 42,50 | 47,91 |
| 3/4 | 2,0 | 34,66 | 35,36 | 38,25 | 30,00 | 34,65 |
| 1 | 2,0 | 25,47 | 27,20 | 28,54 | 23,00 | 26,91 |
| 1 1/4 | 2,0 | 17,66 | 19,85 | 20,08 | 17,19 | 19,87 |
| 1 1/2 | 2,0 | 14,47 | 16,71 | 16,57 | 14,00 | 16,83 |
| 2 | 2,0 | 10,69 | 12,84 | 12,34 | 11,00 | 13,06 |
| 2 1/2 | 2,0 | 7,67 | 9,59 | 8,91 | 8,11 | 9,86 |
| 3 | 2,0 | 6,25 | 8,00 | 7,28 | 6,66 | 8,28 |
| 4 | 2,0 | 4,48 | 5,95 | 5,23 | 5,00 | 6,23 |
| 5 | 2,0 | 3,43 | 4,69 | 4,01 | 3,80 | 4,95 |
| 6 | 2,0 | 2,74 | 3,83 | 3,20 | 3,25 | 4,08 |

**Table 7 - Comparison between values of table 6 and Colebrook-White's estimation**

| ED (in) | Velocity (m/s) | Colebrook-White (m/100m) | Fair-Whipple-Hsiao (m/100m) | Flamant (m/100m) | IoP (m/100m) | Harris (m/100m) |
|---|---|---|---|---|---|---|
| 1/2 | 0,5 | 1,00 | 0,99 | 1,33 | 0,88 | 0,91 |
| 3/4 | 0,5 | 1,00 | 1,05 | 1,37 | 0,92 | 0,98 |
| 1 | 0,5 | 1,00 | 1,10 | 1,39 | 0,94 | 1,03 |
| 1 1/4 | 0,5 | 1,00 | 1,16 | 1,41 | 1,01 | 1,10 |
| 1 1/2 | 0,5 | 1,00 | 1,20 | 1,42 | 1,02 | 1,14 |
| 2 | 0,5 | 1,00 | 1,25 | 1,44 | 1,07 | 1,20 |
| 2 1/2 | 0,5 | 1,00 | 1,30 | 1,45 | 1,07 | 1,27 |
| 3 | 0,5 | 1,00 | 1,33 | 1,45 | 1,13 | 1,31 |
| 4 | 0,5 | 1,00 | 1,38 | 1,46 | 1,14 | 1,37 |
| 5 | 0,5 | 1,00 | 1,43 | 1,46 | 1,20 | 1,43 |
| 6 | 0,5 | 1,00 | 1,46 | 1,46 | 1,24 | 1,47 |
| 1/2 | 1,0 | 1,00 | 0,99 | 1,22 | 0,86 | 0,93 |
| 3/4 | 1,0 | 1,00 | 1,05 | 1,25 | 0,91 | 1,00 |
| 1 | 1,0 | 1,00 | 1,10 | 1,27 | 0,93 | 1,06 |
| 1 1/4 | 1,0 | 1,00 | 1,16 | 1,29 | 0,99 | 1,13 |
| 1 1/2 | 1,0 | 1,00 | 1,19 | 1,29 | 0,99 | 1,17 |
| 2 | 1,0 | 1,00 | 1,24 | 1,31 | 1,02 | 1,23 |
| 2 1/2 | 1,0 | 1,00 | 1,29 | 1,31 | 1,06 | 1,29 |
| 3 | 1,0 | 1,00 | 1,32 | 1,32 | 1,07 | 1,33 |
| 4 | 1,0 | 1,00 | 1,37 | 1,32 | 1,12 | 1,40 |
| 5 | 1,0 | 1,00 | 1,41 | 1,32 | 1,13 | 1,45 |
| 6 | 1,0 | 1,00 | 1,45 | 1,32 | 1,20 | 1,50 |
| 1/2 | 1,5 | 1,00 | 0,97 | 1,14 | 0,85 | 0,93 |
| 3/4 | 1,5 | 1,00 | 1,04 | 1,16 | 0,91 | 1,00 |
| 1 | 1,5 | 1,00 | 1,09 | 1,18 | 0,96 | 1,06 |
| 1 1/4 | 1,5 | 1,00 | 1,14 | 1,20 | 0,99 | 1,13 |
| 1 1/2 | 1,5 | 1,00 | 1,17 | 1,21 | 1,02 | 1,17 |
| 2 | 1,5 | 1,00 | 1,22 | 1,22 | 1,05 | 1,23 |
| 2 1/2 | 1,5 | 1,00 | 1,27 | 1,23 | 1,06 | 1,29 |
| 3 | 1,5 | 1,00 | 1,30 | 1,23 | 1,12 | 1,33 |
| 4 | 1,5 | 1,00 | 1,35 | 1,23 | 1,13 | 1,40 |
| 5 | 1,5 | 1,00 | 1,39 | 1,23 | 1,16 | 1,45 |
| 6 | 1,5 | 1,00 | 1,42 | 1,23 | 1,21 | 1,50 |
| 1/2 | 2,0 | 1,00 | 0,96 | 1,08 | 0,82 | 0,93 |
| 3/4 | 2,0 | 1,00 | 1,02 | 1,10 | 0,87 | 1,00 |
| 1 | 2,0 | 1,00 | 1,07 | 1,12 | 0,90 | 1,06 |
| 1 1/4 | 2,0 | 1,00 | 1,12 | 1,14 | 0,97 | 1,13 |
| 1 1/2 | 2,0 | 1,00 | 1,15 | 1,14 | 0,97 | 1,16 |
| 2 | 2,0 | 1,00 | 1,20 | 1,15 | 1,03 | 1,22 |
| 2 1/2 | 2,0 | 1,00 | 1,25 | 1,16 | 1,06 | 1,28 |
| 3 | 2,0 | 1,00 | 1,28 | 1,17 | 1,07 | 1,32 |
| 4 | 2,0 | 1,00 | 1,33 | 1,17 | 1,12 | 1,39 |
| 5 | 2,0 | 1,00 | 1,37 | 1,17 | 1,11 | 1,44 |
| 6 | 2,0 | 1,00 | 1,40 | 1,17 | 1,19 | 1,49 |

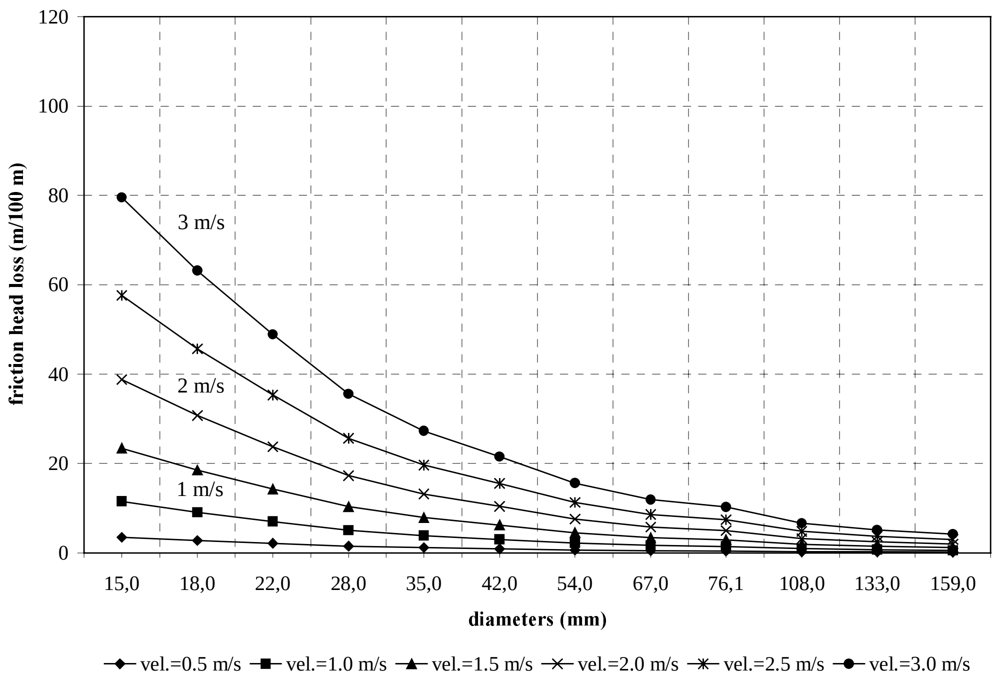


**Figure 2 - Copper pipes.**
**Friction head losses obtained through Colebrook-White's formula.**

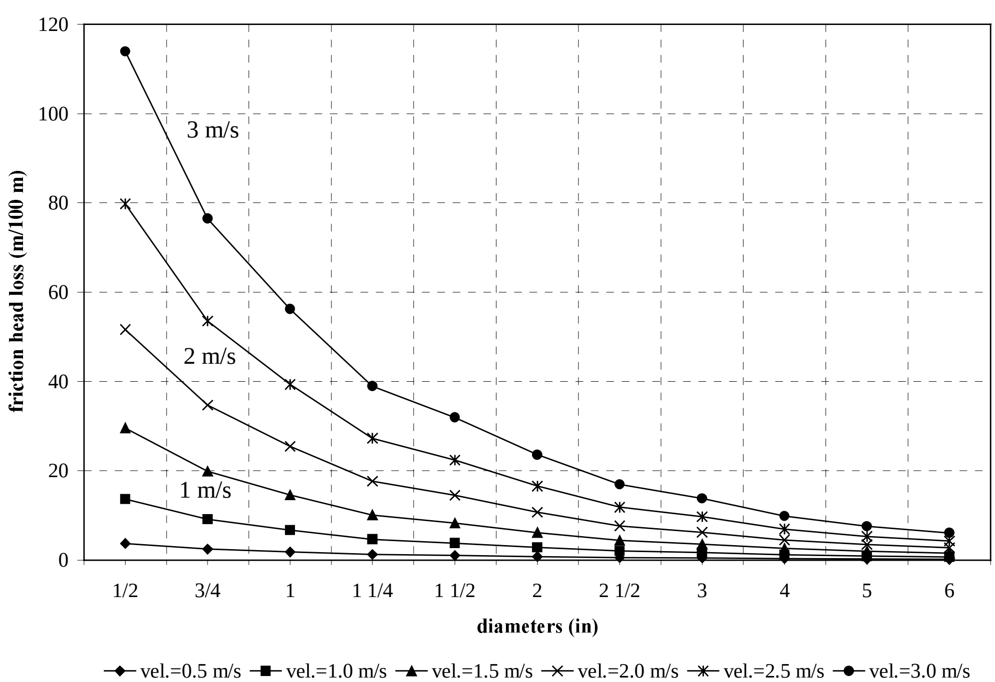


**Figure 3 - Galvanised steel pipes.**
**Friction head losses obtained through Colebrook-White's formula.**

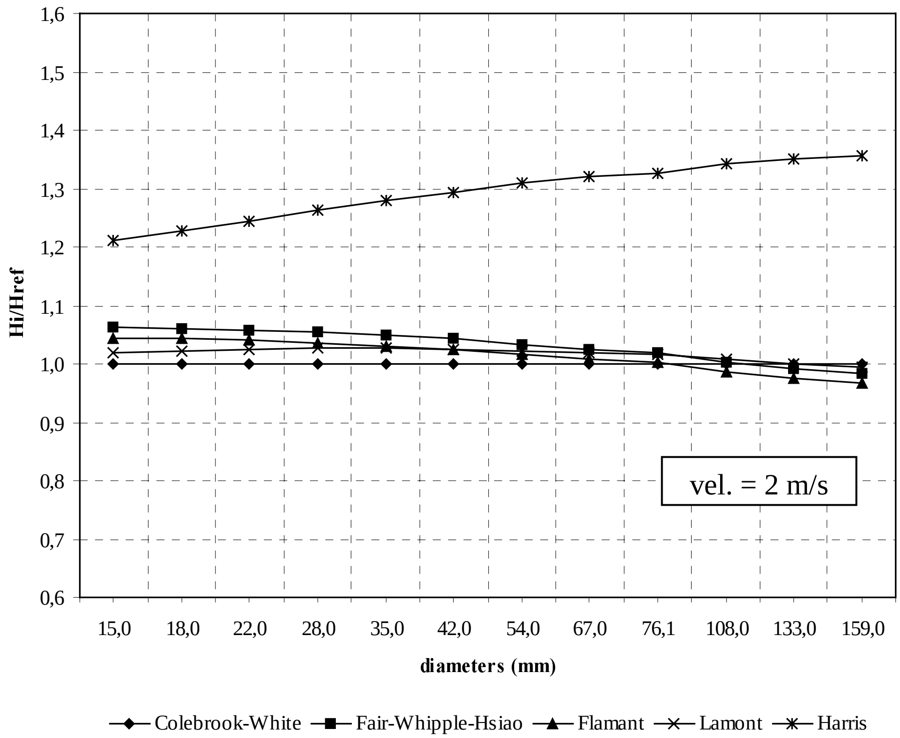


**Figure 4 - Copper pipes. Comparison of friction head losses obtained through different formulas (Colebrook-White taken as reference).**

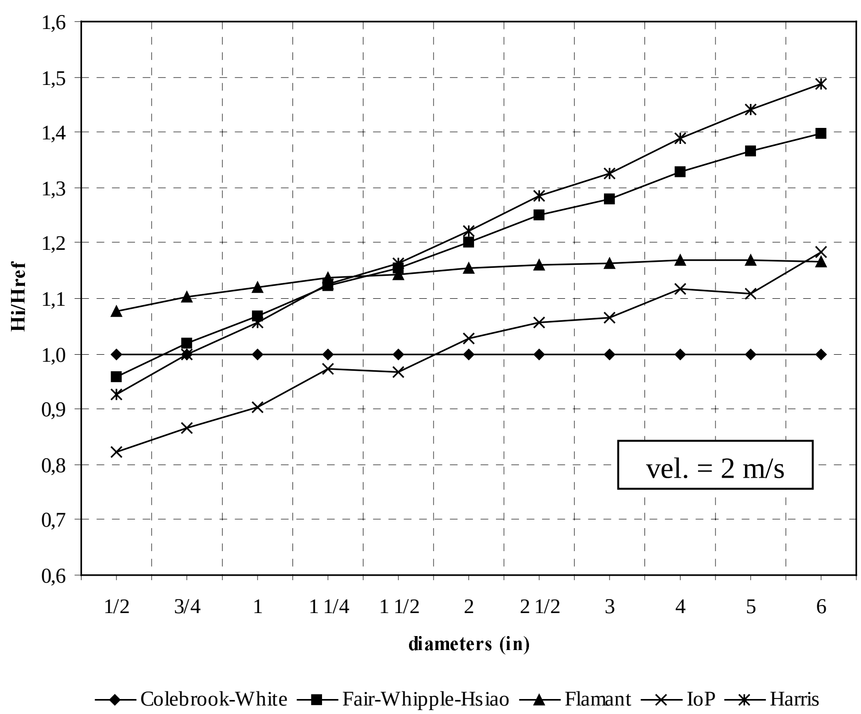


**Figure 5 - Galvanised steel pipes. Comparison of friction head losses obtained through different formulas (Colebrook-White taken as reference).**

**Table 8 - Comparison of various pipe materials**

| | | nom. size | ID (mm) | velocity (m/s) | k | Colebrook-White (m/100 m) |
|---|---|---|---|---|---|---|
| **Generic 1/2" (15 mm) - Flow rate = 0,20 l/s** | | | | | | |
| USA | ASTM Schedule 40 Gal Steel | 1/2 " | 15,80 | 1,02 | 0,1500 | 14,01 |
| USA | Copper ASTM Type L | 1/2 " | 13,84 | 1,33 | 0,0015 | 18,55 |
| USA | Polyethylene ASTM D 2104 Controlled ID | 1/2 " | 15,80 | 1,02 | 0,0070 | 10,07 |
| USA | XLPE ASTM F877 | 1/2 " | 12,32 | 1,68 | 0,0050 | 32,95 |
| AUS | Australian Standard 1432 Copper (Type B) | 15 mm | 10,88 | 2,15 | 0,0015 | 58,27 |
| AUS | AS 2462 Polybutylene Class 16 | 15 mm | 12,50 | 1,63 | 0,0070 | 30,99 |
| AUS | AS 4130 Polyethylene Class 12 | 15 mm | 12,70 | 1,58 | 0,0070 | 28,75 |
| AUS | AS 2492 XLPE PN20 | 15 mm | 11,60 | 1,89 | 0,0050 | 43,79 |
| AUS | AS 1074 Gal Steel | 15 mm | 16,10 | 0,98 | 0,1500 | 12,66 |
| EU | EN 1057 Copper Class X | 15 mm | 13,60 | 1,38 | 0,0015 | 20,23 |
| EU | BS/EN 7291 Polybutylene | 15 mm | 11,30 | 1,99 | 0,0070 | 50,20 |
| EU | DIN 689293 PEX SDR 7.3 | 16 mm | 11,60 | 1,89 | 0,0050 | 43,79 |
| **Generic 3/4" (20 mm) - Flow rate = 0,60 l/s** | | | | | | |
| USA | ASTM Schedule 40 Gal Steel | 3/4 " | 20,93 | 1,74 | 0,1500 | 26,90 |
| USA | Copper ASTM Type L | 3/4 " | 19,94 | 1,92 | 0,0015 | 22,47 |
| USA | Polyethylene ASTM D 2104 Controlled ID | 3/4 " | 20,93 | 1,74 | 0,0070 | 18,27 |
| USA | XLPE ASTM F877 | 3/4 " | 17,30 | 2,55 | 0,0050 | 45,37 |
| AUS | Australian Standard 1432 Copper (Type B) | 20 mm | 17,00 | 2,64 | 0,0015 | 48,14 |
| AUS | AS 2462 Polybutylene Class 16 | 20 mm | 17,60 | 2,47 | 0,0070 | 42,49 |
| AUS | AS 4130 Polyethylene Class 12 | 20 mm | 16,10 | 2,95 | 0,0070 | 65,39 |
| AUS | AS 2492 XLPE PN20 | 20 mm | 18,00 | 2,36 | 0,0050 | 37,60 |
| AUS | AS 1074 Gal Steel | 20 mm | 21,60 | 1,64 | 0,1500 | 23,01 |
| EU | EN 1057 Copper Class X | 22 mm | 20,20 | 1,87 | 0,0015 | 21,10 |
| EU | BS/EN 7291 Polybutylene | 22 mm | 17,70 | 2,44 | 0,0070 | 41,27 |
| EU | DIN 689293 PEX SDR 7.3 | 20 mm | 14,40 | 3,68 | 0,0050 | 110,21 |
| **Generic 1" (25 mm) - Flow rate = 0,85 l/s** | | | | | | |
| USA | ASTM Schedule 40 Gal Steel | 1 " | 26,64 | 1,52 | 0,1500 | 15,08 |
| USA | Copper ASTM Type L | 1 " | 26,04 | 1,60 | 0,0015 | 11,70 |
| USA | Polyethylene ASTM D 2104 Controlled ID | 1 " | 26,65 | 1,52 | 0,0070 | 10,62 |
| USA | XLPE ASTM F877 | 1 " | 22,23 | 2,19 | 0,0050 | 25,32 |
| AUS | Australian Standard 1432 Copper (Type B) | 25 mm | 22,80 | 2,08 | 0,0015 | 21,94 |
| AUS | AS 2462 Polybutylene Class 16 | 25 mm | 22,20 | 2,20 | 0,0070 | 25,86 |
| AUS | AS 4130 Polyethylene Class 12 | 25 mm | 26,00 | 1,60 | 0,0070 | 12,01 |
| AUS | AS 2492 XLPE PN20 | 25 mm | 23,20 | 2,01 | 0,0050 | 20,60 |
| AUS | AS 1074 Gal Steel | 25 mm | 27,30 | 1,45 | 0,1500 | 13,34 |
| EU | EN 1057 Copper Class X | 28 mm | 26,20 | 1,58 | 0,0015 | 11,35 |
| EU | BS/EN 7291 Polybutylene | 28 mm | 22,50 | 2,14 | 0,0070 | 24,20 |
| EU | DIN 689293 PEX SDR 7.3 | 25 mm | 18,00 | 3,34 | 0,0050 | 70,21 |

obs.: the values of k were obtained from W3f [12].

# ONSITE EVALUATION OF AN INSTALLED SIPHONIC RAINWATER DRAINAGE SYSTEM.

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## Abstract

Siphonic roof drainage systems have been in existence for approximately 30 years. In that time, the construction industry has been gradually persuaded by the benefits which these systems offer when compared to the traditional approach. A great deal of these benefits arise from the fact that systems can become de-pressurised. However, this condition only arises at the design condition – typically a storm with a return period in excess of 30 years. When the funding application was being made for the work reported herein, it was known that the majority of data published relating to siphonic roof drainage system performance related to "ideal" laboratory conditions. Additionally, it was recognised that the overwhelming majority of rainfall events any siphonic system would have to drain would be well below the design condition. This, coupled with reports of siphonic system failures, convinced the authors that this was an area worthy of further research.

The work reported herein documents the instrumentation of a large, high profile building within Edinburgh (Scotland), the aim of which is to investigate how a real siphonic system performs under real rainfall conditions in a Northern European climate. Details are given of the instrumentation used, and data collection protocols established. The data generated at the site are discussed in detail. The ability of the system to drain rainfall events of known intensity and duration is considered. Conclusions are drawn regarding the ability of the system to drain the monitored storms, and those outside the envelope of the data collected. Plans for future work are outlined.

## Keywords

Siphonic roof drainage, design, data collection, numerical model.

## 1. Introduction

Over the past 30 years, an ever increasing amount of industrial and commercial roof space has been drained using siphonic roof drainage – currently it is estimated that over 30,000 systems exist in the UK alone. This continuing increase in usage is largely due to the many advantages the systems have over "conventional" systems for equivalent sized roof areas. However, notwithstanding the increasing use of these systems, there are still uncertainties regarding just how these systems operate –

particularly during priming. This lack of understanding of system operation means that if a system fails, it is often difficult to appreciate why the failure has occurred. Furthermore, as siphonic system design represents a higher level of expertise than may be required for conventional systems, the performance of these systems can be more reactive to small inaccuracies or erroneous assumptions. There has also been growing concern about the use of these systems in developments where it is often necessary to minimise the rate at which flows enter drainage systems. To resolve this, over the past 5 years there has been an ever increasing amount of independent research undertaken attempting to understand how siphonic systems actually perform[1-7].

For any given application, siphonic roof drainage systems are normally designed[#] to cope with the steady state pressures associated with a selected 'design storm', which is normally specified in terms of a steady rainfall intensity (in the UK this is in accordance with BS 6367[8]). Selection of a rainfall intensity at the design stage is based upon the geographical location, and by balancing the risk of failure against the cost of allowing for additional roof drainage capacity. However, it can be seen that this approach will lead to one of two post installation eventualities each time a storm occurs:

1. A storm occurs which exceeds the design rainfall intensity

Practically, no matter what design rainfall intensity is selected, this will always eventually occur, and will result in flooding to some extent. Well designed systems make allowance to ensure that any overspill is directed to areas where it can be managed, or any damage caused is limited.

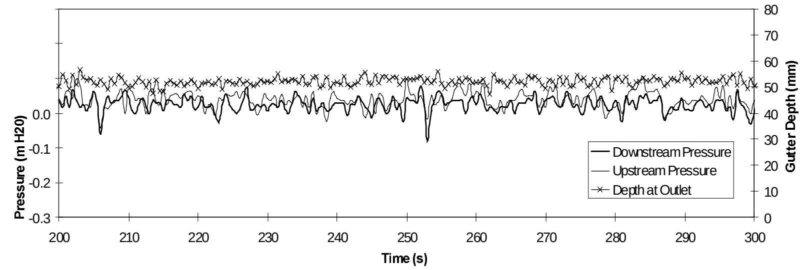
2. A storm occurs which is less than the design rainfall intensity

For any well specified system, the vast majority of the storms encountered will fall into this category. Where rainfall events of low intensity are encountered, the system will perform as a 'conventional' roof drainage system. However, as increasing rainfall intensities are considered partial unsteady de-pressurisation of the system will occur. Laboratory testing[ref] has shown that this de-pressurisation results in air being drawn into the system, this can exceed the volume of water entering the system in some circumstances.. The unsteady nature of the flow regime, which has been observed to be cyclic in nature, leads to varying amounts of noise generation, and structural vibration within the system.

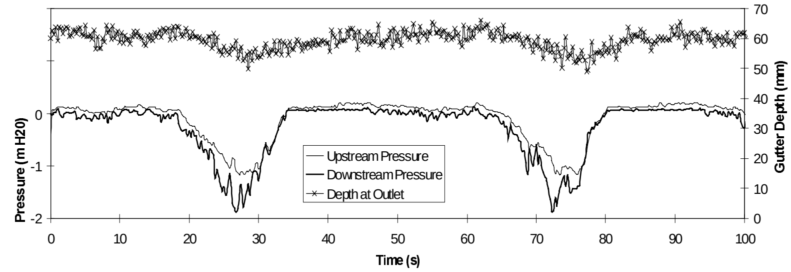
As the first of these eventualities is relatively easy to model, and is currently accounted for in well designed systems (although the priming of the system to reach that eventuality is less well understood), it is the latter of these cases which is of the most interest. Previous work[2] at Heriot-Watt University has investigated how siphonic systems operate at rates of inflow below that of the design. This has lead to a good understanding of the range of flow conditions which can be expected, these are illustrated in Figure 1. As the figure illustrates, the system reacts quite differently to differing rates of constant inflow. At quite low rates of constant gutter inflow it can be seen that free surface flow dominates the mode of operation (*a*). As the rate of inflow begins to increase the pressures plotted indicate that plug flow is the mode of operation (*b* & *c*). Subsequently, as the rate of inflow begins to near the system capacity

[#] Currently siphonic roof drainage systems are designed to accommodate a specified storm which fills, and primes, the whole system rapidly with 100% water. This assumption means that the system may be designed easily using elementary steady state hydraulic relationships. The steady flow energy equation is used almost universally[3] as the backbone of the design procedure for siphonic roof drainage systems. The pressure drop between any two points X and Y can be determined using the energy equation.

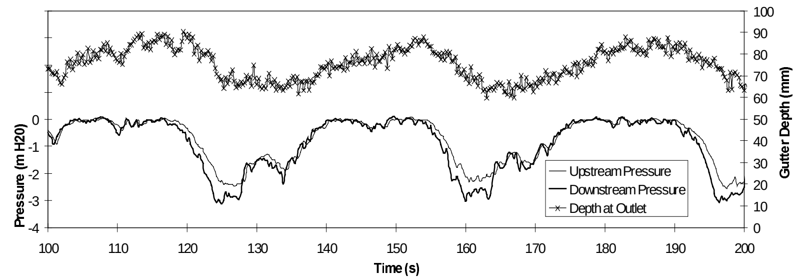
(a) Inflow =
16% of capacity



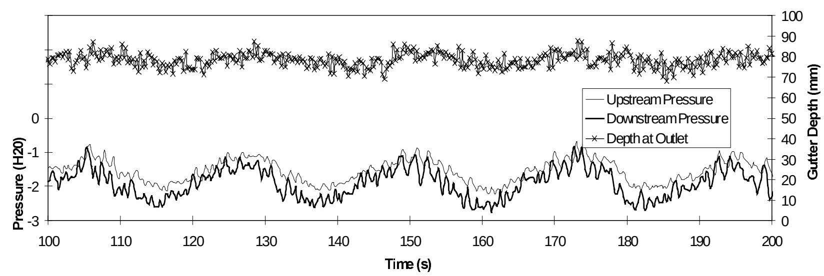

(b) Inflow =
32% of capacity



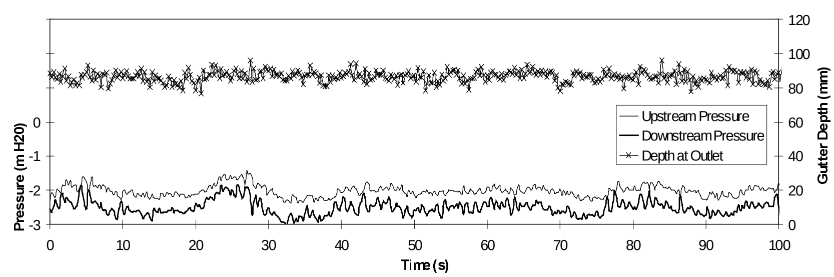

(c) Inflow =
40% of capacity




(d) Inflow =
64% of capacity




(e) Inflow =
80% of capacity




(e) Inflow =
104% of capacity

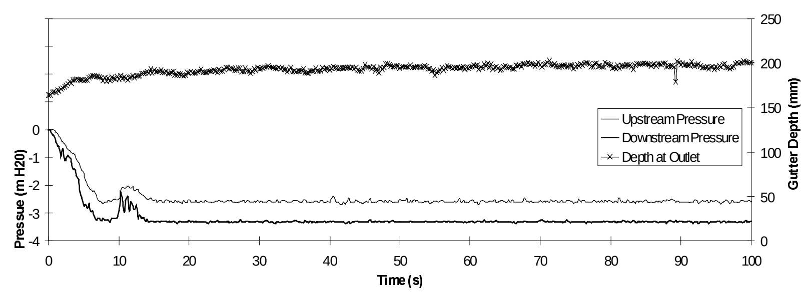



Figure 1: Pressure history data for differing rates of constant gutter inflow.

observations and the pressure data indicate that the phase boundaries between the plugs begin to blur (*d*), bubble flow predominates (*e*). As the rate of inflow approaches the design capacity, the proportion of air within the flow steadily diminishes until the system is primed (*f*). Although it is relatively easy to study these flow conditions by applying rates of steady inflow in a laboratory, it should be noted that in an actual system these flow conditions will be transitory and may well appear concurrently – Figure 1a illustrates how the system accelerates from free surface flow to full bore flow in the space of less than 15 seconds.

## 2. Data Collection Site Details

Based on the considerations outlined above, it was therefore decided to collect data from an installed siphonic roof drainage system in order to understand how these systems drain the vast majority of rainfall events – i.e. those which are below the design capacity of the system. Buildings adjacent to the university campus were surveyed with the aim of finding a suitably sized property which the occupier would allow access to. The building which was selected is the National Archives of Scotland document repository - Thomas Thomson House, which is owned and operated by the Scottish Executive (National Government). The main building has a total roof area of approximately 3000 $m^2$, which is divided into three principle areas. It is the larger of these areas (1988 $m^2$) which is forming the main data collection programme. The building is illustrated in Figure 2.

**Figure 2 : Thomas Thomson House**

The section of roof studied measures 26.8m x 74.2m, and is served by 6 separate roof siphonic roof drainage systems, within which each outlet drains an individual section of roof gutter (a single gutter on each side of the roof which is sub-divided). Only two of the 6 separate roof siphonic roof drainage systems have been instrumented, these are highlighted in the roof plan schematic (Figure 3) and in dimensions are given in Figure 4 . The construction of the roof itself is polished aluminium in a curved form (see Figure 2). The pipework is wholly 50mm internal diameter stainless steel. All bends within the system are 90° smooth radius bends. The siphonic roof drainage system installed at Thomas Thomson house is known to have a high maintenance cost, this is principally due to the roof being used by a large number of birds as an evening roost. The birds then foul the roof surface with their droppings, feathers and occasionally their own expired bodies. This debris then fills the gutters and blocks the siphonic roof outlets. To ensure that the systems operate efficiently, the property manager currently has the roof gutter cleaned at approximately bi-monthly intervals. These maintenance issues should also allow the project the opportunity to evaluate how maintenance effects system performance.

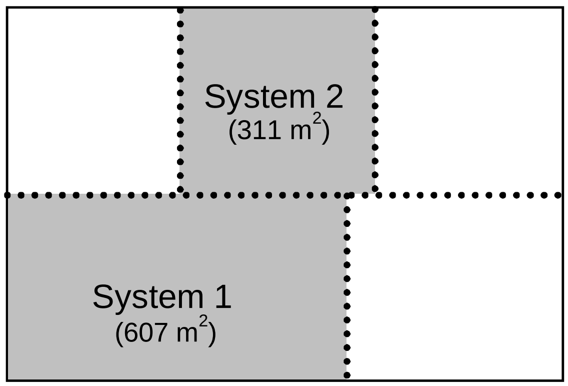



**Figure 3 : Schematic of the test roof area. The diagram indicates which areas of the roof are drained by the respective siphonic systems**

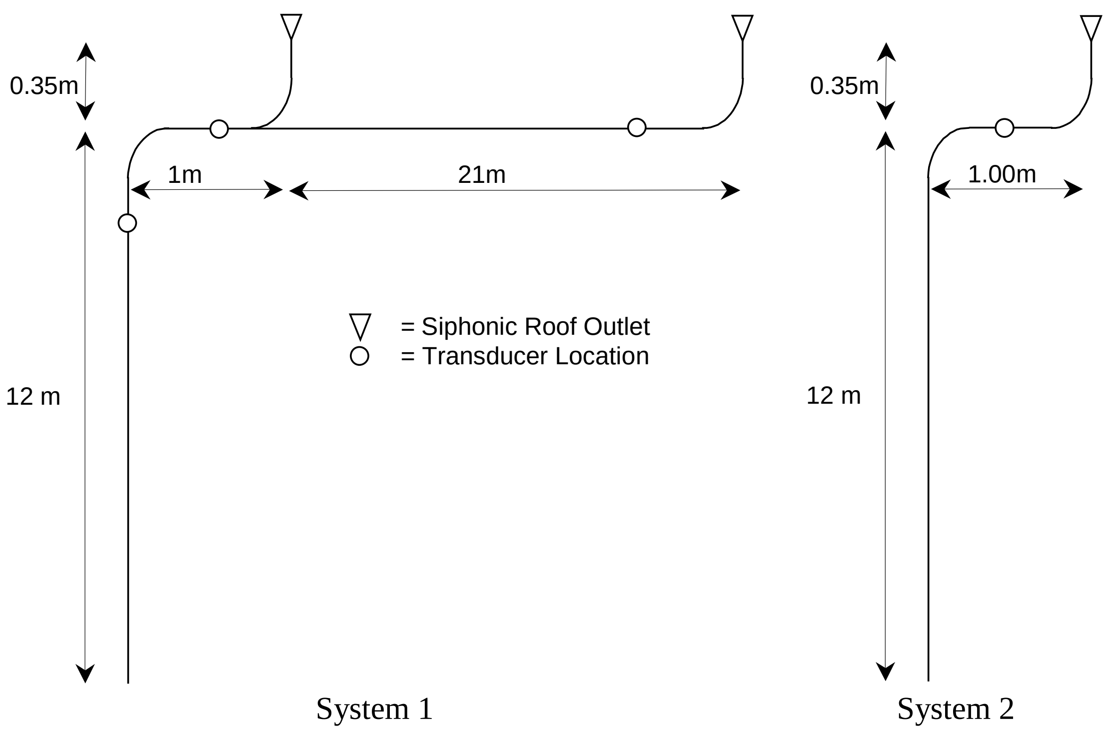



**Figure 4 : Schematic depiction of the two systems being studied. All sizes are based on a preliminary survey of the system.**

## 3. Data Collection Protocols

The main aims of the data collection exercise are as follows:

1. Obtain an accurate survey of the systems under consideration so that their capacity can be accurately estimated.

Subsequently, during rainfall events, the following data are also required:

2. Rainfall intensity variation with time.
3. Wind direction and velocity variation with time.
4. Gutter flow depth variation with time
5. System pressure variation with time.

In Scotland, rainfall is regular – but is predictably unpredictable. Therefore when establishing the test site it was decided to design the instrumentation so that it was autonomous – i.e. automatically controled data collection. This approach reduces the risk that data relating to an important rainfall event would not be lost, and it also means that data does have to be collected continually. To meet these aims the instrumentation was design so that is reacts to real-time rainfall data. Data collection software was coded which continually monitored data from a 0.1mm resolution raingauge. Once rainfall intensity exceeds a  pre-set threshold (5mm/h), the software initiates overall data collection from the roof drainage system. Once data collection is underway, the rainguage input is monitored and the rate of data collection is varied based on rainfall intensity – higher intensity rainfall events are afforded a higher sampling rate. Thirty minutes after the rainfall has ceased, data collection is terminated. Once operating the software will continue to collect data almost indefinitely. Figure 5 illustrates the protocols used by the software for the collection of data.

Data collected relating to the wind conditions is collected separately using a weather station 2 km from Thomas Thomson House.

## 4. Data Collected

At the time of writing, monitoring at the site has been underway for 40 days. In that time data has been collected which with relates to a total of 76.2mm of rainfall. Twelve of the rainfall events which have occurred had peak intensity in excess of 5mm/h.

As expected at the outset, the majority of the storms monitored did not result in any sustained period of depressurisation. However, of the twelve storms monitored, three were found to be of sufficient intensity to result in depressurisation. Each of these three events are illustrated on the cumulative rainfall plot (Figure 6). The following three sub-sections deals with each of these events in turn:

### 4.1 Storm 1 (01.06.00)

This event occurred just a few hours after the instrumentation was installed. Rainfall data relating to the event are illustrated in Table 1. The response of the system in draining this rainfall is illustrated in Figure 7. The data illustrate that although the rainfall event was relatively small, it was sufficient to result in a depressurization of

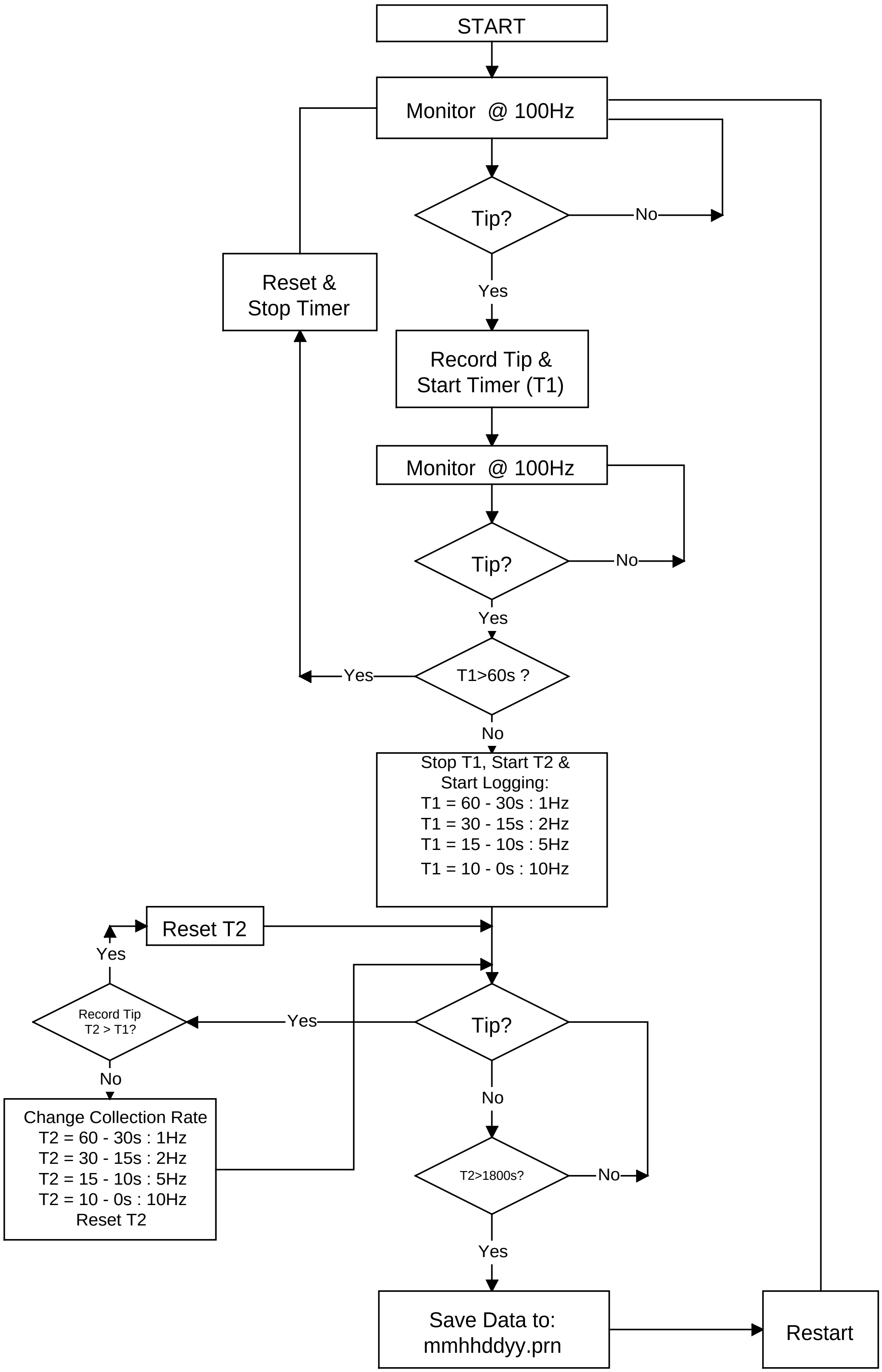



**Figure 5 : Software data collection protocols.**

both System 1 and System 2. The data also indicate that there is a 1.25 minute delay between the rainfall peak intensity and the peak in-pipe depressurisation.

| Parameter | Value |
|---|---|
| Event Duration | 14.4 minutes |
| Peak intensity | 21.1 mm/h |
| Total rainfall depth | 1.2 mm |
| Average rainfall intensity | 5.0 mm/h |
| Total rainfall volume (over 1988 $m^2$) | 2.39 $m^3$ |
| Average run-off rate | 2.76 l/s |

**Table 1 : Data relating to storm of 01.06.00**

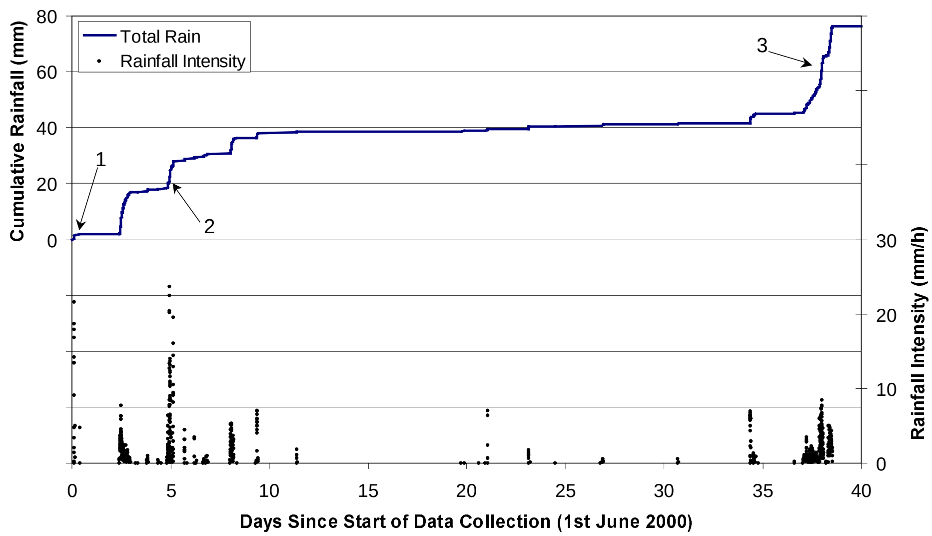



**Figure 6 : Cumulative rainfall data**

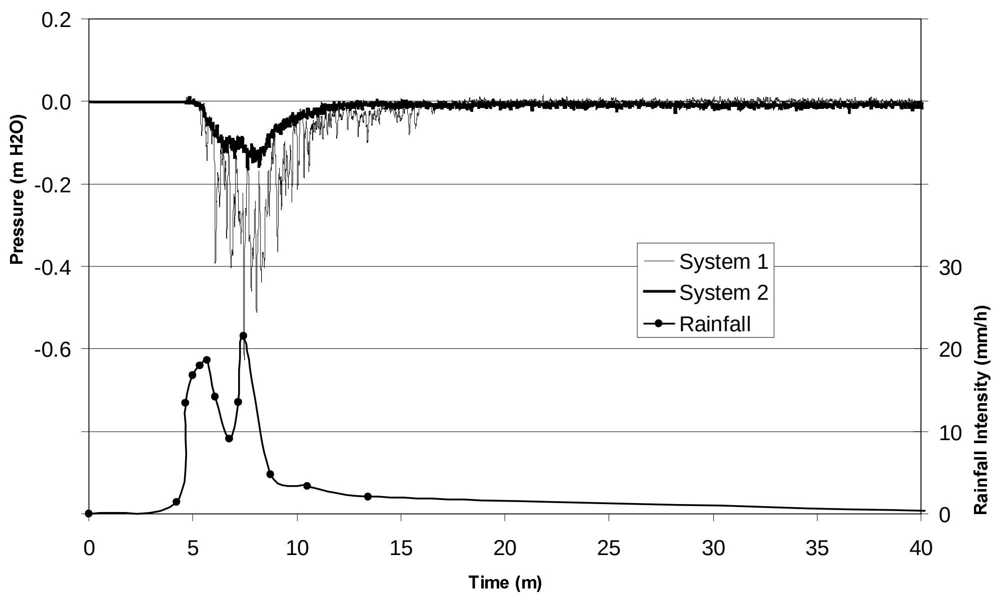



**Figure 7 : Data relating to storm of 01.06.00**

### 4.2 Storm 2 (06.06.00)

Data relating to this event are illustrated in Table 2. The response of the system in draining this rainfall is illustrated in Figure 7. Again this data illustrates that although the rainfall event was relatively small, it was sufficient to result in a depressurization of both System 1 and System 2. This data set also indicated that there is a 1.5 minute delay between the rainfall peak intensity and the peak in-pipe depressurisation.

| Parameter | Value |
|---|---|
| Event duration | 16.9 minutes |
| Peak intensity | 19.5 mm/h |
| Total rainfall depth | 1.5 mm |
| Average rainfall intensity | 5.35 mm/h |
| Total rainfall volume (over 1988 $m^2$) | 2.98 $m^3$ |
| Average run-off rate | 2.93 l/s |

**Table 2 : Data relating to storm of 06.06.00**

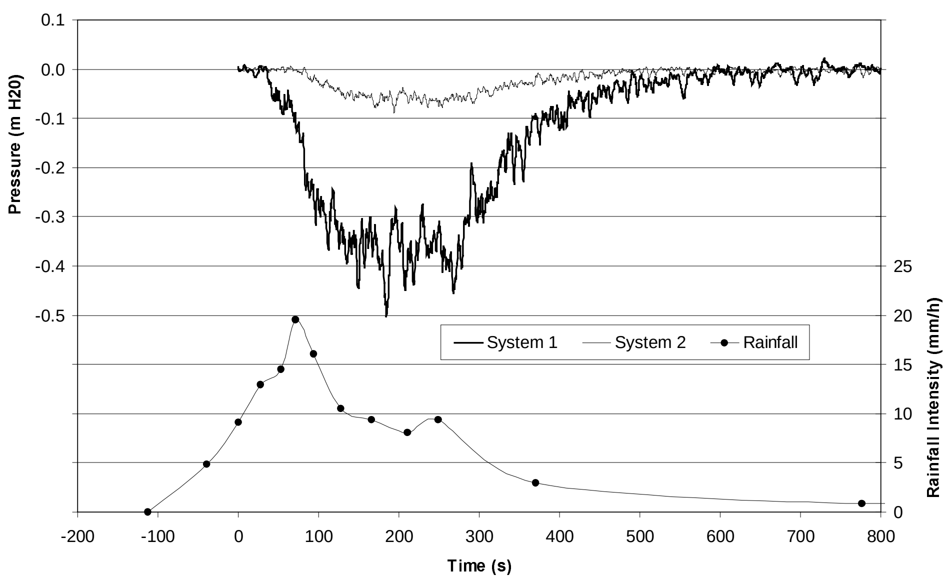



**Figure 8 : Data relating to storm of 06.06.00**

| Parameter | Value |
|---|---|
| Event duration | 5.5 Hours |
| Peak intensity | 8.47 mm/h |
| Total rainfall depth | 10.9 mm |
| Average rainfall intensity | 1.98 mm/h |
| Total rainfall volume (over 1988 $m^2$) | 21.7 $m^3$ |
| Average run-off rate | 1.09 l/s |

**Table 3 : Data relating to storm of 08.07.00**

### 4.3 Storm 3 (08.07.00)

Data relating to this event are illustrated in Table 3. The response of the system in draining this rainfall is illustrated in Figure 9. As the data illustrate, the peak rainfall intensity of this event was only 8.47 mm/h. Figure 9 also illustrates that the 5 mm/h threshold set for data collection was actually too low, as it appears that some of the depressurisation data was not collected (i.e. that prior to t =0). It is not yet clear how representative this particular data set is, as this rainfall event lasted for 36 hours (starting 24 hours before the recorded depressurisation) – the full rainfall data set for this event is illustrated in Figure 10. It is therefore possible that the system responded differently than it would have if the rainfall plotted in Figure 9 occurred in isolation.

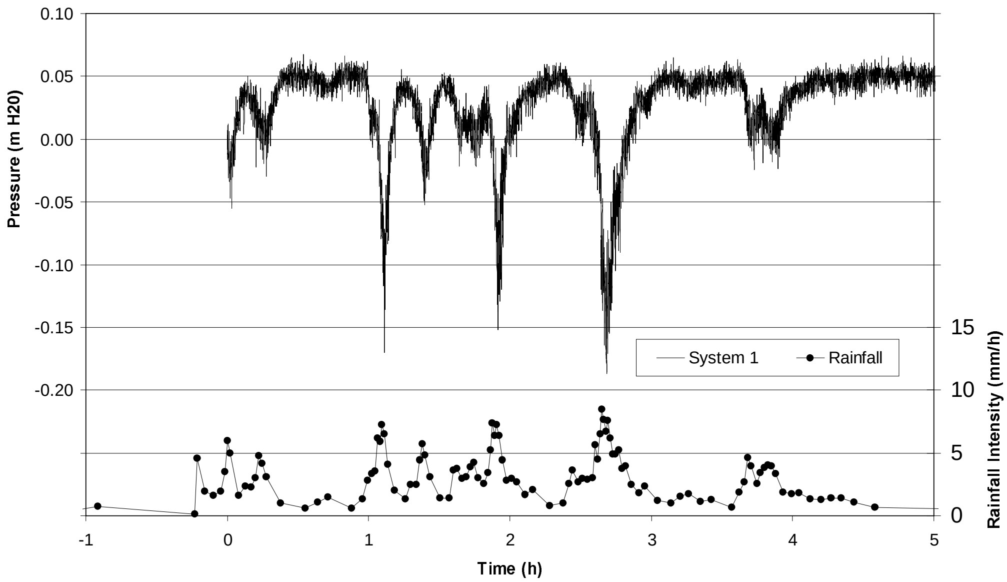



**Figure 9 : Data relating to storm of 08.07.00**

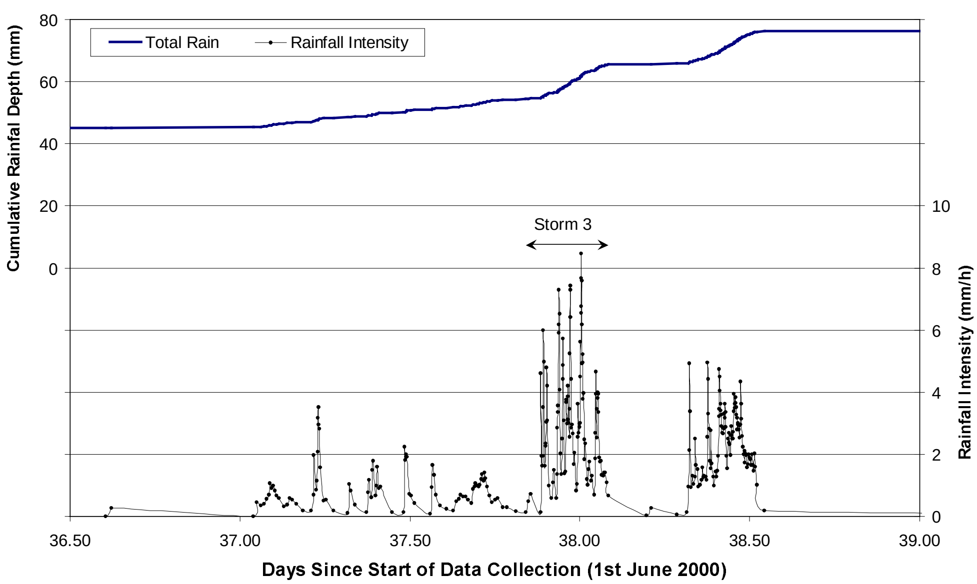



**Figure 10 : Data relating to storm of 08.07.00 – 09.07.00**

## 5. Discussion of results

Based on a preliminary survey of the property, it was estimated that the roof drainage system, as a whole, was designed based on a design rainfall intensity of 100 mm/h. Applying the laboratory findings illustrated in Figure 1 to the system installed at Thomas Thomson house indicated that there would be a degree of measurable depressurisation when the rainfall intensity exceeded 25mm/h (25% of the system capacity). However, the data collected to date indicates that the systems is capable of become partially depressurised at rainfall intensities less than 10% of the estimated design capacity. If this result is transferable to other installed systems it means that they may have better than expected performance when draining rainfall events of lower return periods. Additionally, the ability of the system to become depressurised at quite low rates of inflow means that the system will have an increased propensity to be self cleansing.

## 6. Conclusions

Regarding the work reported herein, the following conclusions may be drawn:

- Laboratory data has been presented which represents the range of flow conditions which lead to the system working at its design capacity.
- To complement the laboratory based work underway at Heriot-Watt University, a field data collection site has been established based on both novel and established data collection techniques.
- Data has been presented which indicates the siphonic rainwater drainage systems have the ability to become depressurised at lower then expected rainfall intensities.
- The ability of the system to become depressurised when draining low intensity storms indicates that the self cleansing velocity may be achieved on a frequent basis.

## 7. Future Work

It is anticipated that data collection will continue for at least one year. It is hoped that in that time a data base of storm events will be established which will demonstrated the ability, or otherwise, of the installed system to operate under varying conditions. The data collected will then be used to validate the numerical model being developed at Heriot-Watt University to represent the flow conditions within siphonic roof rainwater systems.

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# BUILDING DRAINAGE VENT SYSTEMS AND THE USE OF EMPIRICAL DATA IN DEFINING TRACTION FORCES AT THE ANNULAR FLUID-TO-FLUID BOUNDARY.

CIB W62 SEMINAR ON WATER SUPLY AND DRAINAGE FOR BUILDINGS
Rio, Brazil (September 18th – 20th, 2000)

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**ABSTRACT**
Recent advances in the modelling and analyses of air pressure transients within building drainage ventilation systems have clearly demonstrated well defined mathematical links between a wide range of relevant and contributory design parameters – a critical factor in understanding the response of sanitary appliance trap seals and the potential for any fluid depletion. Despite the importance of these findings, these results remain limited in their applicability due to the inherent lack of flexibility that would be required to model multiple inlet, simultaneous discharge flow within the vertical stack and associated pipework.

This paper evolves and applies recent developments within the modelling approach and, utilising empirical data, proposes a new and significant advanced definition of the pressure regime within the drainage vent system. Use of the empirical data in this way reveals important factors in the understanding of the interaction of fluid flows within the system and demonstrates the significance of the theoretical definition of the fluid-to-fluid boundary relating to annular flow. The empirical data provided also allows a theoretical assessment of the assumed fluid flow path associated with a branch connection and the development of fully established annular and terminal flow conditions.

**KEYWORDS**
Building, drainage, ventilation, modelling

**INTRODUCTION**
The sanitary appliance trap seal is a device critical to the operation of any building drainage network, since it's primary purpose is that of providing a barrier between the habitable space and the foul odour present within the system. However, as simple and effective as this seal is, it remains vulnerable when subject to air pressure transient propagation within the drainage network system developed as a direct result of sanitary appliance discharge.

The use of the two-pipe system introduced around 1900 and shown in Figure 1, somewhat 'overcompensated' against the threat of appliance trap seal depletion or loss by providing an elaborate pipework arrangement aimed at minimising the possibility of pressure fluctuations. Constructed of solid and well-coated cast iron, a few of these externally mounted drainage networks still remain intact in some 'older' UK cities today.

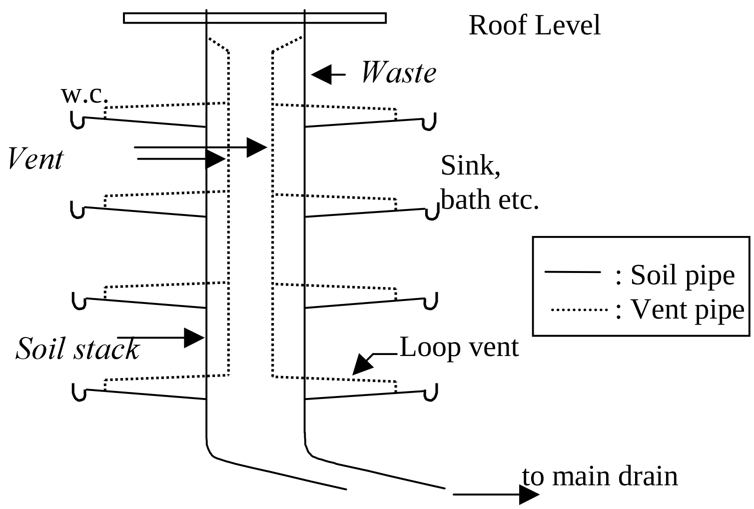


**Figure 1** Two-pipe system, commonly installed in the USA & UK around 1900

As the design of the drainage network progressed and notably, the provision of separate stacks for 'grey' and 'black' water were combined, so the one-pipe and modified one-pipe systems were introduced. Schematic diagrams of these types of systems are shown in Figures 2a and 2b and working examples remain common throughout the USA and in some parts of Europe.

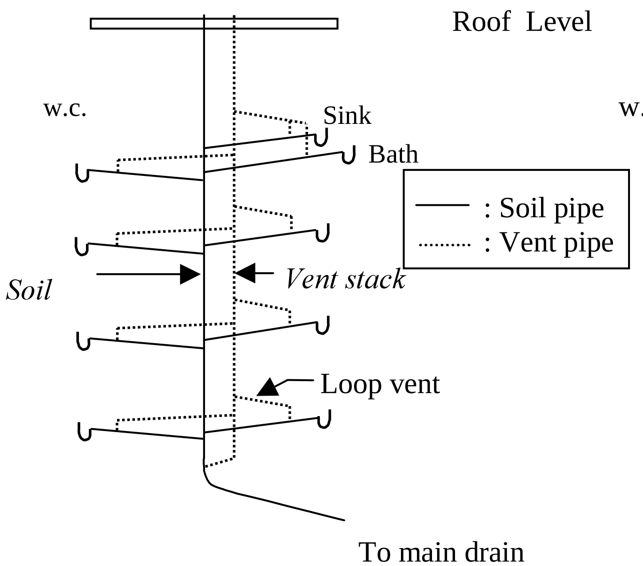


**Figure 2a** One-pipe system, commonly installed in the USA & UK

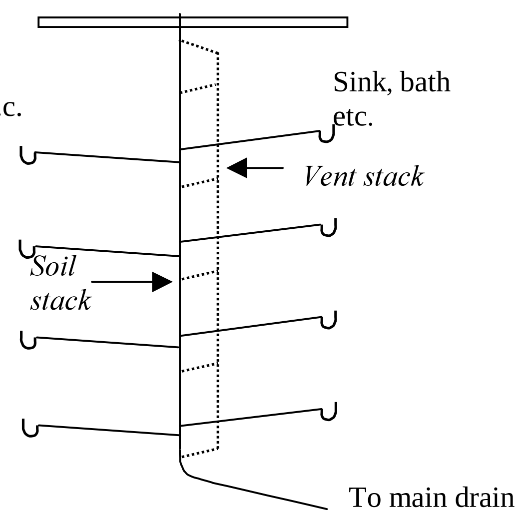


**Figure 2b** The modified one-pipe system, providing extra ventilation

Importantly however, in the UK during the 1960s, developmental work and system application and testing of the 'single-stack' drainage system was undertaken. Early concerns over the increased possibility of appliance trap seal depletion were alleviated by the findings of, for example, Wise[1] and Wise and Croft[2], which demonstrated that through careful and exact network design, combined with accurate pipe sizing, the single stack system could be effectively applied to serve buildings of up to 5 storeys. Subsequent investigations[3] then extended the applicability of the single stack system to heights of up to 30 storeys, thereby facilitating a tremendously significant saving in terms of installation space, installation time and of course, material cost.

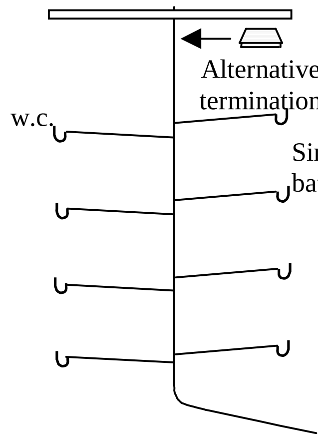


**Figure 3** Single-stack system, commonly installed in the UK from mid 1960s

Since the late 1960s, the design of the single-stack system has changed little, despite the significant differences witnessed with regard to water consumption and the consequent changes in discharge volumes and chemical composition of waste flows. Furthermore, the demands placed upon the drainage network as a whole are widening, as mandatory water conservation measures are steadily introduced into Byelaws, Building Regulations and Codes of Practice. With each new development, there exists a greater need to understand the complex interactions of the fluid flows found within a typical network and move forward from the Discharge Unit Method upon which current sizes are based[4]. In order to achieve this, there are several aspects of the system which require investigation, both individually and combined. These may be defined (simply) as:

- the network design/layout
- the supply/load to the system
- the time dependency of the 'load'
- the unsteady nature of the fluid flows within the system
- the chemical composition of the 'load' (and it's temperature)

**SYSTEM DESIGN**

The ability of the designer in assessing the above parameters relating to a particular application will determine the 'success' or 'failure' of the design – bearing in mind that 'failure' is not only financially costly, but also has important public health implications. The assessment of the input of these influencing factors upon the drainage network design must be analysed interactively and must fully recognise the integral importance of the points noted above. Within the context of existing systems, the network layout will already be known as well as details of the supply to or load on a system, a parameter for which clarity is steadily improving as manufacturers realisation of the importance of discharge volumes develops. Within the time associated with a particular appliance discharge, the volumetric flow will be known or can be reliably estimated however, the issue of frequency of use of any one appliance coupled with estimation of the likelihood of ‘combined’ or simultaneous discharges within the main drain or discharge pipe is still open to interpretation based upon the building type and nature of occupancy.

The unsteady nature of the fluid flow within the system is such that only the advantages presented by numerical simulation are capable of dealing with the complex fluid dynamics therein. It is only since the introduction of numerical modelling techniques applied to building drainage network systems, encompassing both partially filled pipe flow and full bore air pressure transient propagation, that the understanding of the system and fluid interaction and the implications for designers have been fully recognised.

## NUMERICAL MODELLING OF AIR PRESSURE TRANSIENTS

It was in 1960 that Lister[5] introduced the concept of the applicability of the Method of Characteristics numerical simulation technique to the field of fluid dynamics. However, it was not until the early 1980s that the AIRNET model saw it’s initial development, widening the application of the Method of Characteristics technique to full bore air pressure transients such as those found within building drainage network systems. The basis for this approach is the application of the full equations of continuity and momentum and these are combined and linked to air pressure transient propagation through the substitution of shear stress and wetted perimeter variables arising from the full bore air flow within the vertical stack system.

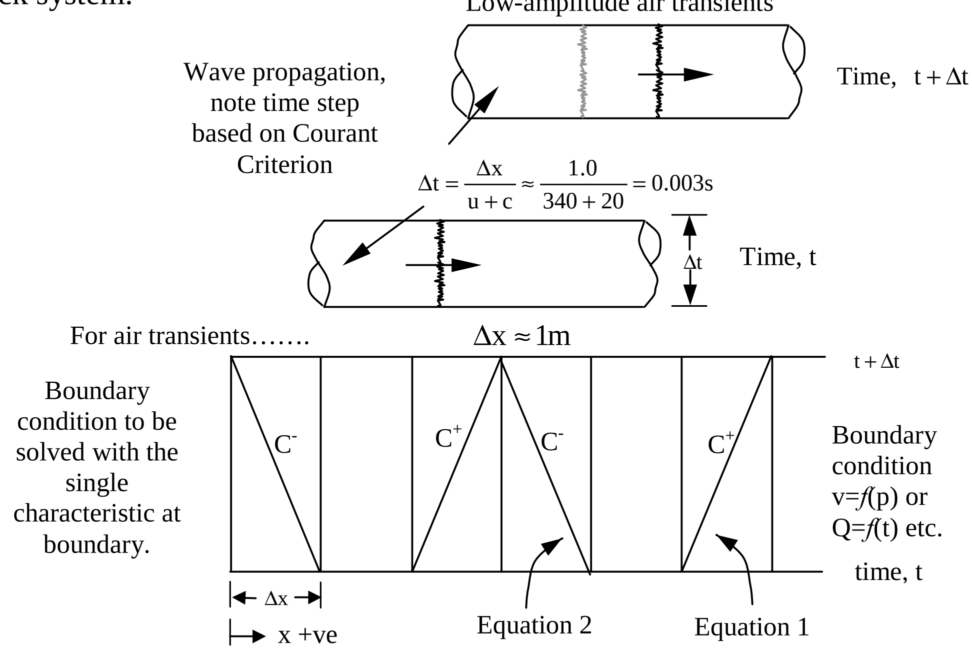


**Figure 4 :** Method of Characteristics applied to low-amplitude air pressure transient propagation. Note importance of boundary equations at pipe entry and exit. [6]

The Method of Characteristics approach is based on the finite difference principle demonstrated by Figure 4. Providing that the Courant Criterion defining time step stability is satisfied, the characteristic equations shown below can be used to represent the air pressure transient propagation.

For the $C^+$ characteristic :

$$u_P - u_R + \frac{2}{\gamma - 1}(c_P - c_R) + 4 f_R u_R \mid u_R \mid \frac{\Delta t}{2D} = 0 \qquad (1)$$

when

$$\frac{dx}{dt} = u + c \qquad (2)$$

and for the $C^-$ characteristic :

$$u_P - u_S - \frac{2}{\gamma - 1}(c_P - c_S) + 4 f_S u_S |u_S| \frac{\Delta t}{2D} = 0 \qquad (3)$$

when

$$\frac{dx}{dt} = u - c \qquad (4)$$

[Note : $f_R$ and $f_S$ are functions of time and location]

Figure 4 clearly demonstrates the requirement for a second boundary condition equation at the pipe entry or exit, thereby completing the set of applicable simultaneous equations solvable for fluid velocity and wave speed. Each of these boundary equations will link flow rate to pressure or flow to time.

In order to facilitate the modelling of air pressure transient propagation within building drainage vent systems, the AIRNET model (developed through a coherent programme of research funded by the Engineering and Physical Sciences Research Council, EPSRC) requires a clearly defined set of boundary conditions which mathematically describe the physical parameters of the drainage network. Much of the early research carried out within this programme, part of which is described here, was aimed at determining such equations[7,8].

Once the model development was such that the air pressure transients within the drainage vent system could be simulated and the response of the network determined, the aim was then to broaden the scope of applicability by releasing the model from the constraints imposed by laboratory testing. This was achieved through a series of site investigations which introduced, through the application of dimensional analysis techniques to the data field established, the flexibility to alter within the numerical simulation, the parameters of stack diameter, wet stack height and stack material (or roughness)[9,10].

This paper will report on how the simulation technique has been further released from remaining restraints through the utilisation of a friction factor term which allows the modelling of simultaneous or ‘combined’ discharge flows within the single stack pipe.

**TRACTION FORCES PRESENT BETWEEN STACK FLUIDS**

Until recently, the modelling of simultaneous discharge flows from one or more appliances connected to the network has been limited in that, although each individual discharge profile could be examined at a particular point in the system, modelling the combined flows within the main vertical stack pipe was limited due to the way in which the single stack pressure profile was defined. By introducing the concept of a ‘traction’ force, applied across the wet stack height, then all possible flow scenarios are catered for. The critical factor in determining the application and subsequent benefits of applying a ‘friction factor’ or ‘traction force’ across the height of the wet stack, is the determination of the velocity difference present at the fluid-to-fluid interface. This requirement arises due to the importance of the velocity (differential) term present within Darcy’s equation, when applied to the annular water flow which entrains the ‘central air core’. Equation 5 shows Darcy’s equation in typical format and Equation 6, the same equation rearranged to show the friction factor as the subject and incorporating single stack discharge flow parameters, for example, the length term is replaced by ‘wet stack height’ and the pipe diameter by the diameter of the central air core.

$$\Delta P_f = \frac{4\rho f L V^2}{2D} \qquad (5)$$

$$ff = \frac{2D_a \left|\Delta P\right|_{sum}}{4\rho_a H_w (V_a - V_{t1}) \mathrm{abs}(V_a - V_{t1})} \qquad (6)$$

The term $(V_a - V_{t1})$ represents the velocity difference at the fluid-to-fluid boundary. Previous reference to the annular downflow and central air core of entrained air has almost always assumed a clear definition of this fluid-to-fluid boundary, as well as consistent velocity profiles within each fluid, and until recently, these assumptions formed the basis for the definition of the velocity difference identified. However, analysis of the data arising from site investigations revealed not only a method by which fluid flows could be combined and modelled, but also that assumptions such as those relating to the fluid velocity profiles and definition of flow regimes were not necessarily accurate. Figure 5 demonstrates the range of possibilities for variation of the velocity difference term and shows how the resultant sign notation is significant in determining the change in pressure gradient. The fact that single point discharge gives rise to a negative friction factor term and a pressure rise, was an important factor within the determination of the interface velocity, discussed further below.

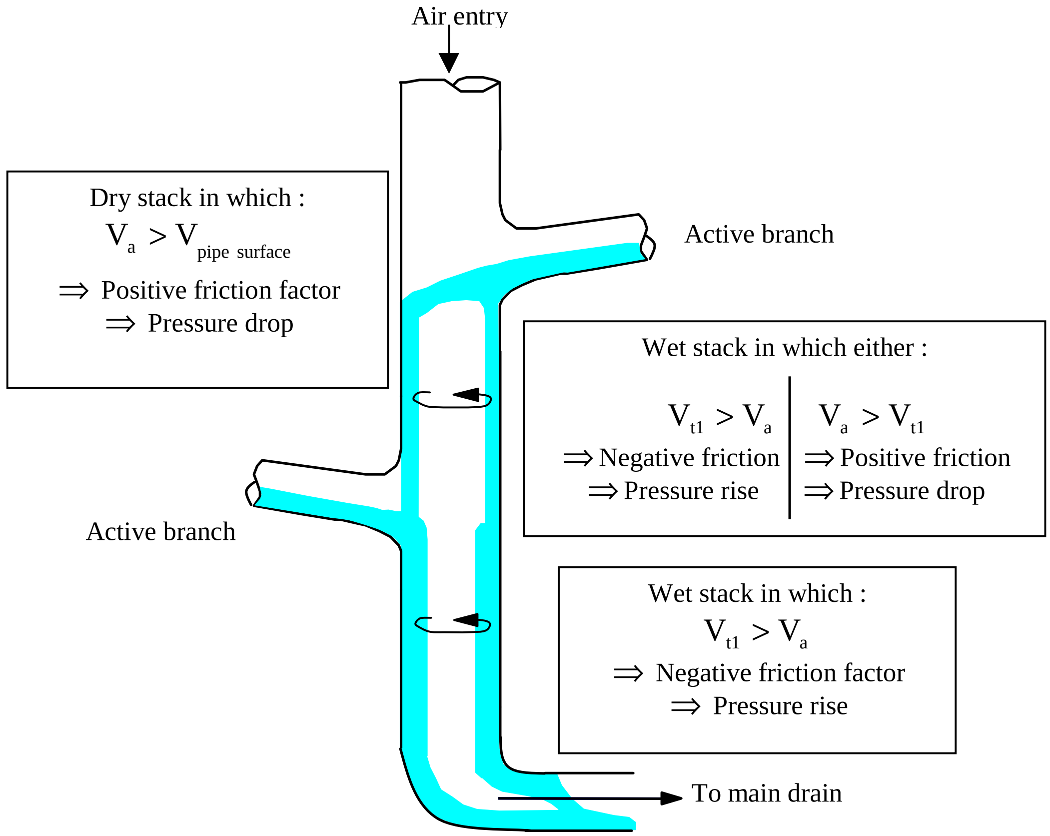


**Figure 5** Definition of friction factor for simultaneous discharge flows.

**DATA ANALYSIS**

The data field was established through the testing of three separate stack systems which allowed variation of the relevant influencing parameters ie. stack diameter, stack material (or roughness) and wet stack height. The fluid flows, although obviously linked through the design of the stack itself were both varied through appropriate control mechanisms. The entrainment of air was permitted via the upper stack termination only. The tests undertaken to establish the data field have previously been reported in more detail within previous publications[9,10] and report in much more detail the equipment utilised and the particular test methodology adopted.

Initial developments from this data allowed significant advances in the understanding of how the single stack system pressure profile is generated[9] and this was of critical importance in establishing the ability to calculate the 'work done' by the system as a whole. The analysis is taken forward through the logical conclusion that this 'work done' upon the air pressure can only arise from the falling column of water. Hence, by summing the absolute values of pressure, another parameter within Darcy's equation has been identified and quantified.

Returning to the issue of velocity difference at the fluid-to-fluid boundary - a term which requires a quantitative assessment in terms of the interface velocity of the annular water film – it becomes clear that in order to calculate a value for the acting friction factor, some estimate is required of the expected or assumed velocity profile. Previous publications[11,12] indicate that it might be reasonable to assume a parabolic function as representative of the annular water velocity profile, thereby giving rise to an interface (water) velocity of three times that of the mean terminal value. However, in all cases it was pre-assumed that the velocity profile would remain consistent in shape regardless of the particular prevalent air flow conditions within the stack system.

In attempting to formulate a solution to the problem of friction or traction force distributed across the wet stack height, it became clear that in order to arrive at a workable solution, it would not be unreasonable to assume that the velocity profile throughout the annular water film is, in part, determined by the velocity of the entrained air at that particular point. In defining this relationship, it was found that in order to ensure the existence of a negative friction factor term (giving a pressure rise) within the single discharge wet stack (as was known to be the case during all test conditions), the following equation was required:

$$V_{t1} = KV_a V_t \qquad (7)$$

where, in this case, K is set to 1.36. It is, of course, appreciated that the actual value of friction factor during testing may have been more negative than the resultant data set and that consequently, the value of K may be greater than 1.36. To carry the analysis forward, the variable parameters were identified as: Qw, $Q_a$, $D_s$ and k (with $H_w$ integrated into Darcy's equation).

By non-dimensionalising the fluid velocities against one another, it was possible to establish trends descriptive of the friction factor, when calculated under varying discharge flow conditions for a set variation in stack diameter and stack roughness. An example is shown in Figure 6, where the discharge flow rate was varied against set values of stack diameter and stack roughness. It should be noted that the dimensionless group based on the radius of curvature of the branch connection was applied throughout the analysis as this value varied slightly between data sets and has an influence upon the formation of the water curtain at the upper limit of the wet stack height.

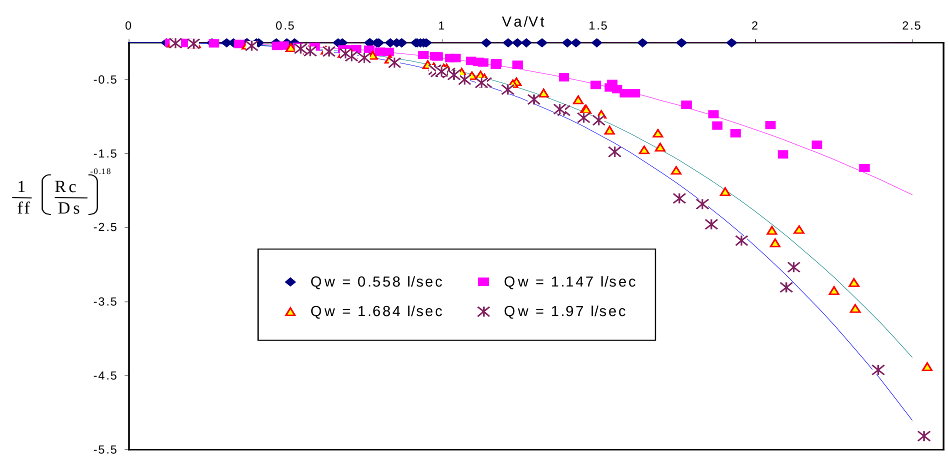


**Figure 6**: Range of water flow rates for a 152mm diameter cast iron (aged) pipe, showing the relative change in friction factor term, plotted against the fluid velocity ratio.

This procedure was repeated for each variation in stack diameter and roughness, thereby allowing a comparison of the influence of these variables on friction factor. Once the complete set of curves and graphs were established and mathematically defined and comparable constants examined, it then became possible to mathematically define the change in constant as a function of the influencing parameter. This methodology lead to the development of a complex but fully-encompassing set of equations defining the friction factor response of the flows within the wet stack where:

$$ff = \frac{1}{a}\left(\frac{R_c}{D_s}\right)^{-0.18}\left(\frac{V_a}{V_t}\right)^{-n} \qquad (8)$$

(with constants a & n quoted in Appendix 1)

These expressions form the input characteristic equations for the numerical simulation model. Referring to equations 1 & 3, it now becomes possible to define $f_R$ and $f_S$ as functions of time and local flowrate, hence providing the time dependent drivers to initiate entrained airlfow within the stack simulation. It is interesting to note that the presence of a 'length' term within Darcy's equation (which translates to 'wet stack height' when applied to the single stack drainage system), means that there should be no differentiation between a discharge input at varying height, however graphical results demonstrated that a height difference was indeed present. This was found to be dependent upon the volumetric flow of the appliance discharge and the stack diameter. It was hence assumed that this length, across which the friction factor or traction force cannot be assumed as being fully functional was attributed to the length required for 'proper formation' of annular flow conditions.

Although the equations quoted for friction factor enable the definition within the model of response of the single stack system when subject to single or multiple discharge flow, there are a small range of conditions under which these equations are not applicable ie when the discharge flow rate is less than 0.5 litres per second and when the entrained air flow is restricted to such an extent that the friction factor must become infinitely large to induce air movement. The former condition is one in which the appliance trap seals are not threatened due to low system pressure, whereas solutions to the latter limitation form the basis for further research investigations.

**THE AIRNET MODEL**

Once incorporated within the model, the equations quoted in the previous section permit the analysis of a network design subject to a fully flexible range of possibilities encompassing discharge frequency, time dependency and the characteristic unsteady fluid dynamics. This takes the model forward towards generation of the characteristic curves analogous with those of a fan, as proposed in an earlier publication[9].

Within the range of typical conditions, and in particular those relating to circumstances under which the appliance trap seal may be jeopardised, the model demonstrates a high degree of accuracy. In addition to which, the robust nature of the model is confirmed by the accurate return to steady-state conditions following the application of a system transient. A comparison of predicted against measured values of friction factor reveals a high degree of accuracy and this is confirmed by Figure 7, which demonstrates AIRNET model predictions under varying flow conditions.

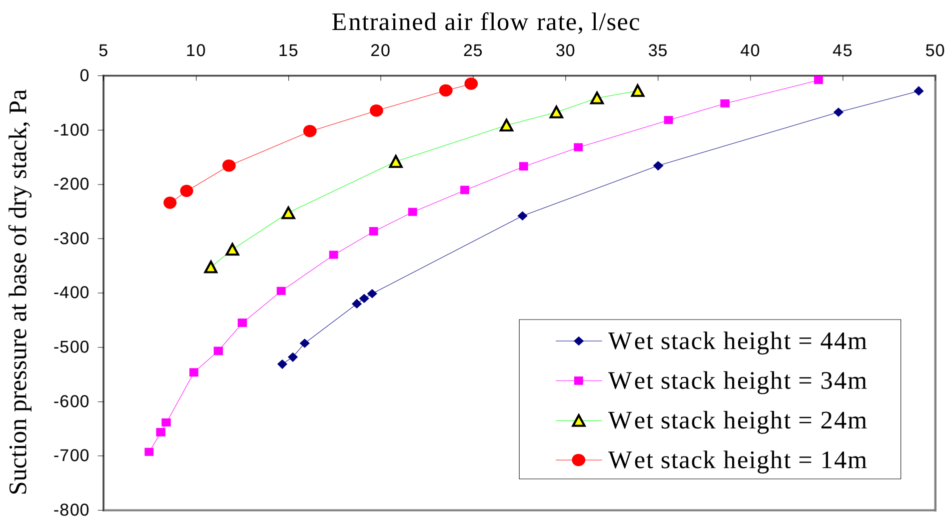


**Figure 7 :** AIRNET model predictions for a variation in the wet stack height for 150mm diameter 'smooth' pipe, when the discharge flow rate is 1.147 l/sec.

## CHEMICAL COMPOSITION

The issue of chemical composition and associated temperature of the discharge into the building drainage system has recently come to be recognised as a significant contributor to variations in the definition of standard accepted boundary condition expressions. The extent of variation associated with hot, detergent-dosed discharge (as opposed to cold clean water used under test conditions) has seen some published results[12] and work in this area is continuing.

## CONCLUSIONS

The outcome of this research is that the AIRNET model is now capable of analysing 'combined' or simultaneous discharge within the drainage stack, through application of system constants. In addition, the effect of the entrained air flow upon the velocity profile with the annular downflow, which in turn influences the differential velocity at the fluid-to-fluid interface has been recognised. Together, these factors significantly enhance the simulation capability of the AIRNET model in analysing the response of the building drainage vent system to the propagation of air pressure transients. The generation of a new range of boundary conditions applicable within the AIRNET model has lead to the subsequent developed ability of the simulation to analyse an increased range of scenarios typical within the building drainage vent system. This is vitally important when examined within the context of recent developments aimed at reducing the overall consumption of water used through appliance cleansing.

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## NOMENCLATURE

| | | | |
|---|---|---|---|
| D | Pipe diameter $(m)$ | $\Delta P$ | Pressure differential $(Pa)$ |
| DP | Back pressure at base of stack $(Pa)$ | k | Surface roughness $(m)$ |
| Le | Equivalent length (m) | $R_c$ | Radius of curvature $(m)$ |
| ff | Friction factor | L | Length (m) |
| c | Wave velocity $(ms^{-1})$ | t | Annular film thickness $(m)$ |
| $H_w$ | Wet stack height $(m)$ | V | Velocity $(m\ s^{-1})$ |
| Q | Volumetric flow rate $(m^3s^{-1})$ | $\rho$ | Density $(kg\ m^{-3})$ |

### Subscripts

| | | | |
|---|---|---|---|
| $a$ | Air | $S$ | Stack |
| t | Terminal | t1 | Entrained air water interface |
| f | Friction | w | Water |

## Appendix 1

Definition of constants 'a' and 'n', as well as Equivalent Length, Le.

$$a = \left[\left(1.043\exp\left(-494.839*Qw\right)\right)-0.793\right]$$
$$-\left[\left(1.704E11*\left(\frac{k-0.01}{0.01}\right)*Qw^{4}\right)-\left(1.22E9\left(\frac{k-0.01}{0.01}\right)*Qw^{3}\right)+\left(3.16E6\left(\frac{k-0.01}{0.01}\right)*Qw^{2}\right)\right]$$
$$+\left[\left(3272.18*\left(\frac{k-0.01}{0.01}\right)*Qw\right)+\left(1.804*\left(\frac{k-0.01}{0.01}\right)\right)\right]$$
$$-\left[\left(-187.8*\left(-\frac{D_s-0.15241}{0.15241}\right)^{1.0935}\exp\left(-5395.288*\left(-\frac{D_s-0.15241}{0.15241}\right)^{1.0935}*Qw\right)\right)+\left(156*\left(-\frac{D_s-0.15241}{0.15241}\right)^{1.0935}\right)\right]$$

and

$$n = \left[\left(-1.398\exp\left(-881.398*Qw\right)\right)+\left(3.05\right)\right]$$
$$-\left[\left(3.92*\left(\frac{k-0.01}{0.01}\right)\exp\left(1720.54*\left(\frac{k-0.01}{0.01}\right)*Qw\right)\right)-\left(1.235*\left(\frac{k-0.01}{0.01}\right)\right)\right]$$
$$-\left[\left(4.75*\left(-\frac{D-0.15241}{0.15241}\right)^{0.005}\exp\left(-2257.3*\left(-\frac{D-0.15241}{0.15241}\right)^{0.005}*Qw\right)\right)-\left(1.2*\left(-\frac{D-0.15241}{0.15241}\right)^{0.005}\right)\right]$$

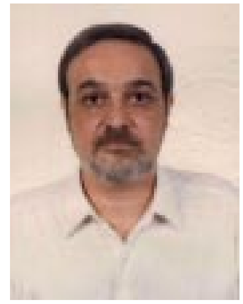
Friction factor based on Darcy's equation originally:

$$ff = \frac{2*D_a*\Delta P_{total}}{4*\rho_a*\left(H_w-Le\right)\left(V_a-1.36V_aV_t\right)*abs\left(V_a-1.36*V_aV_t\right)}$$

where

$$Le = \left[\left(\left(\left(-7.5\exp\left(-1.232*Qw\right)\right)+7.458\right)-\left(\left(-4.92\exp\left(-1.198*Q_w\right)\right)+4.924\right)\right)*\left(\frac{D_S-0.07725}{0.15241-0.07725}\right)\right]$$
$$+\left[\left(-4.92\exp\left(-1.198*Q_w\right)\right)+4.924\right]$$

# Evaluation of the Performance of the Building Drainage System with Different Solutions of Ventilation



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## Abstract

This work establishes, to a five floor building and under certain discharge flow rate of sanitary sewer, a comparison of the performance of a conventional configuration of Building Drainage Systems (single stack) with the performance of alternative configurations of the same system. The conventional configuration is the classic solution in which ventilation is foreseen by the vent stack and for the vent branches, attached on drainage stack. However, the analyzed alternative configurations are several, which include from configurations of the type Single Stack, even configurations that incorporate Air Admittance Valves (AAV). The variables used in the comparative study are the pneumatic pressures differentials in the drainage system, and the variations of the height of the fixtures trap seal. Making possible like this to evaluate the influence of the different ventilation system means on the behavior of the mentioned variables. As the expected, in the configuration Single Stack is where the largest depressions and the largest losses of height of the fixtures trap seal may occur. With base in the laboratory tests, some conclusions are presented.

## 1 Introduction

In the international ambit, the search for quality and for rationalization has been taking to the creation of technological alternatives in several segments of the Civil Construction, especially in the Building Systems, where the development of new systems and devices seek to obtain economy in the implantation and in the use of the same ones, besides they make possible the conservation and rational use of the water resources available. The Building Drainage Systems (SPES), for your importance in the human activities, doesn't flee that such tendency and therefore it has been objective of researches for development of devices and alternative systems that allow the reduction of installation and maintenance costs, without damage of your acting.

In this intention, specific researches have been developed in the sense of reducing total or partially the component piping of the vent system in the Building Drainage Systems, or to substitute them, also total or partially, for devices commercially known Air Admittance Valves (AAV). For example, GRAÇA (1985) demonstrates in his work it can have possibility to reduce the costs of order from 30% to 40%, through the elimination of the piping of the vent stack and vent branches in residential buildings of up to five floors. Specifically considering the use of Air Admittance Valves (AAV), in substitution to the vent stack and vent branches in Building Drainage Systems, the results obtained in a Report of Comparison of Costs of Installation among vent system for piping, elaborated according to norms of different North American Institutions, and a vent system with Air Admittance Valves (AAV), elaborated by independent consultants in Indiana - USA, demonstrated that the use of the valves was redundant in percentile of cost reduction that varied from 47 % to 54%.

Inside of this context, in the present work, it intends to evaluate the acting of several configurations involving the use of conventional vent systems or Air Admittance Valves (AAV), in buildings of up to five floors, on the point of view of the hydraulic and pneumatic behavior of the Building Drainage Systems, in way to obtain lower installation costs.

## 2 Typology of the Building Drainage Systems

The Building Drainage Systems, is composed by the drainage system and for the vent system. The drainage system is admitted here as the group of plumbing fixtures and transport piping of the sewer. The vent system is consisted by a group of piping and devices destined to assure the integrity of the fixtures trap seal to impede the passage of gases for the environment, as well as leading them to the atmosphere.

When the vent system is just composed by piping, it can have two usual types. One type just contains stack vent, the other type contains stack vent, and vent branches.

In spite of, when the vent system is composed by piping and devices, it is configured by a piping group and Air Admittance Valves (AAV), which can substitute vent stack and vent branches. Air Admittance Valves (AAV) are devices whose main purpose is to minimize the variation of the pressures pneumatic actuate in a Building Drainage Systems owed to the drainage generated by the use of the plumbing fixtures in its installed. They are constituted of devices that, in presence of negative pneumatics-pressures, open allowing the entrance of air in the system favoring the reduction of these pneumatic pressures. It fits to point out that several foreign works and FERNANDES (1993) and MASINI (1999) presented studies about the behavior of the vent system endowed with Air Admittance Valves (AAV) in substitution to the conventional vent system, having concluded that was satisfactory its use in that conditions.

## 3 Experimental Research

In the Tower of the Laboratory of Building Systems (LSP) of Escola Politécnica da Universidade de São Paulo was installed a prototype of Building Drainage Systems (SPES), whose assembly characteristics provided flexibility for connection and piping removal and devices, making possible the materialization of several typologies of SPES and configurations of vent system with AAV.

In way to allow the comparison among the acting of the system of composed ventilation for piping with those composed by the association piping-valves, the prototypes were tested codified by SPES1, SPES2, and SPES3 in the under system quality just ventilated by piping and the prototypes codified by A, B, C, D and E, which ventilated by piping and valves.

In this sense, the typology SPES3 had conventional system, through stack, vent stack and vent branches. The typology SPES2 also had alternative system, however through vent stack and stack. However, the typology SPES1 just had single stack. As it can be noticed, the three conceived physical models just present vent system for piping, that are going to reduce in way to allow the study of the behavior of SPES submitted to different ventilation conditions.

For the vent system with AAV, the configuration A was obtained with the installation of an AAV in the stack vent. For the configuration, B stayed AAV installed in the stack vent and it settled an AAV close to the entrance of each discharge horizontal branch in the drainage stack, in each one of the five pavements of the prototype. Already the configuration C was obtained by the installation of AAV in alternate floors, that is, AAV were installed in the 6th, 4th and 2nd floors and maintained AAV in the prolongation of the stack vent. For the configuration, D installation of AAV was maintained in alternate floors and removed, AAV installed in the prolongation of the stack vent. Finally AAV were installed the entrance of the horizontal branch close to in the drainage stack in all the floors, constituting the configuration E.

The figure 01 presents schematic cut of SPES with the observation points and the positions of AAV installation.

The conception of the configurations of vent system with AAV allowed to study the behavior of SPES before the increase of the amount of AAV, from the installation of only one VAA in the stack to the installation of AAV in all the possible points along the prototype. The variety of rehearsed situations allowed not only to discover the vent system for AAV presented satisfactory acting, but also to research which the amount and which the most appropriate location of AAV in the system, considering that NBR - 8160/99 Code allow the use of these devices.

With electric outlet relationship of the data, the respective points were distributed in areas of the SPES where it intended to obtain information on the parameters of interest for the intended analysis, that are the pneumatic negative pressure developed along the drainage stack, the variation of the height of the fixtures trap seal, and the discharge rate. The points for measurement of pressure developed in the system were installed in the discharge extension of the close WC to the junction with the drainage stack, while the measurement points of the variations of height of trap seals were installed in the plumbing fixtures, allowing to obtain the initial and final levels during the tests.

With relationship however to the registration of the data, two systems were developed, which are one of instrumentation and one of acquisition of data. The instrumentation system counts pressure transmitters, amplifying circuits and hydrometers. The pressure transmitters and amplifying circuits registered the pressures developed inside the piping, the variations of the height of the trap_seals and the discharges of the WC, while the hydrometers registered the discharges rate of the showers and lavatories. The system of acquisition of data had a microcomputer endowed with a plate of acquisition of data, and of an analysis program and administration of the rehearsals (Dasylab), that were connected to an interface plate.

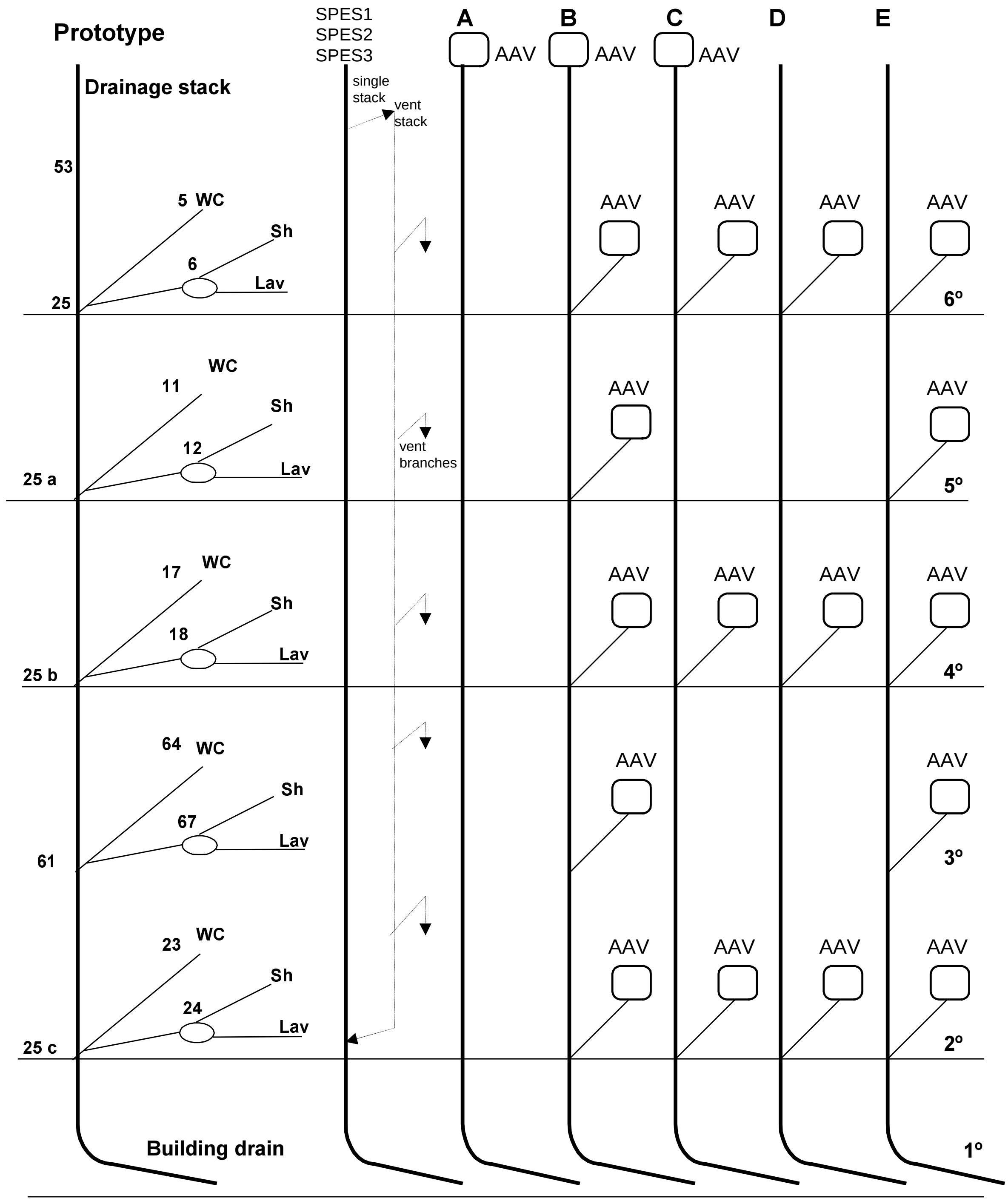


**Figure 01 – Schematic View of AAV and Conventional Vent System Tested**

As the conduction of the rehearsals, initially each configuration was materialized, followed by the fittings of the pressure transmitters and of the discharges rate as the simultaneity criterion mentioned, providing the obtaining of the values of the parameters wanted like this during the flow. The discharge rate, that was a variable controlled in the development of the tests, it was composed by the simultaneous discharge of the last three floors (6th, 5th and 4th), totaling a value 2,6 L/s. It suits to point out that such discharge rate corresponds the simulation of a building of 20 floors, where the last 03 floors are discharging simultaneously. Another opportune observation is that each rehearsal was repeated at least 05 times, totaling 06 tests.

## 4 Test Results

The analysis of the results obtained in the tests and the discussion of the same ones was subdivided in three different stages, as much for the conventional system, as well as for the system with air admittance valves (AAV). First are analyzed the highest negative pressure values developed along the drainage stack. In the sequence, are appraised the behaviors of the fixtures trap seals through theirs maxims height variations and, finally, are compared the acting presented by the studied configurations.

It is worth to point out that such analyses are developed for all the configurations in order to evaluate the influence of the different ventilation solutions on the behavior of the mentioned variables.

This position, being observed the values obtained for the three configurations whose vent system is just composed by piping, as Table 01, is well-known that the depressions are larger in the typology SPES1. However, the difference among the model SPES1 and SPES2 is not very significant, while the depression in SPES3 is practically 50% of the value reached in SPES1. The impact of the vent stack and vent branches however it is more contusing in the comparison between SPES1 and SPES3.

About the variation of the levels of the trap seals, the model SPES1 presented significant losses of height of trap seals. The largest verified variation was in the fourth floor, whose value reached 20,26 mm water approximately. It is interesting to observe that is in the fourth floor that locates the extension below than it is discharging, according to configuration of discharges in subject. However, in most of the trap seals, for the other two configurations SPES2 and SPES3, there were at least losses. Face such reality, fits to interrogate that, in terms of protection of the trap seals, the two configurations in subject, for the worked scenery, possess the same efficiency practically.

**Table 01: Behavior of Pressure in Stack and Trap Seal Level during the Tests**

| | **Typologies** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Open piped vent system** | | | **AAV vent system** | | | | |
| **Variables** | **SPES1** | **SPES2** | **SPES3** | **A** | **B** | **C** | **D** | **E** |
| Pressure In stack (mmwater) | -24,37 | -23,55 | -12,12 | -23,30 | -21,95 | -27,85 | -28,19 | -19,40 |
| Trap seal Level (mm) | -20,26 | 0,00 | 0,00 | -1,00 | -0,99 | -2,64 | -4,98 | -0,66 |

It is also important to observe the space distribution of the pneumatic depressions along the stack vent, for each configuration. According to illustration 02, for them configuration SPES1 and SPES2 is noticed a growth of the depression, starting from the top of the stack vent, until reaching the largest value in the 4th floor (24,37 mm water), which is regarding the top floor that is discharging. This behavior was already expected for SPES1, according to literature. Though the same behavior was also observed for SPES2 (Illustration 02), that is, highest negative pressure in the 4th floor, indicating therefore that for projects whose are just composed by the vent stack and the vent branches, it is also of waiting that the highest negative pressure (23,55 mm water) it happens soon below the last extension that is discharging. However, for SPES3, where besides the vent stack is also the vent branches, the behavior of the pressure along stack is clearly more uniform and, for the study in subject, the highest negative pressure didn't happen below the last extension in discharge (4th floor), but in the 6th floor, as presented in the Table 01.

In the case of the vent system with AAV, it was observed that the maximum negative pressure value in all the configurations happened in the level of the fourth pavement. The configuration E presented the smallest negative pressure 19,4 mm water, while the configuration D reached the highest pressure value verified in all the analyzed configurations, in other words, 28,19 mm water. When it is compared the configurations E and B with the configuration A, we observed that the maximum negative pressure detected in E, it was 16% inferior to detected in A, and that among B and A was a variation of 4%.

Being Compared the results obtained in the configurations C and D, it is observed that both presented maximum negative pressures very close, with variation of 1,5%.

It is observed although when AAV are introduced in the floors, as a continuous way (AAV in all the extensions), as in a discontinuous way (AAV in alternate floors), the introduction of a AAV in the top of the stack vent, presents little influence in the magnitude of the negative pressure developed in your interior. In the case of the trap seals however, they presented appropriate behaviors, because it was noticed that in all the studied configurations the integrity of the trap seals was preserved, according to table 01.

By the obtained results, it is observed that for the conditions of the prototype of SPES (five floor building) and for discharge rate (2,6 L/s), all the configurations of vent system with AAV allowed the development of maximum pneumatic negative pressure acceptable and they provided the stability of the height of the trap seals. It is like this lawful to interrogate that, for such conditions of solicitation of the system, it would be viable the substitution of the vent system for just piping, for vent system with AAV and piping.

Appraised the respective acting of the typologies SPES and AAV, fits in the sequence to compare such acting to each other through the confrontation of the variables already mentioned, that is, the maxims pneumatic negative pressures developed along the stack and the maxims variations of height of fixtures trap seals.

In the case of the maxims pneumatic depressions, it is observed that so much for the configurations SPES1, SPES2 and SPES3, as for the configurations with AAV, the largest negative pressures always happened in the located point in the 4th floor, except for SPES3, where was registered in the level of the 6th floor. It is important to verify that the maximum negative pressure registered for the configurations with AAV were superior in all the cases, to the registered in the typology SPES3. However such fact doesn't make unfeasible the use of the configurations with AAV in substitution to the vent system that constitutes the typology SPES3, once the pertinent values of maximum negative pressure are below the value it limits of -37,5 mm water.

Considering more specific evaluations, the configurations of vent system B (installed VAA in a continuous way) and A (with an only VAA in the stack vent) they presented, with relationship to the maxims registered pneumatic negative pressures, it carry out quite superior in relation to the configurations SPES1 and SPES2, endowed with only stack vent and of vent stack.

Already the configuration of vent system with installed AAV in a continuous way E, presented the best acting; having been registered the smallest negative pressures and losses of height of trap seals. When compared with the vent system SPES2, endowed with vent stack, it reduced in 18% the developed highest negative pessure values, and when compared with system SPES1, only stack vent, reduced in 21% the registered maximum depression. In this way for the conditions of the prototype, the configuration E can be indicated the best to substitute the vent system for piping.

The two configurations of vent system with installed AAV in a discontinuous way C and D presented the highest magnitude of negative pressures along the stack and the largest losses of heights of the trap seals registered. In these cases the developed maximum depressions were 36% superiors to the average of the maximum negative pressure values observed for the configurations with installation in a continuous way, E and B, and 20% superiors to the configuration A, which has an only AAV. The losses of height of trap seals registered were three times superiors to registered them in the other configurations. This way becomes just less suitable to adopt the configurations C and D in substitution to the ventilation subsystem for piping.

The behavior of the fixtures trap seals, when it are compared the results of the configurations with AAV with the results obtained for the configurations SPES1, SPES2 and SPES3, it is observed that the largest loss of height of the trap seals happened in the WC of the 4th floor, so much for the configuration D as for the typology SPES1, being respectively your values 4,98 mm and 20,26 mm.

Considering the analyses and presented observations, it remains to synthesize the behavior of the configurations of ventilation under system with AAV in comparison with the configurations SPES1, SPES2 and SPES3. The table 02 display to percentile reductions, imposed to the maxims negative pressures developed inside the drainage stack, for the use of the air admittance valves (AAV).

**Table 02 - Reduction of Negative Pressures by AAV's Installation**

| Open Piped Vent system prototype | AAV Vent System prototype | Negative Pressure reduction verified (%) |
|---|---|---|
| SPES 1 | | 21 |
| SPES 2 | E | 18 |
| SPES 3 | | 0 |
| SPES 1 | | 10 |
| SPES 2 | B | 7 |
| SPES 3 | | 0 |
| SPES 1 | | 5 |
| SPES 2 | A | 2 |
| SPES 3 | | 0 |
| SPES 1 | | 0 |
| SPES 2 | C | 0 |
| SPES 3 | | 0 |
| SPES 1 | | 0 |
| SPES 2 | D | 0 |
| SPES 3 | | 0 |

## 5 Conclusions

For the conditions of the prototype, all the configurations of vent systems with Air Admittance Valves (AAV) maintained the magnitude of the pneumatic depressions inside of the acceptable limits, and the integrity of the fixtures trap seals was preserved. Another observation to be outstanding is that in all the tested configurations, given the discharge rate of 2,60 L/s, it was verified that the depression of 37,5 mm water, value was not exceeded.

Among the conventional systems, the single stack vent, SPES1, was verified largest pneumatic depressions, while the systems ventilated with AAV, it was the configuration D, that presented the largest pneumatic depression. Even so, it is worth to repeat that such values didn't surpass the acceptable maximum. Therefore, in base to this group of observations, it is ended that to a five floor building, and to the discharge flow rate of 2,6 L/s, it is possible the use of any of the worked configurations, without committing the trap seals.

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# EVALUATION OF VENTILATION CONDITIONS IN THE SEWER SANITARY SYSTEM OF AN OFFICE BUILDING USING AIR ADMITTANCE VALVES

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## ABSTRACT

This article presents an analysis of ventilation conditions within the sewer sanitary system in an office building. In this case, the vent pipe, performed by branches and ventilation pipe, is replaced by air admittance valves.
In this analysis, experiments in real-sized prototypes of office toilets were carried out, which were assembled in the vertical part of the Building Systems Laboratory of Politechnical School of USP-Brazil.
A system of flow automation of sanitary appliances was installed in these prototypes. Besides this, an instrumentation system was installed to store data related to pressure behavior inside pipes and seal water trap variations.
The experiments were performed with flow rates simulations corresponding to a range from a five-storey building to an approximately twenty-two-storey building.

## 1 INTRODUCTION

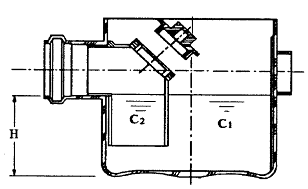
In order to provide a proper flow of the waste originating from the several water uses inside the buildings Collect Systems of Used Water were created, which were conceived and carried out without any care concerning odour coming inside the environment, what compromises the sanitary conditions inside the buildings.
Observing these problems, the systems evolved into the current Building Sewer Sanitary Systems, whose basic requirement is *"to collect and conduct the waste originated from the use of sanitary appliances, without the danger of drinking water contamination and, at the same time, blocking the entrance of odour into the buildings environment"*.
The roles of collecting and conducting are served by the appropriate choice of sanitary appliances, by the appropriate planning and dimension of pipes.
In regard to the odour entrance, this can be avoided by placing the traps, which are devices presenting a water barrier, called water seals. Even though, because of the flow from the

appliances, pressure is created inside the pipes which, depending on the reached levels, may reduce or even break the water seals causing damage to the function of preventing odours to come inside the buildings.
Hence, in order to balance the pressures inside the pipes, a Ventilation System was introduced, what is formed by a set of pipes interlinked to the sewer sanitary system, which allows the air entrance needed to balance the pressure variation and prevent the trap water seals from breaking.

In Brazil, several researches were done, and others have been developed in order to adequate the Brazilian Sewer Sanitary Systems to the world reality, considering new products, dimension methods and execution techniques.
This research was developed within that context, as it presents a study on the application of air admittance valves in office toilets settings, where the main characteristic is the use of sanitary appliances batteries.
Taking into consideration that air admittance valves in replacement to a conventional vent system, that is, performed by branches and ventilation pipe, reduce considerably the sewer system cost, as well as the labour expenses for its execution, and also the possibility of execution errors.

## 2 BRAZILIAN BUILDING SEWER COLLECTING SANITARY SYSTEMS

The Building Sewer Collecting Sanitary System used in Brazil is formed by a group of vertical and horizontal pipes, differing in diameters. The pipes are composed by:
**- discharge branch:** part of the pipe that receives the effluents from discharge branches.
- **sewer branch:** part of the pipe that receives the effluents from discharge branches.
**- vertical stack:** part of the pipe that receives the effluents from sewer branch or discharge branch.
**- building drain:** part of the pipe that receives the effluents from vertical stacks.
In Brazilian installations, the traps may vary in types and sizes, some of them are integrated to the appliance, such as the water closet traps, and also the ones to be connected to the exit of the appliances, for instance, kitchen sinks, tanks to wash clothes, urinals, water basins, etc. These are “S”, “P”, and “Glass-like” types.
Besides the ones cited above, there are floor drain traps, which have a specially designed shape to conceive the used water from various appliances, such as water basins, showers, etc, and also the water from the washing of floors, leading them directly to the vertical stack. It may be said that they serve as a link between the primary and the secondary sewer in sanitary installations. In figure 01, we present the shape and component parts of a floor drain trap




**H – height of trap seal**
**C1 – chamber of entrance**
**C2 – chamber of exit**

**Figure 01 – Parts components of floor drain trap.**

The Ventilation System is composed by a set of pipes interlinked to the Sewer System, presenting as the main component parts, the following:

**- Branch of ventilation:** this part of the pipe interlinks the trap or discharge branch or sewer branch of one or more sanitary appliances to a vertical vent or to a main vent pipe;

**- Vertical vent:** the vertical part of the pipe that interlinks the pipe branches directly to atmosphere, or to a main vent pipe.

**- Main vent:** this vent pipe is a prolongation of the vertical stack above the higher branch connected to it, having its extremity open to atmosphere, situated on the top of the buildings.

This system can be conceived and dimensioned in the following ways, which are:

**- Main ventilation:** is the ventilation performed only by the main vent pipe;

**- Secondary ventilation:** is the ventilation performed by column branches and ventilation interlinked to sewer sanitary systems;

**- Vertical vent:** is the ventilation performed by the vertical vent interlinked directly to the vertical stack, without the ventilation branch.

In the current norms, the NBR 8160 (1999) in the cases where there is need for secondary ventilation, there is the possibility to have it done through air admittance valves.

## 3 METHODOLOGY OF TESTS

The main objective of using tests in prototypes is to reproduce, in laboratory, the most non-favourable conditions in terms of occurrence of self-siphonage, induced siphonage and back pressure phenomena, making the analysis of the usage of air admittance valves possible. It occurs through the magnitude relation of pressure inside the pipes, by the discharge of water closets, and trap seals behaviour present in that installation.

Thus, this experimental research was developed by assembling real-sized prototypes in a sewer sanitary system in an office building.

### 3.1 Description of Building Systems Laboratory

The tests with prototypes were assembled in the vertical part of the Building Systems Laboratory of Politechnical School of University of São Paulo, which is formed by an eight-storey tower, considering that each of them consists of an area of twelve square meters (12 $m^2$).

In that area there is an electrical building system and a cold water building system, composed by an inferior reservoir located on the first floor, next to a pumping system, formed by a set of three pumps connected in parallel, and a superior reservoir.

All system is located on the eighth floor, whose distribution barrel is on the seventh floor, making the distribution to all others floors through columns located in shafts.

### 3.2 Prototypes configuration:

In the prototypes which were tried out, real assembly of the installations forming the configuration of an Office toilet was reproduced in laboratory. It was made up of three water closets tank, three urinals and three water basins. Figure 02 presents a ground plan as well the detail of the sewer configuration

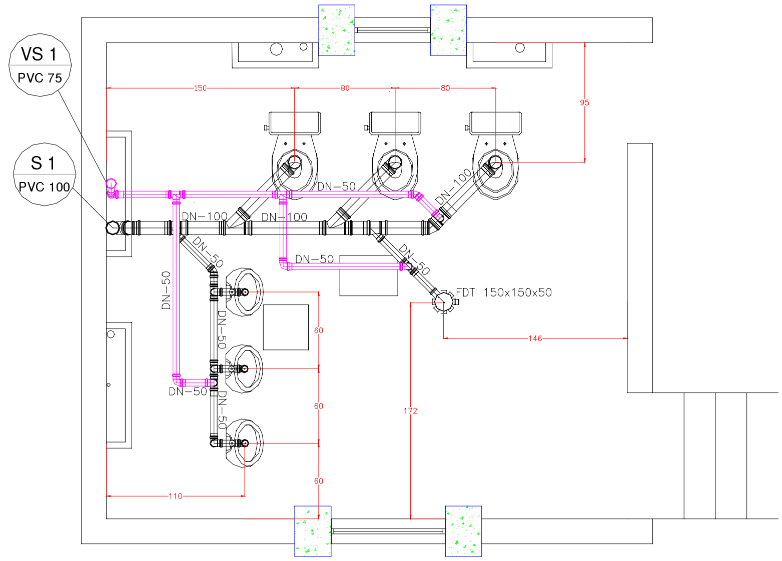



**Figure 02 – Ground  plant and detail of office toilets sewer .**

The sanitary appliances used in the prototypes installation were chosen in order to represent what is usual in the Brazilian Sanitary Sewer Systems. Thus, water closets tanks, with two different volumes of discharge were used, that is, the so called conventional volume (11.5 litres) for being the most commonly used in Brazil and the reduced volume (6 litres) of discharge.

The urinals used in this test were the ones without an attached trap, where a glass-like trap with 1 ½' entrance and 1 ¼' exit and with a 25mm high water seal was connected.

The water basins were not installed, only their respective flows were discharged directly in floor drain traps, with 150x150x50 dimension, with a water seal 40 mm high, as shown in figure 03.


**Figure 03 – Floor drain trap feeding.**

The appliances and components feeding was carried out by the derivation of two columns coming from the barrel. In the derivation of the first stack a hydrometer was placed in the branch in order to measure the several flows which were tested, and from this a single feeding sub-branch was derived to the three attached tanks of the water closets where a solenoid valve was installed in order to guarantee that after each discharge the tanks would always be filled in with the same volume.

From this column it was also derived the feeding sub-branch of the floor drain trap, with the placing of a solenoid valve and the installation of a register aiming to control the flow which is going to be discharged in the floor drain trap, that is, the flow of the three water basins altogether.
Regarding the second column derivation, which was used for feeding the urinals, it was also placed a hydrometer in its branch. Concerning the sub-branches, solenoid valves and registers were placed according to the combination of determined discharge to each of the floors, also aiming to guarantee the discharge of a same flow throughout all the tests. In figure 05 there is a photo of the assembly performed in the test tower.

Derivation of first column — Derivation of second column

**Figure 05 – Detail of s cold water system.**

**3.3 Description of the prototypes measure points:**

In order to focus the pressure behavior which occurs along the vertical stack we situated the measure point in the sewer branch in the installations, near the connection with the vertical stack, based on studies already carried out by MONTENEGRO (1987), AOKI (1991), CHENG (1996) and more recently by COSTA (1998).

Besides the pressure measures near the vertical stack, there were also pressure measures in each of the horizontal installations which are part of the five floors, in order to allow the knowledge of the pressures inside these installations due to the flow that goes through the vertical stack and the flow coming from the discharges of the sanitary appliances installed in each floor, as shown in tables 01 and 02.

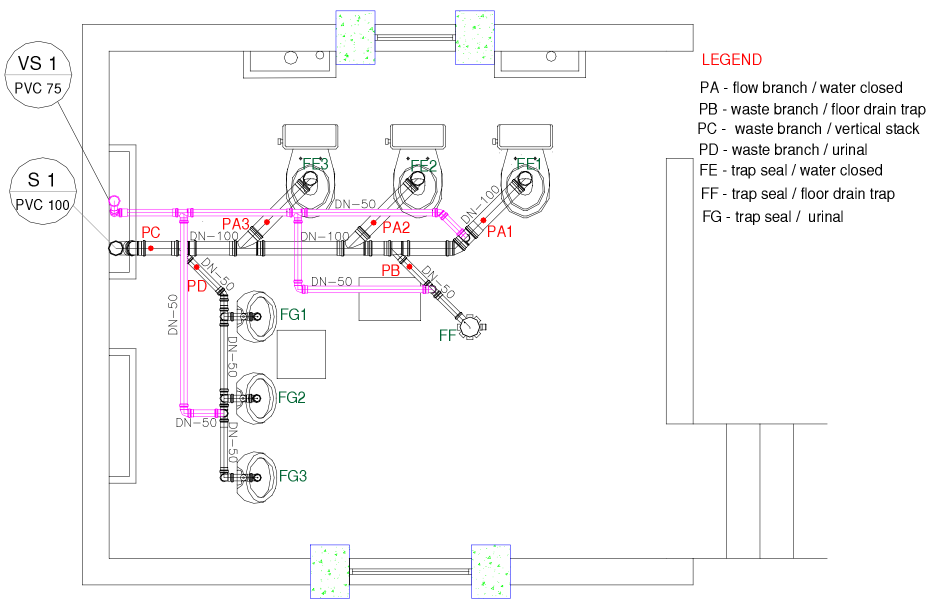
**Table 01 – Pressure measure points.**

| Pressure measure | Floors | | | | | | |
|---|---|---|---|---|---|---|---|
| | 8º | 7º | 6º | 5º | 4º | 3º | 2º |
| Main vent pipe | PH8 | | | | | | |
| Water closet discharge branch | | PA37 | PA26 | PA15 | PA14 | PA33 | |
| Urinal waste branch | | | PD7 | PD6 | PD5 | □D4 | PD3 |
| Floor ` rain tr´ p waste` branch | □ PB7 | PB6 PB5 | | □ PB7 | PB6 PB5 | PB4 PB3 | |
| N´ ar Vert cal Sta´ k waste` branch | □ PC7 | PC6 PC5 | | □ PC7 | PC6 PC5 | PC4 PC3 | |
| Bł ilding ` rain | | | | □ | | | PF2/□G 2 |

**Tab□e 02 – □rap sea□ measur□ points□**

| Trap s□al meas□re | FLOO□S | | | | |
|---|---|---|---|---|---|
| | | 7º | □º | 5º | 4º□ 3º |
| Wat´ r closeŁ trap s´ al | | FE37 FE26 | FE□5 | FE14 | □E33 |
| Ur nal traŁ seal | | F□27 | FG36 FG15 | FG□4 | FG33 |
| Floor dŁ ain traŁ seal | F□7 | FF6 | F□5 | FF4 | F□3 |

FiguŁ es 06 a˚ d 07shoł the lo´ ations f measuŁ e pointł of preł sure an` trap s´ al measł re poinŁ s.




**Fi□ure 06 □ Pressu□e and t□ap seal□measure□points.**

Vertical stack entrance Urinal trap seal


Water closet trap seal Floor drain trap seal

**Figure 07 – Location of measure points of pressure and trap seal.**

### 3.4 Description of instrumentation system and data acquisition:

The pressure measures inside the pipes and the variations in the trap seal were carried out by means of an instrument system together with data acquisition.

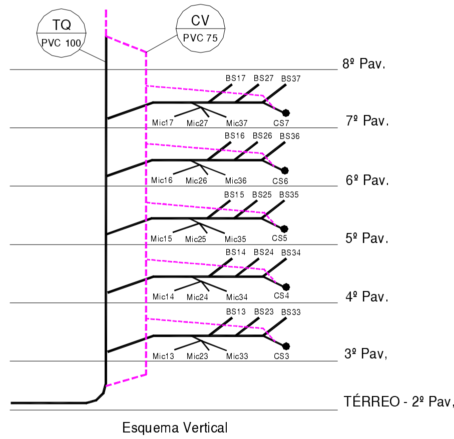
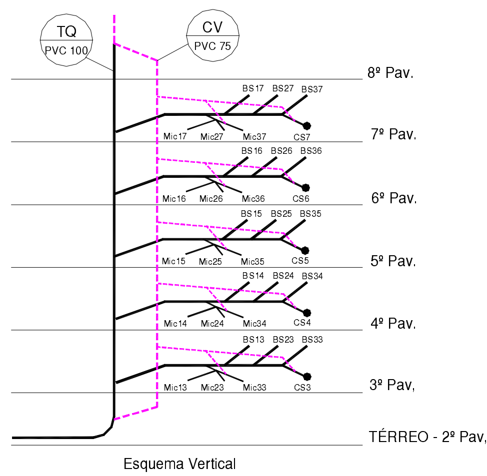
The instrumentation system was composed by pressure transductors attached to an amplifier circuit of tension, in order to have the registered pressure turned into electric impulse and conducted to the data acquisition system.

Concerning the acquisition system, it was formed by an interface board that was used to link it to a data acquisition board, where a management software turned the electric impulses into pressure values by means of transductor caliber equations. All data relating to pressure and height of the trap seals was stored in archives for further analyses.

### 3.5.: Characterization of the Prototypes Vent System

Using the basic configuration, different kinds of vent were analized in order to make a comparison between the use of ventilation performed with branches and columns and the one performed using air admittance valves. In tables 03 an 04 we present the different kinds of ventilation tested

**Table 03 –. Stack and branch vent type description**

| Vent Type | Description | Scheme |
|---|---|---|
| **TYPE 1B** | When the vent subsystem is formed by main and secondary vent, and the secondary vent is placed in the sewer branch of floor drain trap |   ?? |
| **TYPE 1C** | When the vent subsystem is formed by main and secondary vent, and the secondary vent is placed in the sewer branch of floor drain trap and in the urinal sewer branch.. |   |

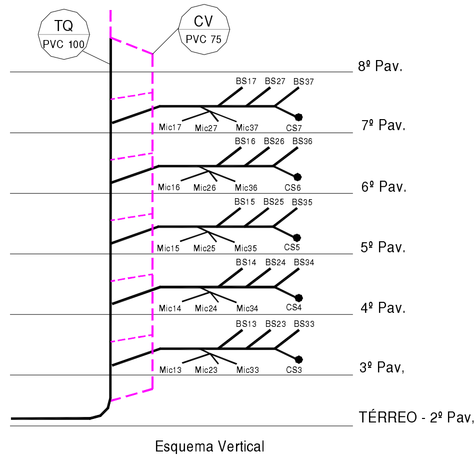
<table>
<tr><td>TYPE 2</td><td>When the vent subsystem is formed by the vertical stack directly connected to the vertical vent, in all floors.</td><td>
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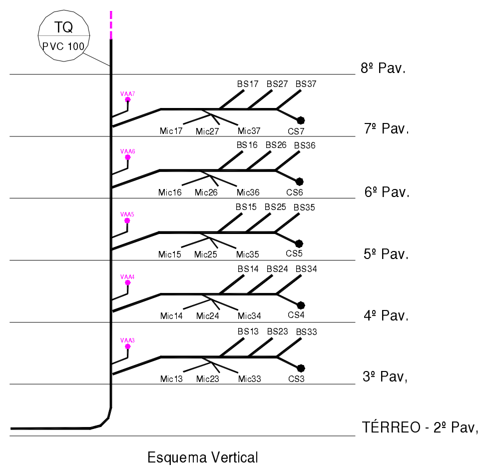
**Table 04 – Air admittance valves vent type description.**

<table>
<tr><th>Vent Type</th><th>Description</th><th>Scheme</th></tr>
<tr><td>Type 4</td><td>When the vent subsystem is formed by the placement of the air admittance valve directly into the vertical stack, in all floors.</td><td>
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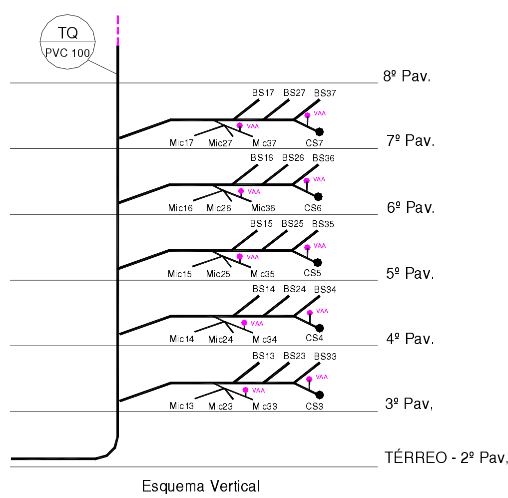
<tr><td>Type 5</td><td>When the vent subsystem is formed by the placement of two air admittance valves. One of them is placed in the floor drain trap sewer branch and the other one is fixed in the urinals sewer branch</td><td>
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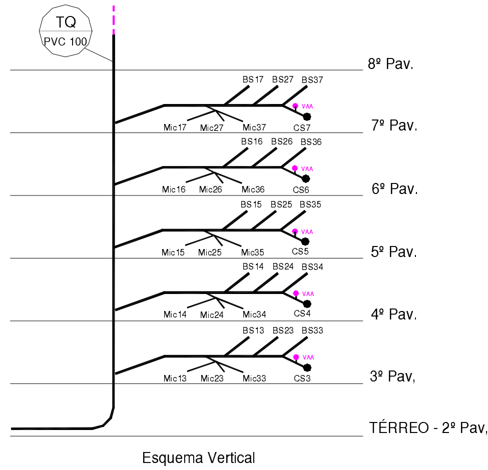
| | | |
|---|---|---|
| **Type 6** | When the vent subsystem is formed by the placement of one air admittance valve, in the floor drain trap sewer branch. |  |

**3.6. Description of discharge arrangements used in prototypes**

To determine the number of sanitary appliances to be discharged simultaneously is necessary to find out the sewer flows which drain by the pipe installations in study. This flow, called project flow is function of the use of simultaneity and the typology of sanitary appliances.

Brazilian Norms of Sanitary Sewer, the NBR – 8160 (1999), presents a method which uses the binomial distribution, where it is possible to determine the project flow for each part of the installation, based on the knowledge of the number of appliances in simultaneous use, considering a failure factor, that is, the reliability level to be stipulated by the project designer Based on these principles, the number of appliances to be discharged simultaneously were determined to simulate, in the five usable floors of the tower, flows that occur in buildings higher than five floors.

3.1.1 Single flow of used appliances:

- Water closet - tank 11.5 liters – Flow = 0.73 L/s
- Wash basin - Flow = 0.15 L/s
- Shower - Flow = 0.20 L/s
- Urinal - Flow = -0.15 L/s

3.1.2 Discharge arrangements for the configurations

The discharge arrangements used in the tests are shown in table 05. The floor drain traps were all tested under a flow discharge equivalent to three water basins in simultaneous use.

**Table 05– Discharge arrangements for the configurations.**

| **Sanitary Appliances** | **Discharge combination** | | |
|---|---|---|---|
| | **Da** | **Dc** | **Df** |
| Water closed of seven floor | | | |
| Water closed of six floor | | | |
| Water closed of five floor | | | |
| Urinal 1 of seven floor | | | |
| Urinal 2 of six floor | | | |
| Urinal 3 of five floor | | | |
| Floor drain trap of seven floor | | | |

| | | | |
|---|---|---|---|
| Floor drain trap of six floor | | | |
| Floor drain trap of five floor | | | |

Based on table 05, and on single flows of appliances, tested flows were the following:
1 – Water closet experiments - 11.5 litre:

- **Da –** Flow rate of 8.37 l/s;
- **Dc –** Flow rate of 5.58 l/s;
- **Df –** Flow rate of 2.79 l/s.

# 4 Results analysis:

For the analysis of the results found in the several tests, it is verified that, for the cases studied, the substitution of ventilation with branches and columns for the air admittance valves, didn't cause significant increase in the negative pressures along the vertical stack and in branches. As it can be observed in the figures 08, 09 and 10, where we presented the pressure behavior in two points different from the installation. With the flow rate of type Da.

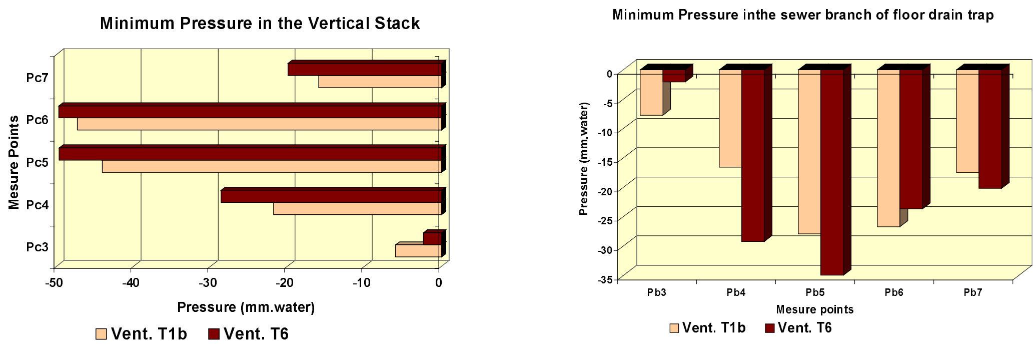



**Figure 08 – Pressure behavior with ventilation T1b and T6.**

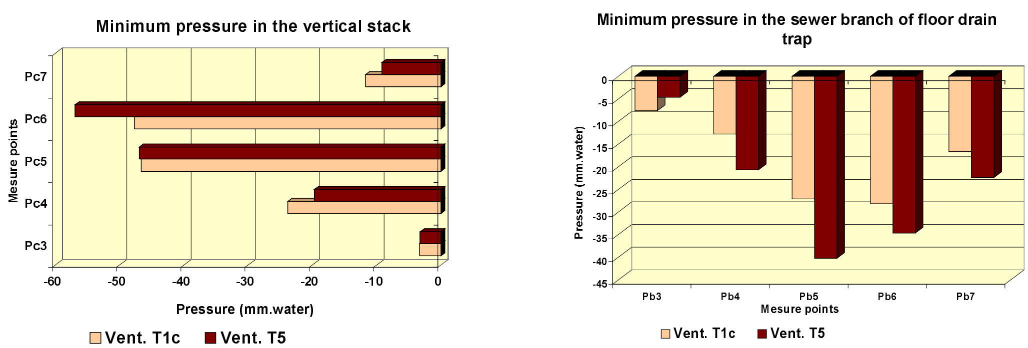



**Figure 09 – Pressure behavior with ventilation T1c and T5.**

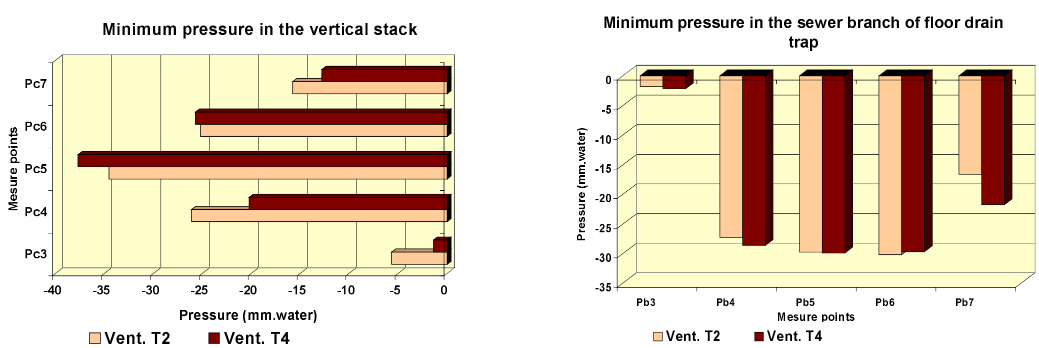



**Figure 10 – Pressure behavior with ventilation T1b and T6.**

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# Detergent Action in Building Drainage Systems

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**Abstract**
Building drainage ventilation design guides are based on steady state experiments utilising cold clean water as a test media. However, most ‘grey’ and ‘black’ water sources are dosed with detergent, and are often warm, which significantly alters the behaviour when compared to clean water. This paper quantifies the effect of detergents in building drainage systems in terms of observed air entrainment rates and previously published research on the factors that contribute to air entrainment, and the experimental techniques used to gather data are outlined.

**Keywords:** building drainage,  detergent, foam, airflow

## 1 Introduction

The successful performance of soil-waste-ventilation (SWV) systems for buildings depends on the isolation of the habitable space from the waste material and its associated odours, achieved by the provision of water trap seals at various points in the networks. Current design guides aim to produce ventilated drainage networks which protect these trap seals from unwanted air pressures, but are based on steady state experiments utilising cold clean water as a test media and the assumption that the water falls in stacks as an annulus. However, most ‘gray’ and ‘black’ water sources are dosed with detergent, and are often warm, which significantly alters the behaviour when compared to clean water, and there is evidence to support the fact that a significant proportion of the water falls as droplets in the air core, thus altering the characteristics of air entrainment.

Recent investigations (Campbell & MacLeod 1999[1]) showed that the work done in airflow entrainment is shared between the water annulus and the water falling in the air core. This model is consistent with previous and current work, and offers scope for further development, in areas such as inclusion of the effects of detergents, which generally increase air flows and other related effects, on DWV system conditions. Further work (Campbell & Macleod, 1999[2]) addressed the need for empirical data on the dynamic response of DWV systems operating with detergent-dosed waste water over typical temperature ranges. This paper quantifies the effects of discharging warmed detergent dosed water into a drainage system and represents various detergent types with equations describing the relationship between water and induced air flows and pressures.

## Surfactant Mechanisms

Surface-active-agents (SurfActAnts) are materials which absorb strongly from solution to the liquid-liquid, liquid-vapor or liquid-solid interfaces in a fluid. Detergents generally are accurately described as surfactants. This paper will concentrate on three commercially used detergent types; anionic: the most widely used domestic surfactant; cationic: used as fabric conditioners; non-ionic: used in washing powders. In a seperate study by the author, sampling surveys demonstrated that users invariably overdosed washing solutions by factors of upto 3. The consequence of this is that detergents are overdosed in many domestic and industrial applications, and testing at only the CMC is a realistic simplification in this investigation: all tests were conducted at the CMC for each detergent.

**Modeling**

Previously published work (Campbell & MacLeod (1999 [2]) attempted to account for water droplets present in the central air core of stack discharges, and which was predicted to account for up to 50% of the measured air entrainment force:

$$\tau_i = \tau_c \pi D_C + \Sigma C_d \tfrac{1}{2} \rho V_{REL}^2$$

This led to a theoretical expression for $\tau_c$ (Campbell & MacLeod (1999 [2]) to represent the suction and entrained airflow generated by detergent-dosed stack water flow, by reducing several variables ($V_a$, $V_w$, D, K, t, $H_w$, g, $\rho_a$, $\rho_w$, $\mu_a$, $\mu_w$, $\sigma$, T) to 9 dimensionless groupings by applying Buckinghams $\pi$ Theorem. For the different detergent classes these can be represented by a general equation of the form:

$$\Delta P = \tfrac{1}{2}\rho V_a^2 \left[ \frac{(f(x))^a}{\left(\frac{D}{t}\right)^{-b}} \right]^c \times d$$

Where the function $f(x)$ =

$$\phi\left(\frac{V_a}{V_w}\right)^f \times Fr^e \times \mathrm{Re}_w^g \left(\frac{D}{H_w}\right)^h \times \left(\frac{k}{D}\right)^j \times \left(\frac{gD^3\rho_w^2}{\mu_w^2}\right)^k \times \overbrace{\left(\frac{\mu^2}{\sigma_w \rho_w D}\right)^m}^{surfactant} \times \overbrace{\left(\frac{TD\rho}{\sigma}\right)^n}^{temperature}$$

The variables a-n will adopt unique values for each detergent type and prevailing water conditions. The $\Sigma C_d$ term is measured experimentally as previously reported (Campbell & MacLeod (1999 [2]) .

## 2 Experimental Testing

**Apparatus**

The apparatus used for the tests is illustrated in Figure 1, and has been reported previously (Campbell & MacLeod (1998).

**Pure Water Tests:**

Data for water velocity profiles was gathered by traversing a 2mm o.d. pitot-static tube across the stack at a point 2m above the stack lower termination. The pitot and static tubes and a short section of their transducer connection hoses were deliberately filled with water (to achieve hydrostatic equilibrium) before each test, essentially forming an inverted ‘u’-tube manometer: otherwise the results were found to rise during testing as air percolated slowly and erratically out of the tube.

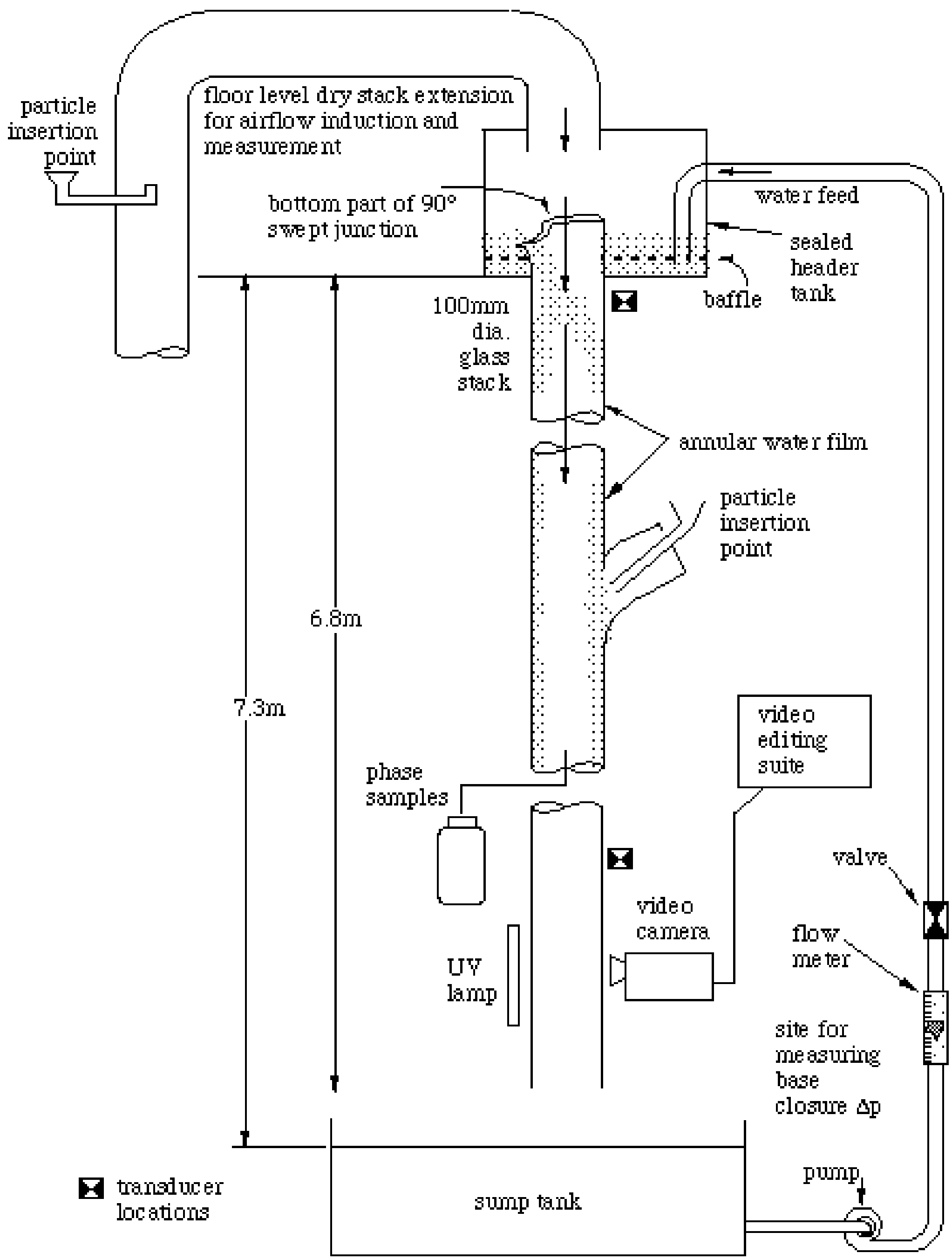


Figure 1. Sketch of the sampling apparatus.

A similar water-filled pitot tube approach was also adopted by Wylie & Eaton[10]. To establish the quality of data from the transducer, a few tests were conducted with dyed water inside the tube and pipe: subsequent spectrophotometry revealed that no dye dilution had occurred. These observations suggest that no water exchange took place during testing.

To supplement the kinetic water pressure data, traverses were also taken to establish the phase composition throughout the flow, essentially repeating the work of Wylie & Eaton[10]. Simply disconnecting the pitot-tube hoses from the pressure transducer and diverting them into a graduated cylinder (Figure 1) provides the phase composition change through the flow, referenced with respect to unity at the stack wall. This supplements the investigation conducted previously (Campbell & MacLeod (1998) illustrated in Figure 2, in which a trace substance was added to the mixed phase flow, and velocity samples were taken across the stack diameter for various flow conditions. Data for airflow calculations employed a reduced diameter section in the dry stack to facilitate volumetric airflow rate measurement, a profile across the dry stack was required so that airflow in the wet stack, measured by the water-filled pitot-static tube, could be verified by calculation..

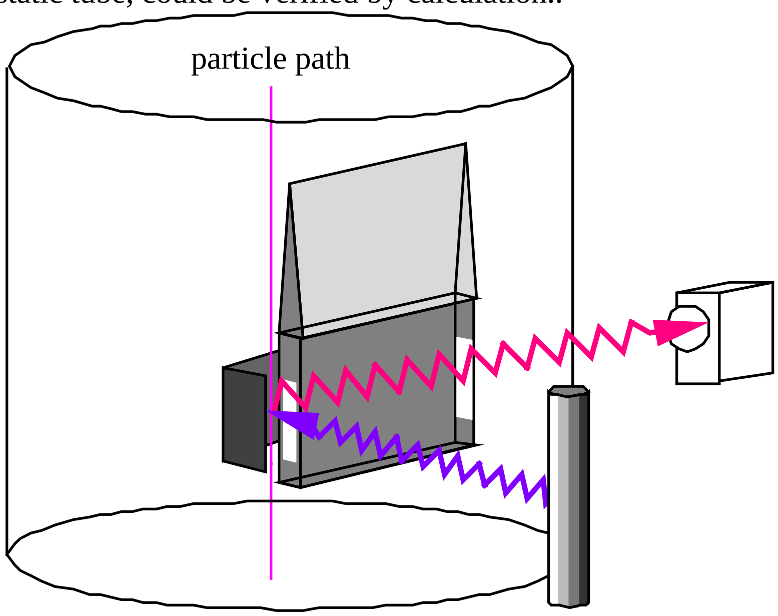


Figure 2 Detail of particle viewing assembly. The view shield ensures that only particles close to the face of the wedge are seen.

**Results & Discussion**

Figure 3(a) shows the variation in phase composition (expressed as density) across the stack diameter for a water flow input of 1.5 l/s, assuming the same 80% catchment figure used by Wylie & Eaton[11]. Note that the data do not span the whole diameter of the stack, as the width of the pitot tube prevented it from approaching closer than about 4mm from the stack wall. Data from Wylie & Eaton is superimposed, although it is inferred from the airflow/waterflow ratio, and was gathered at 100gpm (6.54l/s). Under these circumstances, established theory suggests an annulus of thickness 1.95mm, in which all of the water is contained, yet Figure 3(a) indicates that the annulus contains only about 45% of the total water flow volume, and that the region near the centre of the stack contains about 2% water by volume. The implication is that the water annulus must be thinner or less dense than previously theorized, and that a significant proportion of the water will be falling as isolated droplets with a terminal velocity influenced by the local (moving) air instead of pipe friction.

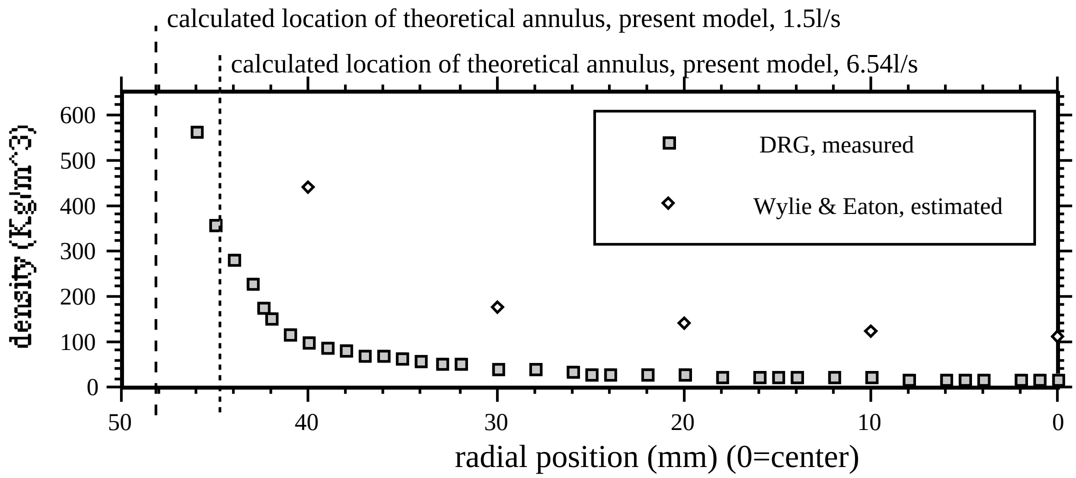


Figure 3(a). Density of the air/water mixture, at a water flow rate of 1.5l/s, moving from the stack wall towards the center.

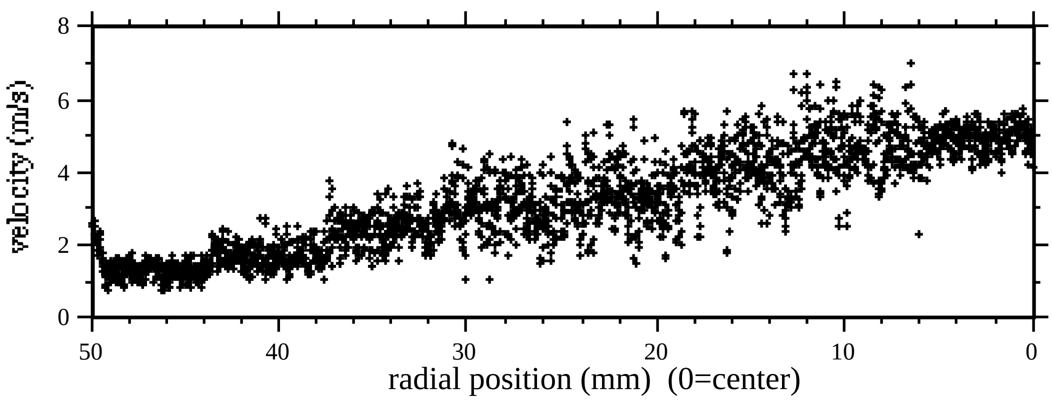


Figure 3(b). Velocity of the phase mixture in the stack at 1.5 l/s water flow, based on the density variation with stack radius.

By allowing for the density variation across the stack diameter, the velocity profile of the phase mixture can be generated, and this is shown in Figure 3(b), which includes velocities in the centre of the stack and down to within 4mm of the stack wall, essentially sampling conditions in the water-only annulus. The center line velocity is much higher than the wall velocity, which is consistent with the assumption that a proportion of the water falls as droplets while interacting with the local air flow. Under these conditions, the water droplet terminal velocity may be influenced partly by the terminal velocity of the air, which is, in turn, determined by the dry stack friction and possibly air/water shear stress if the annulus velocity is locally low. This profile is essentially the inverse of the profile previously assumed to exist.

By subtracting the appropriate density elements, the flow rate of the air and water components of the phase mixture can be extracted, and these are shown in Figure 4. Note that the water flow rate contains two peaks: one close to the stack wall, corresponding to the annular film, and another midway between the stack wall and the center line. The explanation lies in the opposing velocity and density contributions of the water component of the phase: the velocity rises but the percentage water by volume decreases moving towards the stack centre. The volumetric airflow rate calculated from the observed mixed phase profile should match the measured airflow induction rate: the respective figures are 10.5l/s (measured) and 9.8l/s (calculated), based on a water flow rate of 1.5 l/s.

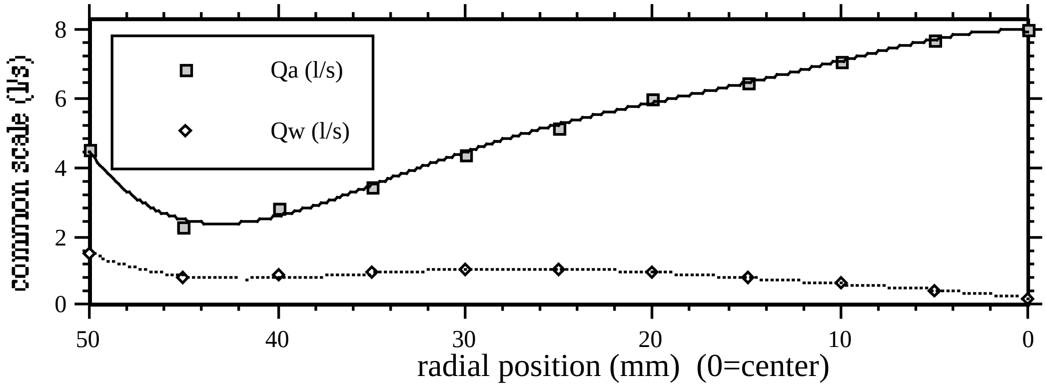


Figure 4 Air and water flow rates at 1.5l/s water input in a 100mm diameter stack

Figure 5(a) shows the air flow rate relative to the water flow rate in the stack, superimposed with data from Wylie & Eaton[11]. Although the Wylie & Eaton[11] data was gathered at a higher water flow rate and a smaller pipe diameter, it is clear that the airflow ratio in the DRG results becomes dominant in the center of the stack. Figure 5(b) shows the results of calculating the shear stress, force and friction factor for 100% annular flow, then re-calculating with 50% reduction in annular flow. The original friction was then used to generate a new shear stress and force: the new force was deficient by about 50%, depending on the flow rate. The deficiency is assumed to be due to droplet drag. Note that below about 2l/s, the droplet force dominates.

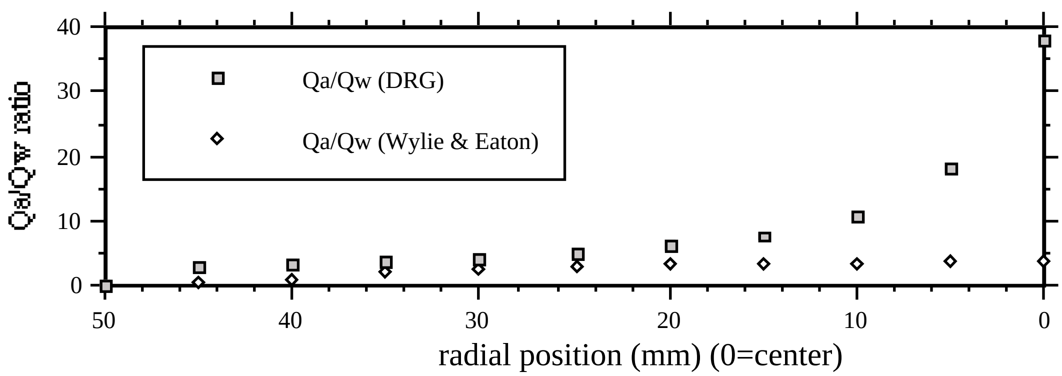


Figure 5(a) Air flow rate expressed as a ratio of the water flow rate, against radial position.

**Detergent Tests**

Due to opacity of the foam generated when detergents were used, the equipment described above was not suitable for tests to determine the phase composition across the diameter of the stack, and this is an area of ongoing research. Instead, data is presented on the final form of the relationship between water flow and induced airflow for various detergent classes, which updates the findings of earlier work (Campbell & MacLeod (1999).

Figures 6-8 show the collapsed data for the three main classes of detergent. For the purposes of mathematical modelling and inclusion into the AIRNET package, the defining equations required for the solution by the method of characteristics are as follows:

Anionic: $\Delta P = \tfrac{1}{2}\rho_a V_a^2 \left[ \dfrac{(f(x))^{3.766}}{\left(\dfrac{D}{t}\right)^{-2.5}} \right]^{1.309} \times 8.506 \times 10^{21}$, where the function $f(x)$ =

$$\left(\frac{V_a}{V_w}\right)^{-0.0708} \times Fr \times \mathrm{Re}_w^{0.2794} \left(\frac{D}{H_w}\right)^{0.7056} \times \left(\frac{k}{D}\right)^{0.3765} \times \left(\frac{gD^3\rho_w^2}{\mu_w^2}\right)^{-0.7} \times \left(\frac{\mu^2}{\sigma_w \rho_w D}\right)^{0.129055286} \times \left(\frac{TD\rho}{\sigma}\right)^{-0.115}$$

Non-ionic: $\Delta P = \tfrac{1}{2}\rho_a V_a^2 \left[ \dfrac{(f(x))^{1.7232}}{\left(\dfrac{D}{t}\right)^{-2.06}} \right]^{3.968} \times 2.713 \times 10^{4}$, where the function $f(x)$ =

$$\left(\frac{V_a}{V_w}\right)^{-0.0709} \times Fr^{1.85} \times \mathrm{Re}_w^{0.4} * \left(\frac{D}{H}\right)^{0.61} \times \left(\frac{k}{D}\right)^{0.21} \times \left(\frac{gD^3\rho_w^2}{\mu_w^2}\right)^{-0.7} \times \left(\frac{\mu^2}{\sigma_w \rho_w D}\right)^{0.2922} \times \left(\frac{TD\rho}{\sigma}\right)^{1.097}$$

Cationic: $\Delta P = \tfrac{1}{2}\rho_a V_a^2 \left[ \dfrac{(f(x))^{3.175}}{\left(\dfrac{D}{t}\right)^{-2.03154}} \right]^{12.02} \times 1.744 \times 10^{17}$, where the function $f(x)$ =

$$\left(\frac{V_a}{V_w}\right)^{-0.07384} \times Fr \times \mathrm{Re}_w^{0.285} \times \left(\frac{D}{H}\right)^{0.61} \times \left(\frac{k}{D}\right)^{0.21} \times \left(\frac{gD^3\rho_w^2}{\mu_w^2}\right)^{-0.7} \times \left(\frac{\mu^2}{\sigma_w \rho_w D}\right)^{0.004175}$$

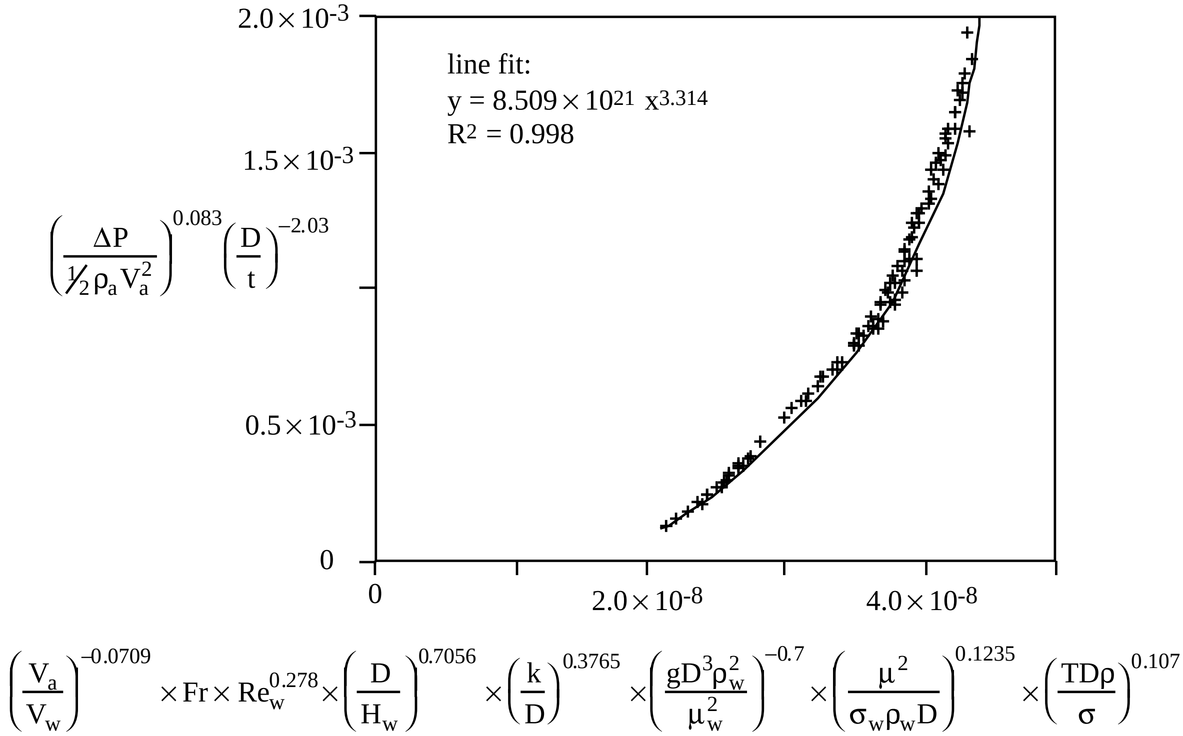


Figure 6. Non-dimensional collapsed data for Anionic surfactants

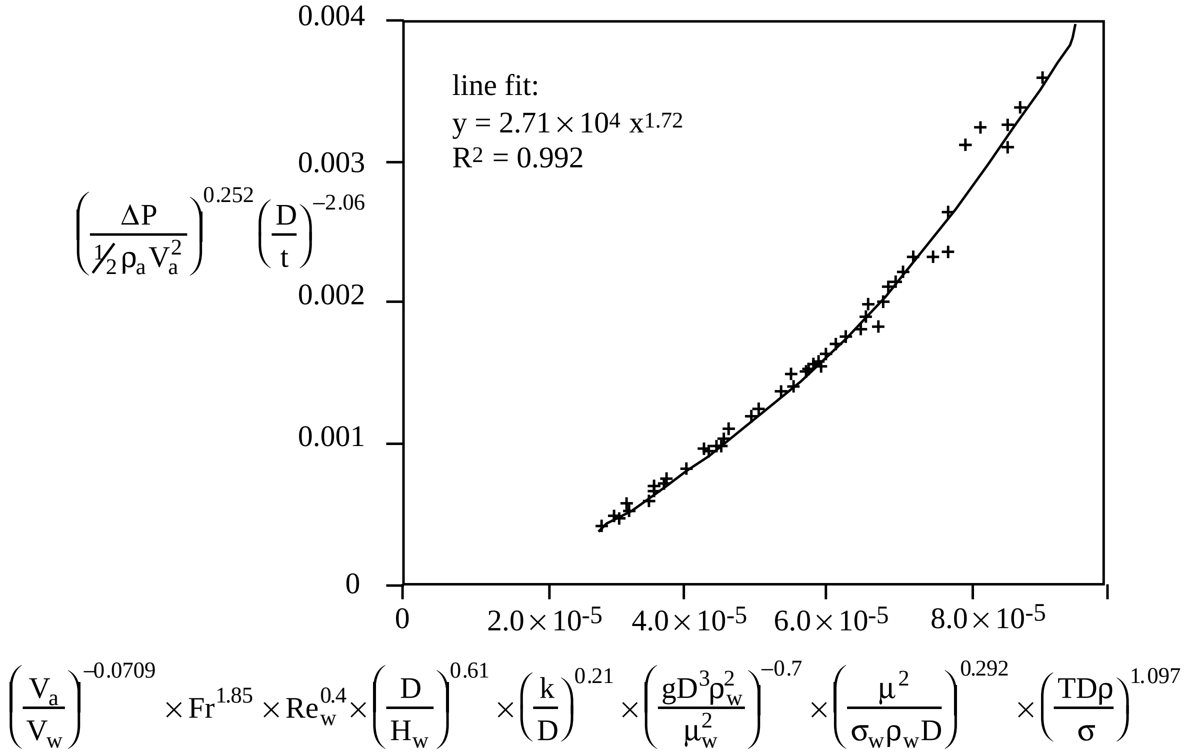


Figure 7. Non-dimensional collapsed data for Non-ionic surfactants

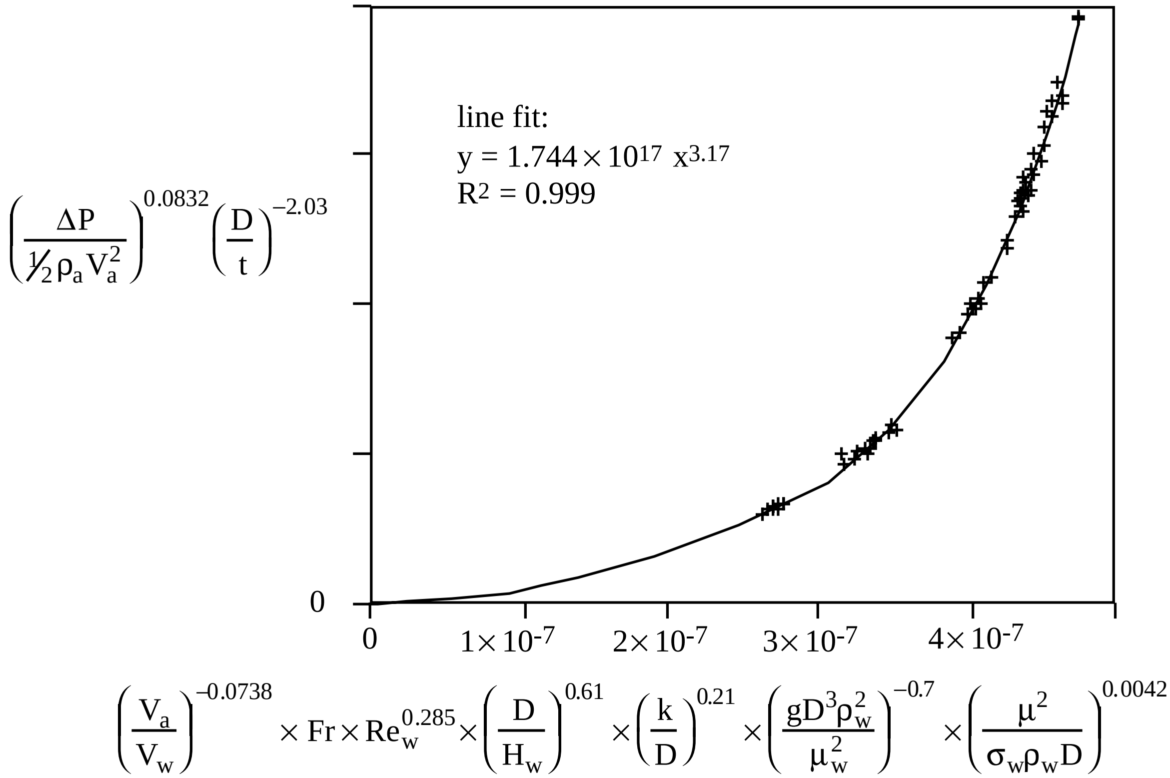


Figure 8. Non-dimensional collapsed data for Cationic surfactants

Figures 6-8 indicate higher airflow entrainment rates for anionic and non-ionic detergents: for anionic and non-ionic detergents, there is a marked increase in suction pressures as shown in Figure 9. This is consistent with the predictions above that decreased $\sigma$ values resulting from detergents will increase the efficiency of airflow entrainment through increases in $\tau_c$.

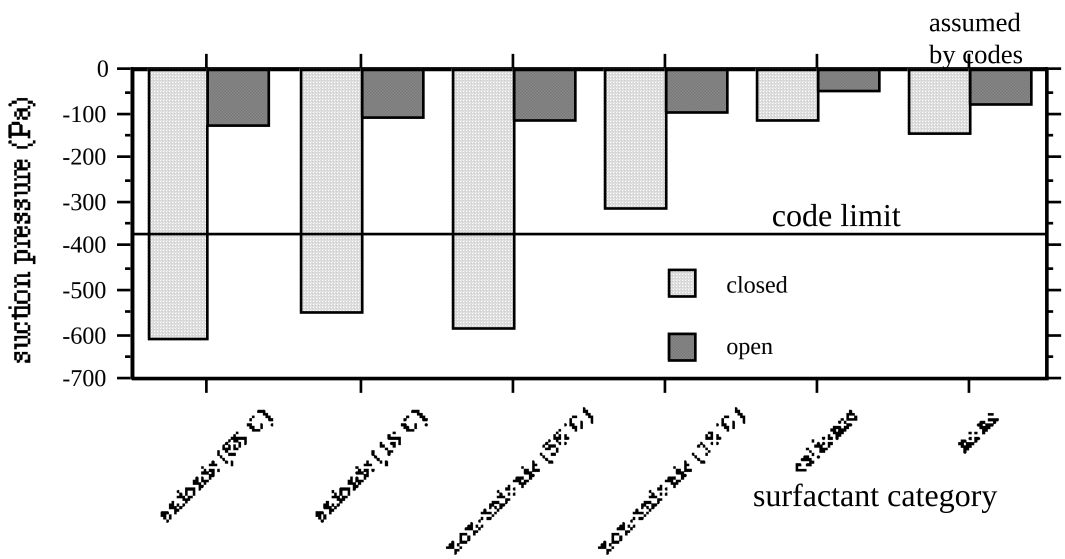


Figure 9. Comparison of suction pressures generated between detergent dosed and clean water discharges

**Conclusions**

The historical development of research in the area of DWV systems has included extensive research into the hydraulic and pneumatic conditions in the stack and vent pipes, revised recently by Wise & Swaffield[12]. Historically, the results were interpreted as suggesting that the water in a stack falls as an annulus which then entrains an airflow causing an associated pressure drop dependant on the dry stack configuration. The model proposed in this paper builds on the research of many previous workers and current DRG work, and suggests that the airflow entrainment is shared between the water annulus and the water falling in the air core. The proposed model is consistent with previous and current work, and suggests a velocity profile in the stack.

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# An Investigation into the Effects of Negative Pressure Upon the Performance of a Syphonic Rainwater Outlet.

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## Abstract

*Through a number of recent research projects the understanding of the hydraulic performance of syphonic rainwater drainage systems has increased. This has resulted in these systems becoming more widely accepted within the construction industry, However, there is still a requirement for further knowledge, particularly with regard to the interface between the performance of a rainwater outlet and the flow conditions within the installed pipe work.*

*The operational pressures experienced within the pipe work of a syphonic rainwater drainage system are often sub atmospheric. Past studies have identified that there is pressure decay within a system downstream of the outlets, with the lowest pressure been experienced at a point located at the top of the greatest vertical drop. The performance of a syphonic rainwater drainage system located within a gutter may be affected by the pressure decay being translated back into the gutter via the rainwater outlet.*

*As part of the ongoing investigation into the performance of syphonic roof drainage systems a method of determining the flow rates through individual rainwater outlets has been developed. This paper describes the development of a dye concentration technique for the measurement of flow through individual outlets, without affecting the performance of the complete system. The results have been used to investigate the effects that the negative pressures within the pipe work have upon the performance of the syphonic rainwater outlet.*

## Keywords

Gutter, hydraulic performance, outlet, rainwater, syphonic roof drainage

## 1. Introduction

One strategic advantage of syphonic roof drainage system over conventional systems, is the ability to rapidly remove large volumes of rainwater safely and effectively. This ultimately leads to significant cost savings with the building drainage. Additionally, current attitudes throughout the construction industry mean that developers and constructors operate under increasing constraints, in order to achieve targets both in time and monetary terms. This is true for all aspects of building construction, including the roof drainage. In some cases the drainage of the roof area of a building does not receive the same level of consideration that many of the more prestigious aspects of the building receive. This maybe due to the fact that the roof drainage only forms around 1% of the project budget. If developers were more aware of the significant costs associated with system failure, then more consideration would be given to the design of the rainwater disposal system.

In the past, this lack of consideration has resulted in systems being installed without due diligence to the accurate assessment of hydraulic performance. This is vitally important when the systems are installed within valley or eaves gutters. Checking engineers, although experts usually work only with the information that is supplied by the individual rainwater system component manufacturers. If such information is not correctly verified, for example through rigorous testing of the particular combination of gutter and rainwater system, it may prove difficult to accurately predict the hydraulic performance of the system.

This paper describes a series of performance evaluations of a syphonic roof drainage system, utilising a full-scale test facility, located on the roof of Department of Civil and Structural Engineering, at The University of Sheffield. A schematic diagram of the system is shown in figure 1

A full description of the system was outlined by Bramhall and Saul (1998). The system has been used to establish the hydraulic performance of a syphonic system containing three rainwater outlets.

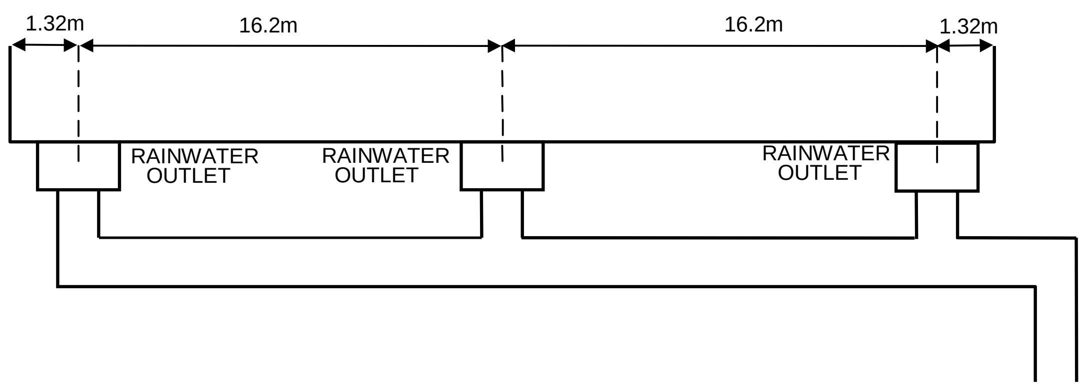


**Figure 1 - Schematic diagram of a full scale test facility**

## 2. Aim of This Study

The aim of this study was to assess the affect that sub-atmospheric pressure within the piping system has upon the depths of water within the gutter for any given rate of flow. Analysis of previous areas of study has highlighted the pressure regimes within a system and the relationship between each component with respect to pressure. The need for the development of a dye tracer technique in order to establish flow rates within any individual part of a system has been highlighted. This has been achieved without compromising the effect intrusive flow measurement techniques may have had on the performance of the syphonic action within the system.

## 3. Sub Atmospheric Pressures within a Syphonic system

Through the understanding of how depressurisation occurs within each element of a syphonic system, it can be shown that there may be a possibility of the translation of the effects of the depressurisation into a gutter.

### The Outlet

Slater (1998) noted that the depressurisation experienced between the inlet and tailpipe of a syphonic outlet was dependant upon the flow. Using a commercial CFD package he was able to show that at a given flow rate of 6 l/s the pressure drop across the outlet was in the region of 0.0315 bar

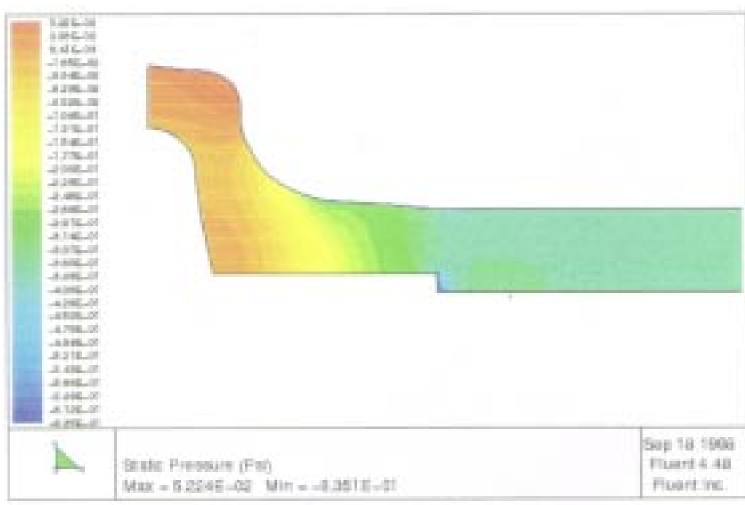

**Figure 2 – Pressure distribution within an outlet at 6l/s**

Maximum pressure = 2.403x102 Pa
Minimum pressure = – 2.913x103 Pa
Pressure drop across outlet = 2.403x102 – (-2.913x103)
= 3.1533 KPa
= 0.0315 bar

When the flow rate was increased to 12 l/s the pressure drop increased to 0.2788 bar. This pressure drop occurred over a relatively short distance as the length of the outlet is only 150mm.Figures 2 and 3 clearly identify the regions of depressurisation within the outlet for steady state flows of 6 l/s and 12 l/s.

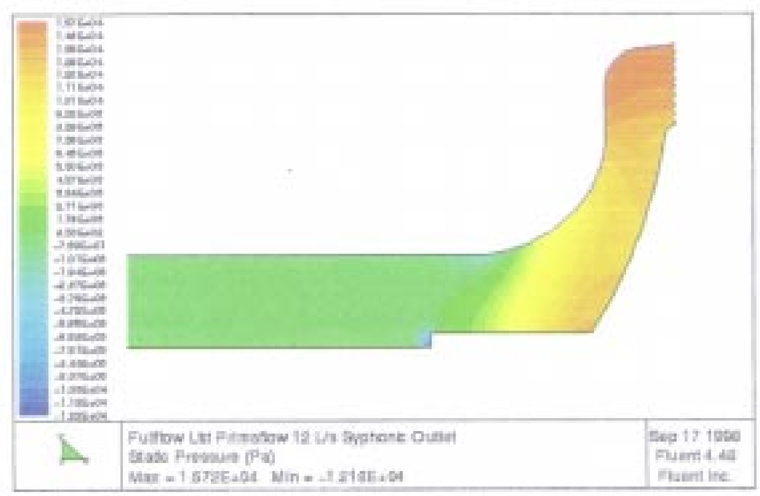

**Figure 3 – Pressure distribution within an outlet at 12l/s**

## The pipe work

The flow regime within the pipe work of a syphonic system develops through a cycle as the rainstorm events unfold. Initially, the flow through a syphonic system will be as shown in figure 4, flow pattern 1. Similar in operation to a gravitational system the resulting flow would partially fill the pipe.

The gravitational flow will be transformed into full-bore flow as the storm intensity rises. Air is excluded from the system as the water level within the outlet approaches the ant-vortex plate. Arthur and Swaffield (1999) described how the syphonic action is initiated within the pipe network as the rainstorm intensity and consequently the flow velocity increases.

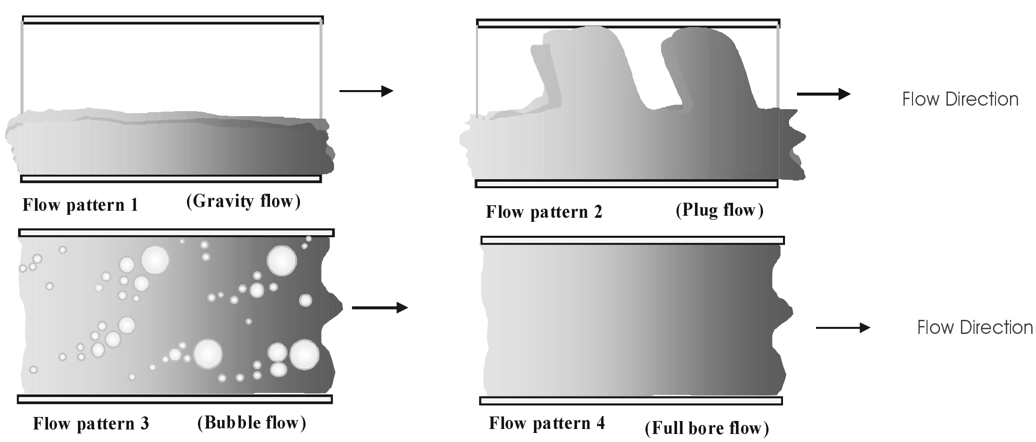


**Figure 4 – Stages of priming of a syphonic system**

As this priming process progresses to the full bore flow condition, a depressurisation of the pipe work occurs, hence the quantity of water discharged from the roof or gutter, is increased.

**Bernoulli's Energy Equation**

A Syphonic rainwater system designer has to solve the fluid mechanism problem presented by the height of the building and the quantity of rainwater generated by the storm event. Currently within the industry the pipes are considered to flow full and consequently Bernoulli's energy equation is used to determine the change in flow conditions between any two points in the system.

$$\left( h_1 - h_2 \right) + \left( z_1 - z_2 \right) + \frac{Q^2}{2g} \left\{ \frac{1}{(A_1)^2} - \frac{1}{(A_2)^2} \right\} = K_{1,2} \frac{Q^2}{2g(A_2)^2} + i_{1,2} L_{1,2}$$

Bernoulli's energy equation

The terms on the left-hand side of the equation indicate the changes in the total energy of the flow, attributable to the pressure energy, ($h_1$-$h_2$), potential energy ($z_1$-$z_2$), and the corresponding kinetic energy.

The two terms on the right hand side of the equation determine the loss of total energy between the two points. The first term is an expression of the losses at bends, fittings and changes in the cross sectional area. The remaining term accounts for the frictional losses of the length of pipe between the two points.

Evaluation of the energy gradient is commonly obtained from the Colebrook-White formula shown.

$$i = \frac{Q^2}{2g(A_1)^2} \left\{ 1\text{og}_{10} \left( \frac{ks}{3.7D} + \frac{2.51\nu}{D\sqrt{2gDi}} \right) \right\}^{-2}$$

Colebrook-White formula

This equation involves factors including the pipe diameter, surface roughness and viscosity of the liquid.

These two equations are applied across the whole piping network in order to obtain the syphonic system design. Essentially the syphonic system is a process of careful analytical sizing of a piping network, accurately matching the resistance of that network to the height of the building at the design flow capacity. Recent research (Arthur and Swaffield 1999) has seen the development of a numerical model that is capable of representing the two-phase flow priming of a syphonic system. Not yet currently adapted to encompass multi outlet systems the results from laboratory test are comparable to the flows predicted by the model.

May (1996) highlighted that low pressures in a syphonic system should be considered for two reasons. One being,  the ability of the pipe material to resist the buckling forces implied by the negative pressure. This area of study has been reported upon by Bowler and Arthur (1999),  who concluded that through the correct choice of pipe material the issue of pipe failure due to buckling should be eliminated. The phenomenon of cavitation was the second consideration of May (1996) who recommended that the cavitation index for pipes and fittings should be incorporated into the design analysis of a syphonic system.

Additional to the work undertaken by May, this author hypothesises a possible third reason for the consideration of negative pressures within a syphonic rainwater system. This reason concerns the performance of a rainwater outlet being enhanced by the negative pressures both in the outlet itself and the associated pipe work. The application of Bernoulli's energy equation, combined with the Colebrook-White equation across a full flowing system, predicts that typically the rainwater outlet located closest to the vertical stack will have a higher capacity than any other individual outlet. Furthermore, the pressure distribution chart for the system highlights that the position of this outlet coincides with the area of least pressure within the system. Figure 5 shows the typical pressure distribution relative to the vertical stack and the rainwater outlets. In an attempt to confirm the hypothesis a series of tests were performed. The first test compared the head of water around an outlet rim with the flow rate and localised pressure. The second test developed a dye tracing technique in order to establish the proportion of total flow attributed to individual outlets.

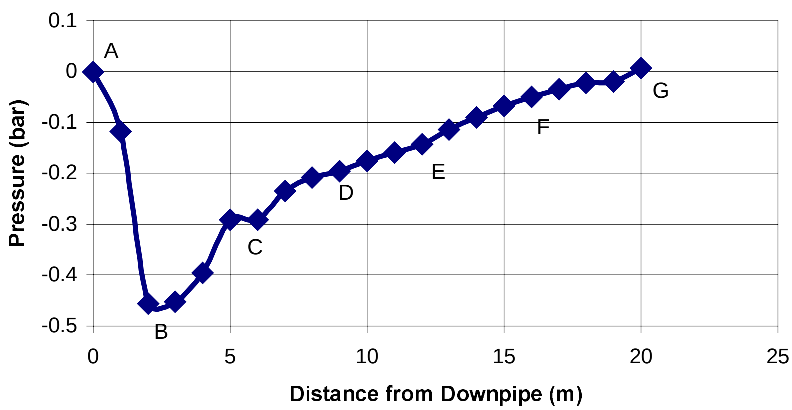


**Figure 5 – Pressure Decay within a syphonic system**

Point A = Discharge point
Point B = Top of vertical stack
Points C,D,E,F and G = outlet positions

## 4. Experimental Methodology

A description of a full-scale test facility located on the roof of the Department of Civil and Structural Engineering at the University of Sheffield, was outlined by Bramhall and Saul (1998). By utilising this facility through data collection and observation, an experiment was undertaken to determine how a negative pressure within the pipe work of a syphonic system affected the flow regime within the gutter. Previous tests, Bramhall and Saul (1999), have concluded that for a given steady state flow entering the gutter, and two outlets being located at the extreme ends of the gutter, the variation in the working head of water around the rim of each outlet was insignificant. The application of a weir flow equation would suggest that the outlets are accepting the same flow rates and contradicting the Bernoulli prediction that the outlet nearest the vertical stack has the capability of accepting greater flow rates than the other outlets. Therefore, if the working heads of water around each outlet rim are similar, but the flows different, then the negative pressure generated within the outlet and associated pipe work may be having an affect upon the outlet's working head of water.

A three outlet syphonic system was installed within the 35 metre long test facility, the distance between each outlet is shown in figure 1. Steady state inflow rates to the gutter were measured through the use of pneumatically controlled valves. Depth measurements of the water within the gutter were recorded around each outlet rim and at the upstream points of zero flow (i.e. the point at which the flow divides to flow between two outlets). Pressure readings were recorded along the main horizontal collector pipe at the branch junction of an outlet, by means of a dial gauge. Steady state inflow rates were measured against water depths and observations of flow patterns within the gutter taken.

## 5. Discussion of Results

Figure 6 shows the relationship of flow against depth at various steady state flow rates. The three outlets were positioned between points 1 & 2, 4 & 5 and 7 & 8. Points 3 and 6 were the positions of zero flow (i.e. the point at which the flow divides to flow between two outlets). As previous studies have shown, and as relevant standards predict, the upstream depth of water within the gutter is clearly definable from the working head of water around the outlet. It should be noted that throughout the tests at varying inflow rates the variation in water depths around the two extreme outlets remains within 5mm. If this were a conventional gravity system the similar water depths would suggest that the outlets have the same flow capacity. However, when Bernoulli's energy equation is applied to the system, the outlet at point 7 is predicted to accept 18.5% more flow than the outlet at point 2.

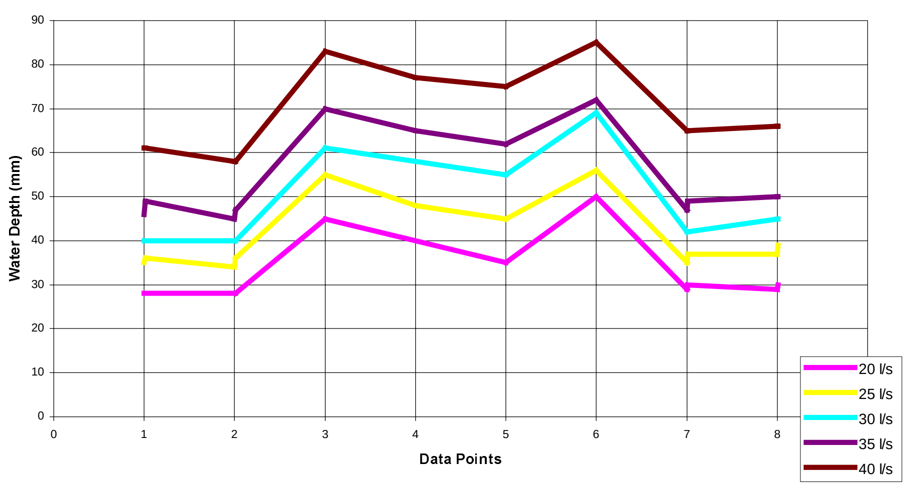


**Figure 6 – Water depths within gutter**

Alongside the Bernoulli's predicted values of pressure, table 1 shows the pressures recorded at the junction of each outlet branch as it connects to the main collector pipe. It may be seen that in both the actual and calculated cases, the values of pressure are lower at the outlet situated nearest the vertical stack, i.e. point 7. The two values of pressure recorded at the steady flow rate were due to the characteristic oscillation of the syphonic system during the priming phase. The effects of the oscillation were transmitted into the head of water around the outlet rim. Figure 6 identifies the fluctuations within the water depths at point 2 and 7. Observation of the water velocities within the gutter revealed the velocity around the two extreme outlets to be different. The highest velocities within the gutter were observed around the outlet located nearest to the vertical stack. As the water depths within the extreme ends of the gutter were comparable the increase in velocity would suggest an increase in flow.

| Flow l/s | Recorded Measurement (bar) | | | Bernoulli's Calculation (bar) | | |
|---|---|---|---|---|---|---|
| | Pt 1 | Pt 4 | Pt 7 | Pt 1 | Pt 4 | Pt 7 |
| **20** | 0 | -0.025 | -0.05<br>-0.1 | 0.03 | -0.003 | -0.065 |
| **25** | 0 | -0.025<br>-0.05 | -0.1<br>-0.15 | 0.022 | -0.013 | -0.19 |
| **30** | -0.05 | -0.05<br>-0.1 | -0.15<br>-0.25 | 0.009 | -0.028 | -0.29 |
| **35** | -0.05<br>-0.1 | -0.075<br>-0.125 | -0.25<br>-0.3 | -0.0069 | -0.045 | -0.42 |
| **40** | | -0.15 | -0.325 | | -0.114 | -0.42 |

**Table 1 – Measured and calculated pressures**

The results of this particular test highlighted the need to assess the flow rates down individual outlets. Inflows to the gutter may be measured accurately through the use of control valves. However, this method of flow measurement does not indicate the proportion of the total flow being drained by individual outlets. A method of determining this individual flow without placing restriction within the pipe had to be found. The insertion of flow meters both mechanical and ultrasonic was considered but these were found to be unsuitable due to the fact that pipes flow part full and the necessary restriction to flow. Fluorometry has been typically used in the measurement of flow within streams, rivers, partially filled sewers and open drainage canals. Adaptation of this tried and tested method of flow measurement into the roof drainage systems has been developed.

## 6. Development of a dye tracer technique for the calculation of flow

A dilution of dye is injected into the bowl of the rainwater outlet located furthest from the vertical stack. Injecting the dye in such a way enables the dilution to mix with the turbulent flow of water within the outlet. The flow rate of the dilution was controlled through the use of a variable speed pump. Figure 7 shows the configuration of the dye injection points and sample retrieval points.

By comparing the initial analysis of the dye concentration and the analysis of the samples retrieved from points 1 and 2 it is possible to calculate the rates of flow within individual rainwater outlets.

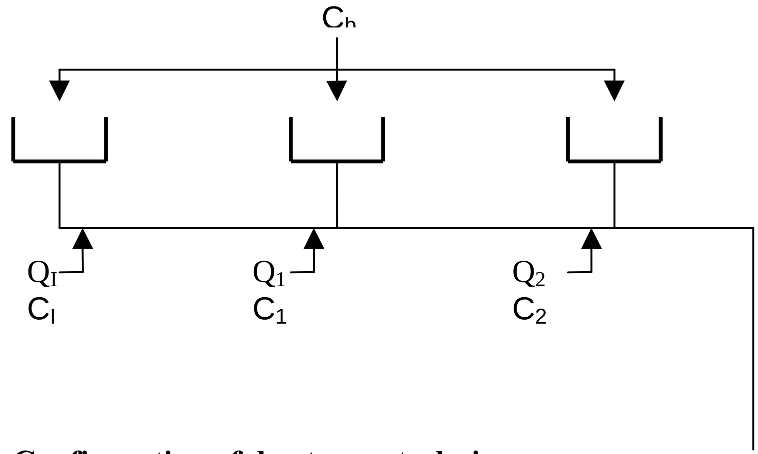


**Figure 7 – Configuration of dye tracer technique**

| | | |
|---|---|---|
| $Q_I$ | = | Flow rate of initial dye water mix (l/s) |
| $C_I$ | = | concentration of initial dye water mix (l/l) |
| $Q_1$ | = | Flow rate at point 1 (l/s) |
| $C_1$ | = | Concentration of dye at point 1 (l/l) |
| $C_b$ | = | Background concentration (l/l) |

## 7. Conclusion

- Areas of negative pressure within a syphonic system have been identified and investigated.
- Pressure decay within a syphonic system has been recorded.
- Previous areas of study have been assessed and reported on
- A dye concentration technique has been developed for the measurement of flow through individual outlets.
- Observed velocities within the gutter suggest the outlet located nearest to the vertical stack of a system accepts more flow than weir flow calculations suggest

## 8. Further Work

By design, negative pressures are experienced within the pipe work of a syphonic system. The initial tests have indicated that due to the existence of the below atmospheric pressure within the associated pipe work, the hydraulic performance of an outlet may be enhanced.

It is the intention that future work will investigate the effects a negative pressure has upon an outlet's capacity. This will be achieved by measuring the steady state flow rate through an outlet using the dilution technique developed within this study, and recording the depth of water above the outlet. Careful manipulation of tailpipe diameters to give different flow velocities and consequently the negative pressure within the pipe work, will enable comparisons to be made. Through a series of such tests, the effects of negative pressure upon an outlet will be determined. It is proposed that the tailpipe diameters will be changed on a maximum of two further occasions (one larger and one smaller than existing).

Once the full series of tests have been completed the tests will be repeated using alternative designs of syphonic rainwater outlets. In addition to confirming the accuracy of the numerical models, the change of outlets would also highlight the adaptability of such models and give credibility to the findings. Repeating the tests in this way would give confidence to all designers and help to ensure that the results are adopted throughout the syphonic rainwater drainage industry with a high degree of confidence.

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# A New Thinking - An Ecological Sewerage System, Nolson System

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## Abstract

Environment work is profitable. One condition for a future durable society is to increase the knowledge of environment, circulate the knowledge in the society and transform it into practical action.

The waste from hoseholds have been a problem for both Communities and State Government.

It is not only a question of sorting the garbage, it is also a question of making the possibility of care-taking with a method for recycling and circulation of waste water, refuse and kitchen garbage.

The aims are reduced household waste, reducing of the nature recourse, reducing flow of material in general and more use of effective energy.

According to EU the number of garbage and refuse shall be gradually reduced.

The Nolson System is developed in order to meet the new requirements.

The system allows using kitchen grinders for grinding down all organic waste in the drainage system, which increaseses the quantity of sludge with 50% but can be used for biogas production. The remaining sludge could be used as a soil fertiliser.

In the same time the quantities of garbage reduces to dry refuse which is burnable and generates energy.

## THE FACT

Clean water into the building and clean waste water out from the building is a common requirement you can demand from all construction and building owners. Households waste water is so contaminated that requirements are needed, (1)

The result from an investigation shows that even the grey-water (kitchen + bathroom and laundry) is contaminated to such an extent, that it must be highly observed. This means the grey-water can not be let out into a recipient without a special treatment.

Many facts indicate that our garbage and refuse dumping places are poisoning our lakes. In Sweden there are about 600 – 700 dumping places, and we produce 7 billion ton consumption garbage and refuse pro year of which 50% ends up in the garbage dumps, the remaining ton are composed or burned up.

* According to EU the number of garbage and refuse shall be gradually reduced, and dumps of garbage and refuse are regarded as the last way to solve the garbage and refuse problems.

* The environment code which comes into force year 2000 prohibits dried burnable refuse and garbage dumping places on the dumps from year 2003.

An inventory of existing refuse and garbage dumping places in Sweden are going on. For the time being one does not know which type of poison substances is in question infecting our lakes. Serious damages have been seen on 80% of a number of fishes where a certain sort of fishes occur. It concerns above all perch, roach and zool.

## BACKGROUND

Environment work is profitable, particular in the long run. We are about sex billion people in the world, and we are getting on towards ten billion. At the same time the productive capacity of the earth "nature" reduces in fields, forests and marine systems. This happens by over- using our nature resources and a wrong dealing with our lands and ground water. The reduction of the base recources are also exposed to the change of climate and the increased content of contamination.

It seems like we are going into a resource funnel, where the inclination of the walls symbolises less and less room for health, welfare and good economy. The industries have here a heavy responsibility.

**What can we do for the future society concerning refuse and garbage circulation ?**

One condition for a future durable society concerning refuse and garbage circulation is to increase the knowledge of environment, circulate the knowledge in the society and transform it into practical action.

*** Research, education, information and practice.**

The aim for such a suggestion is to strengthen the co-operation within research, education and information. Besides, such a proposal offers a space where theory can meet practical application.

The activities containing such a suggestion should not replace but rather complete and strengthen other activities within different fields.

## A Swedish example.

How good are we in Sweden for example to sort kitchen garbage and refuse? An example is from the "News in Österlen", Skåne, (the Communities of Simrishamn and Tomelilla), where about 32 000 inhabitants are connected to the garbage and refuse treatment plant Måsalycka. According to a safe statistic from Måsalycka, the householders in Österlen carry at home about 70 ton packing of metal refuse each year. Unfortunately they are not as conscientious about leaving these packing of refuse back for recycling after having been emptied of their contents. Of the 70 ton packing of metal we carry at home only 27 ton, about 38 % will be recycled.

The Government of Sweden has approved (Government bill 1998/99:84) a future tax on garbage and refuse which are removed to refuse dumping places. This law is valid from 1 January 2000.

From hygienic-, environmental and human welfare point of view it should be desirable to simplify the charge of **waste water and garbage from apartments.**

There are systems ( see figure 1.) which facilitate the care-taking.

One system **NOLSON SYSTEM** is based on seven important components, which are in use separately and not in a total system, namely;

1. Kitchen grinders which are installed under the sink (Where all organic waste can be grinded).

2. Sedimentation chambers are installed in or near the buildings, where sludge and waste water are separated from each other at an early stage.

3. The transport takes place in two small bore pipes, one for waste water, one for sludge.

4. A Biogas reactor for sludge treatment is installed in the house or outside the building.

5. The treating of waste water is done in an infiltration plant or in a conventional treatment plant.

6. Refuse shute (sorting of the rest of refuse) is done in the building. (See fig.2. point 8.)

7. Transport of the rest of refuse from the building is done by normal truck (once a month)

## The quantity of garbage.

Each person produces about 70 m3 waste water pro year and about 700 kg households waste pro year. (The figures of households waste are different in the literature and varying between 400 - 700 kg per person and year). This fraction has increased under the last years [see report from Staffanstorp (3), an investigation of 100 households].

The waste from households have been a problem for both communities and State Governments.

It is not only a question of storing the garbage, it is also a question of making the possibility of care-taking with a method for recycling in a better way than the case is to day. It must be less costly than a conventional system.

**These problems are not only Swedish there are Global.**

## Households waste and recycling.

"If we go back to the households waste, which each person gets into contact with, it can be noticed that the waste is about 40% which the communities take care of and transport to a dumping place. More than 50% are burned up in a thermo power station and a small part is placed for composting etc". Dumping and burning is not a good solution according to some people, others consider the opposite [see article in the Newspaper, eva.hernback@dn.se].Most of the waste can be used. The Compost takes half part of the waste.

Here people agree.

Mostly can be recycled.

The dangerous waste is a small quantity which is specially treated. Of all the waste we throw way in a bin-liner can about 97% be used.

A total picture of the households waste can be divided in burn-able material and not burn-able material.

## Recycling, it is profitable?

The industrial life works for a product development where recycling and responsibility of the producers is natural.

There are a number of articles written about this subject where 50% accepts and 50% refuses recycling as profitable. Most of the articles are dealing with calculating and different approach.

Nobody considers that the environmental responsibility must be costly.

To day the consumer is used to sort the waste and transport it to the disposal plant. This is a direct cost for the consumer. A number of people about 30%, for instance retired and disabled persons, cannot manage or have no possibilities to transport their garbage to the containers. Besides, these are not an ornament to the environs.

To achieve a community in the long run is tenable.

Recycling is one of the most important instruments and it is not an aim itself. The aims are reduced household waste, reducing of the nature resource, reducing flow of material in general and more use of effective energy.

An International agreement describes these aims regarding this background

There are three strong ways we should carry on the recycling because;

1. Recycling stimulates producing of better products.

2. Recycling saves resources.

3. Recycling saves energy

## Sorting of households waste.

The Swedish National Environment Protection Board writes about obvious

environmental benefits in connection with recycling (5). These articlesmtake up questions on packing indudtries. The consumer pays about 2 400:- Swedish Crowns/

person and year for the wrappings, which become a problem for environment.

"Sorting of households waste pays off. Recycling is not possible without sorting.

Recycling saves energy and primary products", writes The Swedish Environment Board.

## Strict environment requirements are a possibility.

Certifying is one way of several possibilities. In the wake of rigorous environmental legislation and new technology we can see adapted transport services, developed business-relations and new sectors grow up.

## Swedish Trade Council Environmental Technique for export.

Swedish Trade Council under management of Rutger Engsäll has published a suggestion plan 2000 for environmental export. It is done with help of a Web-site, which gives a possibility for companies and users to follow up development in this field.
The web-site address is **<http://sed.swedishtrade.se/e/index.htm?go=olsson>**

## NOLSON SYSTEM a Breaf description of one solution

The Wastewater Treatment System consists of three major parts each with their specific functions. These are collection and transportation, waste water treatment and sludge treatment.

The transportation, the sewer system, is characterised by the use of small bore sewers and a specially developed siphon device. This allows a transport of various flows, especially from low flow systems. In this system the available slope is not critical. The sludge transport is achieved by pressure or vacuum system.

The treatment is actually a pre-treatment where the waste is separated from the liquid into an unit similar to the septic tank. The pre-treatment is done close to the waste source, which makes it easy to treat. The sludge is fresh and treatable. The final treatment of the liquid may take place in a conventional treatment plant or in an infiltration/land treatment system.

The third part of the NOLSON SYSTEM is the biogas reactor for sludge treatment. The sludge from the septic tank unit is collected and pre-treated in a thickener. The final treatment is an anaerobic treatment in a reactor where the biogas is collected. The remaining sludge could be used as a soil fertiliser.

The system gives the possibility to initial separation at source.

## Technical information - Nolson System

As mentioned earlier the technical solution is to separate sludge in a very early stage of the transport of waste water form the building. With the help of pressure or vacuum the sludge is transported to a new type of biogas reactor for biological degradation (anaerobic) where the treated material could be used as a soil fertilizer.

Two important units are included in the system, namely the sedimentation chamber placed near the building (service pipe) and the biogas reactor which breaks down the biological material in an anaerobic way.

The following principal figure shows the place of the units in the Nolson System.

In figure 2. are all units in the transporting system mentioned and their location. Even the pipe system with two small bore pipe systems starts and ends up in the treatment plants biogas reactor and infiltration plant, even the Refuse shute is shown in the figure.

## CONSTRUCTION OF THE NOLSON SYSTEM

For construction of the Nolson system needs information about the different units involved in the system, how they work and how the dimension and calculation has to be done.

## DIMENSIONING

**Inside buildings.**

Dimension inside buildings performs after EU-standard System II prEn 12056 1-6. Installing of kitchen grinders does not effect the design of the drainage system.

Installation of kitchen grinders inside buildings is only necessary if it is demanded from the owner or by the habitants in the apartment.

The installation is very easy and can be done by a plumber and an electrician. An electric connection in the kitchen sink is needed.

**Outside buildings - dual-pipe transport system**.

The most important unit is the sediment chamber outside buildings with siphon action. The principal unit construction is shown in the figure 3.

**Example:**

This unit can be designed by the following design figures;

Waste water and sludge calculations;

Following estimated figures are used (Swedish figures) as a basic design;

Each person consume 70 000 litre water pro year.

Each person produce 9,6 litre sludge pro week.

Each person supplies about 60 litre/24 hours to the sediment tank in the reactor

building, which gives about 16% sludge contents which is transported by pressure pumps from the siphon tank.

Each person supplies 195 l/d waste water to the siphon tank.

Connected apartments to one siphon tank are about 15 which correspond to 35 persons to one siphon tank.

## Siphon tank

The siphon tank is divided into two chambers one for waste water and one for sludge. The volume for waste water is 1/3 and for the sludge 2/3.

In the siphon tank the sludge is separated from the waste water in an early stage and before it is transported to the treatment plant.

The transport of waste water will be done by siphon action and the transport of sludge will be done by pressure pumps or by vacuum. These both alternatives give different possibilities to construct the system, which must be considered.

The inlet flow rate to the siphon tank balances the outflow rate.

The mean value flow rate for 35 persons will be 0,11 l/s.

Maximum flow rate in the morning is = 0,20 l/s (one hour)

Maximum flow rate in the evening is = 0,24 l/s.(one hour)

The volume of the siphon tank is under the max. hour = 864 litre. This value is

recommended to be 1000 litre. The safety value is 2 and the tank volume will be 2 m3

The volume of waste water is 700 litre and the volume for the sludge is 1300 litre.

The interval between the emptying periods is controlled by a level registration as for example the siphon unit. For the sludge-emptying it can be once a time each hour, except under the max. time. The emptying will be controlled by a max. signal unit.

The working time for the pressure pump or vacuum is controlled by the capacity value on the pump, as a level registration.

The tank can be made by plastic or concrete material. Actual law (EU-standard) shall be followed by loading value

The emptying capacity from the tank is 1,4 l/s in this case but has to be calculated by a consult engineer.

The construction of the tank shall take in consideration that the sludge slips away towards the middle of the tank where the pump is located. The principal idea for Nolson System presumes intermittent emptying of a given water volume.

This indicates that you must work out from a hydraulic height [H] with a lowest starting flow rate. The principle also indicates to find an acceptable breaking level [h2]. To find a good effect of settling down the sludge chooses a water volume between the maximal starting point [HÖ] and the minimal level for the breaking point [h2]. This also dependens of the tank diameter. The principal figure se fig 3.

Intermittent emptying takes place when the maximal volume is attained. The emptying time [t] may be as short as possible but balance to the pipe dimension, where the filling degree is 4/5 of the pipe diameters. The probability flow rate under the max.- hour /day is t min./60 min. = @.

The construction of the siphon tank gives a max. mean flow rate at [h1/2] and a max. flow rate at the level [HÖ]. This process gives the need of a short emptying time [t], about 2 minutes pro each time, which gives a longer interval between the emptying time and a harmonious settle down of the sludge in the incoming waste water. The high flow rate out from the tank cleans the pipe between the siphon tanks. Research and development has been done in a chamber with diameter of 64 cm with different types of siphon units. The final solution is shown in the figure 4.

The siphon construction is provided with two inlet pipes one opening under the outlet pipe and the other given a chosen high over the outlet pipe.

The outlet of this pipe is provided with an air clock in order to break the function of the siphon. Two inlet pipes make it easier to use a lower starting flow rate, down to 0,1 l/s.

## SETTLEMENT CHAMBER (for thickening of sludge before it goes to the reactor).

Construction of the settlement chamber has to consider that the volume is at least one weeks flow rate from the siphonic chambers. The settlement chamber reduces also waste water from the sludge. This volume is estimated to 50 litre/person and week (1750 litre in the example).

The remaining sludge will be 10 litres/p d and for the whole week 10 x 35 Pe = 350 litre pro sediment tank.

Maximal volume in the tank is 5 000 litres, which correspond to 15 connected siphon tanks or 15 x 35 Pe = 525 Pe.

Standard sizes of the tanks are 3 m3, 4 m3 and 5 m3.

The tank construction shall take in consideration the air inlet but not the outlet.

When the tank fills up again the air in the tank has to go through the filter unit.

A minimum amount of air shall be allowed to get into the tank in order to give the possibility to start a tretment process. A principal figure se fig.3.

## INFILTRATION CHAMBER.

The outlet flow rate from the tickening tank is calculated with 50 l/pd. This corresponds under the max-period (one hour) to a flow rate of 50 l x 525 Pe = 26 250 litre waste water.That means the filter shall have a capacity of 0,4 l/s /m2.

The construction shall take in consideration the air inlet and outlet.

The construction shall be tight and no odour is allowed.

The two filters shall be easy to remove for cleansing and closing valve is required. Principe see figure 5.

Using a small-bore dual-pipe system for waste water and sludge transport give these benefits;

* Diameter dimensioned to meet actual on-site requirements.

* Sludge and waste water are kept separate from start.

* Waste water transport is achieved by syphonic action.

* Sludge transport is achieved by pressure or vacuum system.

NOLSON syphonic technology means a shallower trench depth, and a flatter pipe slop. It transports the waste water at a low flow rate to a nearby settlement (sedimenting) chamber. Separating sludge from waste water near their origin keeps solid particles out of the waste water solution.

## Result of a case studies.

The using of kitchen grinders increases the quantity of sludge with 50% without causing any problems in the drainage system.

These grinders have now been used for 9 years and are still working satisfactory. (Example se point 7 in fig. 2.).

The sediment chambers have a very good settlemented effect and give between 5 - 10% of SS.

Small Bore Systems have been used in many years in the world without any problems.

The Biogas reactor (see point 5 in fig 2.) runs with one to five m3 sludge continuos by each week.

The value of BOD 7 on the inlet sludge is reduced with between 80 - 95%.

Phosphor and Nitrate are still in the composted material, consequently it converts to fertilizer after having been thickened with peat litter and post-composted.

The costs for the system are shown in figure 6 as an estimated cost in Swedish Crone.

The suggested infiltration unit is shown in figure 7 from a project in Komstad By (25 households).

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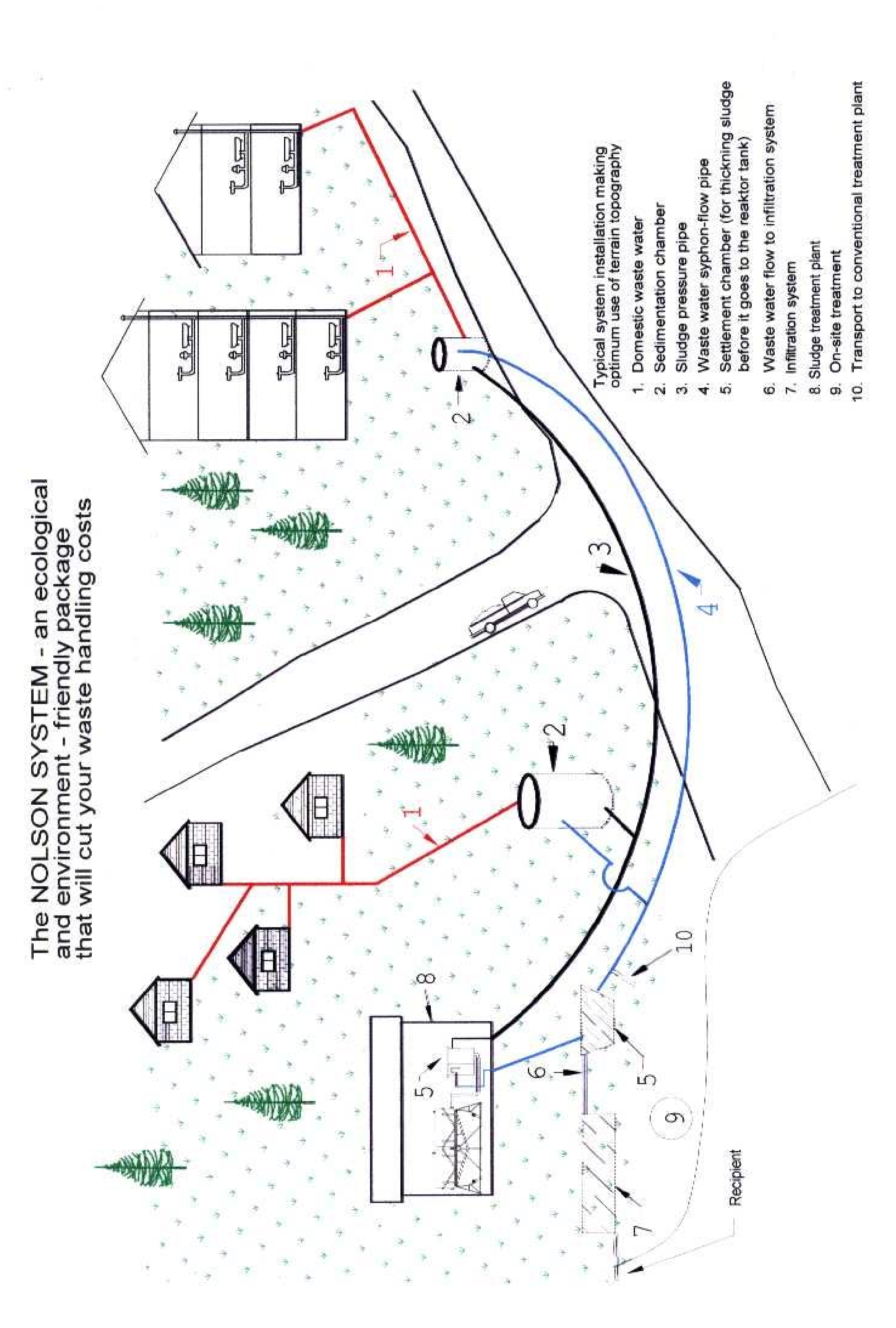
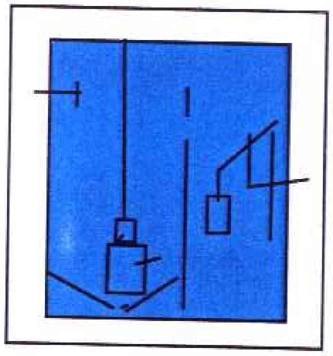

The NOLSON SYSTEM - an ecological
and environment - friendly package
that will cut your waste handling costs
Typical system installation making
optimum use of terrain topography
1. Domestic waste water
2. Sedimentation chamber
3. Sludge pressure pipe
4. Waste water syphon-flow pipe
5. Settlement chamber (for thickning sludge
before it goes to the reaktor tank)
6. Waste water flow to infiltration system
7. Infiltration system
8. Sludge treatment plant
9. On-site treatment
10. Transport to conventional treatment plant
Recipient



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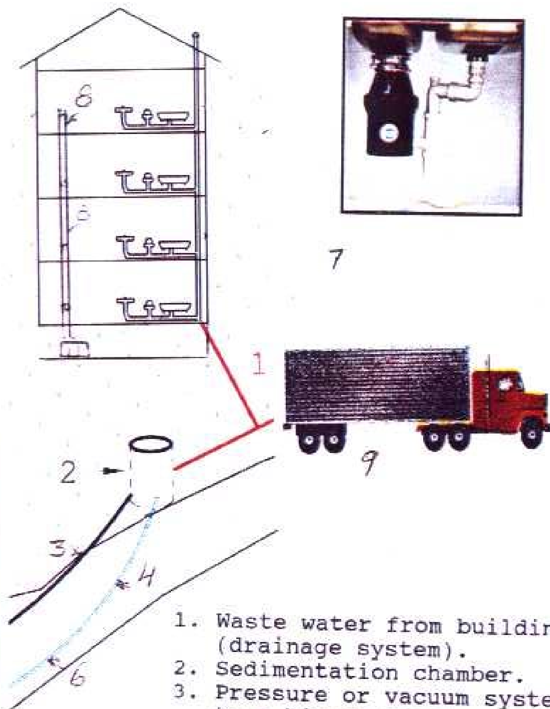


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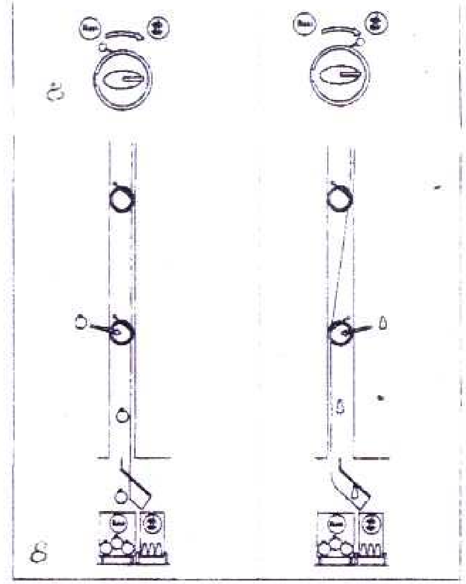

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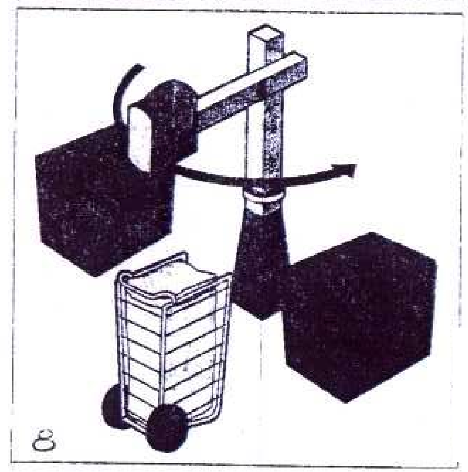


8

1. Waste water from building (drainage system).
2. Sedimentation chamber.
3. Pressure or vacuum system to a biogas reactor.
4. Siphone or pressure system for liquid.
5. Biogas plant for sludge
6. Liquid (waste water) to conventional plant or infiltration unit.
7. Kitchen grinder.
8. Refuse shute (sorting of the rest of refuse).
9. Transport of the rest of refuse from building (once a month).

## Principal figure for the sedimentation chambers

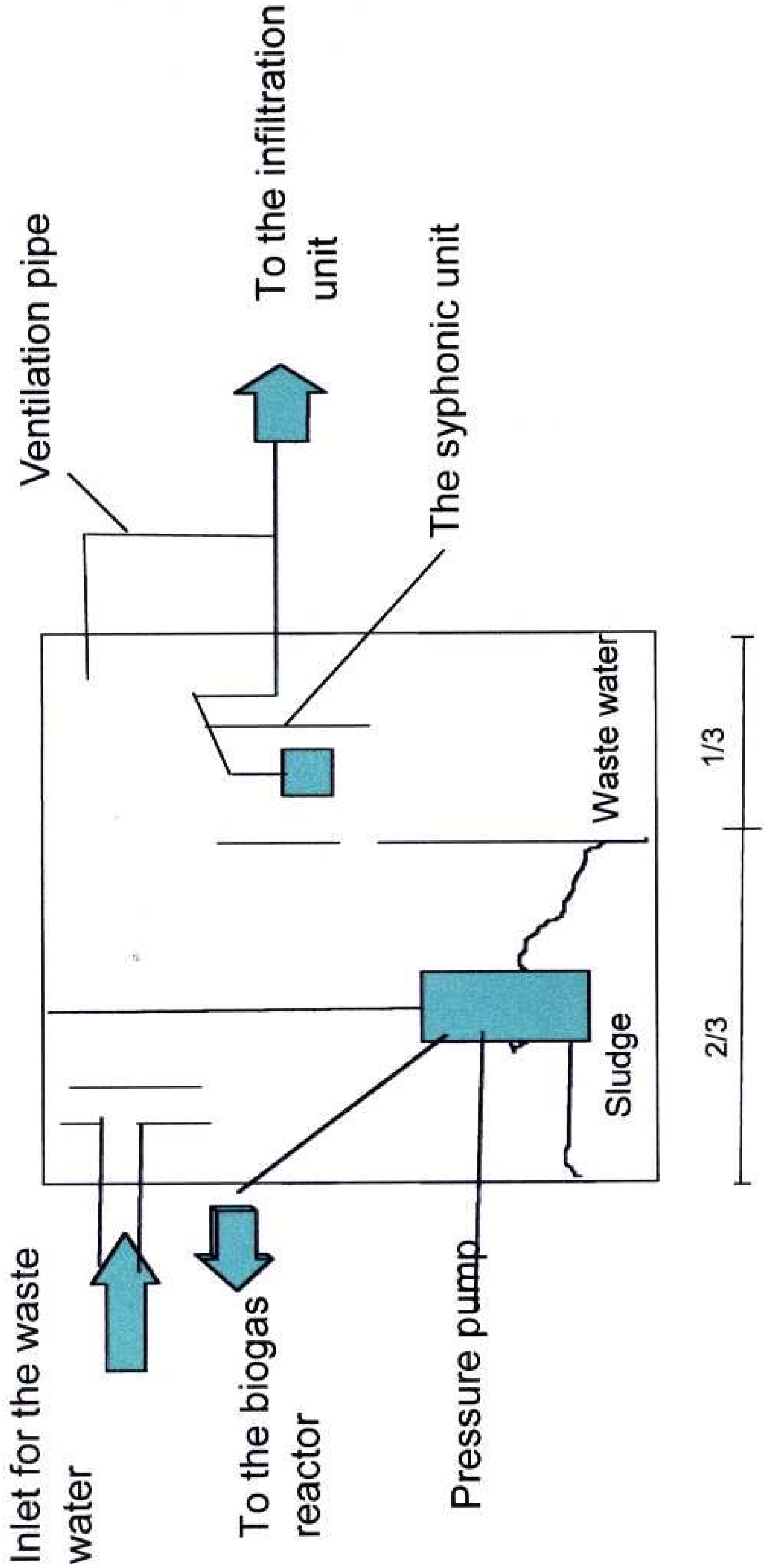
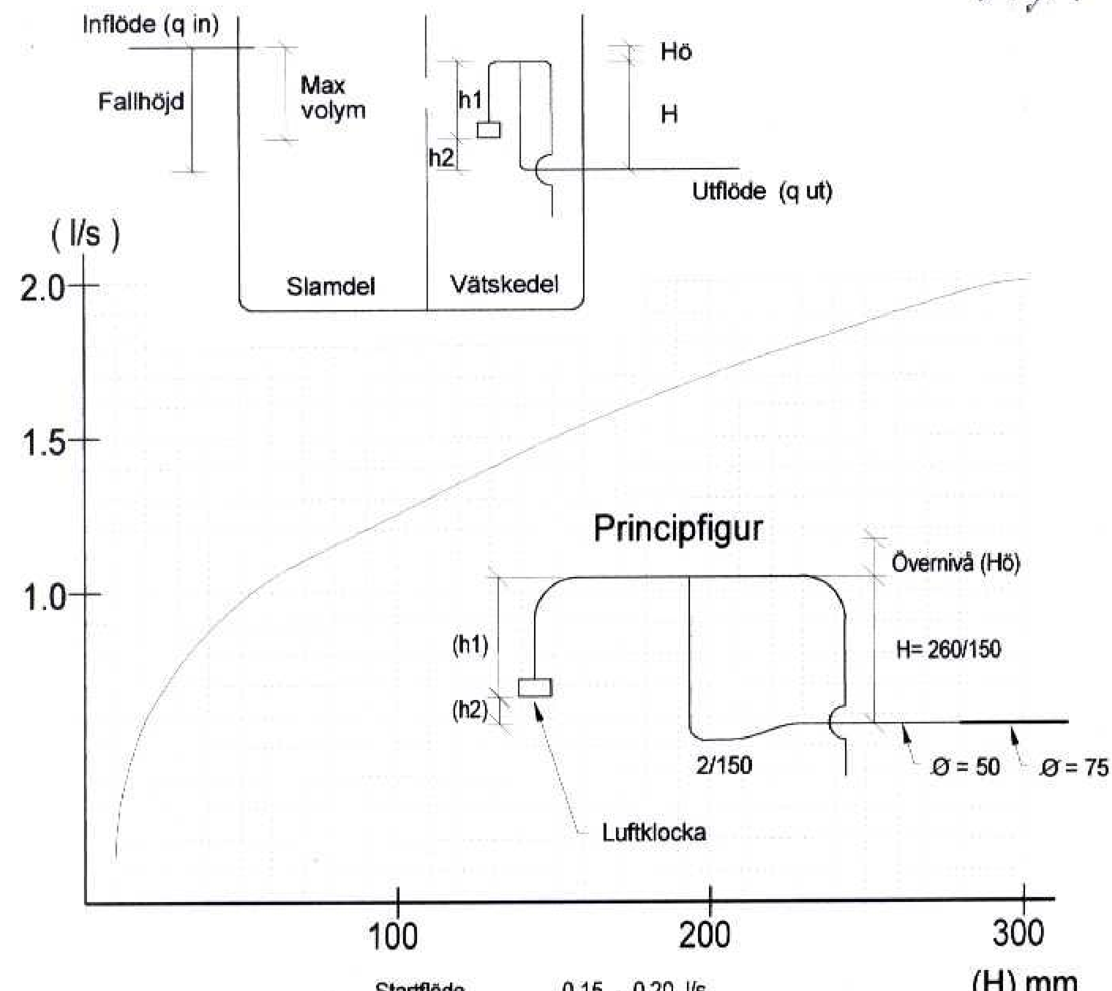


Fig. 4




| | |
|---|---|
| Startflöde | 0,15 - 0,20 l/s |
| Maxflöde | 1.9 l/s vid H = 260 mm |
| Medelflöde | 1,4 l/s vid H = 130 mm |

| För konstruktion H = 260 mm | | | H = 150 mm |
|---|---|---|---|
| Övernivå (Hö) | = | 50 mm | = 50 mm |
| Brytpunkt min (h2) | = | 20 mm | = 15 mm |
| Hydralisk höjd (H) | = | 260 mm | = 150 mm |
| Flöde vid (H) | = | 1,90 l/s | = 1,50 l/s |
| Flöde (H + Hö)= 3102 | = | 2,00 l/s | = 1,70 l/s |
| Startflöde (H) | = | 0,1 l/s | = 0,18 l/s |
| Flöde vid brythöjd (h2) | = | 0,6 l/s | = 0,45 l/s |

Fig. 3 KONSTRUKTIONSDIAGRAM HÄVERT

Fig. 5

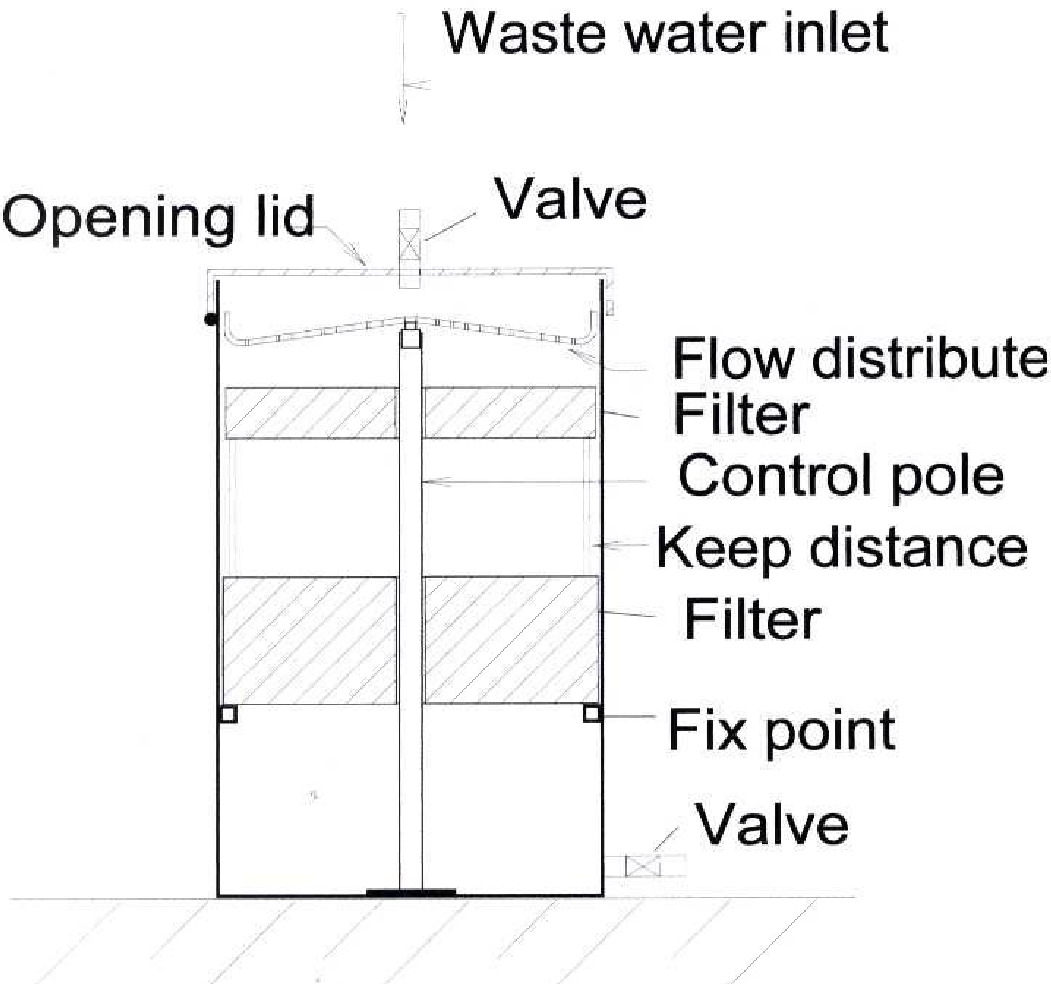



Fig. 6 Filter unit
Scale 1:200

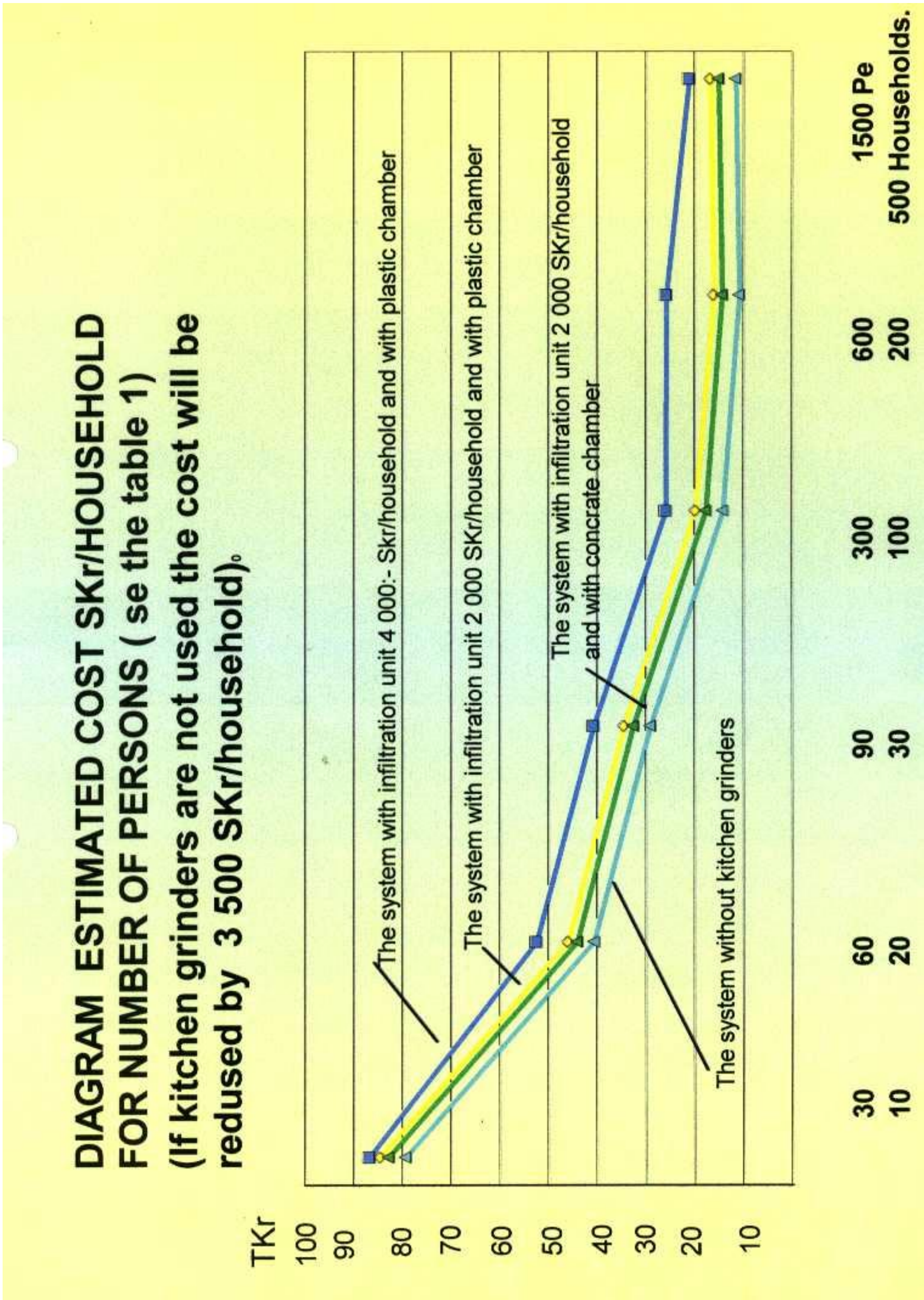
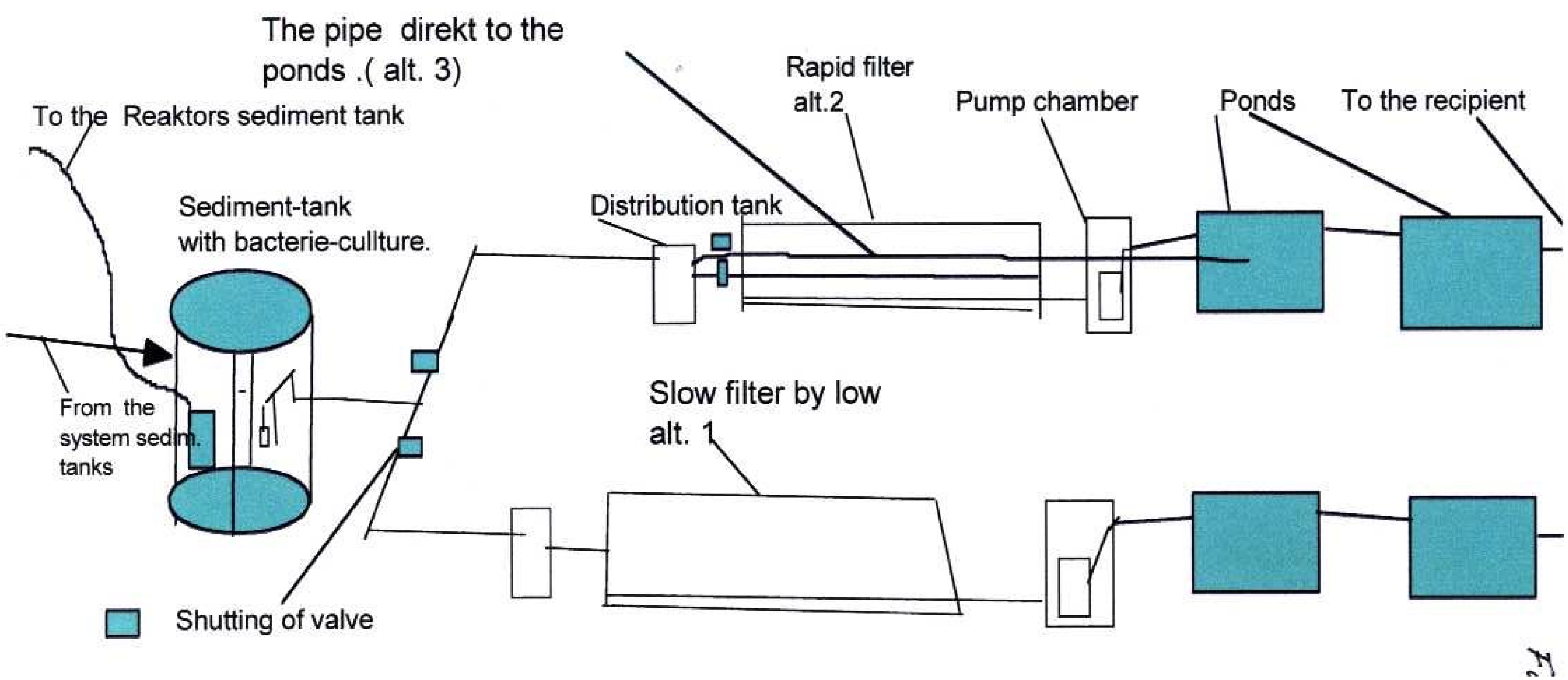


DIAGRAM ESTIMATED COST SKr/HOUSEHOLD
FOR NUMBER OF PERSONS ( se the table 1)
(If kitchen grinders are not used the cost will be
redused by 3 500 SKr/household)。
TKr
100
90
80
70
60
50
40
30
20
10
The system with infiltration unit 4 000:- Skr/household and with plastic chamber
The system with infiltration unit 2 000 SKr/household and with plastic chamber
The system with infiltration unit 2 000 SKr/household
and with concrate chamber
The system without kitchen grinders
30
10
60
20
90
30
300
100
600
200
1500 Pe
500 Households.

# INFILTRATIONS UNIT FOR KOMSTAD BY IN PRINCIPAL

Under the research period must earlist three diferent alternativ be tested.
The alternativen must give the posibility within the beginning if it is possible.



# Water efficient housing in the UK

Prepared for:
**CIB W62 2000**
**in Brazil**

Prepared by:
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**Fiona Thomas BEng**

**August 2000**

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# WATER EFFICIENT HOUSING IN THE UK

**Martin Shouler BSc, MSc and Fiona Thomas BEng**

## Executive summary

BRE have been commissioned by a UK water supply company, Essex & Suffolk Water, to develop and assess a water efficient specification for new housing suitable for use in the UK. Other partners in the project include the housing association on whose behalf the houses were built, Moat Housing, the British Bathroom Council, and the UK's Environment Agency.

The objectives of the project are to:

i) investigate the practicalities of specifying and installing a range or water efficiency measures,
ii) evaluate the reduction in water consumption from their use, and
iii) determine user reaction to the measures.

The paper contains information on the following issues:

- identification of a suitable host housing association organisation and development site,
- development of a performance specification for water efficiency measures,
- selection, installation and commissioning of the water efficiency measures,
- installation and commissioning of meters,
- tenant information and feedback,
- publicity,
- the flow signature monitoring equipment, and
- lessons learnt to date.

Water efficient measures, appropriate for use in a new housing association development, were selected by agreement between BRE, Essex & Suffolk Water, and Moat Housing Group. The measures consisted of:

- water efficient showers,
- low volume flush WCs,
- low flowrate taps,
- greywater systems, and
- water butts.

The paper gives initial findings from the research which continues until October 2000.

**CONTENTS**

# 1 INTRODUCTION

## 1.1 Background

Water conservation is important in the UK as demand for water has increased and shortfalls in supply have occurred. There is growing public awareness of the scarcity of water in some areas of the UK and of its economic value. This project identifies and evaluates demand management techniques appropriate for installation in new build social housing schemes.

Domestic use accounts for a high percentage of water, approximately 17,250 million litre of water each day (64%), see figure 1, which is broken down as shown in figure 2. Hence, there are opportunities for reducing water consumption within the home using efficient water-using appliances and technologies.

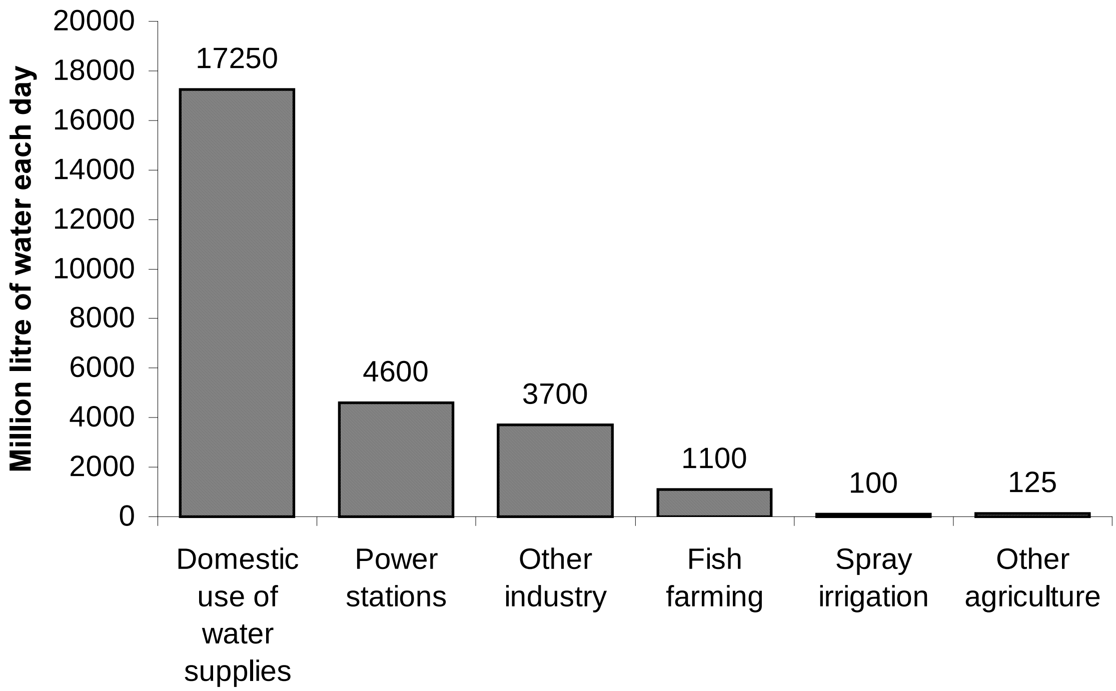
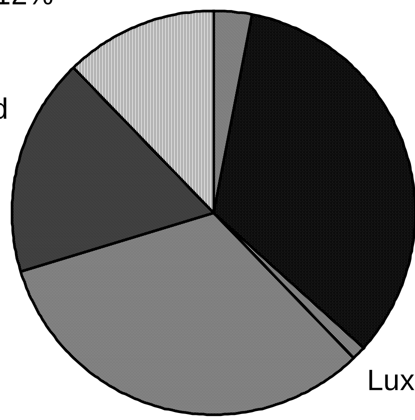



Figure 1. Uses of abstracted public water supplies in the UK




Note:
1. There is considerable variation in water-use between household size, socio-economic group and from region to region.
2. External use includes water used for gardening and car washing.

Figure 2. Typical household water-use in the UK

### 1.2 Research Programme progress

The paper gives initial finding of a water efficient housing project commissioned by Essex & Suffolk Water. The objectives are to:

i) investigate the practical issues related to specifying and installing a range of water efficiency measures,
ii) evaluate any reduction in water consumption resulting from their use, and
iii) determine user reaction to the measures.

The paper contains information on the following issues:

- identification of a suitable host housing association organisation and development site,
- development of a performance specification for water efficiency measures,
- selection, installation, and commissioning of the water efficiency measures,
- installation and commissioning of meters,
- tenant information and feedback,
- publicity,
- the flow signature monitoring equipment, and
- lessons learnt to date.

The first stage of the project consisted of a scoping study to investigate the feasibility of undertaking a water efficient housing scheme and the second, and current phase 2, is the monitoring part of the study given in section 2.4 to 2.8.

# 2 DESCRIPTION OF THE PROJECT

## 2.1 Development of performance specification

Following discussions with Moat Housing Group (MHG) and Essex & Suffolk Water, a performance specification for water-using appliances was developed based on current best practice with regard to demand management techniques, see tables 1a and 1b. It was important that products conforming to the specification were available commercially. However, some difficulty was experienced, by the plumbing sub-contractor, in identifying suitable products. This is discussed in section 3.1.

**Table 1a - Water efficient specification**

| | |
|---|---|
| Shower | Maximum flowrate less than 10 litre/minute |
| Bath | 150 litre to overflow |
| WC | Nominal flush of 6 litre or less<br>Dual flush systems |
| Tap | Basin taps, flowrate less than 5 litre/minute |
| Water butt | With a closed fitting lid |
| Greywater system | Recycles water from bath, shower and basin for WC flushing |
| Garden hose | If installed, must be trigger operated |

**Table 1b - Standard specification for water using appliances**

| | |
|---|---|
| Shower | Not installed |
| Bath | 180 litre to overflow (rinse shower attachment) |
| WC | Nominal flush of 7.5 litre |
| Tap | Basin taps, flowrate 10 litre/minute |
| Water butt | Not installed |
| Greywater system | Not installed |
| Garden hose | Outside tap fitted, no hose |

In agreeing the performance specification, Moat (host housing association) wished to ensure that there would not be any significant maintenance and cost implications. The greywater units installed have an annual energy cost for pumping of about UK£5 and a cost for the soluble disinfecting tablets of UK£10 annually, as given by the manufacturer's data. The costs were acceptable to Plume and are borne by the tenants.

## 2.2 Identification of suitable site and host organisation

Following consultation with members of the BRE Housing Group, MHG was identified as a suitable host for this project together with Plume Housing Association, an associate member of MHG. MHG provides its member associates with strategic direction and group wide services including housing development.

Plume Housing Association, based in Heybridge, Essex, UK, has a stock of over 2,000 homes and is expanding through MHG, with a number of new developments in the region. The site at Holloway Road, Heybridge, Essex, UK was identified by BRE as being suitable for the project and consists of a mixture of two, three, and four bedroom homes, totalling 37 for rent. These consisted of the following types of houses.

**Water efficient houses**

There are 12 houses with water efficient appliances installed, and with each water-using appliance metered. These consist of 4 two bedroom houses, 7 three bedroom houses and a four bedroom house.

**Control houses**

There are 12 houses with standard water-using appliances installed, and with each water-using appliance metered. These consist of 4 two bedroom houses, 7 three bedroom houses and a four bedroom house.

**Greywater houses**

There are 3 houses with a greywater system and standard water-using appliances installed. The WCs and the greywater top-up water supply are metered. They consist of 2 three bedroom houses and a four bedroom house.

**Outline houses**

There are 10 houses with standard water-using appliances installed, and with the incoming water metered by the revenue meter only. These consist of 3 two bedroom houses, and 7 three bedroom houses.

Construction work was scheduled to start in February 1997 and completion by November 1997. However, the timetable was revised and construction started in January of 1998 and 8 houses were occupied by tenants on 20 July 1998.

### 2.3 Selection and installation of water efficiency measures

#### 2.3.1 Selection

The construction contractor and sub-contractor were responsible for the selection of products to meet BRE's water efficiency performance specified. Also, the water efficient measures specified included MHG's requirements, including installing:

i) WC cisterns that are close-coupled, and
ii) baths that are made of enamelled steel with a non-slip base.

#### 2.3.2 Installation

Some difficulties were experienced during the installation of the water butts. Although the installation of water butts appears to be a simple operation they could be installed only at one house which had suitable design of rainwater system. In the remaining installations remedial action has been established to alleviate the problem, for example, by using rainwater diverters.

Since showers were specified as water efficiency measures (compared with the provision of a bath) partially tiled walls above the baths were required.

No other installation problems were identified.

#### 2.3.3 Commissioning

Some WCs had been incorrectly set at a higher volume than required. Care is required when setting water levels for appliances.

## 2.4 Installation and commissioning of water meters

### 2.4.1 Installation

There are four different levels of monitoring used in the project, defined as:

**Water efficient houses**
Houses with water efficient appliances installed, and with each water-using appliance metered.
**Control houses**
Houses with standard water-using appliances installed, and with each appliance metered.
**Greywater houses**
Houses with a greywater system installed, and with the WCs and the greywater top-up water supply metered.
**Outline houses**
Houses with standard water-using appliances installed, and with the incoming water metered by the revenue meter only.
Meters were installed by BRE in all test, control, and greywater houses. Meters were installed to allow the use of all appliances to be recorded.

Pulsed outputs from meters are relayed to readouts by a concealed cable to an external and lockable meter box at the front of each property. This removed the need to enter properties to record meter readings.

## 2.5 Tenant information and feedback

Tenant feedback is an important aspect of the project and it is essential that tenants are informed fully of the research project that is being undertaken. BRE has produced information sheets on the project for inclusion in the tenant information packs provided by Plume to all its tenants. All houses received general information on the project together with information on water saving in the home and garden provided by Essex & Suffolk Water. An additional information sheet was provided for the tenants in the test and greywater houses giving details of the water efficiency measures installed and their correct operation. In addition, information was provided on the efficient use of water for gardening.

Tenant information has three functions, to:

i) explain the background to the purpose of the project and alleviate any concerns over the monitoring,
ii) explain the presence of different fittings in the different houses, and
iii) help to ensure the co-operation of tenants throughout the project.

## 2.6 Public relations

BRE has co-ordinated a public relations programme for the project through its press office, resulting in coverage in national and regional newspapers, as well as, trade and professional papers and journals.

## 2.7 Flow signature monitoring

Flow signature monitoring has been trialed during the project to determine the appropriateness for determining water usage patterns for typical UK cistern fed systems. The system has been used successfully in the USA, where systems are fed from the water supply main.

The flow signature flow monitoring system has three main components:

i) water meter (turbine type),
ii) datalogger with an interface for monitoring the output from the water meter; the datalogger converts the pulse output from the water meter into volumetric water use every 10 second, and
iii) Trace Wizard software, which is a software package, to analyse the flow data recorded by the datalogger and assign a water-using event to a flow signature characteristic determined by flowrate and duration.

The Trace Wizard has a library of water-using appliances and flow characteristics. By comparing the library of characteristics with the observed flow patterns, the software can assign water-using events. However, the system has been developed with mains water supplied appliances and is not entirely suitable for use in the UK, but with suitable empirical evidence the system may be developed on typical UK water systems, ie low pressure cistern fed systems.

### 2.7.1 Limitations

#### 2.7.1.1 Flow attenuation

The flow signature monitoring system works most effectively when there is no time delay between drawn water and the water meters registering the flow, ie systems supplied directly from the water main. Typical UK systems are cistern fed and, therefore, the characteristics of the water using appliances are not directly registered by the flow meter.

#### 2.7.1.2 Simultaneous usage

Simultaneous usage occurs when water flows from more than one appliances, eg whilst running a bath, a WC is flushed. The software must resolve and identify these events; the flow meter registers an increased flow for the simultaneous flow of these events. Identification is possible in the case of mains water supply fed systems. However, with typical UK systems all appliances except the kitchen tap and the kitchen appliances are fed from a cold water storage cistern, often in the roof space.

The use of the signature flow monitoring system in this project has been partially successful. The system can resolve and identify, most of the individual water using appliances, ie kitchen taps, baths, showers, washing machines, basin taps and WCs. At present, simultaneous usage of appliances cannot be resolved for UK water systems.

Modification to the system, such as, the use of larger capacity float operated valves and cisterns with larger down services would reduce flow attenuation due to the cold water storage cistern and make the successful use of the Trace Wizard software possible.

## 2.8 GREYWATER QUALITY MONITORING

The three greywater houses (house numbers 14, 16, and 18) in the project are being monitored for water quality issues.

### 2.8.1 Microbiological tests

Standard water microbiology tests have been carried out in accordance with Report 71[(2)], and analytical quality control was carried out in accordance with the requirements of the Water Supply (Water Quality) Regulations[(3)]. The following parameters have been determined:

- temperature (on-site determination),
- free chlorine (on-site determination),
- total chlorine (on-site determination),
- combined chlorine (calculated),
- pH,
- turbidity,
- biological oxygen demand (BOD), and
- chemical oxygen demand (COD).
- coliforms,
- total E.coli,
- Total Viable Count (TVC) at 37°C,
- Total Viable Count (TVC) at 22°C,
- Salmonella (not speciated),
- Faecal streptococci,
- Specific bacteriophages,
- Clostridium,
- Aeromonas species, and
- Legionella species.

### 2.8.2 Procedures for greywater sampling

The water samples have been taken at three places in the greywater system:

- collection tank (installed below ground),
- header cistern in the roof space, and
- WC cistern,

and, also, from the cold water cistern and the kitchen tap, ie directly from the water main's drinking water supply. Water samples have been taken from the same position each time using 'aseptic' procedures.

Due to specific site requirements, the following procedure has been carried out:

At the three greywater sites, the volumes of water and the order in which sample bottles will be filled at each sampling location are:

a) a 500 ml sterile bacteriology bottle with thiosulphate for Coliforms, E.coli, TVC and Aeromonas species,
b) two 500 ml sterile bacteriology bottle with thiosulphate for Salmonella species,
c) a 500 ml sterile bacteriology bottle with thiosulphate for Legionella species, and
d) 1 litre bottle and a 500 ml bottle for pH, chlorine, turbidity, BOD and COD.

Note: a sterile dip tube, to reduce the potential of disturbing surface films, has been used, as appropriate.

# 3 LESSONS LEARNT TO DATE

### 3.1 Identification of products

i) Water-usage information is not provided always by manufacturers in general product information. This makes the selection of suitable products difficult.

ii) A list of products conforming to a water efficiency specification could be produced without prejudice for distribution to specifiers.

iii) The construction contractor and plumbing sub-contractor had difficulty in sourcing and obtaining products to meet the agreed water efficient specification. Guidance on the selection and installation of water efficient measures is required to inform specifiers.

### 3.2 Installation of water butts

Initially, a number of water butts could not be installed due to the lack of, or appropriate location of, rainwater pipes. This problem could be eliminated in other new housing developments by appropriate design of the rainwater system, ie surface water drain positioning.

## 4 DISCUSSIONS AND CONCLUSIONS

A BRE water efficient product specification has been developed, following discussions with Moat Housing Group, and Essex & Suffolk Water for current best practice in the UK without requiring a significant change in lifestyle for tenants. However, initially, there were some difficulties in identifying suitable products by the plumbing contractor. Assistance in the selection of products could be by the production of a directory of products, which would contain the water-usage volumes of products, which could be distributed without prejudice to specifiers and suppliers.

In order that the occupants have an understanding of the objectives of the project, general information was presented to each tenant and specific information was given to the tenants in the test and greywater houses, identifying the water efficient measures which were installed.

The project is partially complete and results will be discussed at the CIB W62 2000 Symposium in Brazil.

# 5 REFERENCES


1 Shouler M, Griggs J, and Hall J. Water conservation related to the built environment. Presented at the Chartered Institution of Water and Environmental Management. London, 1996.

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3 Department of the Environment, Transport and the Regions. The Water Supply (Water Quality) Regulations 1989. London, 1989.

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5 Department of the Environment, Transport and the Regions. The Water Supply (Water Fittings) Regulations 1999. London, 1999.

# STEADY FLOW (BASE FLOW) STABILITY MANAGEMENT OF RAW WATER IN THE ENVIRONMENTAL SETTLEMENTS

**Sarbidi**

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## ABSTRACT

*Pressure to conservation region through development need of housing area in the last two decades tends to increase continuously. Beside that, the use of ground water in the working region on urban area is very difficult to be controlled by government, so that, the condition can disturb a natural water balance in the human settlements. The problem has caused the supply to steady flow of stream flow in dry season decrease and stream flow frequencies of flood season tend to increase significantly.*
*Increasing of run-off in urban and rural area, industrial region, real estate, resort and other region can cause flood disturbance to production activity, social conflict and other negative impact.*

*Phenomenal change of water balance is the rainfall directly flow fast to the plain, then uselessly flow to ocean. In that case, water can not be used by human and steady flow of the river decrease at dry season. Therefore the function of hydrological space (run-off coefficient) should be controlled. The controlling is really useful to: (a) keep sustainable of stability of steady flow (by rehabilitating and raising ecological quality of hydrological space), (b) keep natural water balance in hydrological space (through rehabilitation water balance technology).*
***Key word:*** *sustainable of steady flow, landscape controlling, conservation region, working region, conservation technology in housing area.*

## INTRODUCTION

The regional government policy develops the industrial estate, housing area, tourism and soon in the human settlements has already caused the decreasing of hydrological space, which has disturbed natural water balance. For example, it can see in Bandung, Bogor, and plateau area of Puncak and Cianjur West Java.

In the other hand, raw water exploitation increase continuously and tends to obey the determinations concerning the technical guidance of hydrological space quality of that area, in order to sustainable of raw water (base flow in the space and time) will disturb, that mean, will be flood in rain season and less water in dry season.

## BASIC CONCEPT OF BASE FLOW (STEADY FLOW)

Base flow stability is water, which is fallen by rainwater plus ground water. Existence and sustaining of steady flow stability in the river body and watershed (hydrological space) can be explained with the following hydrology environmental model in Figure 1.

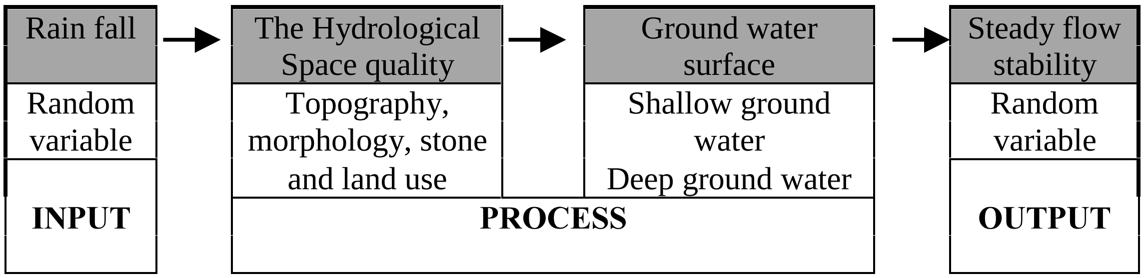


**Figure 1.**
The diagram of Existence and sustaining of steady flow stability

Steady flow stability depends on rainfall variable, hydrological space quality. They very affect to the natural water balance (infiltration and surface water run-off) in the water shed area. Infiltration rate in the ground at raining time will affect to infiltrate the ground water (ground water level), and then, they are going to warranty to steady flow stability, especially in the dry season.

## RESEARCH RESULT

### 1. General Equation and Determination of Coefficient Run-off

To know the relation between rainfall, ground water, land use, and hydrological space quality, both of naturally and actually conditions of the natural water balance in a region can be expressed with the mathematics regression linear and non-linear. The mathematics linear, which describes between rainfall and water debit is expressed on Equation 1.

$$Q = C\,(PA) + b - E_t\,(A) \quad (1)$$

Legend:

Q = Minimum rate of river
Calculated by the distribution method of Gumbel Type III or Pearson Type III.
C = Run-off coefficient (naturally and actually conditions)
To determine the C natural and C actual has to make a scoring on the affect factors, namely: rain fall, geology (kinds of stone & soil), land use and slope of overland (see Table 1.). Then can make a statistic mathematics equation.
P = Rain intensity, can use the method of arithmetic, Mononbe or Thiessen.
A = Catchment area, can be determined with the overlapping map manually or GIS.
$E_t$ = Evapotranspiration, can be determined with the Penman Formulae

**Table 1.**
Scoring of geology, slope overland, rainfall based on run-off coefficient

| Code | Geology ( Kinds of stone & soil ) | Score | Slope of Overland ( % ) | Score | Rainfall ( mm/year ) | Score | Kinds of Land use | Score |
|---|---|---|---|---|---|---|---|---|
| 1. | Cibeureum Formation | 0,03 | 0 - 3 | 0,02 | 1,000 - 1,500 | 0,02 | Forest | 0,02 |
| 2. | The result of young mountain fire | 0,06 | 3 - 8 | 0,05 | 1,501 - 2,000 | 0,05 | Wood and garden | 0,05 |
| 3. | Cikidang Formation | 0,37 | 8 - 15 | 0,20 | 2,001 - 2,500 | 0,20 | Dry land | 0,20 |
| 4. | Cikapundung Formation | 0,49 | 15 - 25 | 0,30 | 2,501 - 3,000 | 0,30 | Agriculture | 0,30 |
| 5. | Kosambi Formation | 0,58 | 25 - 40 | 0,50 | 3,001 - 3,500 | 0,50 | Rice land | 0,50 |
| 6. | The result of old mountain fire and tertiary sediment | 0,80 | > 40 | 0,80 | 3,501 - 4,000 | 0,80 | Developed region | 0,80 |

Source: Data analysis of research result in Bandung region (field research, 1998)

The result of coefficient run-off C based on naturally condition is value of regression coefficient each other variable respectively: geology, slope overland, rainfall are the same, namely 0.333. Equation regression for coefficient run-off C based on naturally condition.

$$Y = 0.333 X_1 + 0.333 X_2 + 0.333 X_3 - 1.249 * 10^{-5} \quad \text{..........................................} \quad (2)$$

Legend: Y = C indicator ( land use range )
$X_1$ = Geology condition range
$X_2$ = Slope overland range
$X_3$ = Rainfall range

By inserting the scoring to the overlaying map yield (geology, land use, slope overland and rainfall map) can be known the value of C region and its square ( see Table 2. ).

**Table 2.**
Region category based on naturally C score in Bandung

| Region with actual C score | Square ( $m^2$ ) | Percentage ( % ) | Minimum C actual | Maximum C actual |
|---|---|---|---|---|
| Little | 58,058,537.28 | 20.58 | 0.0023 | 0.1333 |
| More little | 769,627,676.91 | 34.58 | 0.1334 | 0.2667 |
| Middle | 662,128,599.72 | 29.75 | 0.2668 | 0.4001 |
| Big | 251,692,616.30 | 11.31 | 0.4002 | 0.5335 |
| Bigger | 83,958,404.00 | 3.77 | 0.5336 | 0.6669 |
| Biggest | --- | --- | 0.6670 | 0.8000 |
| Total | 2,225,465,834.21 | 100.00 | 0.1957 | 0.3242 |

Source: Data analysis of research result in Bandung region ( field research, 1998 ).

Next result is coefficient run-off C based on actually condition is valuing of regression coefficient each other variable respectively: geology, slope overland, rainfall and land use. Equation 3 is regression for coefficient run-off C based on actually condition.

$$Y = 0.4192\ X_1 + 0.4192\ X_2 + 0.3789\ X_3 + 0.3506\ X_4 + 0.0215 \quad \text{..........................} \quad (3)$$

Legend: Y = C indicator ( land use range )
$X_1$ = Geology condition range
$X_2$ = Slope overland range
$X_3$ = Rainfall range
$X_4$ = Land use

By inserting the scoring to the overlaying map yield (geology, land use, slope overland and rainfall map) can be known the value of C region and its square ( see Table 3. ).

**Table 3.**
Region category based on naturally C score in Bandung

| Region with actual C score | Square ( $m^2$ ) | Percentage ( % ) | Minimum C actual | Maximum C actual |
|---|---|---|---|---|
| Little | 194,979,118.71 | 8.76 | 0.0023 | 0.1333 |
| More little | 939,911,239.86 | 42.23 | 0.1334 | 0.2667 |
| Middle | 825,119,030.94 | 37.08 | 0.2668 | 0.4001 |
| Big | 252,234,924.40 | 11.33 | 0.4002 | 0.5335 |
| Bigger | 13,221,520.30 | | 0.5336 | 0.6669 |
| Biggest | --- | --- | 0.6670 | 0.8000 |
| Total | 2,225,465,834.21 | 100.00 | 0.2040 | 0.3371 |

Source: Data analysis of research result in Bandung region ( field research, 1998 ).

By comparing naturally condition Table 2. and actually condition Table 3. can be got the hydrological condition of the region.
The following category of hydrological condition is completely:

- Good, if the actual C value < the natural C value
- Normal, if the actual C value = the natural C value
- Critical start, if the actual C value > the natural C value
- Little bit Critical, if the actual C value > 2 x the natural C value
- Critical, if the actual C value > 3 x the natural C value
- Very critical, if the actual C value > 4 x natural C value

Table 4. has seen the hydrological condition in Bandung area.

**Table 4.**
The category of Bandung Hydrological Condition

| Region with hydrological category | Square ( $m^2$ ) | Percentage ( % ) |
|---|---|---|
| Good | 313,993,513.04 | 14.11 |
| Normal | 1,384,101,614.74 | 62.19 |
| Critical start | 525,804,084.93 | 23.63 |
| Little bit Critical | 1,566,621.50 | 0.07 |
| T o t a l | 2,225,465,834.21 | 100.00 |

Source: Data analysis of research result in Bandung region ( field research, 1998 ).

## 2. Technology to Control the Steady Flow Stability in the Hydrological Space

The technically controls the steady flow stability needed to help the infiltration of the overland flow into the land as a shallow ground water and deep ground water. In other to naturally condition can be got, and if it's impossible can be increase properly. More and more critical of land condition will be higher the priority of using the technology for controlling the based flow stability.

The Technical alternatives that can be used to manage the steady flow are:

1. Good category region (if the actual C value < the natural C value) uses the vegetative method, mechanical method and law enforcement.
2. Normal category region (if the actual C value = the natural C value) uses the technical method (rainwater infiltration vertical fit, rainwater infiltration horizontal fit, porous drainage) and law enforcement.
3. Developed region relatively (critical start little bit critical) uses the human resettlement/layout, vegetative method, combination and law enforcement.
4. Has developed region (critical until very critical) uses (rainwater infiltration vertical fit, rainwater infiltration horizontal fit, porous drainage) and law enforcement.

To support the method of steady flow stability is still needed the following conditions:

1. To make law enforcement and good policy of the water resources (using the technical standard or standard procedure to develop the conservation area and working region).
2. To build the institution which works good quality of human resources for monitoring, supervision and implementation of law enforcement continuously).
3. To establish and involve the community participation in other to ready does surrounding land conservation, so that the land can be to infiltrate the overland flow into the ground.
4. To increase recharge/infiltrate rainwater into the ground through the rainwater infiltration vertical or fit, porous drainage, and vegetative technically).

**3. Computer Software**

Making the steady flow stability computer software used Visual Basic and Access. The following is step by step the software program:

1. To definite some table, namely: scoring, data sample, and controlling method. To translate some formulae, namely: statistic mathematics for natural coefficient C and actual coefficient C.
2. To make some form, namely: list data form, editing data form, calculation coefficient form, and son.
3. To determine value of $X_1$, $X_2$, $X_3$, and $X_4$ in the scoring table. The value of $X_1$, until $X_4$ are scoring value between o until 1. For instant:

   - Cibeureum formation, have score 0,03.
   - Slope overland between ( 0 - 3 ) % have score 0.02.]
   - Rain intensity between 1,000 - 1,500 mm/year have score 0.02.
   - And land use ( forest ) have score 0.02, etc.

Step by step in using the program, namely:

1. Highlight the name of the program *" ALIRAN MANTAP "*.

2. Initial performance will appearance on the monitor computer. It gives name with *" PILIHAN PENGERJAAN "*. Please choosing the order number is needed, namely:
   - *Mengisi data kawasan* ( filling the region data )
   - *Mengedit record data kawasan* ( editing the region record data )
   - *Menghitung koefisien limpasan* ( calculating the coefficient run-off )
   - *Kesimpulan hasil perhitungan* (conclusion of calculation result )
   - *Menghitung record data kawasan* ( calculating the region record data )
   - *Selesai* ( stop )

3. *INPUT DATA KAWASAN* ( region data input ), namely:
   - *Nama kawasan* ( name of region )
   - *Jenis tanah batuan* ( kinds of soil and stone )
   - *Kemiringan lahan* ( slope overland )
   - *Curah hujan per tahun* ( rain intensity per year )
   - *Tata guna lahan* ( land use )
   - *Keterangan* ( legend )

4. *PERHITUNGAN KOEFISIEN LIMPASAN* ( calculation of run-off coefficient )
   - *Nama kawasan* ( name of region )
   - *C alami dan aktual* ( C natural and C actual )
   - *Metoda pengendalian* ( controlling method )
   - *Kesimpulan* ( conclusion )
   - *Keterangan* ( legend )
   - *Kembali* ( back )
   - *Cetak* ( print )

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# Rainwater Use System in Building Design

## ---- A Case Study of Calculation and Efficiency Assessment System

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## Abstract

Water shortage had become one of the most serious issues, which was concerned by many countries of the world. It is estimated that more than two billions people have not enough clean water to drink or use in this century. Even though, Taiwan is the most rich rainy place which located in monsoon area of the earth, the characteristic is hot, rainy and high humidity, water shortage also shake this island within these years. Just like many other countries all over the world, we have to face the situation which to build a new and huge dam is impossible or very difficult for Taiwan environment at present. Then, to develop many little dam system into buildings or urban is an acceptable idea for government and experts. That means we could formally lead the rainwater use system into building design and housing plan. In this paper, we concern about the situation of architect and designer with less engineering background and try to offer a design concept and easy utility to fit to building design. We also arranged the database of precipitation from 1985 to 1994 in Taiwan. Furthermore, we would propose a computer program to help architect or designers to simulate the efficiency of rainwater use and to help the decision making.

## Keywords

Rainwater use, Building design, Precipitation, Efficiency, Simulation, Assessment.

## 1 .Introduction

Fresh water shortage and pollution is becoming one of the most critical problems all over the world at present. There is a comprehensive assessment of the freshwater resources of the world from United National Organization in 1997, which pointed out the fresh water demand grow up by twice speed of population growth. It is very possible that two third of the population in the world have the problem of water shortage, and might also cause the crisis of public hygiene and staple food supply in this century. In order to supply good quality and sufficient fresh water for all people, the Agenda 21 in the global summit meeting hold in 1992 had a guiding principle in the issues of water resource[1]. Many organization and conference concerning water resource policy and issues have a common consensus and warn that water shortage might cause the war in this century. Actually, there are also many discords about water supply in this period in Taiwan. Because of the environmental problems, to build new dam is no longer the acceptable solution for water shortage.

In the previous study, we got the conclusion that water savings are not only for water conservation but also for reducing the energy consumption [6]. Taiwan is located in the Asia monsoon area and has rich rainy water. The average amount of yearly precipitation is about 2,500 mm. But water shortage is still becoming the most critical problem in a dry season during the past few years. Such an issue is mainly from the unevenly distribution of torrential rain, steep hillside, rivers of short duration. On the other hand, a great demand of domestic water use in municipal area and the difficulty of building new reservoirs are also the critical reasons. The government departments are making efforts to spread the concept of water-wise to the public. The achievements of water-efficiency are excellent in industrial and commercial enterprises. However, the efforts achieved from the public are extremely poor. Following the development of global environmental common consensus and green building technology, we try to offer a concept of miniature and dispersal dam in municipal area or buildings. That is rainwater use system in building design. The issues of this paper included the method of design system, database of rain water and quantification assessment model. All of these topics are prepared for a building designer to follow and those results can also evoke a concept of water-wise to the public.

## 2 . Rainwater And Local Situation

According to the records of meteorological precipitation, there are average 2369mm per year for past ten years (1985~1994) in Taiwan. The precipitation of these ten years in Taiwan is shown in figure 1. Although it is about 2.5 times of the world average (about 970 mm/year), but there are only 4300 $m^3$ for distributing to one person per year. The quantity is the one sixth of the world average which is about 27000 $m^3$/year/perason. Figure 2 shows this situation and that of Taiwan is similar to Japan. On the other hand, the tap water consumption for daily life of people is largely increasing for these years in Taiwan. Figure 3 shows the increasing tendency in Taipei City from 1985 to 1994. Concerning the tap water consumption, table 1 shows the distribution quantity and proportion of daily purpose [5]. We can see the water consumption proportion for toilet, cleaning and others is totally above 24%. These purposes of water consumption can consider to be replaced by gray water or rainwater. If we consider the building function for school, hospital or other public buildings, the substitution proportion would be higher than the housing.

The meteorological precipitation usually is not evenly distribution for everyday and any place which was mentioned above. In order to consider the rainwater utilization, we have to grasp the database of the meteorological precipitation. Figure 4 shows the precipitation from 1985 to 1994 in 12 measurement points which dispersal in Taiwan. This diagram indicates that the precipitation with large variety from the maximum of above 5000 mm/year to the minimum of below 1000 mm/year. We focus on the potential rainwater utilization in Taipei City. There is about 271.8 kilometer square and about 2641000 population. The precipitation is about 2400mm/year, then the total rainwater for one year is about 6.52 hundred million ton. On the other hand, the tap water supply is about 3.85 hundred million ton for one year from outside of this city. That is to say theoretically the demand of water consumption can be covered by rainwater in the area of this city. Figure 5 shows the potential diagram of rainwater utilization for Taipei City. Actually, rainwater always becomes the burden of the city drainage or treatment device. On other words, there are high potential of rainwater utilization in Taipei City or many other place of Taiwan.

## 3 .Concept Of Rain Water Use System In Building

There are many concepts of water-wise for building offered by experts and some organizations. Those ideas could roughly separate into three subjects: the first is the consciousness or habit of water user, the second is the promotion of water supply equipment, and the third is the gray water system in building. Gray water system is mainly a concept of water reuse system, and rainwater is usually treated as gray water. A rainwater system would include collecting part, piping, treatment and storage device. Rainwater has an acceptable quality in many ways of water usage except for drinking. There are about 24% of the water usage in our daily livelihood consumed on the water closet or other low qualification of water demand. We usually satisfy all demand of daily water usage by potable water. If we replace the water used in water closet or other low quality demand of water use by rainwater, then much water could be saved. Not only the benefit of saving water, it could also reduce the damage of flooding[5]. That is the consideration or concept of miniature and dispersal dam in municipal area or buildings.

As the process or method of rainwater use system design, first of all, the designer have to evaluate the quantity of rain water and usage demand. Then, the area of rainwater collection device and volume of storage tank have been decided. Actuarially, The calculation of rainwater quantity could be solved by a simple equation with precipitation (mm) and area of collection device. But the precipitation is not equally in any day and any location. Especially, there is concentrated rainwater in some season and some locations. Therefore, the critical point of calculation is the estimation and assessment of meteorological precipitation. Meteorological precipitation records generally include yearly, monthly, daily and hourly precipitation. Yearly and monthly precipitation is suit for roughly estimation and assessment in very initial stage. But for its large inaccuracy, it can not be the accordance of decision making for the area of rainwater collection device and volume of storage tank. Daily precipitation is records for day by day, and usually adopted as the accordance of rainwater use assessment in the past documents or practical cases. The hourly precipitation could theoretically be more accurate accordance for assessment. But according to the increasing of parameters and great deal of calculation data, that would largely raise complex process and the calculation time. It is inefficient for beneficial result. Therefore, the daily precipitation is adopted as the calculation accordance and we would work up an assessment system for rainwater use system in building.

## 4 . Calculation Method And Procedure Of Rainwater Use System

First of all, we need to know the quantity of rainwater from collection and for usage. According to the basic balance concept of input and output, it can be concluded as four parameters to calculate the rainwater use system. Those are rainwater from collection device and replenish from tap water system in the side for input, and the others are consumption quantity for user and overflow from storage device. We can indicate this concept as the diagram shown in figure 6[10]. According to the daily precipitation database, at first, we must conform the location of design object (for example: in Taipei) and the meteorological precipitation data for simulation object or assessment as the calculation process of utilization quantity of rainwater. Then, we have to decide the area of collection device, object character of water utilization as the condition for simulation and assessment. We show the daily precipitation format of Taipei City as an example for calculation in table 1. The calculation process is as the following:

(1) The collection quantity (CRW) from daily precipitation (Rd) and collection area(CA).

$$CRW(m^3)=CA(m^2)\times Rd(mm/day)\times \gamma\times 10^{-3}$$

($\gamma$ is the flow out coefficient, according to the character of collection location, it is usually adopted 0.85-0.95 as general roof.)

(2) The overflow quantity (OFV) from collection quantity (CRW), volumes of storage tank (SV) and remains quantity in storage tanks (RSV).

When CRW+RSV>SV($m^3$), then OFV=CRW+RSV-SV

When CRW+RSV<SV($m^3$), then OFV=0

(3) The first remains quantity in storage tank (RSV') after above calculation.

When CRW+RSV>SV, then RSV'=SV

When CRW+RSV<SV, then RSV'=CRW+RSV

(4) The quantity replenish water (CW) from the remains quantity in storage tank (RSV') and consumption quantity for user (UW).

When RSV'- UW<0, then CW= -(RSV'-UW)

When RSV'-UW>0, then CW=0

(5) The second remains quantity in storage tank (RSV") after above calculation.

When RSV'-UW<0, then RSV"=0

When RSV'-UW>0, then RSV"=RSV'-UW

(6) We adopt the second remains quantity in storage tank (RSV") as the initial data of RSV for next day's data to add up all parameters and yearly utilization by looping calculation.

(7) According to the above add-up calculation, we can get the yearly rainwater utilization quantity (YRU), yearly rainwater collection quantity (YRC) and yearly consumption quantity (YTU).

$YRU = \Sigma (UW-CW)$ ， $YRC = \Sigma CRW$ ， $YTU = \Sigma UW$

(8) The rainwater utilization rate (PRU%) and substitution rate of tap water (PCW%) can be calculated as following:

$PRU(\%) = YRU \div YRC \times 100$,  $PCW(\%) = YRU \div YTC \times 100$

The above calculation procedure of rainwater assessment had been written into the computer program, and we can get the simulation results very rapidly. The program flowchart is shown in the figure 7.

## 5 . Case Study And Analysis

According to the above procedure, we take a primary school building which adopt the rainwater use system as an example to perform the simulation procedure and verify assessment results. This building located in Taipei City with building area is 1260 ($m^2$) and total floor area 6960($m^2$), and it is a synthesis teaching building. We estimate 80% of the building area could be roof, then the rainwater collection area is 1008 ($m^2$). The rainwater use as gray water for water closet, we set 20($m^2$) per day as utilization condition and the flow out coefficient ($\gamma$) is 0.9. The database of meteorological precipitation in 1992 Taipei was adopted. Storage tank for rainwater is an initial condition for the start before the simulation procedure. We performed four conditions of tank volume to simulate the utilization of rainwater, those are $15m^3$ ‘ $25m^3$ ‘ $50m^3$ ‘ $100m^3$. Figure 8-11 show the results of simulation.

These diagrams indicate that the more large volume of storage tank the less volume of overflow and the more utilization quantity of rainwater. When the storage tank is equal to $50m^3$, the quantity of rainwater collection is very close to the utilization quantity of rainwater. That means the adequate volume of storage tank is almost reached in this condition. When the volume of storage tank is 100 $m^3$, we can see that the utilization rate is almost 100% and overflow quantity is near to 0. Although it is good for the view of utilization, but it might take large space and be no good for planing of space. Therefore, we must to consider the balance of all condition for design concept. The building of this study case is six floors height, roof area is comparable small to total floor area. The consumption in water closet is 7280 $m^3$ per year, but the maximum quantity of rainwater collection is 2136 $m^3$ per year. That need quite a few replenish from tap water system. This should be said that high-rise building would be less efficiency in the rainwater use system. Contrary, the low height building (e.g. below three floors) can be good efficiency of rainwater utilization and reduce the quantity of replenish from tap water system.

Concerning the assessment of efficiency of rainwater storage tank, we can make decision according to the utilization rate of rainwater and substitution rate of tap water. Owing to the different yearly precipitation and rainfall distribution, the index would be different. In order to analyze the difference of rainwater utilization and efficiency assessment, figure 12 and figure 13 show the results of the same calculation procedure as above mention. The simulation period is 10 years from 1985 to 1994 and with four volumes of storage tank. As the results of this case simulation, when the volume of rainwater tank is 50 $m^3$, the utilization rate of rainwater can reach above 80% and about

25% substitution of tap water. By this program and assessment procedure, the volume of rainwater storage can be decided and rainwater use system can be performed in building design.

## 6 . Conclusion

We rise a concept that to develop little dam system into buildings or urban is an acceptable idea for substitution of large dam and that can reduce the impact of environment. According to the balance concept between input and output, we work up a simulation procedure and assessment method for rainwater use system in building. That included a calculation program and a meteorological precipitation database in Taiwan. Concerning the decision of rainwater storage volume, we can evaluate the rainwater utilization rate and substitution rate of tap water to help the decision making of system design. Furthermore, we also find that low height building would have better efficient for rainwater system than high-rise building. This research focuses on the simulation and assessment of rainwater use system in building design. On the other hand, the issues of rainwater quality and device for the water treatment or filter are also important topics for the future study.

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Table 1. Estimation of water consumption for daily life

| purpose / volume | bath | cloth washing | light washing | toilet | kitchen | cleaning | others | total |
|---|---|---|---|---|---|---|---|---|
| Proportion (%) | 20% | 24% | 12% | 16% | 20% | 4% | 4% | 100% |
| Daily average | 50 | 60 | 30 | 40 | 50 | 10 | 10 | 250 |
| Daily maximum | 75 | 80 | 40 | 55 | 70 | 15 | 15 | 350 |

(unit: liter/day.person)

Table 2. Daily precipitation of Taipei in 1992

| Date | Jan. | Feb. | Mar. | Alp. | May. | Jun. | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 34.0 | 0.0 | 0.0 | 1.0 | 20.6 | 0.5 | 0.0 | 0.0 | 1.7 | 0.0 | 0.0 | 0.0 |
| 2 | 3.6 | 0.0 | 5.3 | 35.0 | 4.2 | 0.0 | 8.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 0.0 | 0.0 | 0.0 | 15.5 | 0.0 | 43.5 | 0.0 | 0.0 | 22.0 | 0.0 | 0.0 | 0.0 |
| 4 | 0.2 | 6.2 | 6.2 | 14.2 | 0.0 | 0.0 | 0.4 | 0.0 | 14.0 | 0.0 | 0.0 | 0.0 |
| 5 | 0.5 | 9.0 | 27.9 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 | 16.0 | 1.7 | 0.0 | 0.0 |
| 6 | 2.0 | 28.5 | 11.5 | 1.4 | 0.3 | 0.0 | 0.0 | 0.0 | 18.0 | 0.0 | 0.0 | 0.0 |
| 7 | 1.2 | 17.0 | 33.6 | 0.0 | 0.2 | 31.9 | 17.5 | 0.0 | 5.8 | 5.0 | 0.0 | 0.1 |
| 8 | 8.5 | 0.2 | 5.5 | 0.0 | 7.1 | 81.1 | 12.2 | 9.8 | 0.0 | 0.0 | 5.5 | 0.3 |
| 9 | 0.5 | 10.5 | 12.7 | 8.2 | 28.2 | 5.6 | 0.5 | 5.5 | 0.0 | 0.6 | 2.0 | 0.0 |
| 10 | 0.0 | 26.5 | 39.6 | 3.5 | 0.0 | 1.7 | 0.5 | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 |
| 11 | 1.0 | 57.5 | 21.1 | 72.9 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 12 | 0.0 | 27.0 | 0.0 | 11.6 | 0.0 | 5.0 | 0.0 | 0.0 | 0.0 | 6.4 | 0.0 | 0.1 |
| 13 | 0.2 | 18.7 | 0.0 | 1.7 | 0.0 | 88.7 | 0.0 | 0.0 | 0.0 | 17.3 | 2.7 | 0.0 |
| 14 | 2.2 | 0.5 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 15.5 | 0.0 | 19.0 | 10.4 | 0.5 |
| 15 | 0.0 | 47.8 | 0.0 | 0.0 | 41.5 | 0.0 | 0.0 | 0.7 | 0.1 | 8.4 | 10.8 | 13.8 |
| 16 | 0.0 | 12.5 | 0.0 | 0.0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.0 | 25.7 | 4.2 | 0.4 |
| 17 | 0.0 | 16.0 | 0.3 | 0.0 | 14.1 | 0.1 | 22.0 | 10.0 | 0.1 | 0.0 | 4.9 | 0.0 |
| 18 | 0.0 | 10.2 | 0.0 | 0.0 | 3.6 | 3.8 | 27.5 | 2.7 | 32.2 | 0.0 | 0.0 | 0.0 |
| 19 | 6.5 | 39.5 | 0.0 | 10.7 | 5.4 | 1.0 | 4.5 | 1.3 | 16.3 | 0.0 | 0.2 | 0.0 |
| 20 | 3.0 | 18.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 79.1 | 106.1 | 0.0 | 4.8 | 0.0 |
| 21 | 0.1 | 1.2 | 0.0 | 0.0 | 18.4 | 0.0 | 0.0 | 0.0 | 40.9 | 0.0 | 0.0 | 0.0 |
| 22 | 0.0 | 22.3 | 0.0 | 30.1 | 43.5 | 0.0 | 0.0 | 13.1 | 50.5 | 0.0 | 0.0 | 0.0 |
| 23 | 0.0 | 16.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 | 0.8 | 5.0 | 0.0 | 0.0 | 0.0 |
| 24 | 12.5 | 0.1 | 0.4 | 8.5 | 0.0 | 6.7 | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 25 | 2.6 | 0.0 | 0.4 | 0.3 | 2.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.0 |
| 26 | 0.0 | 0.0 | 0.0 | 0.3 | 4.4 | 0.0 | 21.5 | 9.1 | 0.0 | 0.4 | 0.7 | 0.0 |
| 27 | 0.0 | 0.0 | 0.0 | 2.5 | 0.0 | 4.4 | 0.0 | 27.1 | 0.0 | 0.0 | 4.8 | 0.0 |
| 28 | 0.0 | 0.0 | 4.5 | 0.0 | 0.0 | 7.5 | 0.0 | 34.4 | 0.0 | 0.2 | 1.2 | 18.4 |
| 29 | 0.0 | 0.0 | 6.1 | 0.0 | 0.0 | 0.0 | 0.0 | 47.1 | 0.0 | 0.5 | 12.9 | 4.0 |
| 30 | 0.0 | — | 3.0 | 4.2 | 10.9 | 3.1 | 0.0 | 42.1 | 0.0 | 0.0 | 0.0 | 31.8 |
| 31 | 12.7 | — | 1.6 | — | 16.6 | — | 0.0 | 29.5 | — | 0.0 | — | — |
| Total | 91.3 | 385.8 | 179.7 | 221.6 | 222.2 | 285.0 | 122.6 | 329.0 | 329.2 | 85.2 | 65.9 | 69.4 |

(yearly precipitation 2386.902mm/year)

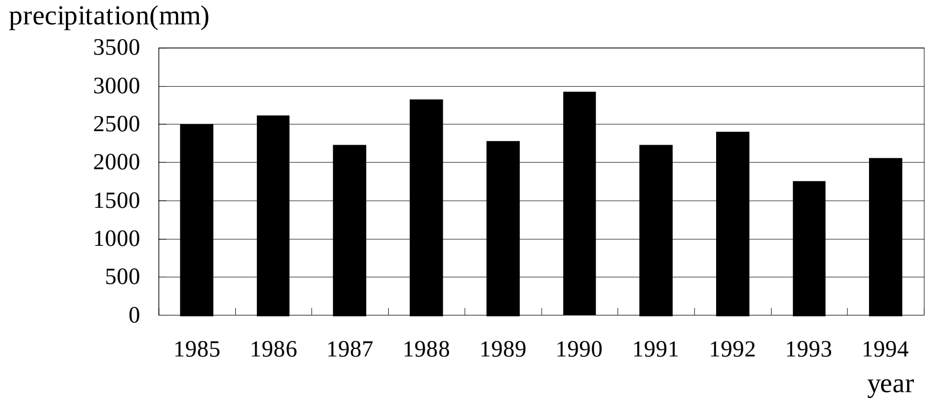


Figure 1. The yearly precipitation of Taiwan from 1985 to 1994

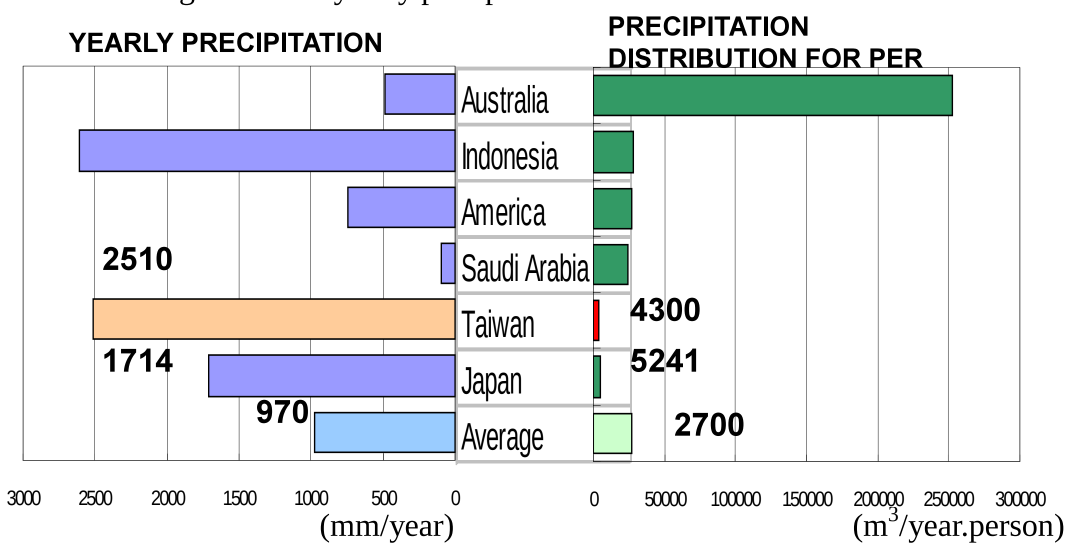


Figure 2. Situation of rainwater resource in the world

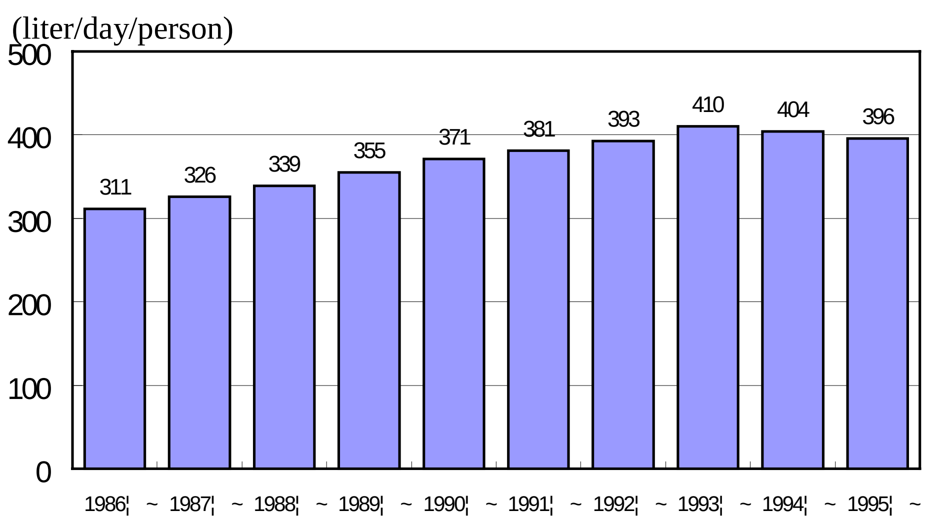


Figure 3. Tap water consumption of Taipei from 1986 to1995

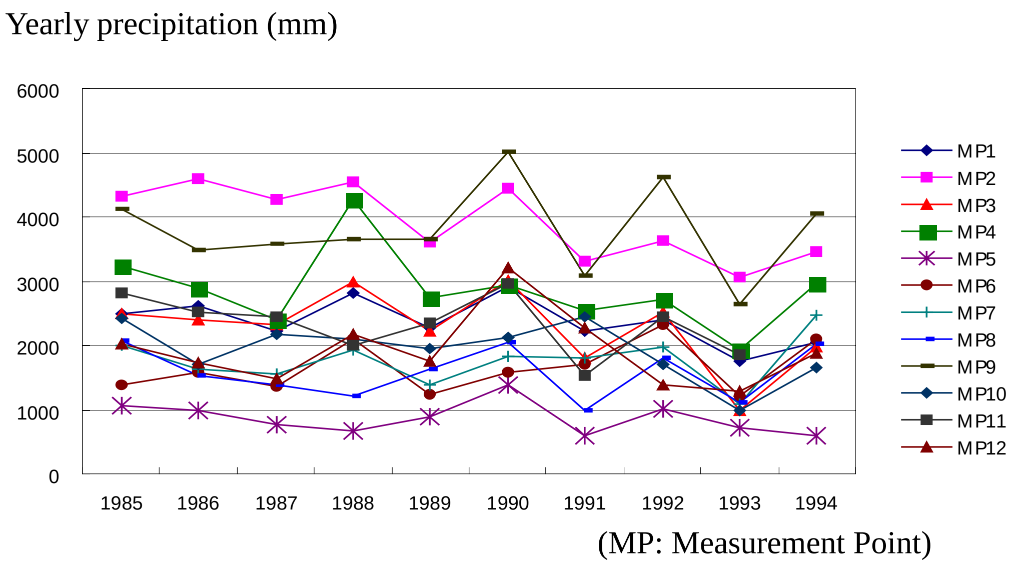


Figure 4. Precipitation from 1985 to 1994 in twelve measurement point in Taiwan

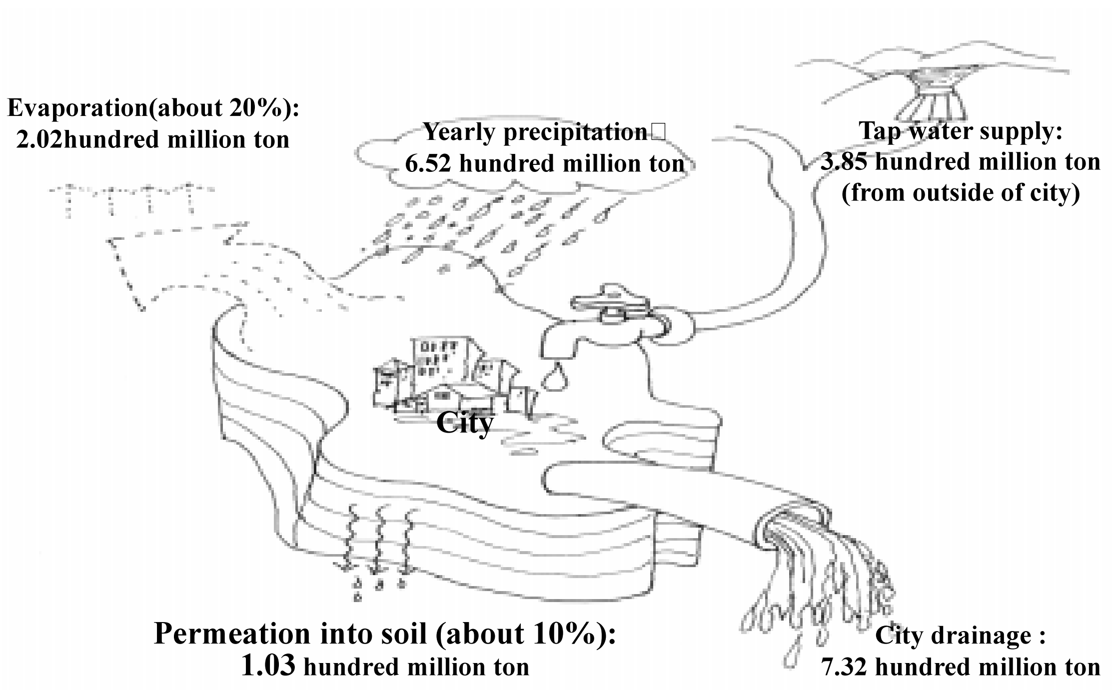


Figure 5. the potential diagram of rainwater utilization for Taipei City

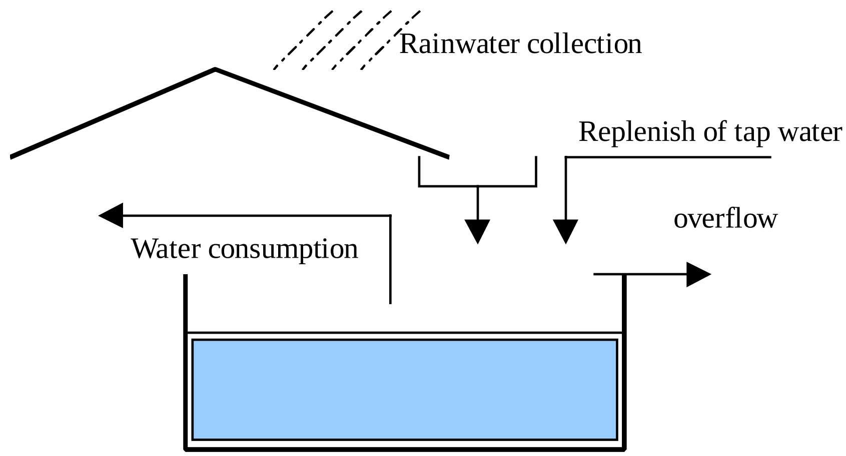


Figure 6.  Balance of input and output for rainwater utilization

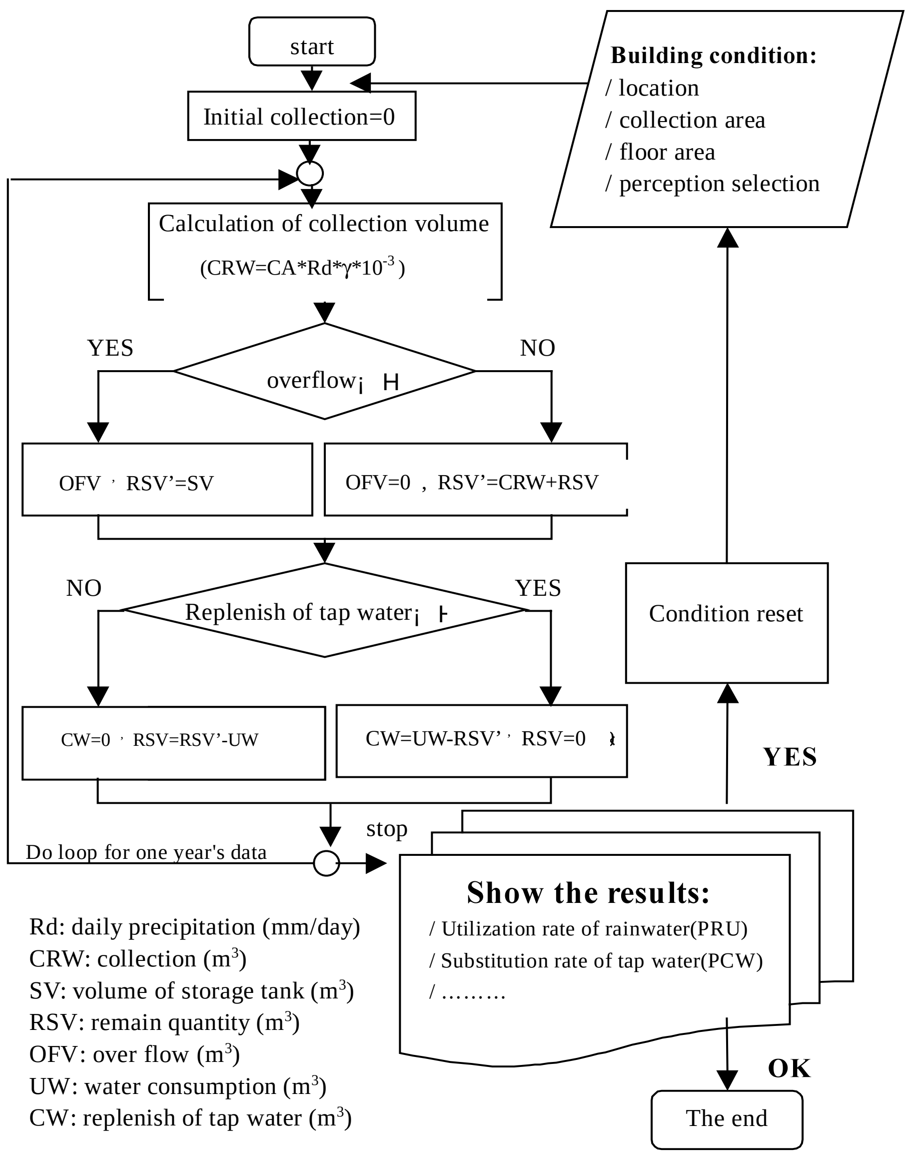


Figure 7.  Flow chart of rainwater utilization simulation

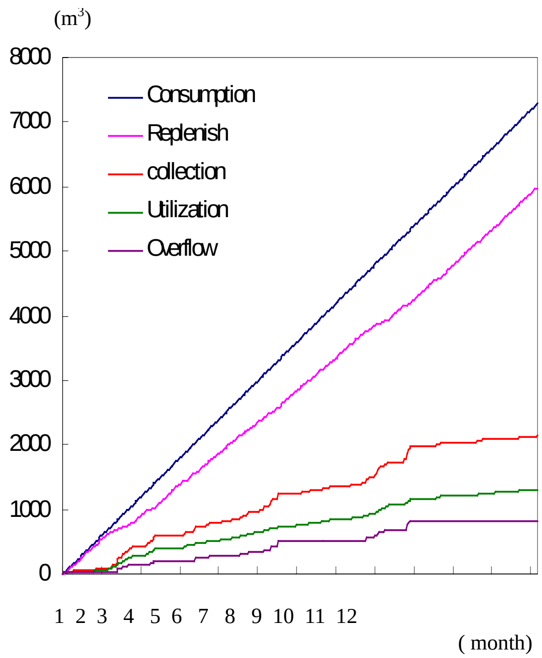


Figure8. Simulation of rainwater utilization
(Storage tank: 15m$^3$)

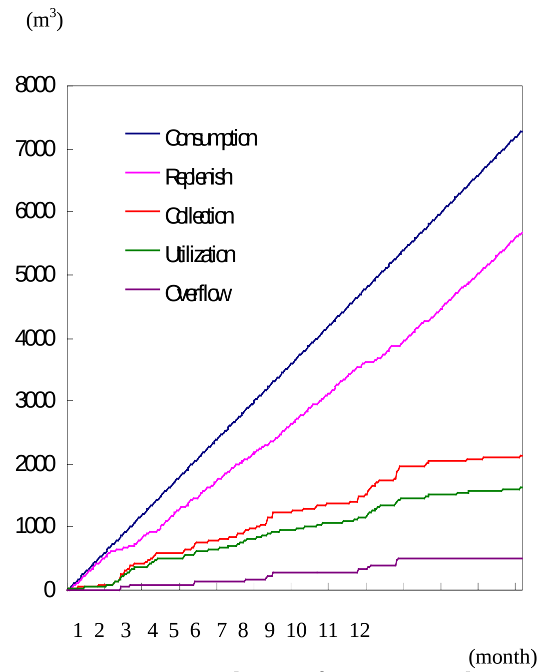


Figure 9. Simulation of rainwater utilization
(Storage tank: 25m$^3$)

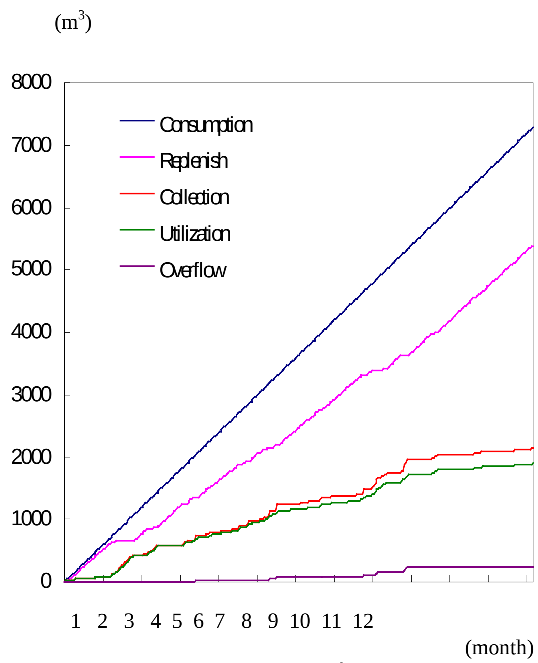


Figure 10. Simulation of rainwater utilization
(Storage tank:50m$^3$)

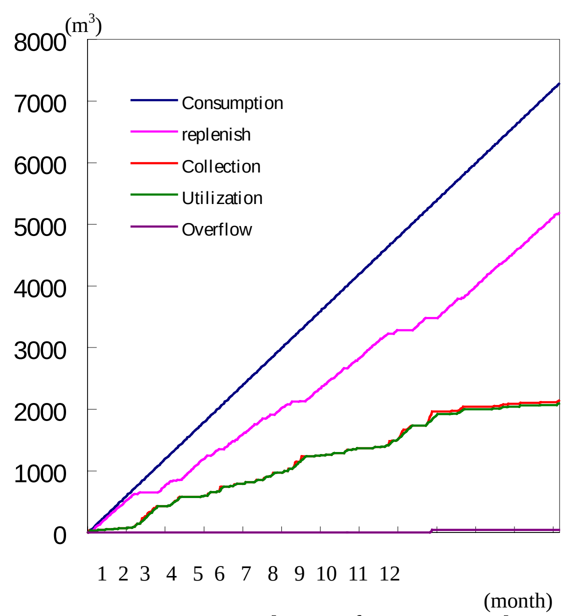


Figure 11. Simulation of rainwater utilization
(Storage tank:100m$^3$)

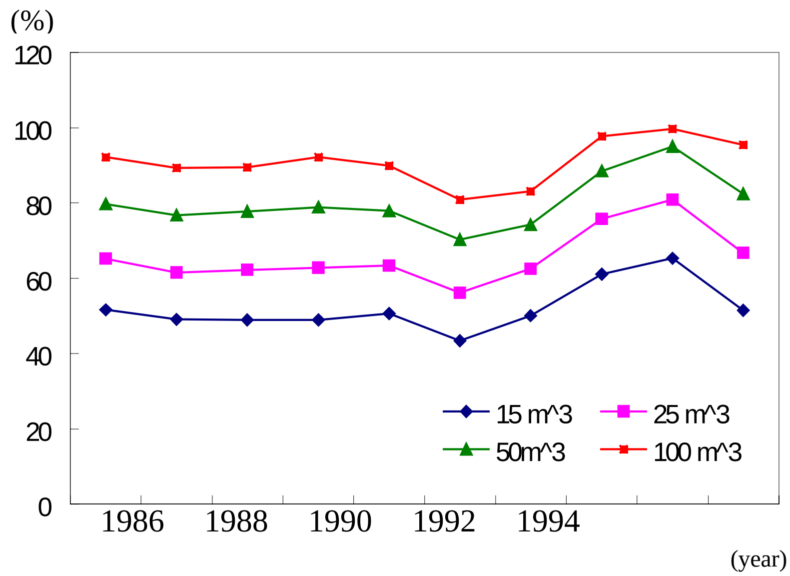


Figure 12. Rainwater utilization rate from 1985 to 1994

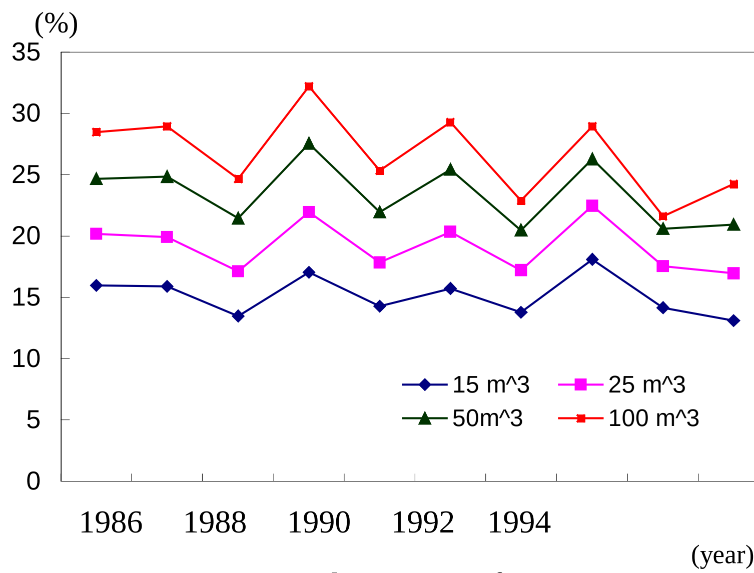


Figure 13. Rainwater utilization rate from 1985 to 1994

# The evaluation of building water conservation program employing forecasting water building consumption approach.

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## Abstract

The aim of this present paper is to present the particular results of a Building Water Conservation Program carried out in a hospital building. The Program establishes a methodology considering a group of actions to be applied in order to obtain reduction of water consumption inside the building. The evaluation was an important activity considered by the methodology and was applied a statistical model to forecasting water consumption to evaluate the program results. The model shows the amount of water savings achieved around of 19% to 31 % considered the two years covered by this study.

## Keywords

Water saving, Forecast water demand, Water uses, and Water economy.

## 1 Introduction

The main problem in evaluating the effects of the water economy achieved by Water Conservation Programs relays on the identification of which portion of water can be considered as water saved by the effect of the actions program.

Generally the water economy due to a specific action can be jeopardised by the random variation of water consumption imposed by the users activities inside the building.

To identify the real water economy achieved it was proposed the evaluation of water consumption by considering a statistical model to foresee the consumption considering the users activities and comparing against the real consumption were the program actions were taking effect.

## 2 Methodology

A specific methodology was adopted by using forecasted water consumption established through a statistical model considering parameters associated to the activities in a hospital building.

A detailed internal water consumption was carried out in order to know the internal water distribution among all the possible uses considering the hospital activities. The Hospital is the “Instituto da Criança” (Children Hospital) with 8 floors and totalling of 10.000 square meters of built area.

A classification of the main variables was done to find out the group of acceptable variables that could be used in the statistical model. A comparison of three regression equations was performed. A best-fit equation was used to forecast the water consumption and was defined the equation that would be adopted to forecast the consumption.

## 3 Internal use of water

It has been usual to evaluate the water consumption of a building by the analysis of the water bills where the amount of water is metered by the water supply company. This is acceptable to verify the level of water consumed but it is not enough to identify which portion of internal water use the program should be focused.

Thus it was used a metering system composed by electronic hydrometers connect to a computer were a supervisor software gathered the water consumption data. The software outputs were a file that contents were full compatible with an electronic worksheet that makes tables and graphics.

The system was capable to take care of 60 meters but for Water Conservation Program was identified six places to monitoring:

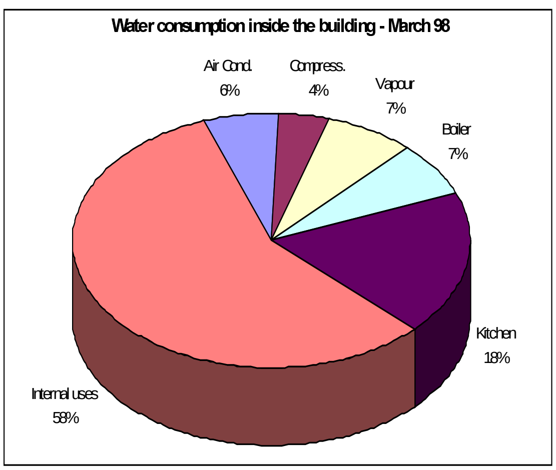
- The Air conditioning
- The Air compressor
- The boiler
- The Vapour Chamber
- The Kitchen
- The Main supply

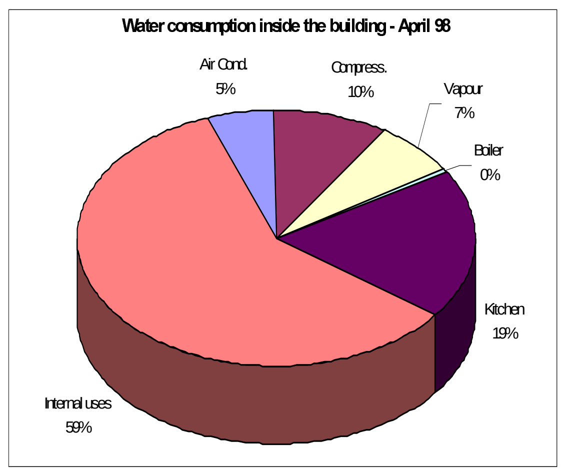
In these places were installed hydrometers connected to the microcomputer and it was possible to quantify the water consumed in intervals of 10 minutes. Considering that the difference of water registered by main supply compared with the others metes it can found the amount of water consumed internally by sanitary uses like WCs, lavatories, fountain drinking water and etc. The Table 1 shows the results yielded by monitoring internal water consumption for eight months. The figures 1 and 2 show the graphics of water consumption.

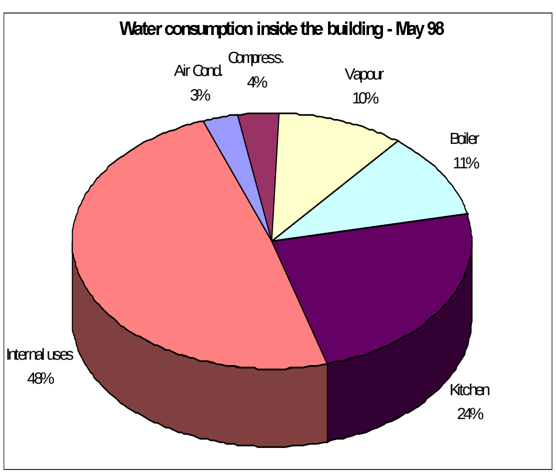
Table 1 – Internal water consumption since march to october 1998 ( in $m^3$/month)

| Month | Air Conditioning | Compressor | Vapour | Boiler | Kitchen | Internal uses | Main supply |
|---|---|---|---|---|---|---|---|
| **March**(*) | 148,6 | 98,5 | 167,6 | 170,7 | 431,6 | 1.365,6 | 2.382,6 |
| **April** | 291,4 | 540,7 | 377,4 | 26,3 | 1.074,7 | 3.337,6 | 5.648,1 |
| **May** | 139,3 | 181,3 | 525,8 | 552,8 | 1.232,7 | 2.522,7 | 5.154,7 |
| **June** | 99,8 | 156,9 | 620,0 | 576,5 | 1.029,4 | 2.808,5 | 5.291,1 |
| **July** | 99,4 | 84,8 | 334,7 | 620,9 | 1.096,4 | 3.077,3 | 5.313,5 |
| **August** | 135,2 | 124,0 | 86,7 | 601,7 | 1.283,7 | 2.553,7 | 4.784,9 |
| **September** | 128,9 | 78,2 | 66,1 | 611,5 | 1.248,4 | 2.391,5 | 4.524,8 |
| **October** | 123,7 | 97,5 | 53,9 | 620,1 | 1.228,3 | 2.567,9 | 4.691,5 |

**Note:** (*) The monitoring system started up in the middle of the month.



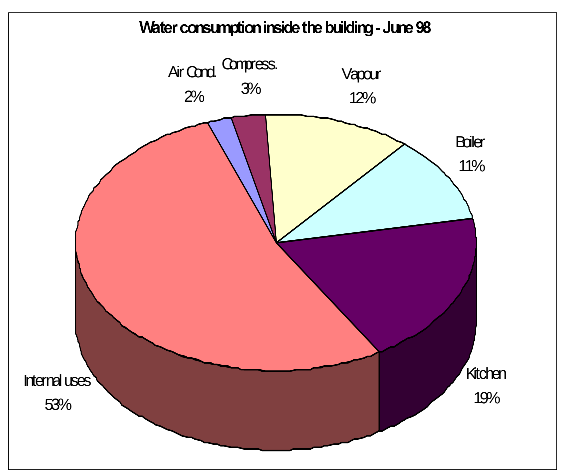



Figure 1 – Water consumption inside building from March to June 1998

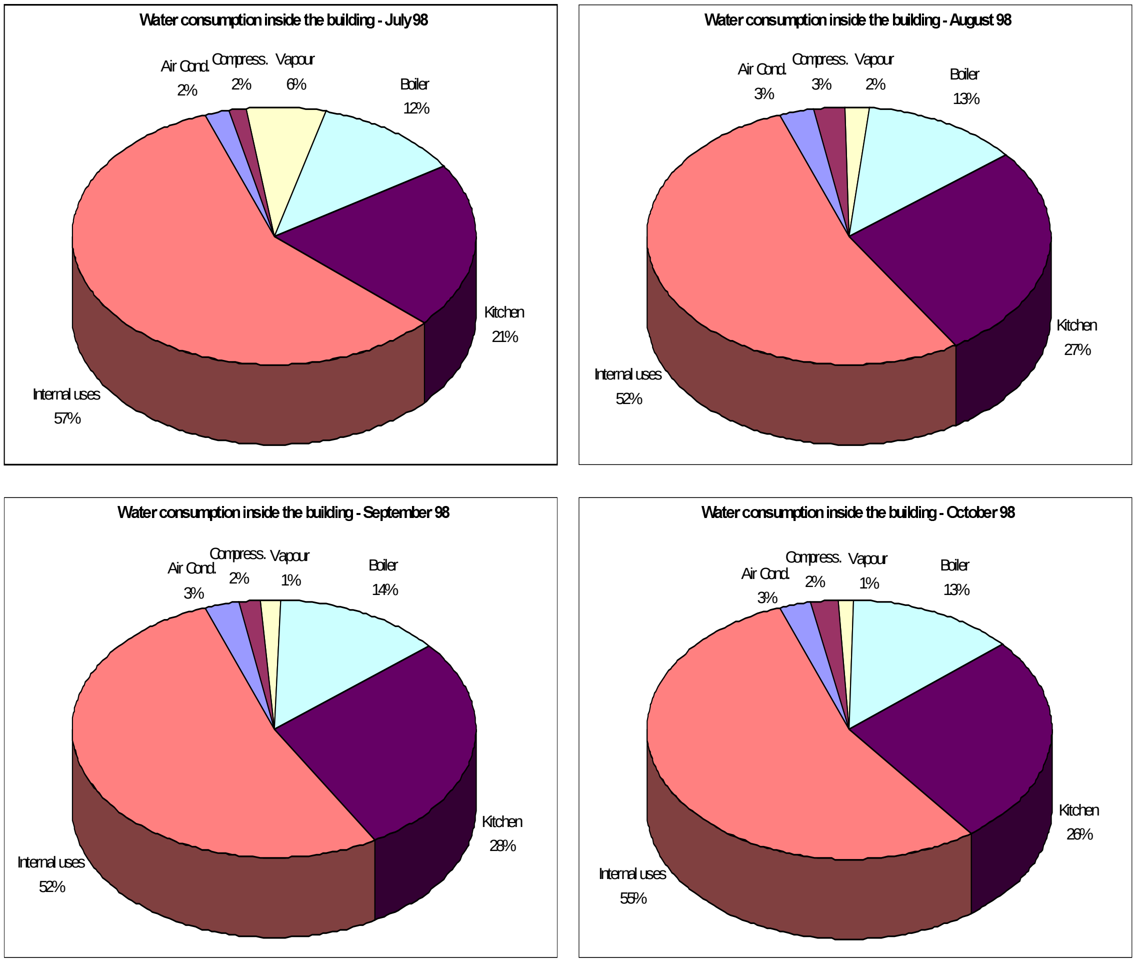



Figure 2 – Water consumption inside building from July to October 1998

From the pictures can be seen that the main inside water consumption relays on the internal use involving the water demanded by the users during their presence inside building developing some activity. The amount of water achieved more than 50% of total water supplied to the building during the month.

The equipment water consumption was divided among activities considered as minimal to maintain the Hospital working. The highlight is to kitchen consumption with an average of 23% of total water. Others equipment could considered as normal in face of the building Hospital.

An important point to mention is the water consumption related to internal use where the Water Conservation Program concentrated its actions aiming the reduction in water sanitary uses. Also this amount of water is due to the activities developed by the users so it can be seen the users directly influence of the variation in water consumption.

## 4 Variables definition

During the development of the program was collected a group of information about the activities carried out by the hospital employee's al well the users of medical care. These information were related to the quantitative variation of people covered by the Hospital attendance along the several months.

After analysis of all this information it was identified among those which could be considered as influent in the variation of water consumption and than it were denominated variables to be used to describe the water consumption due to building inside activities. Finally it yield a small group of variables that is shown in the table 2. Figures 3 and 4 shows the level of variation for two variables.

Table 2 – Variables considered as influent in the water consumption inside building

| Variables |
|---|
| **Patient meals** |
| **Employee meals** |
| **Patient accompany meals** |
| **Milk bottle preparing** |
| **Exam in Laboratory** |
| **Exam Radiological** |
| **Input registration** |
| **Surgery** |
| **Patient Attendance** |
| **Number of employees** |
| **Average monthly temperature** |

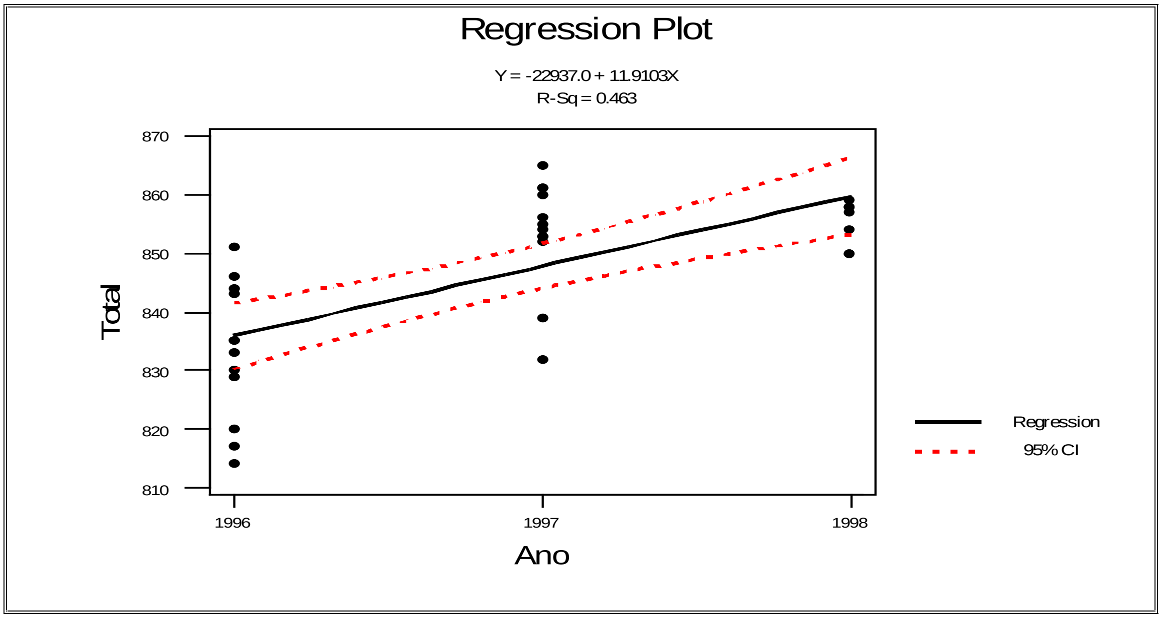



Figure 3 – Variation in the number of Hospital employees

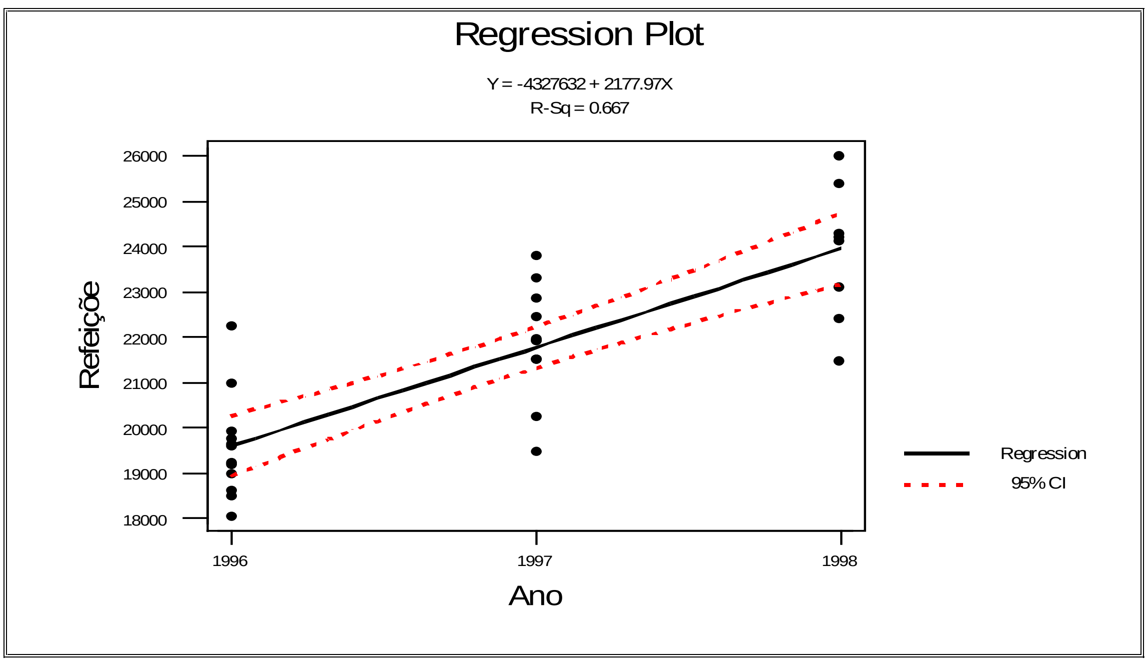



Figure 4 – Variation of meals served to the Patient, employee and patient accompany

## 5 Water reduction actions

As a part of the Water Conservation Program was established to carried out water reduction actions. These actions aimed to reduce the water consumption and were defined based on the analysis of the internal water consumption and the activities variation levels. The table 3 presents the actions defined by the program and the figure 5 presents the effect in reduction water consumption level achieved due to implementation of these actions.

Table 3 – Actions for water reduction

| Actions |
|---|
| **A0-Average consumption before the Program[(a)]** |
| **A1-External leak detection** |
| **A2-Internal leak detection** |
| **A3-Maintenance** |
| **A4-Monitoring System[(b)]** |
| **A5-Change in WC pans (6 litre per flush)** |
| **A6-Shower flow restrictions** |
| **A7-Tap aerators** |
| **A8-Automatic taps and urinal flushes** |

Note: (a) This action establish the water consumption reference.
(b) This activity is not related to water reduction but the possibility to water monitoring was considered as a action by the program.

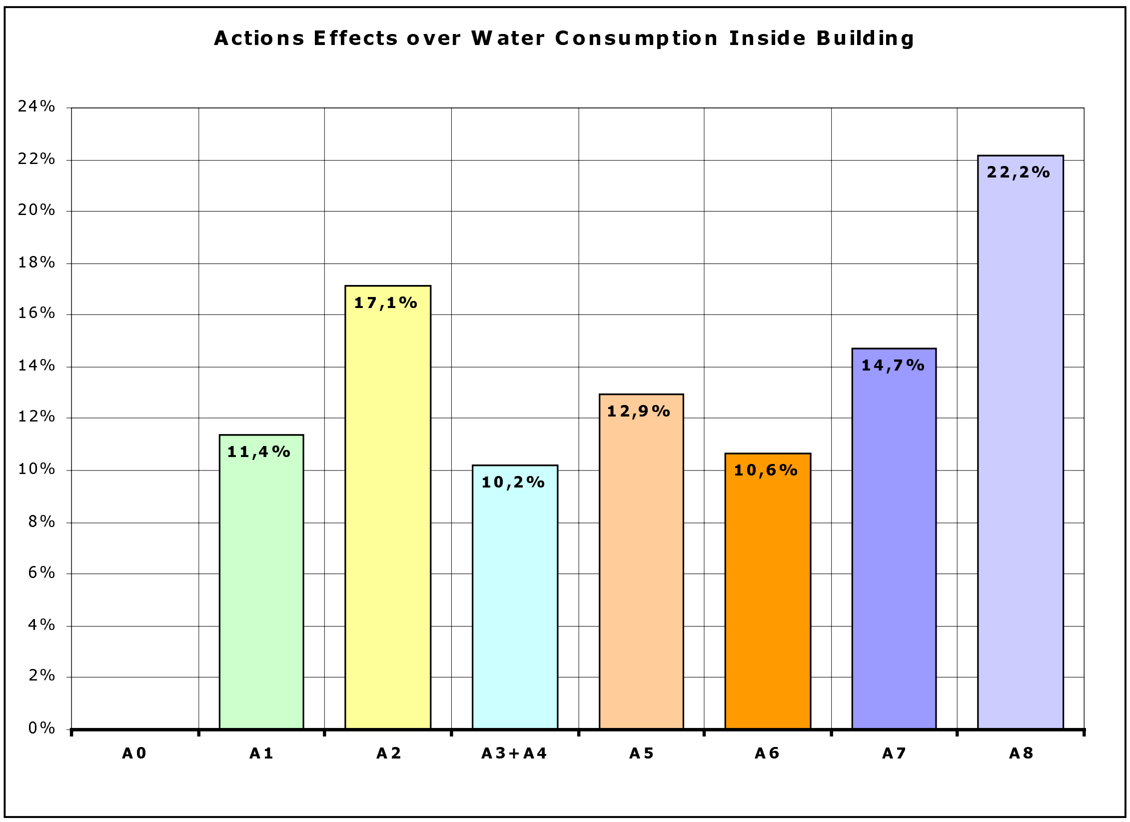



Figure 5 – Actions Effects over the water consumption inside building.

## 6 Forecasting Model development

With the data relative to the water consumption and the behaviour of the variables it was possible applying statistical concepts the establishment of a statistical model that could be used to foresee the water consumption considering the level of variables.

Basically was adopted a foreseeing model based on linear regression as the following:

$$\mathbf{Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + .....+ \beta_k X_k + \xi}$$

Where:

$\beta_0$ = constant

$X_1$, $X_2$, $X_3$, $X_k$ = variables

$\beta_1$, $\beta_2$, $\beta_3$, $\beta_k$ =variables coefficient

$\xi$ = error

It was employed the MINITAB® as a tool to calculate the best-fit equation considering constrains offered by the MINITAB®, the technical knowledge involved, and the Pearson correlation coefficient.

Three sets of variables were grouped and processed by MINITAB® and the runs yielded the equations for forecasting water consumption by the Program. Each model was called as A, B and C and the results can be shown in the tables 4 to 6.

Table 4 – Results for model A

| | Coefficient | Standard error | t | P |
|---|---|---|---|---|
| **Constant** | 12.148 | 5.016 | 2,42 | 0,073 |
| **Patient meals** | 0,63877 | 0,09667 | 6,61 | 0,003 |
| **Employee meals** | -0,5163 | 0,1488 | -3,47 | 0,026 |
| **Exam in Laboratory** | -0,13835 | 0,04928 | -2,81 | 0,048 |
| **Surgery** | 9,420 | 4,448 | 2,12 | 0,102 |
| **Patient attendance.** | -0,3544 | 0,1722 | -2,06 | 0,109 |
| **Number of employees** | -4,738 | 4,565 | -1,04 | 0,358 |
| **Temperature** | 31,32 | 28.45 | 1.10 | 0.333 |
| **Coefficient (r2)** | 97.7% | | | |
| **Linear regression equation:** **Water consumption** = 12.148 + 0,639***Patient meals** – 0,516***Employee meals** – 0,138***Exam in Laboratory** + 9.42***Surgery** – 0,354***Patient attendance** – 4.74***Number of employees** + 31,3***Temperature** | | | | |

Table 5– Results for model B

| | Coefficient | Standard error | t | P |
|---|---|---|---|---|
| **Constant** | 10.932,2 | 874,6 | 11,88 | 0,053 |
| **Patient meals** | 0,49926 | 0,01887 | 26,46 | 0,024 |
| **Patients accompany meals** | 0,08795 | 0,01742 | 5,05 | 0,125 |

| | | | | |
|---|---|---|---|---|
| **Employee meals** | -0,30809 | 0,02626 | -11,73 | 0,054 |
| **Milk bottle preparing** | 0,008464 | 0,001613 | 5,25 | 0,120 |
| **Exam in Laboratory** | -0,107148 | 0.006894 | -15,54 | 0,041 |
| **Input registration** | -2,5539 | 0,1573 | -16,23 | 0,039 |
| **Surgery** | 13,2455 | 0,7007 | 18,90 | 0,034 |
| **Patient attendance** | -0,24324 | 0,03305 | -7,36 | 0,086 |
| **Number of employees** | -4,3541 | 0,7936 | -5,49 | 0,115 |
| **Temperature** | 14,805 | 4,480 | 3,30 | 0,187 |
| **Coefficient (r2)** | 100.0% | | | |

**Linear regression equation:**
**Water consumption** = 10.392 + 0,499***Patient meals** + 0,00846***Milk bottle preparing** + 0,0879***Patients accompany meals**– 0,308***Employee meals** – 0,107***Exam in Laboratory** – 2,55***Input registration** + 13,2***Surgery** – 0,243***Patient attendance** – 4,35***Number of employee** + 14,8***Temperature**

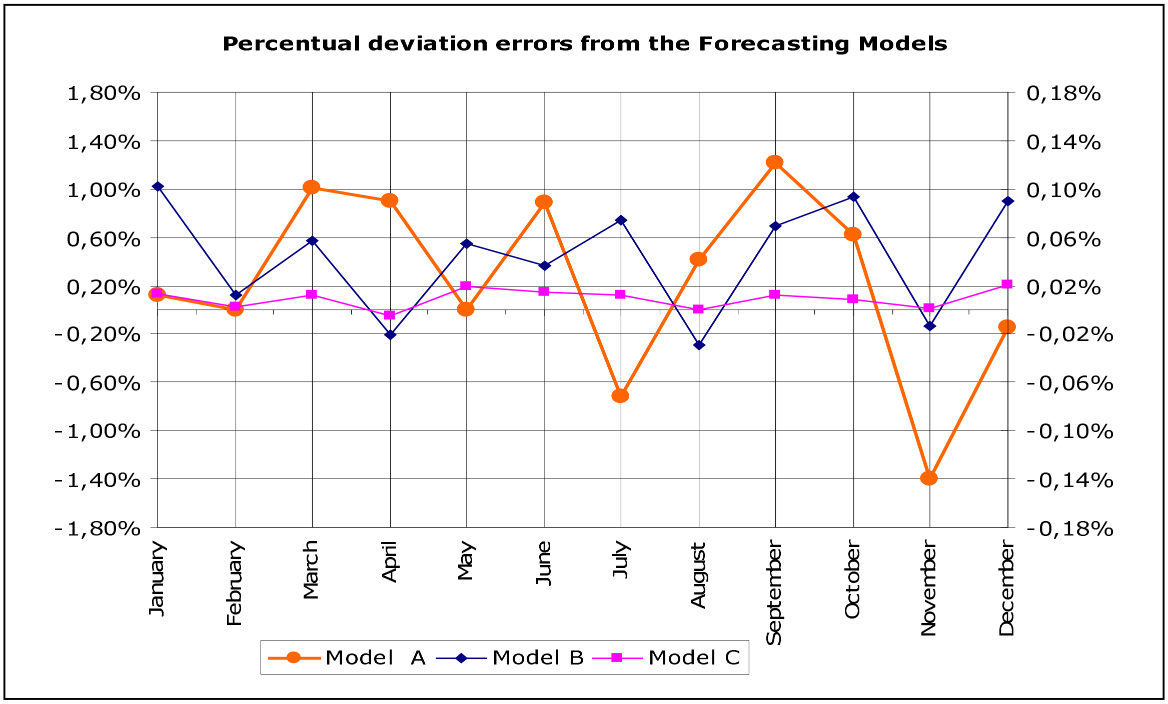
Table 6 – Results for model C

| | **Coefficient** | **Standard error** | **t** | **P** |
|---|---|---|---|---|
| **Constant** | 5.196,1 | 216,8 | 23,97 | 0,027 |
| **Patient meals** | 0,583623 | 0,001895 | 308,03 | 0,002 |
| **Patients accompany meals** | -0,052403 | 0,003617 | -14,49 | 0,044 |
| **Employees meals** | -0,354783 | 0,004301 | -82,48 | 0,008 |
| **Exam in Laboratory** | -0,083219 | 0,001434 | -58,02 | 0,011 |
| **Exam Radiological** | 0.174908 | 0,005054 | 34,61 | 0,018 |
| **Input registration** | -2,58298 | 0,02454 | -105,25 | 0,006 |
| **Surgery** | 10,6091 | 0,1400 | 75,76 | 0,008 |
| **Patient attendance** | -0,278556 | 0,004504 | 61,84 | 0,010 |
| **Number of employees** | 1,9698 | 0,2185 | 9,02 | 0,070 |
| **Temperature** | 16,6073 | 0,7023 | 23,65 | 0,027 |
| **Coefficient (r2)** | 100.0% | | | |

**Linear regression equation:**
**Water consumption** = 5196 + 0.584***Patient meals** + 0.175***Exam Radiological -** 0.0524***Patients accompany meals -** 0.355***Employee meals -** 0.0832***Exam in Laboratory -** 2.58***Input registration** + 10.6***Surgery -** 0.279***Patient attendance** + 1.97***Number of employees** + 16.6***Temperature**

The equations of water consumption of the three models were tested with the data collect and the deviation error was obtained for each one comparing with the real metered water consumption. The figure 6 shows the result where can be seen that the model C was the best equation and consequently was the model adopted.

Figure 6 – The deviation errors from the forecasting models




## 7 Model application

The model adopted was the equation yielded by model C and considering a confidence interval of 95 % the results were closed to the real metered curve of consumption pointing that the model could be used to analyse the program results. The figure 7 to 9 shows the result of the comparison between estimate consumption considering the confidence interval and the metered consumption for the year 1996, 1997 and 1998.

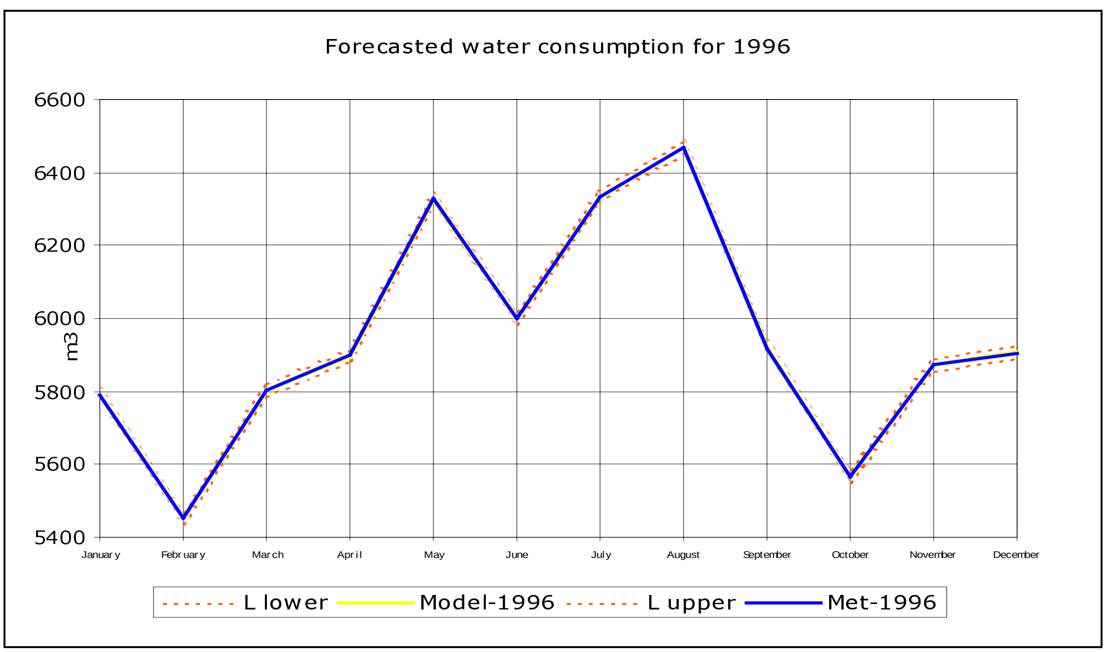


Figure 7 –Water consumption forecasted and metered for 1996

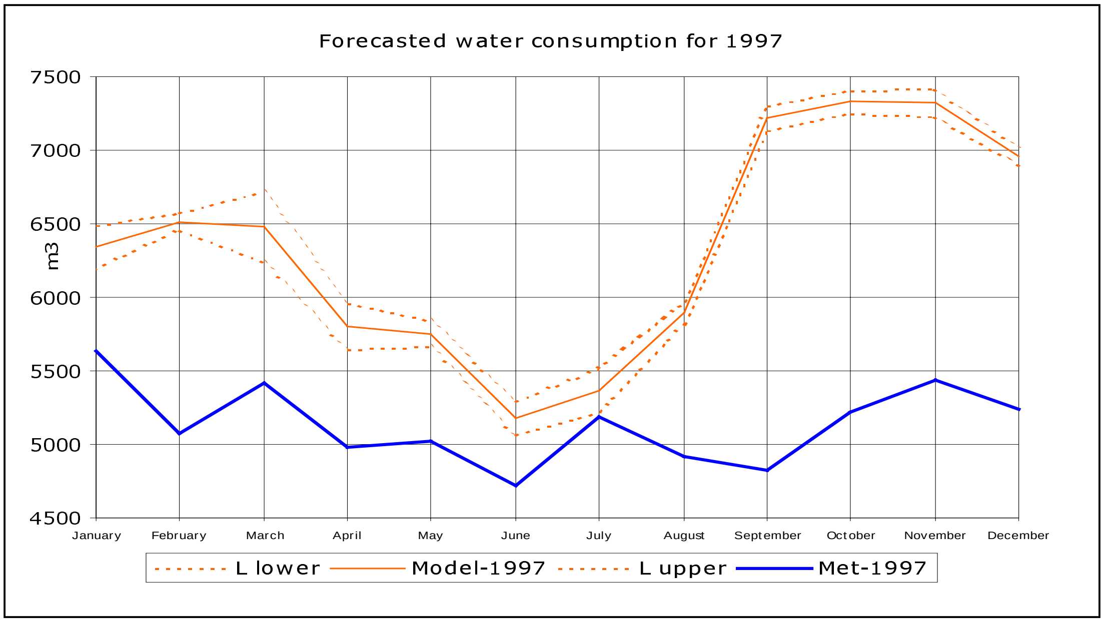



Figure 8 –Water consumption forecasted and metered for 1997

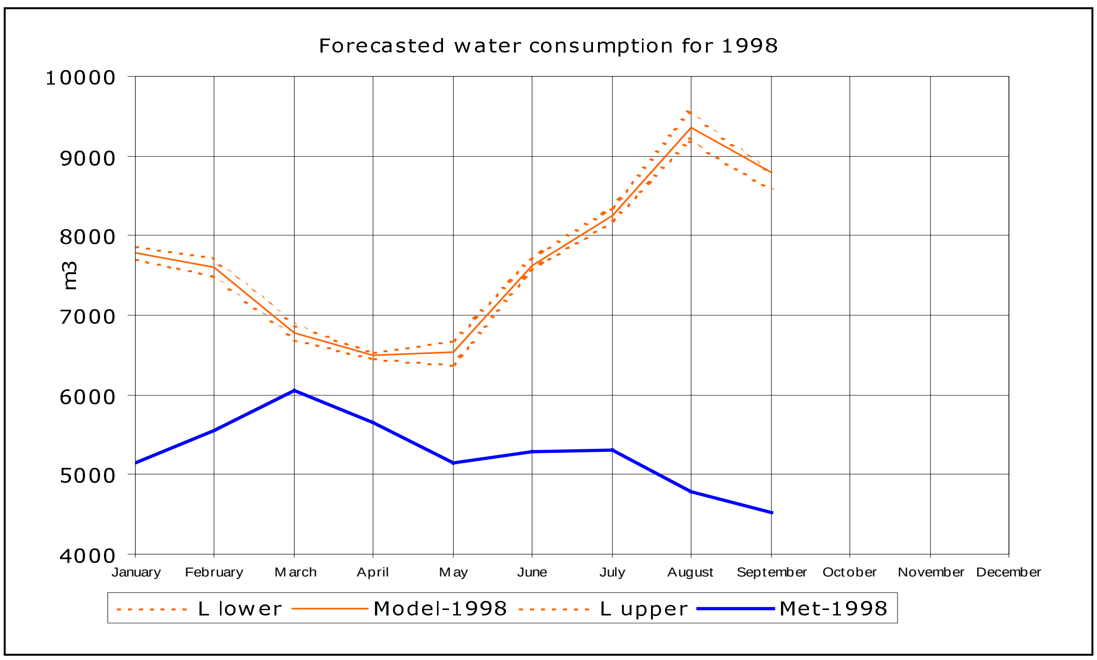



Figure 9 –Water consumption forecasted and metered for 1998

## 8 Modelling analysis

The Water Conservation Program effectiveness could be identified by applying the model of forecasting water demand presented. As can be seen in the figure 6 for the year 1996 the output of the model was perfectly coincident with the consumption metered by the water monitoring system (electronic hydrometers).

As the actions of the Program took place in 1997, the first action started on January it can be seen that the metered water consumption curve start to move down while the forecasted water consumption curve move up. This is due to effectiveness of the action that reduced the consumption. The model was developed considering the total consumption of the building therefore the model still work with the original behaviour of water consumption building.

For the years 1997 and 1998 it can be seen that the consumption curves given by the model always were displaced from the metered water consumption curves. This means that if not has been done the consumption level should be that stated by the model instead of the real level given by the metered curve.

This is important to highlight the amount of water saved by the Water Conservation Program. Because of the variation in the activity level inside the building caused by the users the identification of the water saved would cover the effect of the water reduction action.

## 9 Conclusions

As main conclusion it can be assumed that the model helped to know the estimated consumption by using statistical tools to compare the effectiveness of reduction actions proposed by the water conservation program. The figure 10 shows the accumulated annual water consumption where can be point out the difference between the forecasting model and the metered water consumption.

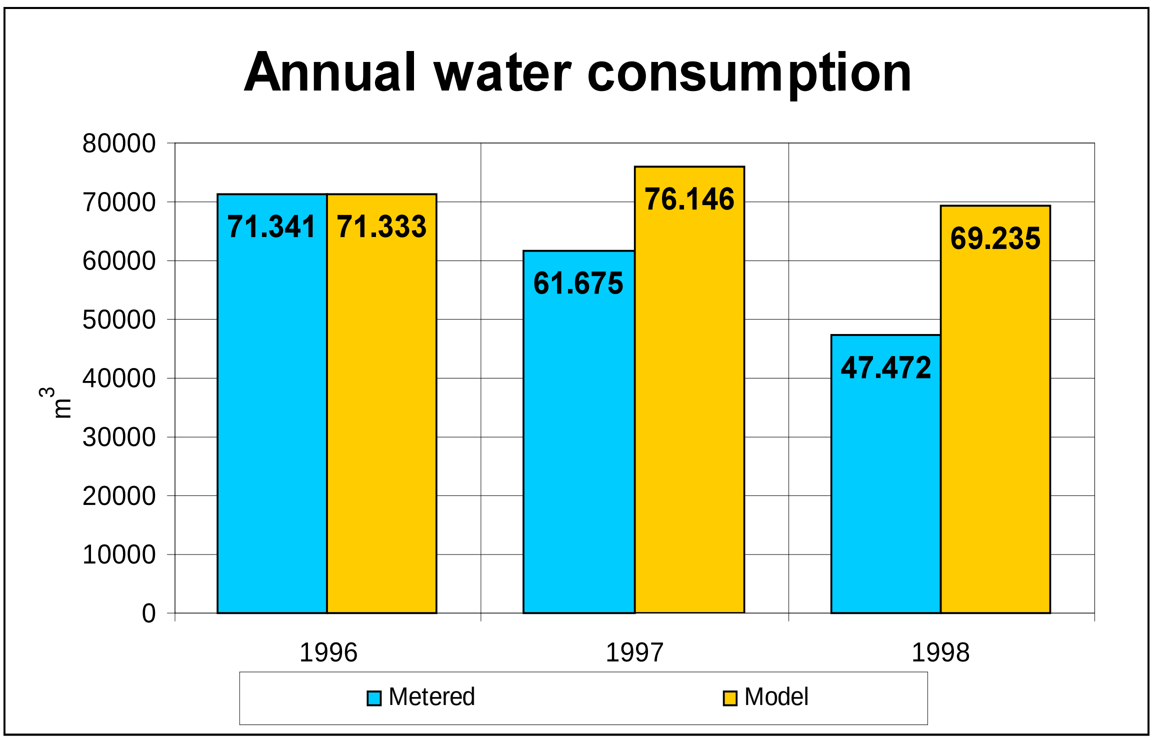


Figure 10 – Annual water consumption in the Hospital

Another point to be highlighted is that the Water Conservation Program carried out achieved all objectives proposed. The methodology developed was adequate to the building activity mainly considering the Program took place in a Hospital Building were the activities can not be interrupted as well the hygienic conditions must be guaranteed in order to avoid contamination.

In relative terms the model pointed out that the water saved in 1997 was around 19% compared with metered consumption and 31% for 1998 compared in the same basis. This means the amount of water that leave to be demanded by the building and of course stayed available for use by others buildings connect in the water main supply.

Must be recommended that the model be developed only for the building studied and any other application should be done with necessary care in order to avoid undesirables' results. Also is important to point out that the model can suffer modifications in order to incorporate in the equation some terms considering the effect of each action performed and so making possible to forecasting the water consumption considering water conservation parameters.

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# Rainwater Catchment Availability for Buildings in Drought-prone Okinawa and Proposed Numerical Appraisal

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## Abstract

Although the scope that this paper deals with outsteps the discussion about one locality, much mention is made of Okinawa; Okinawa is chronically drought-prone since it has no deep mountains nor large rivers, depending mainly on the rainfall as its water resources ; its climate is oceanic and subtropical, subject to being hit by occasional typhoons, which bring *heavenly* sea-rain. The national government encourages house- and building owners to install rainwater catchment systems by financing with additional building-loan allocations since 1991, this institutional means has certainly lead to a remarkable increase of rainwater utilization amounting to for about one thousand houses and buildings. And the prefectural government has prepared some guiding reports on publicity and propagation for rainwater utilization. We are partly associated with such action program, and have proposed a methodology of predicting numerically the availability of rainwater catchment system for buildings.

We usually take up a method simulated on personal computer for availability calculations to know how much rainwater could be utilized for a specific combination of reservoir or tank capacity, collection area, and daily water consumption.

Our methodology starts with the inquiry into annual rainfall patterns ; we employ a key word Duty factor, a borrowing of pulse theory due to their analogy to pulse configurations, irregular as they are; here a Duty factor is defined as a ratio of the number of a rainy day or successively rainy ones, to that of the subsequent non-rainy day(s) plus the immediately precedent rainy day(s). These accumulative Duty factors thus obtained on one-year basis, coupled with conventional availability calculations — usually considered as relating to the system efficiency — show an index of short-cycled rainfall patterns in a specific year.

With this modified efficiency appraisal we discussed the rainwater catchment availability in Okinawa and other principal cities of Japan.

**Keywords**
Okinawa; Rainwater catchment; System efficiency

## Okinawa's water problems

A proverb saying that it never rains but it pours, literally makes sense when we examine the rainfall statistics for various localities *even* in a country. With those for Japan we realize that some localities are likely to have a few occasions of raining, but amounting to much annual total rainfall. Okinawa where we live is a small island located in the merging waters of the Pacific and the East China Sea, about 1,700km distant south-west from Tokyo, and frequented annually by typhoons originating in the Philippine waters. Its annual total rainfall exceeds the national average by around 500mm, nevertheless Okinawa is threatened from year to year with water shortages mainly due to its absence of deep mountains and large rivers, mostly lost as run off.


**Fig. 1-Location of Okinawa and its vicinity**

Since 1991,governments, both at national and prefectural levels, have implemented an action program to promote introduction of rainwater catchment facilities, and that seems to have successfully settled in the Okinawan society. For houses, the use of rainwater is almost limited to toilet flushing, car washing, and gardening. In general, the water quality is considered suitable for other use such as laundering and, sometimes cooking.

For a long time, people in Okinawa have been taking it for granted to use the rainwater, often called "TENSUI" (heavenly water) in daily life. With the increasing demands for water in the household sector for the past two decades, water consumption per head has been steadily enhanced.

Also, Okinawa features another water resource —desalinated seawater, and several plants are now in service, mainly installed in isles at smaller capacities. In these climates for developing more stabled water conditions, we have been involved in the study of rainwater catchment for houses and buildings, from a viewpoint of developing optimal evaluation methodology, in cooperation with architects and engineers in Okinawa.

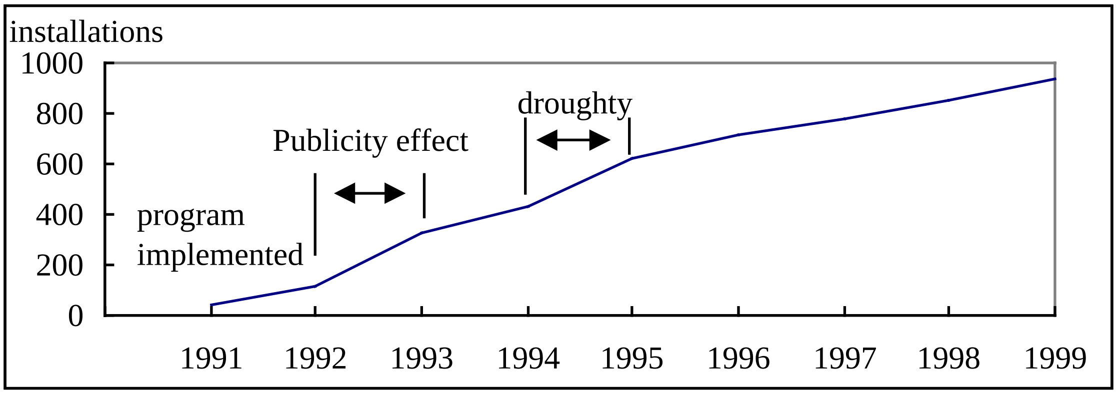



**Fig. 2-Okinawa’s cumulative number of rainwater catchment houses and larger structures installed with financial incentives.**

Fig.2 is a cumulative curve showing the number of houses and larger buildings with rainwater catchment installations which have been built in Okinawa on the national incentive finance program with a view to diversifying water resources against water shortages. The program is so planned as to finance applicants a long-term loan for rainwater catchment necessities to be installed. The program has started in Okinawa since 1991. It is clearly shown from the curve that in Okinawa the application of the program is steadily increasing, and that after the starting of the program it took up one year to get the full recognition of the program; it also indicates that just in the tumultuous drought of 1994, the number of application has more sharply increased than in 1993.

## Evaluation methodology outlined and discussions on the results

### The three essential variables and related factors

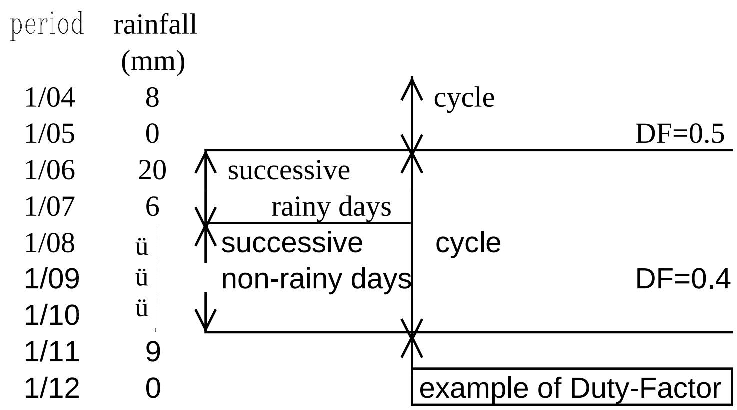
In order for a rainwater catchment system at a location to predict how much rainfall is to be available and how much tap water is to be replaced by the rainwater. We commonly employ the computer simulation whatever different the procedures may be; the former is denoted as “availability factor” and the latter “ substitution factor”. Both of the factors vary with the following three variables. The simulation results may differ according to a number of interrelated combinations of the essential three variables — reservoir tank capacity, rainwater collection area, and daily water consumption.

Probably the most authoritative literature in Japan on rainwater catchment system design so far published is the SHASE manual (The society of Heating, Air-Conditioning and Sanitary Engineers of Japan). It presents the rainwater catchment system design items in practical order and gives definitions clearly to terminology that is somewhat confusing. Here, we particularly proposed several terms anew, adding to the conventional ones; they are Duty Factor (DF), UA (short for Use and Area ratio), TA(Tank and Area ratio) and System Efficiency; Substitution factor seems to be a common term, in that it is a ratio of rainwater that replaced tap water, to total quantity of water to be used. UA and TA are expressed as follows:

$$UA=(\text{daily water consumption})\times(\text{collection area})\times 10^4$$

$$TA=(\text{tank capacity})\times(\text{collection area})\times 10^4$$

The proposed Duty factor is illustrated as below (the term itself is a borrowing from pulse science, in that its configuration is apparently analogous to a pulse wave pattern). One “Cycle” comprises successive rainy days and successive non-rainy ones (including both single rainy-and non-rainy day); the average number of cycles amounts to 62 in one year. The illustrated example shows that if a non-rainy day comes just after one rainy day — making one cycle and the Duty factor is defined as 0.5, and in the same manner the other cycle gives a Duty factor of 2/5 or 0.4.



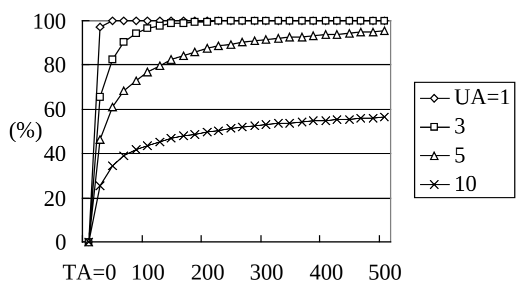




Fig.3 rainwater substitution for Naha

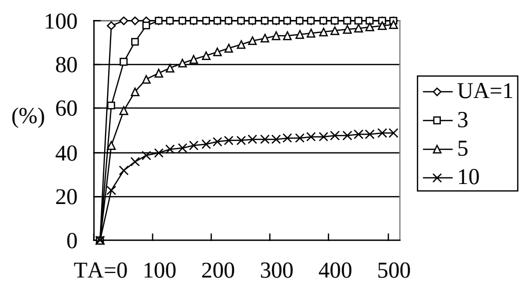



Fig.4 rainwater substitution for Naha(1994)

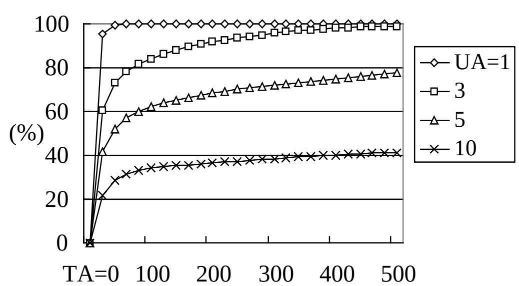



Fig.5 rainwater substitution for Osaka

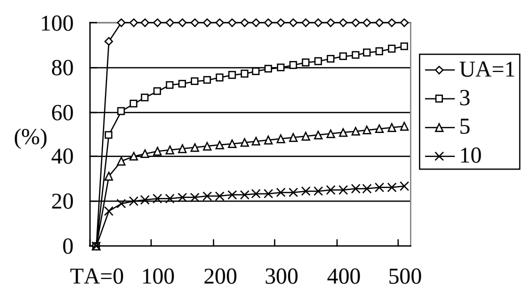



Fig.6 rainwater substitution for Osaka(1994)

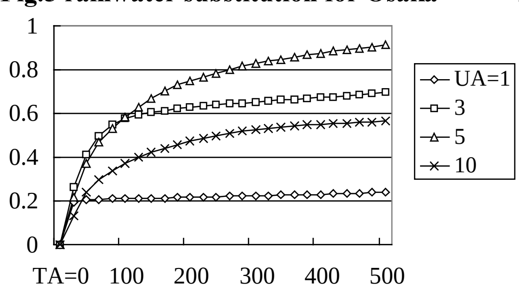



Fig.7 system efficiency for Naha

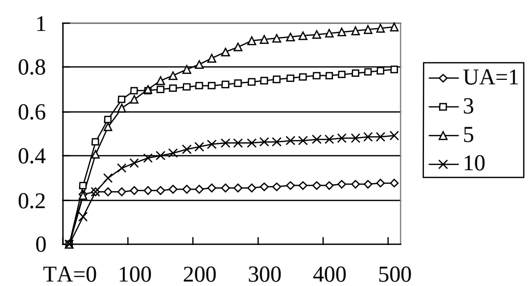



Fig.8 system efficiency for Naha(1994)

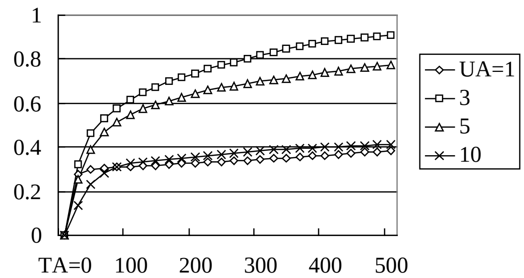



Fig.9 system efficiency for Osaka

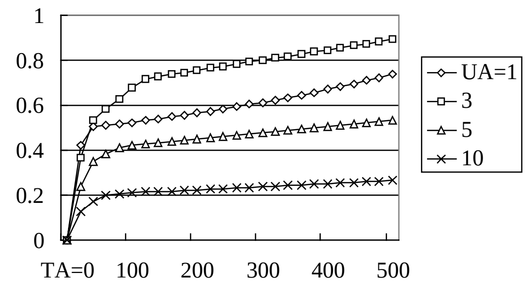



Fig.10 system efficiency for Osaka(1994)

Fig.3 to fig.6 are the rainwater substitution (%) versus TA relations with some UAs as parameters for Naha and Osaka; fig.4 and fig.6 are presented for 1994 droughty year for comparison.

Fig.7 to 10 illustrate the System Efficiency versus TA curves calculated for a 10-year period and the year of 1994 for both Naha and Osaka.

**Table 1 Combination of UA & TA for maximum system efficiency (4 locations)**

| | Niigata | Tokyo | Osaka | Naha |
|---|---|---|---|---|
| UA | 5 | 3 | 3 | 5 |
| TA | 300 | 360 | 360 | 420 |
| System efficiency | 0.906 | 0.806 | 0.858 | 0.883 |

Table 1 denotes the combination of UA and TA when a system efficiency for each of four location is reached to the maximum. As the table shows, UA for the maximum occurs at 3 or 5 while TA is between 300 and around 400; however, if we stick to these values, it will occur that the three variables, namely, reservoir tank capacity and collection area, and daily water consumption must be considered closely in the stage of system design.

**Table 2 Rainfalls and calculated Duty factors for major locations in Japan.**

| | | Niigata | Tokyo | Osaka | Naha |
|---|---|---|---|---|---|
| rainfall | latest 10 years (mm) | 1758 | 1536 | 1353 | 1864 |
| | 1994(droughty) (mm) | 1437 | 1131 | 744 | 1570 |
| DF | latest 10 years | 0.53 | 0.40 | 0.37 | 0.44 |
| | rainy season | 0.48 | 0.48 | 0.48 | 0.44 |
| | 1994 | 0.49 | 0.35 | 0.30 | 0.42 |
| | 1994(rainy season) | 0.43 | 0.38 | 0.38 | - |

Table 2 shows the calculated Duty factors for 10-year period and also for the year of 1994 which brought a harsh and confusing water shortages over a wider portion of the country.

According to the table, Niigata seems to be best suited for rainwater catchment among four locations because the amount of its annual rainfall is considerable and its Duty factor also among the national highest; Naha has seemingly favorable figures of Duty factor in addition to its large amount of annual rainfall.

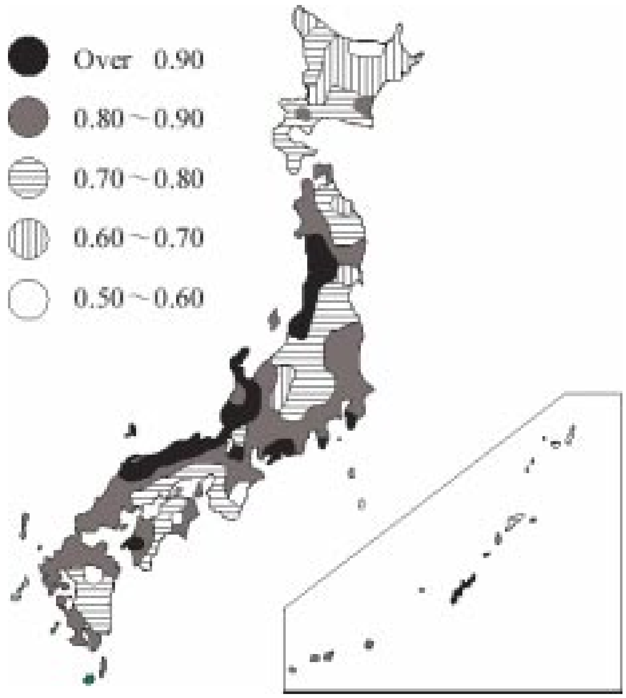



**Fig. 11-System efficiency distribution (Japan)**

Fig. 11 illustrates an example of a nationwide distribution of system efficiency, drawn for Japanese 150 major urban regions assuming that the UA is at 5 and the TA at 500; this illustration is subject to change if other combinations of UA and TA are applied.

## Conclusions

We made a brief review, in the first, on the present Okinawa with special emphasis on its institutional means for combating with frequent water shortages, especially in the household sector by employing rainwater catchment systems. Consequently our academic interest has been concentrated on the appraisal effectiveness of such rainwater catchment for structures as a whole.

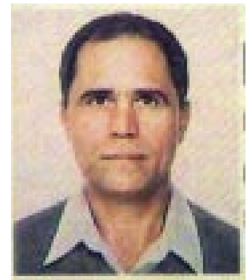
1)It may safely be said that the rainwater catchment systems have now been accepted in the society of Okinawa both in concept and practice, and are deeply rooted in.

2)And the institutional incentives have proved effective.

3)The defined Duty factor lies between 0.3 and 0.6 for Japan on the average, and at locations severely affected in the nationwide droughty year of 1994, as a natural consequence, reduced to as low as 0.3.

4)The defined system efficiency tends to become nearly highest when UA is taken for around 3 to 5 in rainwater catchment system design, it is advisable to enhance the reservoir tank capacity and adjust the other two variables, namely, daily consumption rate and collection, so as to approximate UA as nearer to appropriate figure as possible.

# The Impacts of Individual Water Metering System (submetering)



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**ABSTRACT**
*Nowadays in most of Brazilian's residential buildings, there is a great concern related to the way that water consumption is metered and rated among the water users. Traditionally, in Brazilian's culture, the water consumption metering system in a residential building is done by only one hydrometer (collective metering) and the global water bill is shared among all users according to different sharing methodologies. The great part of them takes into account quantitative characteristics, such as number of apartments and apartment size (area). But the most applied methodology is related to the number of apartments, which is totally unfair to the users: equal sharing among the number of residents. The ideal and logical situation is when water consumption is metered by an individual hydrometer and rated by an individual water bill, as what happens to Brazilian's electricity and public gas consumption metering system. Many authors from different parts of the world already confirmed the water consumption reduction in relation to collective metering system, with the implantation of submetering (individual metering) systems in residential buildings. But most of them have not considered an important water use factor that is directly related to the variation of consumption: social and cultural (behavior and habits) characteristics of the water users. The objective of this paper is related to a data analysis and comparison of a research in buildings which presents two kinds of water metering system (collective and individual metering system), considering the water users social and cultural characteristics and the water consumption reduction impacts. The research was applied in a case study of residential buildings, which present identical physical characteristics but different water metering system and water users.*

## 1. INTRODUCTION

According to OLIVEIRA (1999), there are several technological options which contribute to the water reduction and control, such as:

- submetering system of water consumption;
- water saving components and systems;
- water leaks detection and correction.

Among all the presented actions, technically, the submetering system is the one which is related to an indirect intervention action in methodologies for economy of water, so much for the water users as for the condominium. The other options are direct intervention actions to the buildings hydraulics systems, which seek the reduction and control of water waste through the performance in damaged and inefficient hydraulic projects.

With the submetering system, the user begins to acquire larger conscience of the water use, because he will be asked to pay the water bill according to its consumption. So, the water saving happens spontaneously, or indirectly, without any application of water conservation methodologies.

For the condominium, the submetering system contributes indirectly to the water waste and problems through the attribution of facilities and efficiency in water leaks verification and detection in the habitational units, due to the individual water consumption, causing with that, shorter detection time and smaller damages in the maintenance intervention actions.

It is still worth to remind that, in the users' case, there is an important social and cultural characteristic which should be considered, because it is directly related to the behaviors and procedures of water use: the water users' habits and procedures. Each user presents a certain behavior of water use. Some, with larger conscience in relation to the water economy, and others, with less concern, or even, totally dissembled of water rationalization procedures.

## 2. OBJECTIVES

This article intends to present a detailed characterization of the users' social and cultural behavior, of a study's case, for verification of the parameters that can generate great variations impacts, when compared such characteristics in buildings with different water metering systems: collective and submetering.

## 3. METHODOLOGY

### 3.1. Characteristics of the analyzed habitational group

It was verified the existence of a habitational group composed by several standardized buildings (blocks). So they are identical to each other. The only building system technical difference between them is the water metering system. Almost 40% of the buildings (30 blocks) have the collective water metering system, and the others 60% (48 blocks) have submetering system. This habitational group is the CECAP, located in the Guarulhos municipal district in São Paulo state, Brazil.

The habitational group possesses the following characteristics:

- group composed by 10 condominiums (4 possess collective water metering system and the left 6, submetering system);
- each condominium possesses 8 buildings (blocks);
- the blocks are all identical to each other. So, all buildings possess same physical characteristics (apartment size) and architectural project;
- each building possesses 60 apartments, distributed in 3 floors (20 apartments per floor);
- each apartment possesses 52,5 $m^2$ of total area and it is composed by the following spaces: 3 bedrooms, living room, kitchen, bathroom and service area (S.A.). The following illustration (Figure 1) shows the architectural plant of a standard apartment.

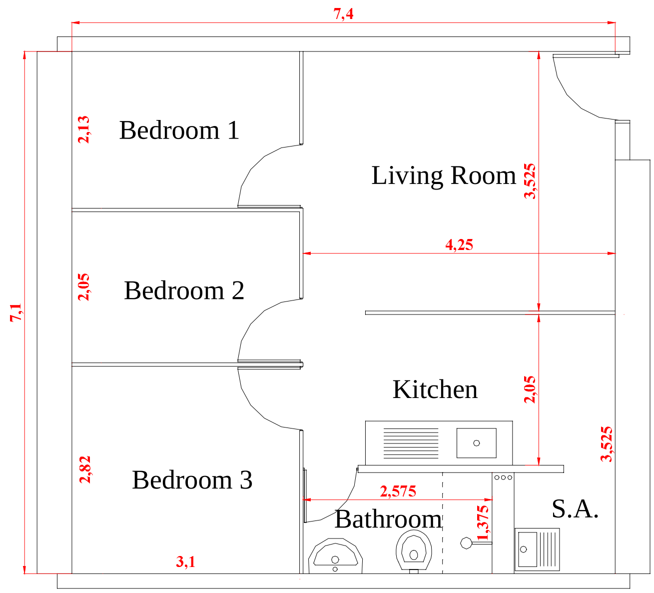



**Figure 1**: CECAP's standard apartment architectural plant.
Measures in meter (m).

### 3.2. Hydraulic and piping system characterization

The water supply system of all condominium is made by the public water net system. There's no water storage (tanks) and water pumping system. So the water distribution system to whole apartments is classified as being direct (Direct supply system) served by public water net. The average water pressure verified in the public water system is about 301 Kpa, showing to be very high, which can contribute to higher water consumptions. The following figures schematize the type of water supply and distribution system in the two kinds of buildings (Figures 2 and 3).

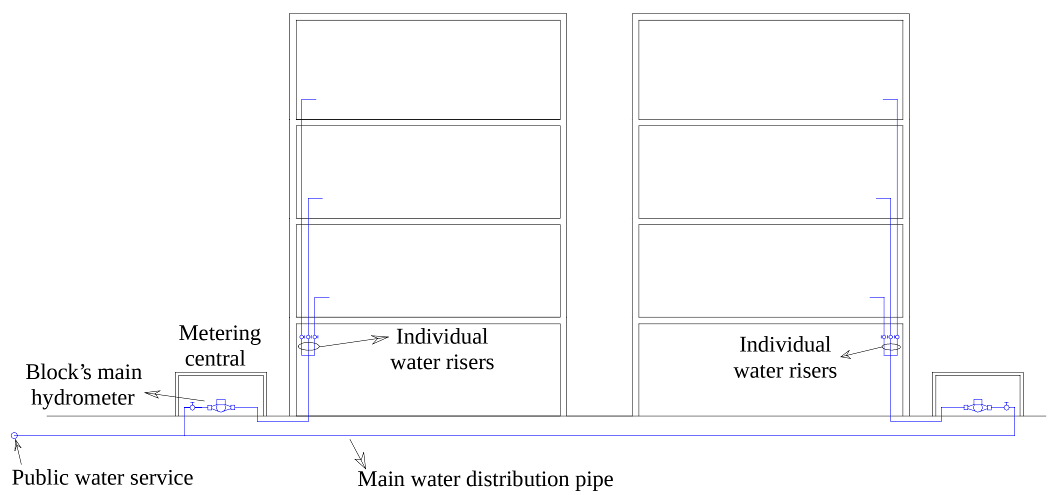



**Figure 2**: Water supply and distribution system in buildings with collective metering system.

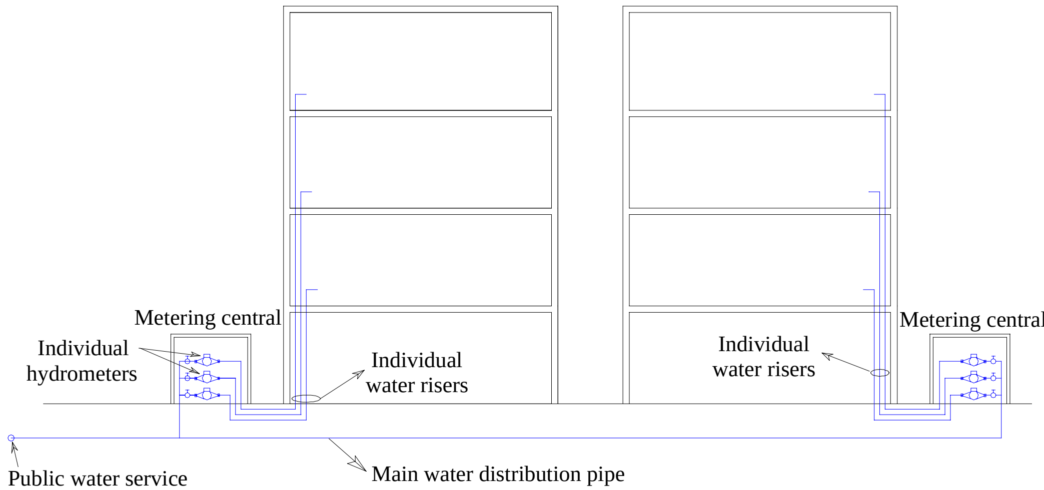



**Figure 3**: Water supply and distribution system in buildings with submetering system.

- **Water metering and reading system**

The metering system in buildings with collective metering is composed by only one hydrometer per building (See Figure 2), which control the water consumption of whole apartments present in the building. The total water bill of each building is shared equally among all the apartments. In buildings with submetering system, there is a hydrometer per apartment, placed in a common area (Metering central), as seen in the Figure 3. So each apartment has its own water bill. There's no automatic water metering reading system in the buildings. All the readings are made manually by a professional (reader) hired by the water public concessionaire.

### 3.3. Users' characterization data

With an average of 3,4 habitants per apartment in all researched buidings, an extensive distribution of the frequencies was verified, being found up to 6 fixed people living in an apartment. From the total population verified, 57% are feminine and the 43% left, from masculine. The following picture (Figure 4) illustrates the population's relative frequency considering the number of people per apartment.

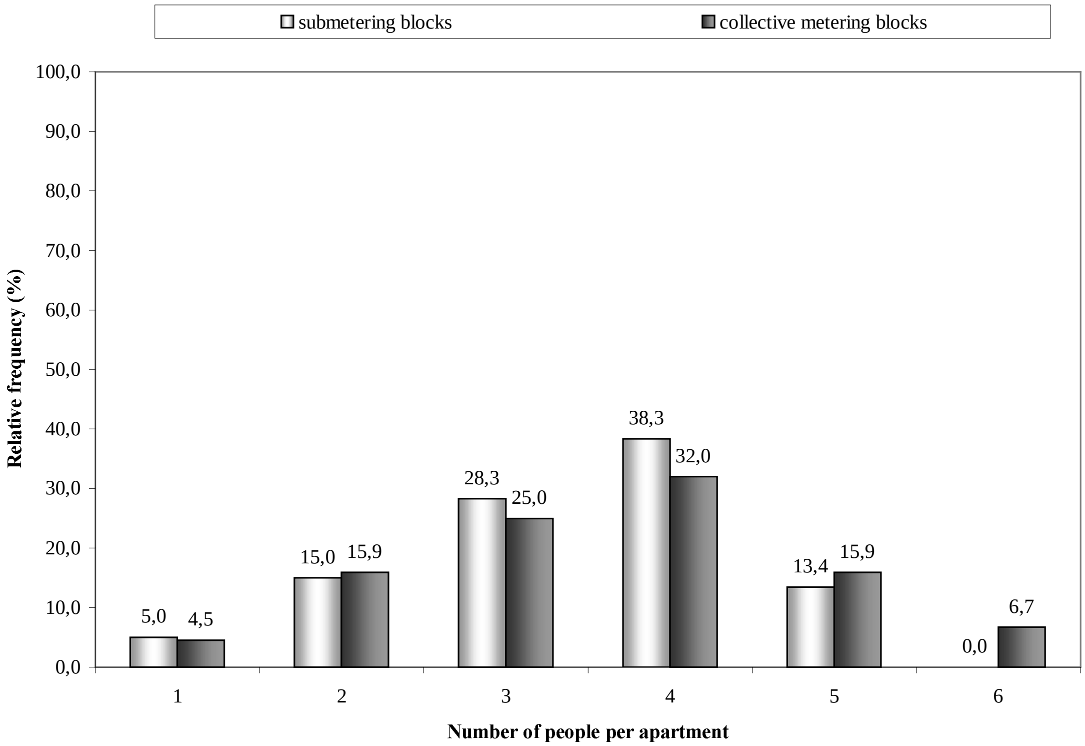
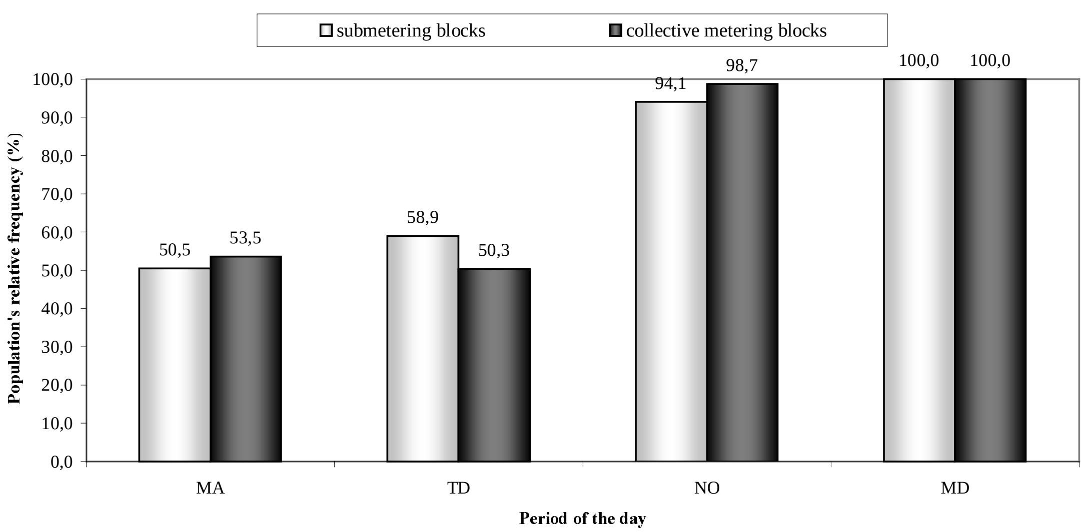



**Figure 4**: Relative frequency graph of the number of people per apartment.

- **Occupation period**




**Legend – Occupation period of the day:**
MA: morning - period from 6:00 o'clock to 11:59 am;
TD: afternoon - period from 12:00 o'clock to 17:59 pm;
NO: night - period from 18:00 o'clock to 23:59 pm;
MD: dawn - period from 24:00 o'clock to 5:59 am.

**Figure 5**: Population's occupation period distribution.

It is verified in Figure 5, that:

- so much in the morning period as in the afternoon, 50% of the population are in their apartments in both blocks with different water metering systems. It was also verified that there's an uniform and close distribution in both kinds of blocks with different metering system. That is very important to consumption comparison study.

### 3.4. Water consumption historical

The obtained average monthly water consumption per apartment, in blocks with collective metering system, was of 21,1 $m^3$/month/apartment, or 703,3 L/day/apartment, while, in blocks with submetering system, the average was of 17,6 $m^3$/month/apartment, or 586,7 L/day/apartment, resulting in a difference of 16,6% in relation to the average of the collective part, and 19,9% in relation to the average of the submetering blocks. Therefore, it was verified a reduction impact of almost 17% in buildings with submetering system, in relation to the collective metering buildings. It was estimate an average of per capita water monthly consumption, obtaining 5,3 $m^3$/month/person, or 177 L/day/person, in submetering system blocks, and 6,2 $m^3$/month/person, or 207 L/day/person, in collective metering system blocks. The follow illustration (Figure 6) shows the monthly water consumption historic.

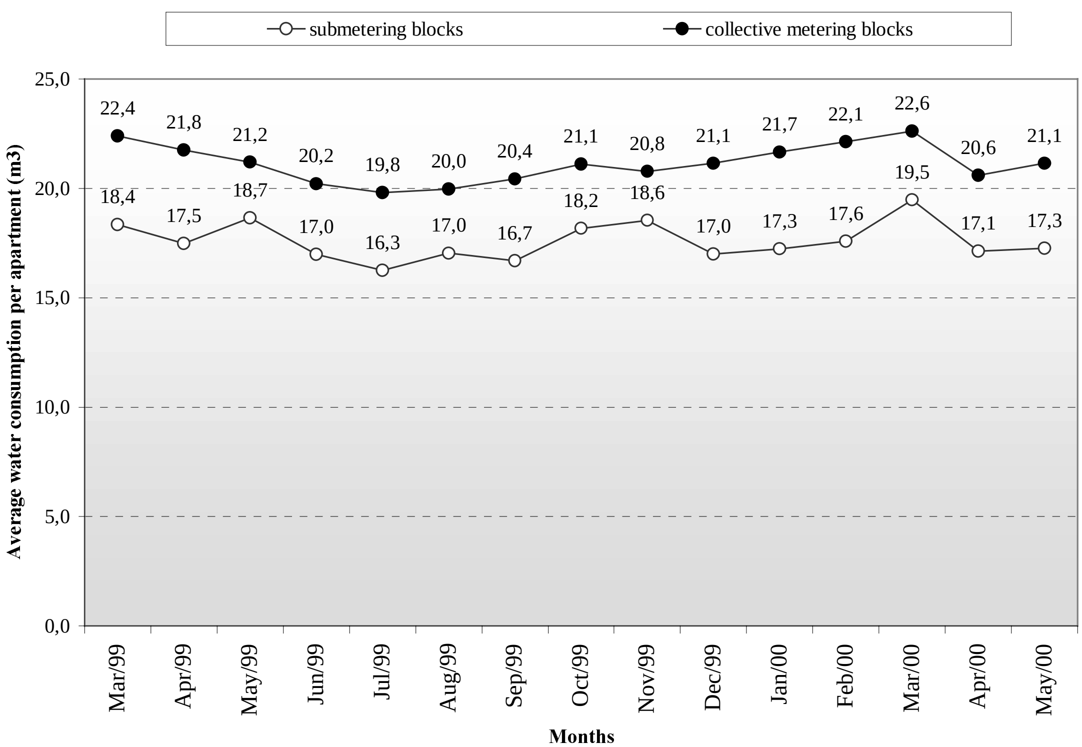
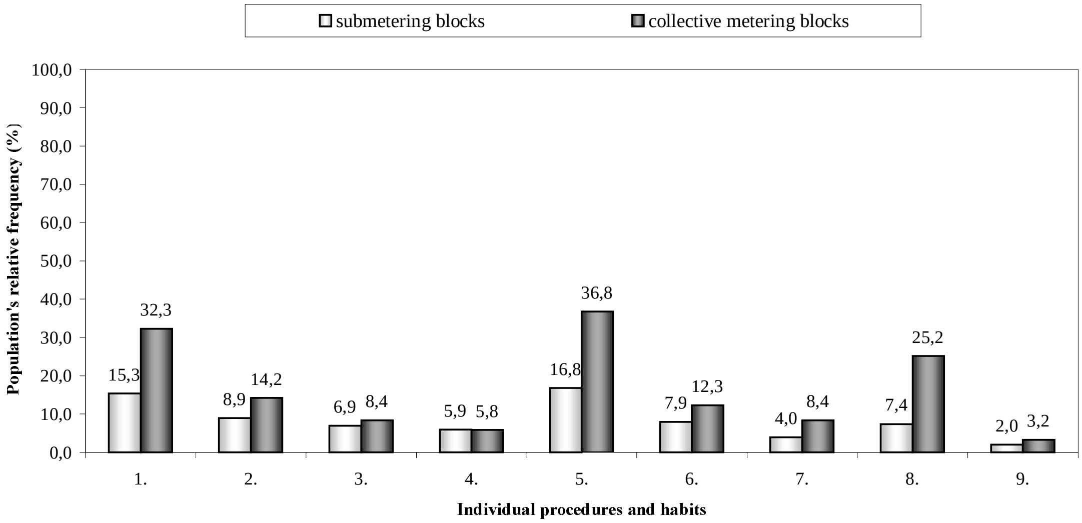



**Figure 6**: Water monthly consumption (historical) graph of the CECAP's buildings.

## 3.5. Water users procedures and habits




**Legend – Individual procedures and habits:**
1. to delay in bathing (above 20 minutes);
2. to wash dishes with opened faucet between the cleaning and watering;
3. to wash face with opened faucet between cleaning and watering;
4. to shave with opened faucet between cleaning and watering;
5. to brush teeth with opened faucet between brushing and watering;
6. to use the toilet as a trash;
7. inadequate closing of faucets providing water leaks;
8. to use the toilet flushing more than 1 time;
9. to operate the washing machine with inferior recommended load.

**Figure 7**: Population distribution in inadequate water consumption procedures and habits.

Observing the Figure 7, it is verified, mainly, that:

- the actions and habits that provide larger water wastes, as the procedures 1, 5 and 8, are most observed in the blocks with collective metering system, presenting occurrence frequencies above the double in relation to blocks with submetering system;
- the frequency of people who uses toilet flushing more than 1 time, in collective metering system blocks, is superior to 3 times the frequency of the ones who live in apartments with submetering system.

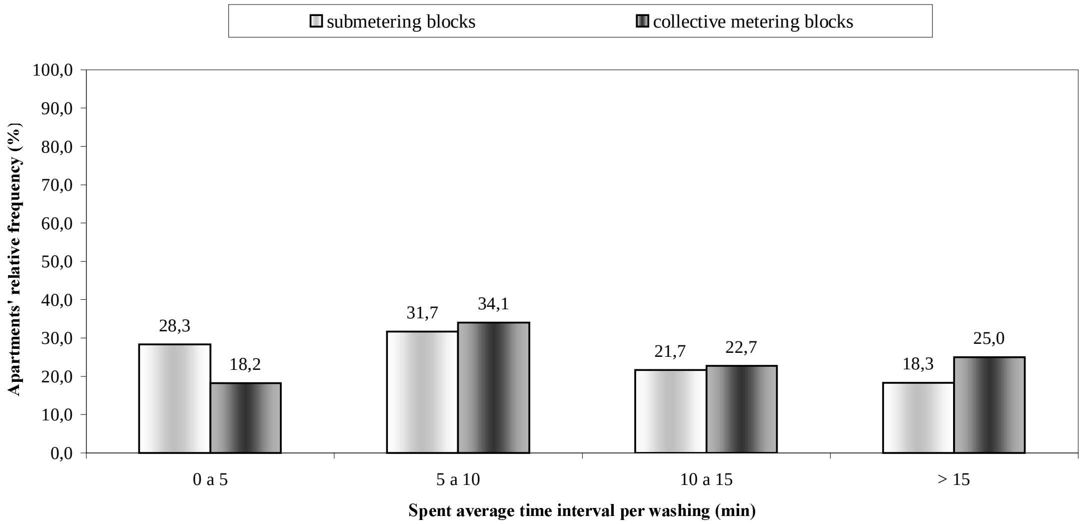



**Figure 8**: Population's distribution in the spent average time interval in each washing dishes procedure.

Observing the Figure 8 above, it is verified that:

- there is a frequency values proximity in both blocks with different metering system in the time intervals of " 5 to 10 minutes " and " 10 to 15 minutes ";
- in 25% of the apartments in both kind of blocks, the average spent time to wash dishes in blocks with collective metering is, at least, 3 times higher than the one spent in blocks with submetering system.

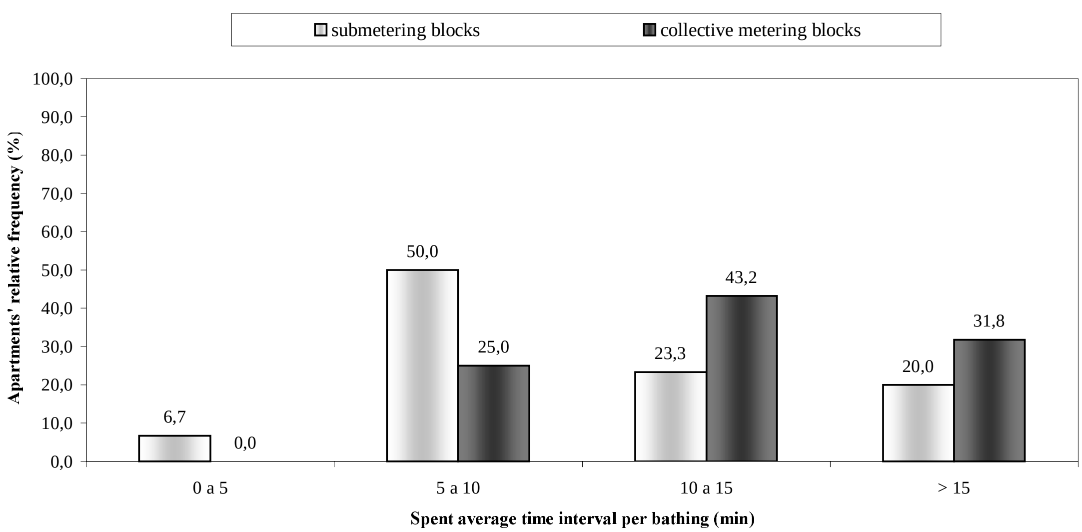


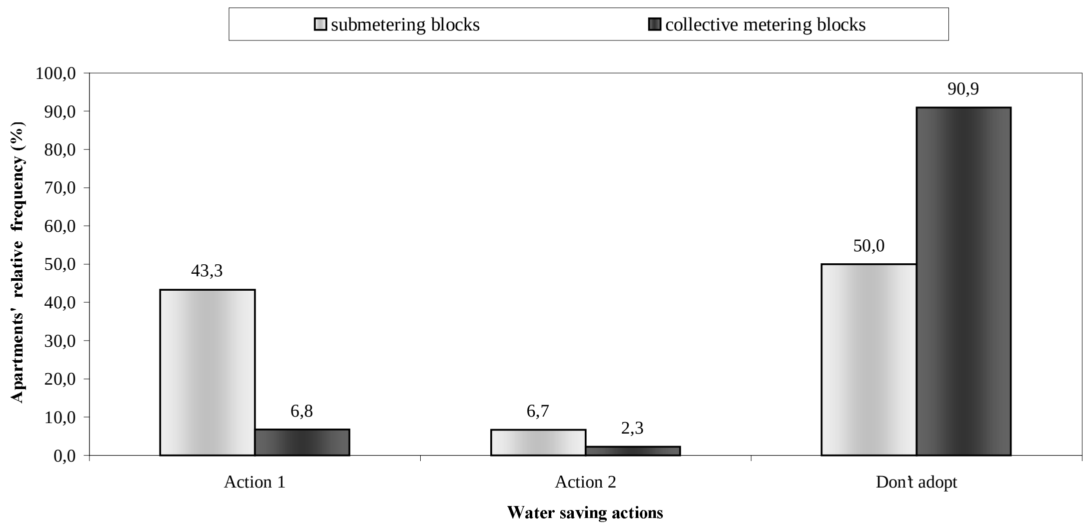

**Figure 9**: Population's distribution in the spent average time interval in each bathing.

It is verified, in the Figure 9 above, that:

- the whole population who lives in blocks with collective metering spent, at least, 5 minutes in each bathing, while the most part of the population (57%) who lives in blocks with submetering system spends up to 10 minutes in each bathing;

- the second higher frequency of time interval, in blocks with collective metering is revealed to be the highest time interval (“above 15 minutes"). This justifies the obtained data in the graph of the picture 7, related to the inadequate habit of delaying in bathing above 20 minutes (Procedure 1).

### 3.6. Water saving procedures and actions



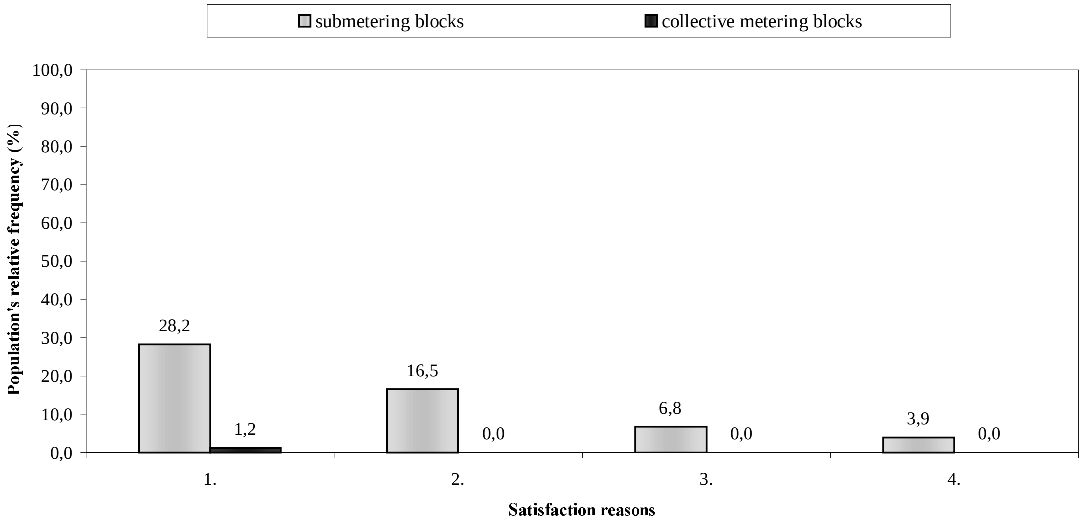

**Legend – The most use water saving actions:**
Action 1: reuse of the washing machine water when washing clothes;
Action 2: storage and reuse of the tank water.

**Figure 10**: Population’s distribution in adoption frequency of water saving actions.

In the graph of the Figure 10 above, it is verified that:

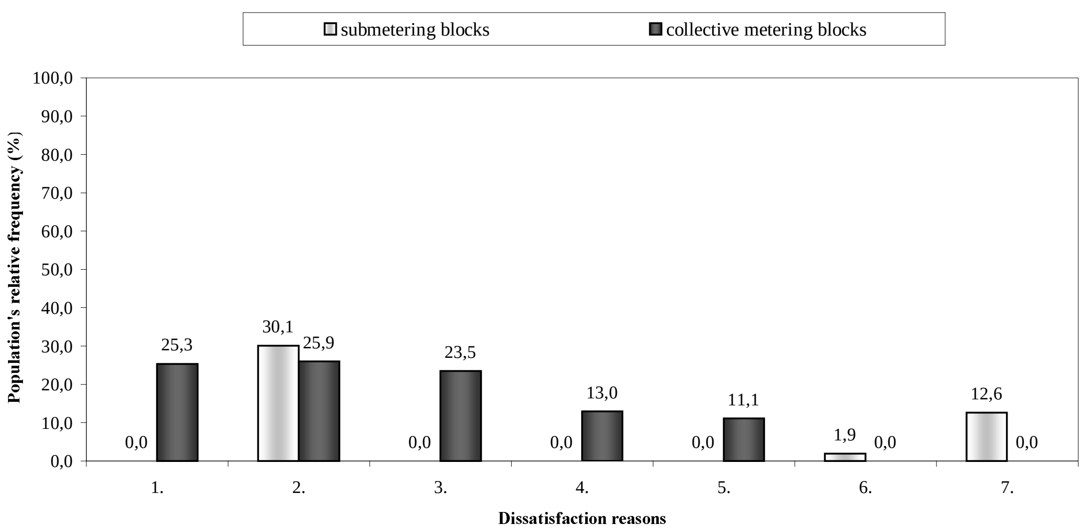
- half of the habitations with submetering system adopts water saving actions, while, in case of blocks with collective metering system, less than 10% of the habitations adopt this procedure. So, it is clearly observed that there’s a great ignorance of the population in habitations with collective metering in water saving methods and consumption rationalization.

## 3.7. Water metering system evaluation




**Legend - Satisfaction reasons:**
1. the metering system and the total water bill sharing procedure of water consumption are fair;
2. the water bill is under the expectations;
3. the metering system facilitates the water leaks detection;
4. the metering system facilitates the hydraulic equipments maintenance.

**Figure 11**: Population's distribution according to the satisfaction reasons of the metering system evaluation.




**Legend - Dissatisfaction reasons:**
1. the metering system and the water bill sharing procedure of water consumption are unfair;
2. the water bill is above the expectations;
3. there's no knowledge of the actual water consumption per apartment;
4. the metering system turns difficult the hydraulic equipment maintenance in case of water interruption needs;

5. the metering system turns difficult the water leaks detection;
6. obligated to pay the minimum tax for the water consumption below the minimum consumption range (under 10 $m^3$ per month);
7. the water bill is higher if compared to those of isolated residences (houses).

**Figure 12**: Distribution of the population for dissatisfaction of the mensuration system.

We verified, in the graphs of the Figures 11 and 12, that:

- more than the half of apartments with submetering system is satisfied with the metering system. Even so, just 28,2% attributed to be fair this water metering method;
- only 11% of the apartments (reasons 3 and 4 of the Figure 11) have knowledge of the facilities that the submetering system can provide to the hydraulic system maintenance actions. In case of blocks with collective metering, 24% (reasons 4 and 5, of the Figure 12) of the apartments have knowledge of these actions, due to possible faced difficulties verified in apartments with this kind of metering system;
- in spite of the majority of the apartments with submetering system is satisfied with this metering system, 30% of the units are dissatisfied with the method because of high price of the water bill, being above of the users foreseen expectations. Such fact is still reinforced when we observe that 13% of the habitations complain that the water bill is very high, if compared to those of isolated residences (reason 7, of the Figure 12).

## 4. FINAL CONSIDERATIONS

In this research we intended to show the main variation impacts of the buildings with different kind of water metering system. So, we can highlight the following considerations:

- even being observed a certain frequency equivalence of the social characteristics (number of people per apartment and occupation period) of the population, it was verified several divergences in the cultural characteristics (water consumption habits and procedures), reflecting the consumption reduction impacts between buildings with different water metering systems;
- even verified a water consumption reduction impact of almost 17% in blocks with submetering system, front to the ones with collective metering, it was observed that this impact presented below the expectations. In agreement to some authors mentioned in the CIBW62 1999, by YAMADA *et al* (1999), it was verified that some researches realized by other authors presented a reduction impact of, at least, 20% in this kind of comparison study of metering system. This fact can be justified according to the follow situation verified in the research in some interviews: it was verified apartments with submetering system which was presenting identical and pretty close user’s social and cultural characteristics, but with great difference in their monthly water consumption values. So, for a same user’s characterization (number of people, occupation period, habits, etc.) in different habitations, but with the same metering system (submetering), great divergences of water consumption were verified, which can only be justified by mistakes and wrong metering reading caused by the readers;
- it was verified great unknowledge and ignorance of the population that resides in habitations with collective metering system, front to the water saving actions and water use rationalization. That is probably justified by the unfair sharing procedure of the total water bill among all the users, motivating these populations to consume in agreement to

their needs, without being conscious with their actual consumption, because this is not metered individually.

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# Case Study on Life Cycle Carbon Dioxide Emission of Water Supply and Drainage System

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**ABSTRACT**
In this paper we have discussed the carbon dioxide emissions when constructing the water supply system, drainage equipment, rainwater facilities, fire extinguishing system and domestic hot water supply system, turning our attention to the plumbing system as a whole of an office, and compared the electric power consumption when operating water system facilities. The findings are as follows. The consideration of $CO_2$ emission concerning the construction may curtail the environmental load through the selection of the water supply method and piping materials. The reduction in $CO_2$ emission relating to the maintenance and administration will lead to some great effect in reducing the environmental load in the water system facilities as a whole all through saving the water consumption in any building.

## 1. Introduction

There exist bustling movements, home and abroad, that surround the building facilities. The adoption of Agenda 21 in the "United Nations Conference on Environment and Development(Earth summit)" held in June 1992 in Rio de Janeiro elicited one of the international trends. In 1985 the "Vienna Convention for the Promotion of the Ozone" was adopted under the leadership of the international environment plan. Japan agreed to reduce its $CO_2$ by 2010 by 6% compared with that in 1990 in the "COP3" (the "Third Concluding Meeting" relating to the "Global warming effect prevention treaty") held in 1997. The global environmental problems have thus been brought to the fore. We have discussed the carbon dioxide emissions when constructing the water supply system, drainage equipment, rainwater facilities, fire extinguishing system and domestic hot water supply system, turning our attention to the plumbing system as a whole of an office, and compared the electric power consumption (corresponding to $CO_2$ emission) when operating water system facilities.

## 2. Carbon Dioxide Emissions in Office When Constructing

Such a model building was selected in the calculation of carbon dioxide emissions when constructing. The $CO_2$ emission per weight was multiplied by the weight of each member. The same when operating was calculated out from the operating time of each sanitary fixture. As the carbon dioxide emission per weight we adopted the value proposed by the Committee for Global Environment of the Society of Heating, Air-conditioning and Sanitary, which is based on the interindustry analysis in 1985 fiscal year.

## 2-1 Model Building

Shown below are the outlines of building construction and plumbing installations in the model building of an office that formed the subject of our study.

*Outline of Building

Use of building: Office with 5 stories and one basement

Total floor area: 6090 $m^2$

*Water Supply System

Average water supply quantity/day: 60 $m^2$

Receiver tank/Gravity water tank: FRP

Lift pump: 460 L/min

Piping material: VLP

*Drainage equipment

Sanitary sewage/waste water: Combined or separate

Materials of drain pipe and vent pipe: CIP, SGP, double layer pipe, with sewage pump

*Rainwater facilities: Natural discharge, VP

*Fire equipment system: Indoor hydrant, SGP

*Sanitary fixtures: Water closet, urinal, wash basin

*Domestic hot water supply system: Electric water heater (30 L)

## 2-2 Useful Life

The useful life of each region was assumed to be as follows:

| | |
|---|---|
| VLP: 30 Years | VP: 30 Years |
| SGP: 20 Years | Electric water heater: 10 Years |
| CIP : 30 Years | Lift/sewage pumps: 16 Years |
| Double layer pipe: 30 Years | Water closet: 25 Years |
| Extinguishment pipe (SGP) : 25 Years | Urinal: 30 Years |
| Receiver tank/Gravity water tank: 20 Years | |

## 2-3 Coupling Joint for Feeder Water and Drain Piping

The length of piping was calculated out assuming no coupling joint nor valve, as a rule.

## 2-4 Combined Conditions for Calculation

Table 1 shows the useful life and piping materials for feeder water, drain, rainwater and extinguishment pipes.

Table 1 Combination of Useful Life and Piping Materials

<table>
<tr><td rowspan="2"></td><td rowspan="2">Water supply system</td><td colspan="2">drainage equipment</td><td rowspan="2">rain water system</td><td rowspan="2">fire extinguishing system</td></tr>
<tr><td>sanitary sewage / waste water / vent</td><td>sanitary sewage waste water / vent</td></tr>
<tr><td rowspan="5">each useful life</td><td>V</td><td colspan="2">RUN1</td><td>V</td><td>S</td></tr>
<tr><td></td><td colspan="2">RUN2</td><td></td><td></td></tr>
<tr><td>L</td><td colspan="2">RUN3</td><td>P</td><td>G</td></tr>
<tr><td></td><td colspan="2">RUN4</td><td></td><td></td></tr>
<tr><td>P</td><td colspan="2">RUN5</td><td></td><td>P</td></tr>
<tr><td rowspan="5">uniform 30 years</td><td>V</td><td colspan="2">RUN1</td><td>V</td><td>S</td></tr>
<tr><td></td><td colspan="2">RUN2</td><td></td><td></td></tr>
<tr><td>L</td><td colspan="2">RUN3</td><td>P</td><td>G</td></tr>
<tr><td></td><td colspan="2">RUN4</td><td></td><td></td></tr>
<tr><td>P</td><td colspan="2">RUN5</td><td></td><td>P</td></tr>
</table>

RUN 1: Sanitary sewage/waste water separated. Sanitary sewage: CIP, SGP for others;
RUN 2: Sanitary sewage/waste water separated, Double layer pipe for any and all;
RUN 3: Sanitary sewage/waste water combined, CIP for any and all;
RUN 4: Sanitary sewage/waste water combined, SGP for any and all;
RUN 5: Sanitary sewage/waste water combined, Double layer pipe for any and all;

## 2-5 Results of Estimation

(1) $CO_2$ emission per useful life accompanying the construction

1) Feed water/drain piping - No coupling joint

a) Feed water system

The $CO_2$ emission is as below for each useful life with the receiver tank, gravity water tank, lift pump (2 units), and piping (46.5 m, 65 A). The total $CO_2$ emission with the respective useful lifes amounts to 1266.77 kg/useful life. As shown in Fig. 1 the 1266.77 kg - $CO_2$/each useful life was broken down into 2.1% for vertical pipes, 0.7% for horizontal pipes, 62.2% for receiver tank, 17.6% for gravity water tank, and 17.6% for lift pump. The water tanks occupying 79.8%, it was recognized that the $CO_2$ emission from piping is very little. The total $CO_2$ emission at uniform 30 years is 819.68kg-$CO_2$/useful life. This was broken down into 3.3% for vertical pipes, 1.1% for horizontal pipes, 64.0% for receiver tank, 18.1% for gravity water tank, and 13.5% for lift pump. The water tanks occupies 82.1%. The total $CO_2$ emission at uniform 30 years was lower than the numerical value as estimated for each service life.

### 2) Drainage System

(i) Piping separating sanitary sewage and waste water (distribution)

Our discussion included separate pipes for sanitary sewage and waste water, assuming three piping materials: CIP, SGP and double layer pipe. The $CO_2$ emission per useful life was calculated assuming CIP and double layer pipes for soil pipe system and CIP, SGP and double layer pipes for waste water system. Tables 2 and 3 show respectively the $CO_2$ emissions for each useful life and that for uniform 30 years of useful life.

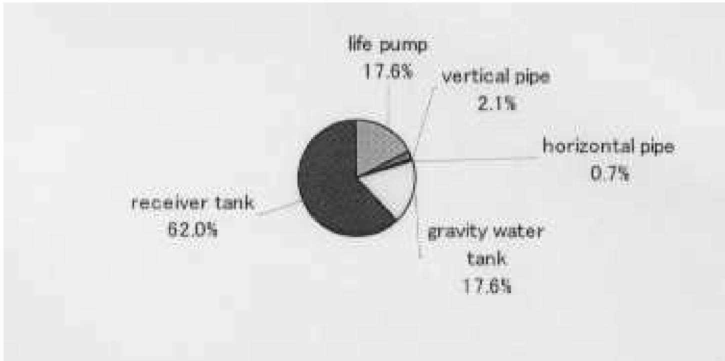


Fig. 1 Breakdown of $CO_2$ Emission in Feed Water System

Table 2 $CO_2$ Emission in Each Useful Life (kg~$CO_2$/useful life)

| | CIP | DOUBLE LAYER PIPE | SGP |
|---|---|---|---|
| Soil vertical pipe | 490.6 | 137.2 | |
| Soil horizontal pipe | 181.0 | 28.6 | 133.0 |
| Waste vertical pipe | | 14.0 | 47.6 |
| Waste horizontal pipe | 178.5 | 24.9 | 124.4 |
| Vertical vent(soil) | | 3.4 | 19.4 |
| Horizontal vent(soil) | 18.9 | 2.6 | 13.2 |
| Vertical vent(waste) | | 5.0 | 19.4 |
| Vertical vent(waste) | 35.8 | 5.0 | 25.0 |

DUBLE LAYER PIPE: fire-proof asbestos covered vinyl chloride pipe

(ii) Single piping for soil pipe and waste water pipe (combined)

In the case of discharging together the combined sanitary sewage and waste water, Tables 4 and 5 shows respectively the $CO_2$ emissions for each useful life and uniform 30 years of useful life.

Table 3 $CO_2$ Emission in Uniform 30 Useful Years(kg ~ $CO_2$ /useful life)

| | CIP | DOUBLE LAYER PIPE | SGP |
|---|---|---|---|
| Soil vertical pipe | 490.6 | 137.2 | |
| Soil horizontal pipe | 181.0 | 28.6 | 133.0 |
| Waste vertical pipe | | 14.0 | 47.6 |
| Waste horizontal pipe | 178.5 | 24.9 | 124.4 |
| Vertical vent(soil) | | 3.4 | 19.4 |
| Horizontal vent(soil) | 18.9 | 2.6 | 13.2 |
| Vertical vent(waste) | | 5.0 | 19.4 |
| Vertical vent(waste) | 35.8 | 5.0 | 25.0 |

Table 4 $CO_2$ Emission in Each Useful Life(kg ~ $CO_2$ /useful life)

| | CIP | DOUBLE LAYER PIPE | SGP |
|---|---|---|---|
| Drainage sack | 490.6 | 137.2 | 486.7 |
| Horizontal pipe | 294.1 | 53.5 | 212.3 |
| Vent stack | 20.3 | 3.4 | 19.4 |
| Branch vent pipe | 54.7 | 7.6 | 38.1 |

Table 5 $CO_2$ Emission in Uniform 30 Years Useful Years(kg ~ $CO_2$ /useful life)

| | CIP | DOUBLE LAYER PIPE | SGP |
|---|---|---|---|
| Drainage sack | 318.5 | 137.2 | 316.0 |
| Horizontal pipe | 247.5 | 53.5 | 207.6 |
| Vent stack | 13.5 | 3.4 | 12.9 |
| Branch vent pipe | 36.5 | 7.6 | 25.2 |

2 Feed water and drainage piping with coupling joint

a) Feed water system

It was recognized for each useful life that the $CO_2$ emission is by 0.8% higher with the pipes provided with GV, CV, flexible fittings, vibration-proof fittings, elbows and tees than that of straight pipes without any coupling joint.

b) Drainage system

In the case of separate piping for sanitary sewage and waste water, the $CO_2$ emission increases by 3.4% for soil pipe than that for straight pipe without any coupling joint, and $CO_2$ emission increases by 5.7% for waste pipe than that of the straight pipe without any coupling joint.

3) Sanitary fixture

Assuming that the building as a whole has 16 urinals, 16 water closets, 20 wash basins, 5sinks for cleaning, 5 kitchen sinks, and 20 bin cocks, the $CO_2$ emission for each useful life has come to be 75.77 kg-$CO_2$/useful life and 65.22 kg-$CO_2$/useful life for 30 years of uniform useful life.

4) Rainwater facilities

The $CO_2$ emission for rainwater vertical pipe plus rainwater pipe in the premises (both higher quality material) resulted in 140 kg-$CO_2$/useful life.

5) Fire extinguishing system

Assuming SGP as the piping material, the calculation of $CO_2$ emission from this system resulted in 103.1kg-$CO_2$/useful life for each useful life and 50 kg-$CO_2$/useful life for30 years of uniform useful life.

6) Domestic hot water supply system

The calculation of $CO_2$ emission from this system resulted in 28.7 kg-$CO_2$/useful life for 10 years of useful life and 9.6 kg-$CO_2$/useful life for thirty years of useful life.

(2) $CO_2$ emission per total floor area for useful life accompanying the construction

Fig. 2 shows the calculation results of $CO_2$ emission per total floor are a accompanying the construction against the useful life of each piping material including 5 types of drainage pipes. The conditions including the Run 1 resulted in 0.416 kg-$CO_2$/useful life/$m^2$, those including the Run 2, 0.301 kg-$CO_2$/useful life/$m^2$, those including the Run 3, 0.398 kg-$CO_2$/useful life/$m^2$, those including the Run 4, 0.398 kg-$CO_2$/useful life/$m^2$, and those including the Run 5, 0.298 kg-$CO_2$/useful life/$m^2$. The Run 1 in which separate sanitary sewage pipe and waste water pipe both made of CIP and SGP gave the highest $CO_2$ emission, while the Run 3 came next with combined sanitary sewage and waste water pipes in CIP. Then came the Run 4 with SGP piping. The Runs 2 and 5 containing the double layer pipes manifested the least numerical values. As shown in Fig. 2 the breakdown of these under the conditions including the Run 1 resulted in: 51.4% for feed water system, 3.0% for sanitary fixtures, 34.9% for sanitary sewage/waste water (vent) system, 5.7% for rain water system, 4.2% for extinguishment system, and 1.1% for hot water supply system. It was noted that the $CO_2$ emission is especially plenty in feed water system.

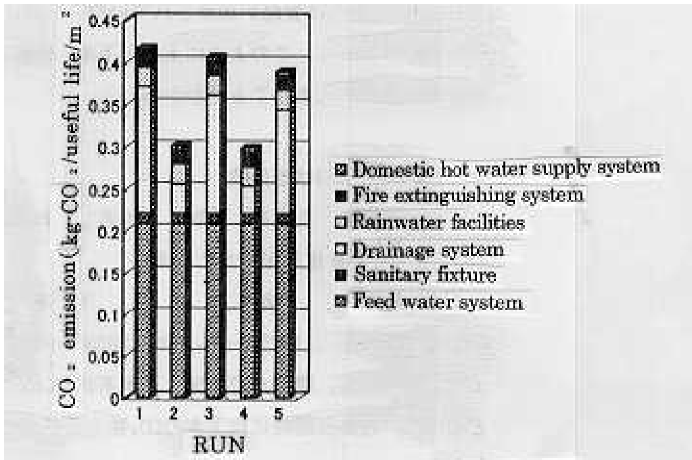

Fig. 2 $CO_2$ Emission per Total Floor Area

2-6 Reduction in $CO_2$ Emission

- The electric water heater should be as efficient as possible.
- Since the feed water system occupies 51.4% of the total $CO_2$ emission when constructing, other methodologies would have also to be taken into account.
- Because the $CO_2$ emission depends largely on the method of drainage system, it is necessary to consider most appropriate drainage system.

3.Electric Consumption ($CO_2$ Emission) in Water System Facilities

There exist varied forms of water environments that surround the building. Starting from the rain, there come a series of flows, first of the rain that seeps into the soil to become the ground water, and then of the water running out into the rivers, which will be collected and made potable. The drinkable water will then be distributed into the building, where it will be used and discharged. Then, the water will be treated to the extent that will not give any adverse effect on the surrounding environment.
We should necessarily utilize some energy to progress these processes. We should necessarily utilize some energy to progress these processes. Fig.3 illustrates this flow of water. Turning our attention only to the electricity in this long of water, we will elucidate how the energy has been used and propose some measures to save energy.

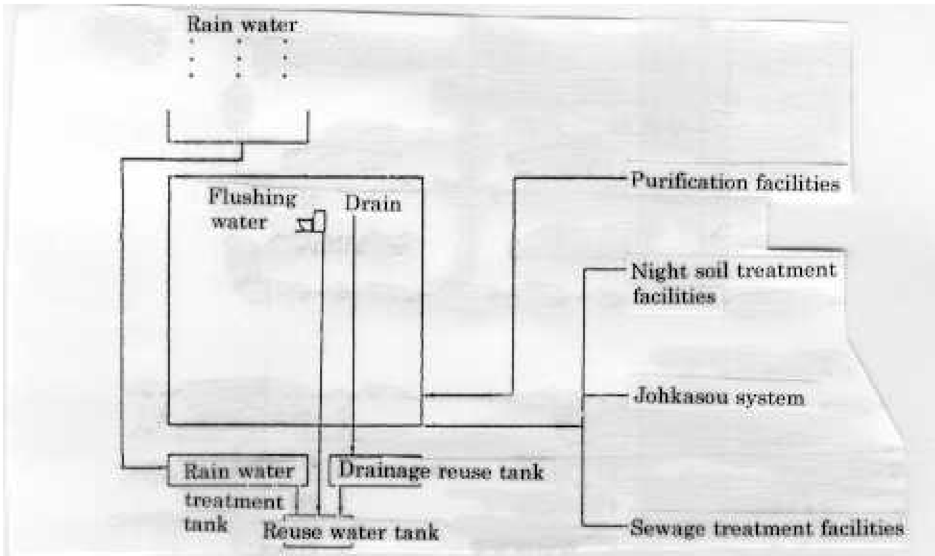


Fig. 3 Illustrates this flow of water.

3-1 Purification Facilities

According to the Water Supply Statistics in 1997, there are 15.492 units of purification facilities in Japan, and the population supplied amounts to 121,291,000 persons, which results in 96.1% of dissemination rate.The quantity of water used is converted into 389 L/person/day. Also according to the Water Supply Statistics in 1997, the electric consumption reaches 7,864,550,242 kWh. If it is divided by 16,546,766,000 $m^3$ of clear water volume, the electric consumption for 1 m3 of water comes to be 0.475 $kWh/m^3$ (0.24kg-$CO_2/m^3$). We then attempted to compare with each other the slow sand filtration, rapid sand filtration, and membrane filtration at the level of 10,000 $m^3$/day. The electric consumption turned out to be 8 kWh/day for the slow sand filtration, 170 kWh/day for the rapid sand filtration, and 1100 kWh/day for the membrane filtration. From this it is clear that there are large differences seen between and among the different filtrations.

3-2 Advanced Drinking Water Treatment System

From 1991 onward an extra-governmental body of the Ministry of Construction has performed individual evaluation based on the Building Standard Law, which led to the installation of numerous facilities and equipment as shown in Fig. 4. Table 6 depicts the results of electric consumption studied on the basis of the materials of an S Company. The subjects of electric consumption shall be supply pump, circulation pump and lift pump. Calculating the comparison objects within the range of 1 to 7.5 $m^3$/day, the electric consumption resulted in19.33 to 30.82 $kWh/m^3$(corresponding to 9.86 to 15.7 kg-$CO_2/m^3$).

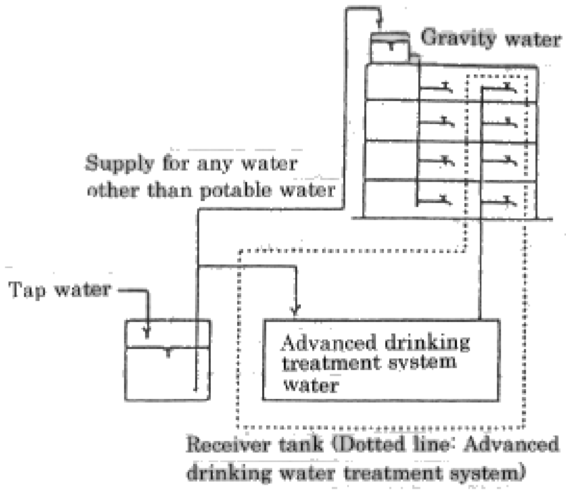


Fig.4 Outline of Advanced water treatment system

Table 6 Electric Consumption of Advanced Drinking Water Treatment System

| DRINKING WATER VOLUME ($m^3$/d) | ELETRIC CONSUMPTION (kWh/$m^3$) |
|---|---|
| 1 | 30.82 |
| 1.5 | 30.82 |
| 3.75 | 26.21 |
| 5.0 | 19.66 |
| 7.5 | 19.33 |

3-3 Water Recycling System

The water recycling system includes three methods: individual, district and wide area circulations. Installed as of the end of August 1997 were 1366 individual recycling systems (180,000 $m^3$/d), 109 district systems (20,000 $m^3$/d), and 627 (59 districts) wide area recycling systems (130,000 $m^3$/d). In this study we discussed the individual recycling systems. Table 7 indicates a standard treatment built up of the respective processes of: screening → flow control tank → biological/physicochemical treatment → disinfection. The biological/physicochemical treatment may roughly be divided into the following two: biological treatment + sand filtration + disinfection, on the one hand, and biological treatment + UF membrane treatment + disinfection, on the other. The disinfection method includes the chlorination, disinfection by ultraviolet light and concomitant use of ozone. Combining these, 6 types of standard treatment flows and 5 types of treatment water volumes were designed to show their electric consumption in Table 6.The method using the membrane treatment was compared with the biological treatment, which revealed its electric consumption twice or larger that of the former.

3-4 Rainwater Facilities

Studied was a 4~story building of a junior high school with 2,332 $m^2$ of roof area, 435 pupils and 26 teaching and clerical staff. The yearly use volume of rain water is 3,100 $m^3$, and the treatment flow of rainwater is screening + grit chamber + storage tank + disinfection equipment.The operating time of the lift pump was calculated out by dividing the yearly rainwater use volume by the power of life pump, and the electric energy by multiplying the same by the motive power. The resulting electric consumption was 0.25 kWh/$m^3$ (corresponding to 0.13 kg-$CO_2$/$m^3$).

Table 7  Electric Consumption in Model Designing (kWh/$m^3$)

| Treatment | 50 m /d | 100 m /d | 200 m /d | 400 m /d | 800 m /d |
|---|---|---|---|---|---|
| B+S+U | 2.58 | 1.4 | 1.19 | 1.24 | 1.27 |
| B+S+O | 1.4 | 2.14 | 1.95 | 1.93 | 1.72 |
| B+S+O | 2.7 | 1.5 | 1.22 | 1.28 | 1.33 |
| B+U+D | 5.16 | 4.5 | 4.14 | 3.43 | 3.39 |
| B+U+A+D | 3.32 | 4.69 | 4.21 | 3.5 | 3.48 |
| B+U+O | 4.02 | 5.33 | 4.93 | 4.22 | 3.87 |

B: biological treatment S: sand filtration treatment  U: UFmenmbrane treatment  D: disinfection (cloronation) A: activated carbon treatment

3-5  Building

The Building was designed as follows.  An office with 5 floors, total floor area: 6090 $m^2$.  Water is supplied from the gravity water tank, volume of water used: 60 $m^3$/day, lift pump capacity: 428 L/min. The drain tank system as adopted did separate the sanitary sewage from the waste water. The electric consumption has thus come to be 0.687 kWh/$m^3$.

3-6  Waste Water Facilities

According to the water supply statistics in 1997, the waste water facilities in Japan amounted to 1,438 in number with population of 73,110,000 persons served, resulting in 58% of dissemination rate.  The electric consumption at waste water facilities in 1997 reaches 5,304,383,000 kWh, and amounts to 5,840,241,000 kWh (0.47 kWh/$m^3$, 0.24 kg of $CO_2/m^3$) including the pumping stations.  The ratio to the total electric consumption in Japan is 0.57% for waste water facilities and 0.63 % if the pumping stations are to be included.  The electrical consumption is 0.46 times the sludge treatment cost, 0.22 timesthe chemicals cost, and 1.5 times the fuel cost.

3-7  Johkasou System

As of 1994, there are 7.77 million units of johkasou system, 92.3% out of which are the flush toilet wastewater treatment systems. The required power was assumed to be 0.04 kWh/$m^3$ for up to 100 persons served as flush toilet wastewater treatment system because there is no distinction between the flush toilet wastewater treatment and the domestic wastewater one.  For the case with 101 or more persons, the required power for the domestic waste water treatment system was assumed to be 0.08 kWh/$m^3$. The total electric consumption as assumed was calculated, which resulted in 0.81% of the total electric consumption all over Japan that was consumed by the johkasou system.  The designing was made assuming the provision of raw water pump for 10 $m^3$/d or more in 20 mg/L of final effluent for 5 to 500 users for designing.  The electric consumption was min. 1.22 kWh/$m^2$ (0.62 kg-$CO_2/m^3$)
and max. 2.14 kWh/$m^3$ (1.09 kg-$CO_2/m^3$) as shown in Fig. 5.

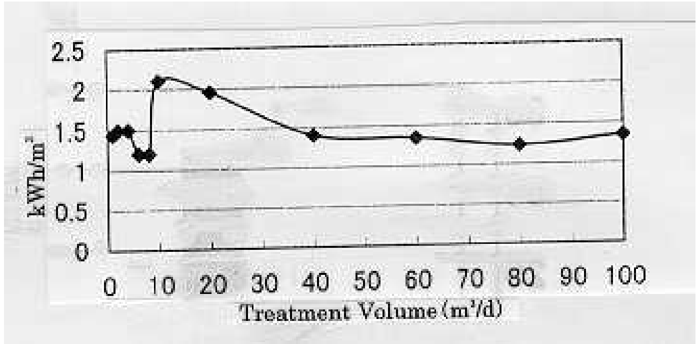


Fig. 5 Electric Consumption over 20 mg/L of Final Effluent of Johkasou System

3-8 Night Soil Treatment Facilities

With reduced night soil volume, the treatment volume has been decreasing little by little, as against the johkasou system sludge which has been increasing. As for the number of facilities installed, the aerobic treatment process has been reducing, while the standard denitrification process, denitrification-membrane filtration high load process have been increasing. From two years ago the sludge recycling treatment center has been implemented, and the whole situation of the treatment is about to change strikingly. In the standard denitrification process, the electric consumption is 83 kWh/kL (42 kg-$CO_2/m^3$) as the mean value out of 63 investigated cases, while in the aerobic treatment process it is 31kWh/kL ($m^3$) (16 kg-$CO_2/m^3$) as mean value out of 78 cases.

3-9 Reduction in Electric Consumption ($CO_2$ Emission)

The current electric consumption has been shown in the unit per water volume for eight fields: purification facilities, advanced drinking water treatment system, water recycling system, and rainwater utilization facilities as well as plumbing system, wastewater facilities, johkasou system, and night soil treatment facilities in the building. Fig. 6 lists up these units. The electric consumption of the advanced drinking water treatment system ranges from 64.7 times (max.) to 40.7 times (min.) that of the purification facilities, while that of water recycling system ranges from 7.6 times (max.) to 3.7 times (min.) that of the purification facilities. The electric consumption in the rainwater utilization facilities features 0.53 times. The plumbing system in the building features 1.4 times of electric consumption over that of purification facilities. The electric power consumed at the facilities. At the johkasou system, the electric consumption is 4.6 (max.) to 2.6 (min.) times wastewater facilities is of the same order as that of the purification that at the wastewater facilities. In the night soil treatment facilities, the consumption of electricity amounts to 176.6 times that at the wastewater facilities in their standard denitrification process, and 660 times in the aerobic treatment process.

- Purification facilities:

Though the slow sand filtration is an ideal sand filtration, the contamination of the raw water for water catchment should be controlled as far as possible so that as little as possible membrane treatment may be required. Viewed from the cost standpoint, the repair cost is 2.4 times the power cost and chemicals cost 0.18 times the power cost. We think it necessary therefore to consider some other costs than electricity.

- Advanced drinking water treatment system:

The principal policy should be to make use of the purification facilities so that the quality of tap water may not be reduced. The operating time of the advanced drinking water treatment system shall be as short as possible.

- Water recycling system:

Though the electric consumption is larger than that of the purification facilities, its necessity has widely been recognized from the viewpoint of the water demand. However, higher efficiency of this system should be taken into consideration because the membrane treatment requires more electricity.

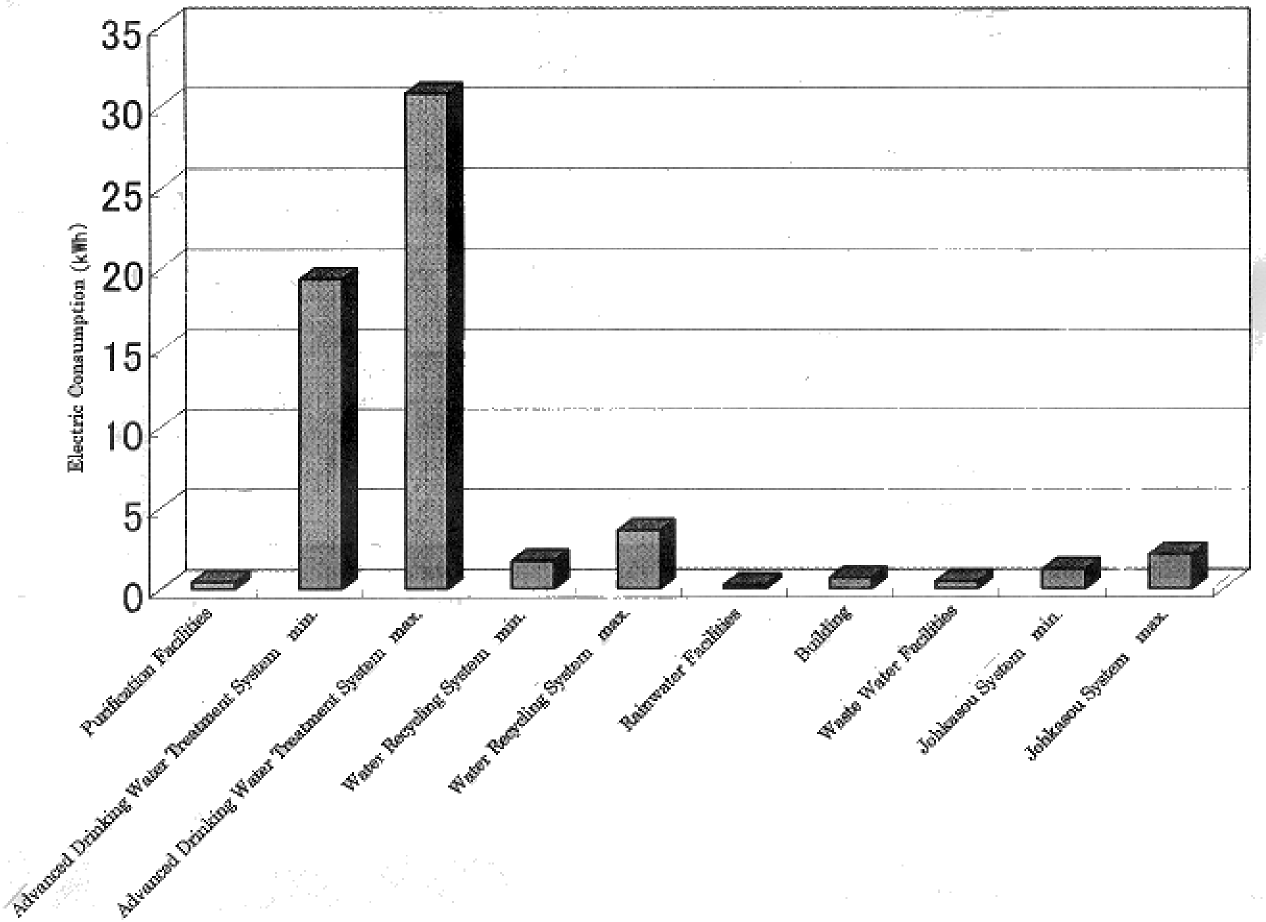


Fig.6 Electric Consumption in water System Facilities

- Rainwater utilization facilities:

Considered shall be such water catchment site that does not degrade the quality of catch water, simplified treatment and such position of storage tank that does not require any motive power for displacement.

- Johkasou system:

Since the numerical value calculated out here does not include any sludge treatment, it would become higher if it includes this treatment. Designing any good johkasou system would allow to exclude the pump cistern for raw water. It would be important to discuss the selection of individual treatment or centralized one in the installation districts. In future, we would have to evaluate the feasibility of the johkasou system in due connection with the night soil treatment facilities.

- Wastewater facilities:

They must make every possible effort for energy saving in the background where their dissemination rate will go ever increasing.

4. Conclusion

The consideration of $CO_2$ emission concerning the construction may curtail the environmental load through the selection of the water supply method and piping materials. The reduction in $CO_2$ emission relating to the maintenance and administration will lead to some great effect in reducing the environmental load in the water system facilities as a whole all through saving the water consumption in any building. It has therefore been recognized that the consideration of $CO_2$ emission may contribute to the reduction of environmental load in the plumbing system.

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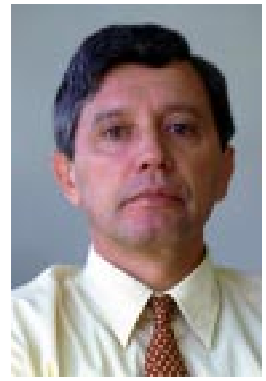
3) The Japan Sewage Works Association (corporation): Sewage Works Statistics, 1999 Fiscal Year

# Final Water Consumption in Building Installations Using the Flow-Rate Trace



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## Abstract

The knowledege of water consumption in building sanitary appliances, or end use in the north American terminology, is of paramount importance to establish decision take models in water conservation programs. This is in an incipient degree in Brazil up to now. Brazilian huge territorial extension, climatic differences, typical constructive patterns and economic, social and cultural differences, point out in the direction of obtaining segmented water consumption profiles.
In the process to determine typical consumption profile the methodology and techniques involved in direct field measurement are very important, since activities use to be time-consuming and related costs are considerable.
This article presents a methodology to analyse the flow rate trace, i.e. the flow hydrogram, in order to obtain the participation of several sanitary appliances in the water consumption. Previous knowledge of appliance discharge profile permits to identify it in the general water consumption flow rate trace.
The generalised use of cisterns in building water installation in Brazil, implies in a modified form of applying the technique. The building supplying pipe flow rate trace analysis shall be complemented with the analysis of the reservoir derived pipe flow rate trace.
The technique is described and pilot field measurements applied to bakeries in the Metropolitan Region of São Paulo, São Paulo State and residences in Juazeiro, Bahia State, are presented. Measurement analysis permited to identify and quantify typical flow rate traces of appliance discharges leading to the composition of total water consumption through particular appliance incidences.

## 1 Introduction

The knowledge of water consumption profile through sanitary appliances incidence, or end use consumption as has been used to be termed in the USA, is an essential element in water conservation programs in order to establish strategies aiming to rationalise and reduce water consumption in building installations. Furthermore, the effectiveness of water conservation programs actions only is safely verified when data referring water consumption incidence of sanitary appliances are available [1, 2].

Earlier literature presents the classic situation of appliance consumption in the USA and Great Britain, where the toilet was responsible for the major proportion among other appliances. As a consequence, an wide effort to reduce water consumption in that appliance was promoted since 80's beginning. This movement spread out to other countries, although in some cases without a cost-effectiveness approach.

Water consumption profile through sanitary appliances incidence, aiming to determine typical consumption profiles in buildings, has being object of experiments and have been performed incorporating instrument based technologies. A classic example of work in this field is the research in Malvern and Mansfield [3] in Great Britain, where the field survey combined water meter measurements, user participation in counting number of appliance use and typical measurement of appliance discharges.

Montenegro, 1986 [4] presents research carried out by IPT where specific instrumentation for water meters were developed with the intent of measuring total building water consumption. Since middle 80's IPT had been working with electronic instrument development to measure consumption in sanitary appliances. This effort permitted to get technology, i.e., instruments and methodology, to measure several parameters of interest in sanitary appliances utilisation [5, 6, 7].

More recently (1996), DeOreo et al. [8], developed an analysis technique of the building water consumption hydrogram to identify which and how certain appliances were particularly used onto the general circumstance of continuous building water utilisation. This technique makes use of statistical analysis of the hydrogram, i.e., the curve given by (time x flow-rate), that has been termed as flow-rate trace or flow trace [8]. The analysis of continuous flow-rate reading on the building supplying pipe, obtained by water meter endowed with data logger, provides the identification and quantification of previously known profiles referred to certain sanitary appliances. Through this analysis the number of each appliance utilisation, during a certain period, can be known.

In the flow-rate trace technique a statistic based software is used to analyse the trace. The analysis encompasses a sequential flow-rate trace reading, selecting each particular discharge profile previously measured for each sanitary appliance. This procedure permits, on the end, to add every occurrence of the same type, i.e., to add every typical appliance flow-rate trace. They can be presented as histograms and, finally, to be presented as the incidence of the appliance in the global building installation water consumption. Generalising it, the proportion of each appliance participation in the global consumption, can be achieved.

A quite clear restriction to the flow-rate trace analysis technique employment is the situation of simultaneous appliance utilisation. In this condition the typical flow-rate traces of two or more appliances are indistinguishable. This is a limit of the technique field application, but as shows DeOreo [8], the phenomenon is not pronounced in one-family dwellings. Thus, in this case, the technique can be utilised.

Employment of appliance direct measurement consumption techniques is conditioned by a series of factors, among which can be quoted:

- Building constructive characteristics;
- Water building installation characteristics;

- Sanitary appliances and fixture types;
- Available measurement technologies in face of building installation and constructive characteristics;
- Measurement costs;
- Problems pertaining to intrusive indoor interventions;
- Several other particular problems.

The advantages of the flow-rate trace analysis technique is promptly identified: relatively simple measurement technology, relative lower cost, greater flexibility and suitability for several types of sample installation measurement groups, among others.

Specific procedures to the flow-rate trace technique utilisation are necessary, when considering Brazilian building installation peculiarities. Generally, in one or two stored buildings, two combined water installation systems are present to distribute water: a direct system, i.e., a installation where water come directly from the public supply network to the sanitary appliances; an indirect system, i.e., a installation endowed with a cistern from which one or more pipes conduct water to the sanitary appliances. The cistern is supplied with water from the public network and the water level into it is controlled by a ball valve. In buildings with several stores the installation is a bit more complex. Part of the appliances are supplied through direct installation, as in the former case, up to two stores. As the water from the public water has not enough pressure to reach the building cover in the case of several stores, a lower reservoir is provided. This reservoir, supplied directly from the public network, has it water level controlled through a ball valve. The water from the lower reservoir is pumped to the building cover reservoir, from which one or more pipes derive water, by gravity, to sanitary appliances below.

Taking into account this peculiarities it is evident the limitation of the flow-rate trace analysis technique, since appliances are, in the direct and indirect combined system, supplied by water coming directly from the mains and from the elevated reservoir. Diversely of other countries where direct supplying system are more frequent, in Brazil, in many cases, will be necessary the simultaneous analysis of flow-rate traces from the pipe directed supplied and from the pipe deriving from the elevated reservoir. Even in this situation, the technique is less intrusive than others that require indoor direct appliance instrumentation.

This article describes the application of the flow-rate trace technique in the consumption profile of bakeries of the Metropolitan Region of São Paulo, São Paulo State, Brazil south-east. These bakeries are typical small commerce establishment of São Paulo Metropolitan areas. They make bread, serve sandwich, hot and cool beverages, make other fast-food and sell several other products for quick lunches. Also are shown results from the application of the technique to one-floor residences in the city of Juazeiro, Bahia State, Brazil north-east. In this case, residences with consumption varying from 7 to 56 $m^3$/month in two districts of the city, were measured.

## 2 Flow-Rate Trace Analysis Technique and Results

The continuous consumption flow-rate trace diagrams obtained in the field applications in São Paulo and Juazeiro were obtained using volumetric water meters, where the rotation of a magnetic part provides a pulse for each water meter volumetric camera turn. The signal is detected by a sensor that transmits it to a electronic register circuit that associates the signal to time. This provides a pair (signal, time) that is recorded continuously. Since the signal is representative of a certain volume, corresponding to a water-meter camera turn, it is possible to associate that volume to the time between consecutive water-meter camera turns. Thus is promptly obtained the flow-rate in time, i.e., the flow-rate trace, a pair (time, flow-rate).

In quoted applications, were used volumetric water-meter “C” class [9], 1.5 $m^3$/h of nominal flow-rate, with resolution of 0.1 L. The signal sensor detected and registered the time departed between each pulse associated to the 0.1 L volume. The flow-rate trace originated from these data acquisition resolutions, permitted to get necessary parameters to identify the typical appliance discharge profile for each particular sanitary appliance.

Each particular appliance discharge profile was identified according to one or more of the following information approaching:

1. Interview and questionnaires applied to users searching appliances use time, other habits and varied uses of sanitary appliances;
2. Appliance flow-rate trace characteristics, taking into account previous knowledge of profile of each appliance;
3. Direct observation of consumption habits, registering time and duration of use for each appliance;
4. Simulated use of each isolated appliance, acting as close to the real use as possible – generally overnight – observing that no other appliance would be used simultaneously. In the case of indirect water distribution systems (with an elevated reservoir), the ball valve was verified to assure non occurrence of flow through it.

First and second approach has shown more suitable to residential installations, where the variability of use are not pronounced, nevertheless, in some cases, the fourth approach has shown to be very effective when there is an easy access to the water building installation. In the bakeries, were also performed previous audits in the water installations, drawing the lay-out.

The typical flow-rate trace of appliance discharges affords the identification of discharge duration, the flow-rate values during the discharge and, after data processing, the discharge volume of each appliance. When suitable amplified, the trace provides visual identification of to which appliance the profile refers, due to its geometric characteristics, as well due to some of each characteristics values: duration time and flow-rate values. Alternatively, the flow-rate trace typical appliance profile can be determined in controlled laboratory measurements.

Figure 1 illustrates the flow-rate trace typical profile of lavatories and toilet cistern in bakeries.

It shall be remembered that the flow-rate trace depends on water pressure in the appliance. Pressure variation can change considerably the appliance profile. In the field measurement this aspect was controlled. Water pressure measurement was performed together with the flow-rate trace measurement, to detect any problem.

In the city of Juazeiro, pressure control was considered not to be important, since that in the monitored districts there was not a historic variation of pressure values.

In the case of considerable water pressure variation, the trace profiles should be associated with the pressure range variation during supplying.

Water meters were installed in the building supplying pipe, derived from the public water supply network. In the cases where the characteristics of elevated reservoir required an extra water-mater, it was installed in the pipe deriving from the reservoir.

It shall be remarked that in the districts of Juazeiro city where the measurements were carried on, almost all the appliances were supplied direct from the public supply netwo vated cisterns, in these case, have a subsidiary function, not important to surements.

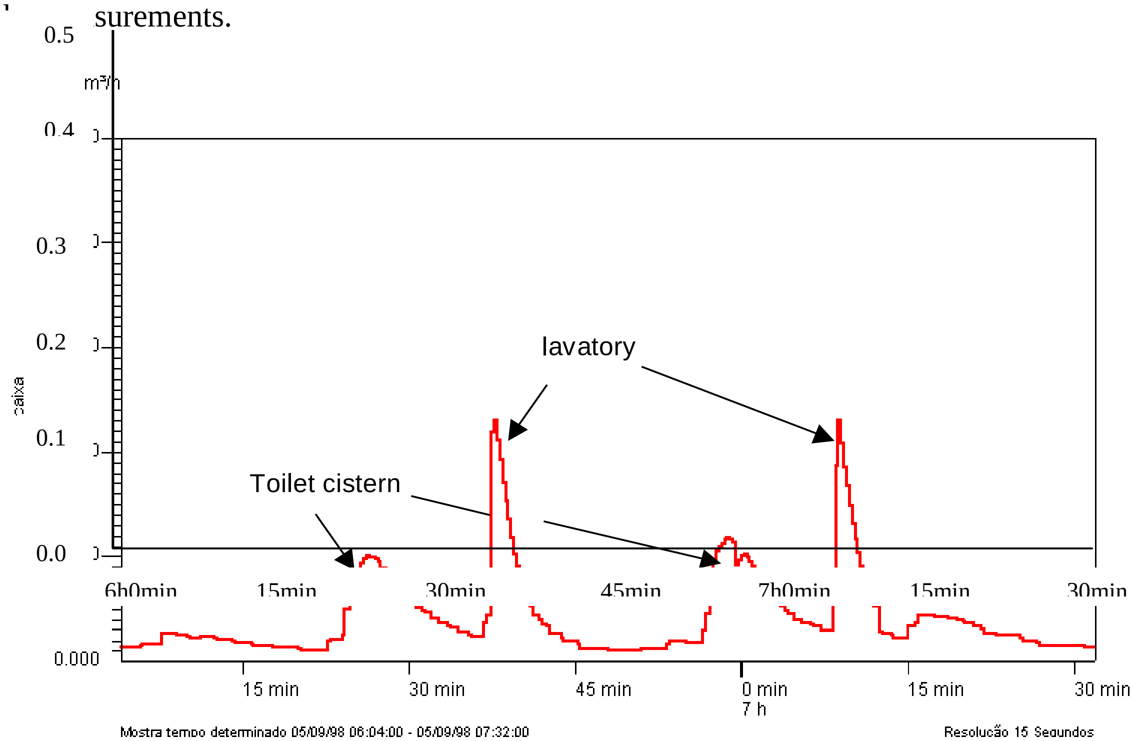


Figure 1 – Flow-rate trace typical profile of lavatories and toilet cisterns in bakeries.

The identification of flow-rate trace of appliances served by pipes deriving from the elevated cistern, required two types of procedures. In the first case the discharge profile was inferred from the registered flow-rate trace measured at the pipe supplied from the public network.  The inference is possible when the flow-rate trace characteristic of the ball valve serving the cistern is altered through the effect of the use of one appliance served by the elevated reservoir. In this case the reservoir acts as a softening camera for the discharge trace. However, in many cases it is possible to observe in the ball valve characteristic trace,  that has long duration, the occurrence of an appliance discharge, through its known trace, over the ball valve trace. It shall also be observed that this same procedure can be is applied to the discharge of appliances served by the direct installation part, in a direct and indirect typical Brazilian system. It should be remembered that in  this case the water meter and its instruments will be registering simultaneously the directed served appliances functioning plus the flow through the ball valve that serves the elevated cistern. In the latter case, obviously, it will not be observed the reservoir softening effect, but only the appliance typical flow-rate trace over the long trace of the ball valve.

In some cases, however, will not be possible to identify the appliance discharge trace over the ball valve trace. This will occur, for example, when the appliance trace appears excessively dumped over the ball valve trace. The phenomenon can be observed in large building reservoirs or when the water surface area into the reservoir is quite large. In these conditions the water level  inside the reservoir will not change too much, and, thus the effect in the ball valve trace will be not too pronounced.

In the depicted condition it was necessary to install another instrumented water meter in the pipe deriving from the reservoir, serving other appliances below it.

In any of the remarked cases the condition of non simultaneous functioning shall be verified. In most of the studied cases here presented this hypotheses was observed.

Used data loggers have inside batteries. The sets of volumetric water meter, magnetic transmission equipment and electronic registers, have about 10 days of use capacity. Data logger memory capacity are big enough for this period.

In the field measurements in Juazeiro and São Paulo the flow-rate traces correspond to a 7 days data acquisition period. It comprises a week end so that particular effects of these days can be diluted in the entire period.

Figure 2 presents the flow-rate trace of a typical residence in Juazeiro [10] durir
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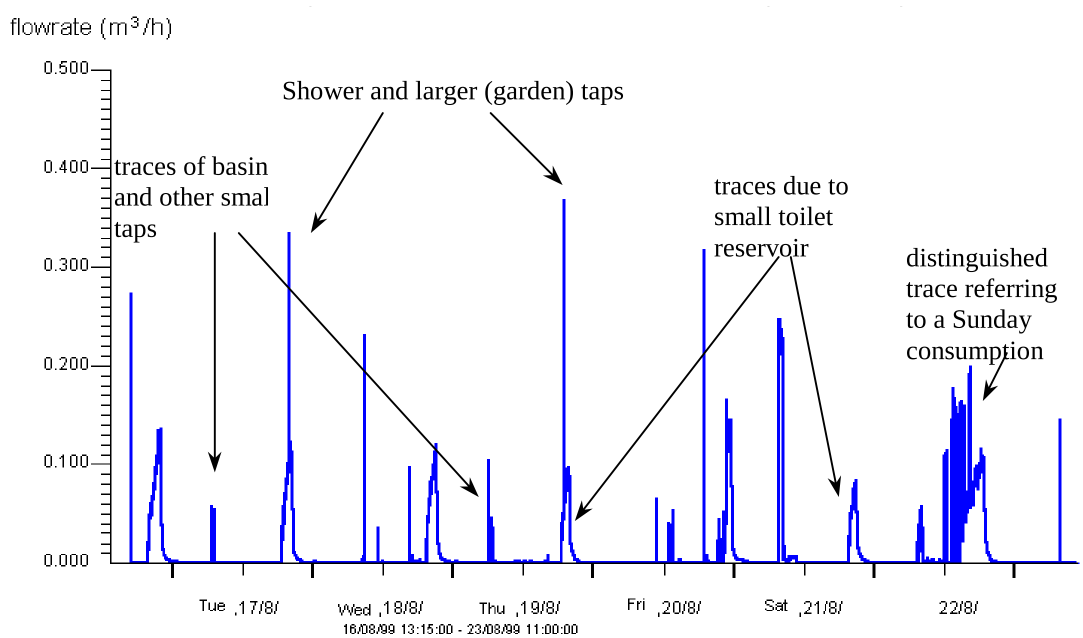


Figure 2 Flow-rate trace of a residence of 20 $m^3$ per month consumption, with the identification of several water uses.

In the trace the use of common taps can be correlated to cloth washing and garden taps. The higher peaks represent higher flowrate devices connected to the main distribution net, in this case identified as showers, that in Juazeiro commonly uses cold water and have high flowrates.

The water reservoir, in this consumer, is small and related to kitchen uses, toilet and the bathroom basin tap. It can be also observed that there is a consumption concentration in the afternoon, and that there shower is used every day, approximately at the same time.

It can be observed by the consumption distribution,  that the trace identifies the device and that some times is not totally possible correlate it to the water use. In Other words, by trace analysis it is possible to identify which device is been used but not if this water is used to cook or to wash dishes, for example.

In figure 3 is presented the average consumption histogram for four residences with monthly consumption varying from 17 up to 24 $m^3$. It can be observed that most of the water is consumed at intermediate flow rates, that confirms that the use of reservoirs, that have characteristic low inlet flow rate, is mainly related to toilet uses and for drinking water.

The identifiable consumption at flowrates over 400 L/h, shows that high flow rate devices, as showers, spite this not frequent use, plays a significant role in the whole water consumption.

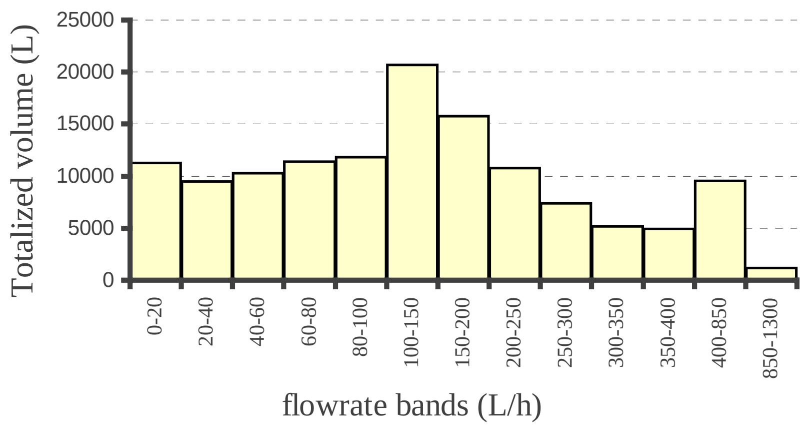


Figure 3 – Water consumption histogram of residences with monthly consumption from 17 up to 24 $m^3$, in Juazeiro, Bahia .

Figure 4 presents the flow-rate trace of a bakery with direct and indirect water distribution system [11]. Figure 5 shows the participation of several parts of a bakery in the total consumption [11].

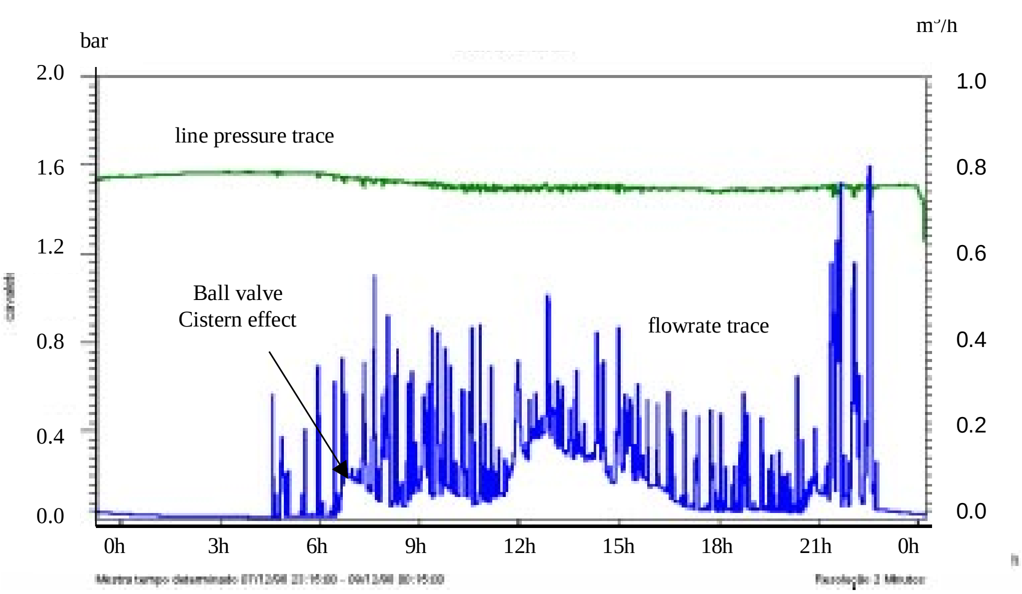

Figure 4 – One day flow-rate trace of a bakery in São Paulo, showing the effect of the cistern ball valve

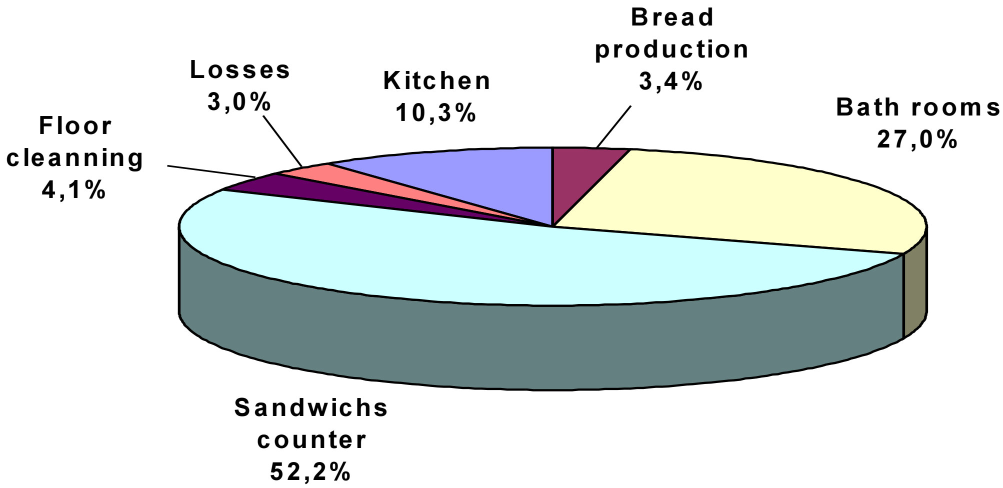


Figure 5 – Water consumption proportion in a bakery in São Paulo according to activicties

## 3 Analysis of results

The indirect water distribution system, using the elevated building cistern, was the preliminary doubt referred to the flow-rate trace use efficacy in the application to the Brazilian practical cases. Field results, here presented, has shown that is possible to incorporate the effect of the flow through the reservoir ball valve. Thus, apparent problems in the technique use can be supplanted.

In some cases, however, the flow-rate traces of appliance discharges appear too damped, requiring a complement in the original procedure. This is simply performed getting the flow-rate trace in the pipe, or pipes, that deriving from the elevated cistern serves the sanitary appliances below it.

The accuracy degree obtained is satisfactory and fulfil the necessity referred to future works of determining the water use profile according to sanitary appliances through field measurements. The accuracy and appropriateness are mainly due high resolution water meters and associated equipment availability. Also it is important the extremely low data reading time of electronic registers and the reliability acquired in manipulating data using statistic based software.

In the field measurement and further flow-rate trace technique application it was possible to incorporate the participation of following appliances: toilets discharged with cisterns, toilets discharged with flush valves, registers and faucets associated with several appliances (lavatory, kitchen sink, laundry, shower, filter, urinals and general floor cleaning faucets). Besides, as its is clear from the above exposition, it was possible to incorporate the reservoir ball valve role.

## 4 Further work

The work continuity refers to a wide application field for the flow-rate trace technique. It can be foresee applications in field measurements to establish water consumption profiles as a powerful tool for water conservation programs; field measurements aiming to establish the consumption parameterisation of great water consumers; field measurements to determine the undermetering in water meters, etc.

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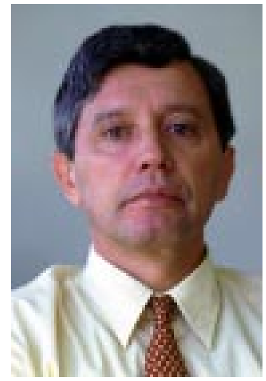

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Water meters were installed in the building supplying pipe, derived from the public water supply network. In the cases where the characteristics of elevated reservoir required an extra water-mater, it was installed in the pipe deriving from the reservoir.

It shall be remarked that in the districts of Juazeiro city where the measurements were carried on, almost all the appliances were supplied direct from the public supply netwo ated cisterns, in these case, have a subsidiary function, not important to f surements.

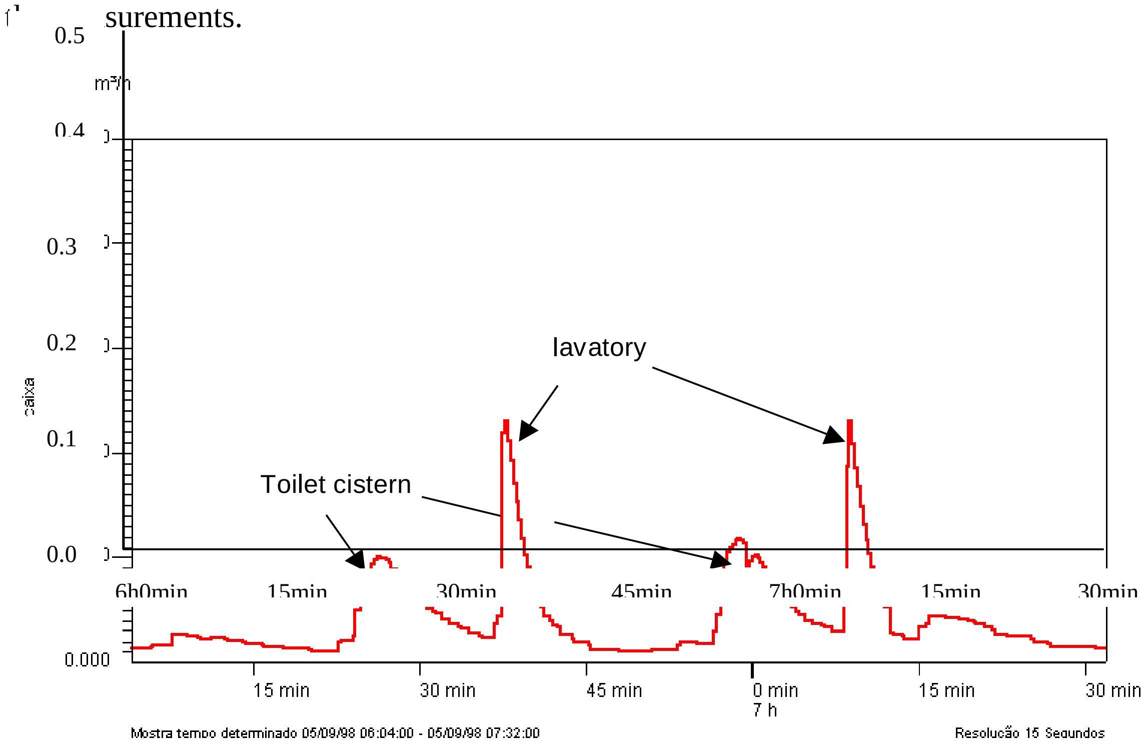


Figure 1 – Flow-rate trace typical profile of lavatories and toilet cisterns in bakeries.

The identification of flow-rate trace of appliances served by pipes deriving from the elevated cistern, required two types of procedures. In the first case the discharge profile was inferred from the registered flow-rate trace measured at the pipe supplied from the public network. The inference is possible when the flow-rate trace characteristic of the ball valve serving the cistern is altered through the effect of the use of one appliance served by the elevated reservoir. In this case the reservoir acts as a softening camera for the discharge trace. However, in many cases it is possible to observe in the ball valve characteristic trace, that has long duration, the occurrence of an appliance discharge, through its known trace, over the ball valve trace. It shall also be observed that this same procedure can be is applied to the discharge of appliances served by the direct installation part, in a direct and indirect typical Brazilian system. It should be remembered that in this case the water meter and its instruments will be registering simultaneously the directed served appliances functioning plus the flow through the ball valve that serves the elevated cistern. In the latter case, obviously, it will not be observed the reservoir softening effect, but only the appliance typical flow-rate trace over the long trace of the ball valve.

In some cases, however, will not be possible to identify the appliance discharge trace over the ball valve trace. This will occur, for example, when the appliance trace appears excessively dumped over the ball valve trace. The phenomenon can be observed in large building reservoirs or when the water surface area into the reservoir is quite large. In these conditions the water level inside the reservoir will not change too much, and, thus the effect in the ball valve trace will be not too pronounced.

In the depicted condition it was necessary to install another instrumented water meter in the pipe deriving from the reservoir, serving other appliances below it.

In any of the remarked cases the condition of non simultaneous functioning shall be verified. In most of the studied cases here presented this hypotheses was observed.

Used data loggers have inside batteries. The sets of volumetric water meter, magnetic transmission equipment and electronic registers, have about 10 days of use capacity. Data logger memory capacity are big enough for this period.

In the field measurements in Juazeiro and São Paulo the flow-rate traces correspond to a 7 days data acquisition period. It comprises a week end so that particular effects of these days can be diluted in the entire period.

Figure 2 presents the flow-rate trace of a typical residence in Juazeiro [10] durir
cons

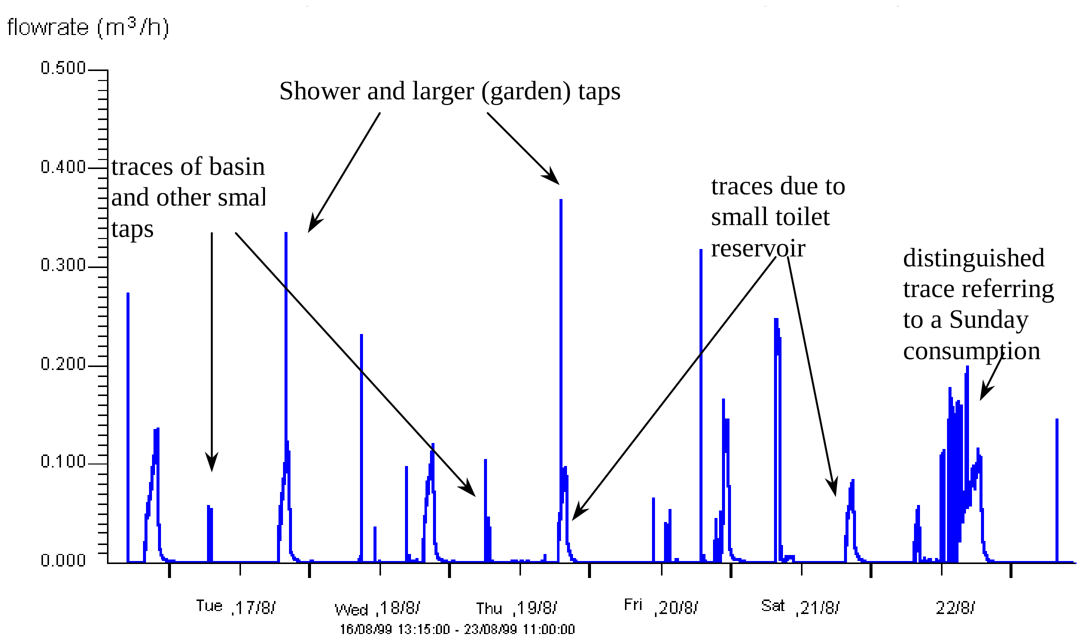


Figure 2 Flow-rate trace of a residence of 20 $m^3$ per month consumption, with the identification of several water uses.

In the trace the use of common taps can be correlated to cloth washing and garden taps. The higher peaks represent higher flowrate devices connected to the main distribution net, in this case identified as showers, that in Juazeiro commonly uses cold water and have high flowrates.

The water reservoir, in this consumer, is small and related to kitchen uses, toilet and the bathroom basin tap. It can be also observed that there is a consumption concentration in the afternoon, and that there shower is used every day, approximately at the same time.

It can be observed by the consumption distribution, that the trace identifies the device and that some times is not totally possible correlate it to the water use. In Other words, by trace analysis it is possible to identify which device is been used but not if this water is used to cook or to wash dishes, for example.

In figure 3 is presented the average consumption histogram for four residences with monthly consumption varying from 17 up to 24 $m^3$. It can be observed that most of the water is consumed at intermediate flow rates, that confirms that the use of reservoirs, that have characteristic low inlet flow rate, is mainly related to toilet uses and for drinking water.

The identifiable consumption at flowrates over 400 L/h, shows that high flow rate devices, as showers, spite this not frequent use, plays a significant role in the whole water consumption.

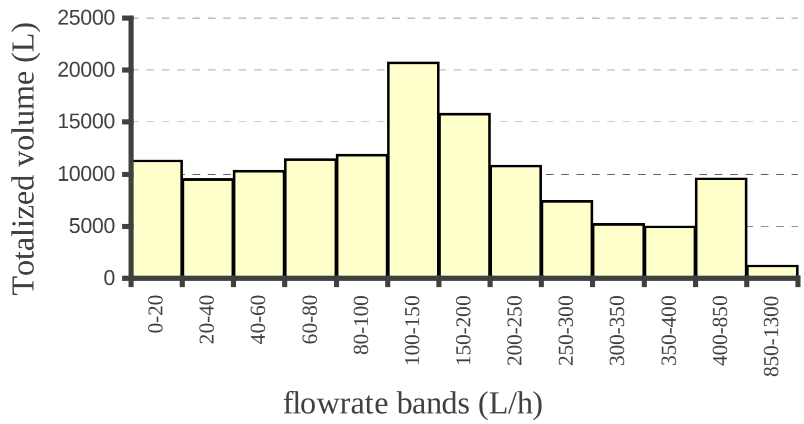


Figure 3 – Water consumption histogram of residences with monthly consumption from 17 up to 24 $m^3$, in Juazeiro, Bahia .

Figure 4 presents the flow-rate trace of a bakery with direct and indirect water distribution system [11]. Figure 5 shows the participation of several parts of a bakery in the total consumption [11].

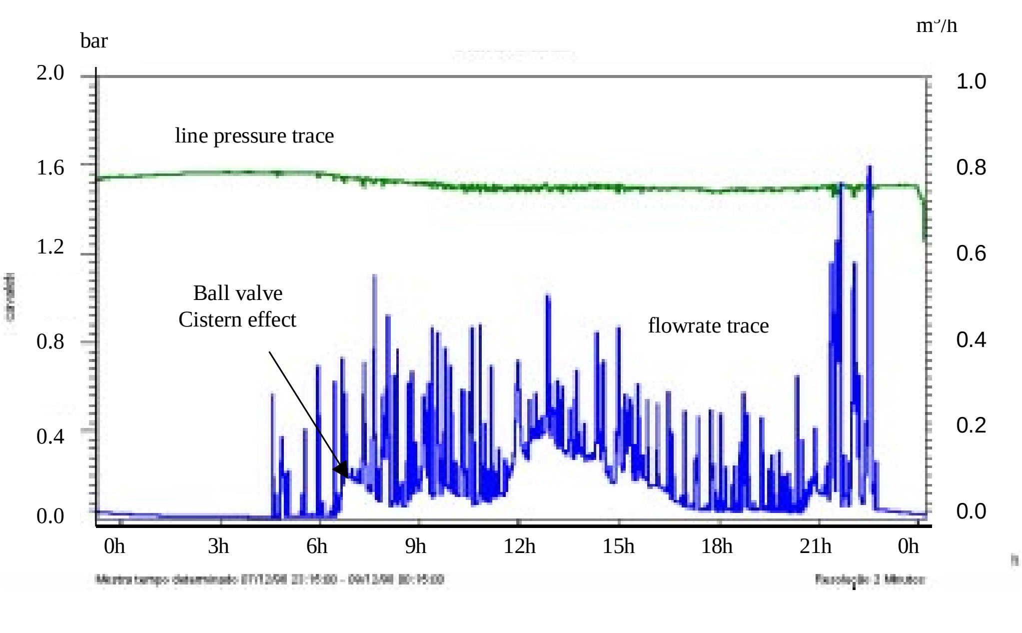

Figure 4 – One day flow-rate trace of a bakery in São Paulo, showing the effect of the cistern ball valve

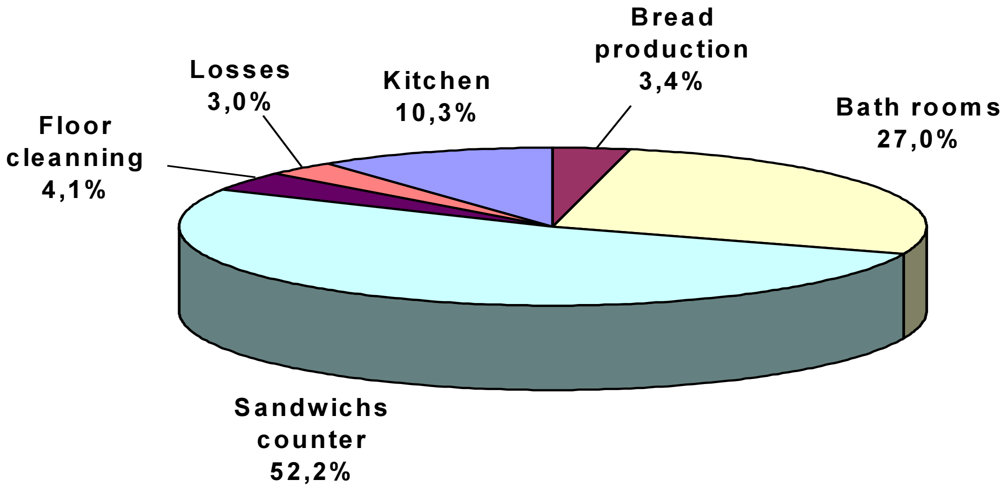


Figure 5 – Water consumption proportion in a bakery in São Paulo according to activicties

## 3 Analysis of results

The indirect water distribution system, using the elevated building cistern, was the preliminary doubt referred to the flow-rate trace use efficacy in the application to the Brazilian practical cases. Field results, here presented, has shown that is possible to incorporate the effect of the flow through the reservoir ball valve. Thus, apparent problems in the technique use can be supplanted.

In some cases, however, the flow-rate traces of appliance discharges appear too damped, requiring a complement in the original procedure. This is simply performed getting the flow-rate trace in the pipe, or pipes, that deriving from the elevated cistern serves the sanitary appliances below it.

The accuracy degree obtained is satisfactory and fulfil the necessity referred to future works of determining the water use profile according to sanitary appliances through field measurements. The accuracy and appropriateness are mainly due high resolution water meters and associated equipment availability. Also it is important the extremely low data reading time of electronic registers and the reliability acquired in manipulating data using statistic based software.

In the field measurement and further flow-rate trace technique application it was possible to incorporate the participation of following appliances: toilets discharged with cisterns, toilets discharged with flush valves, registers and faucets associated with several appliances (lavatory, kitchen sink, laundry, shower, filter, urinals and general floor cleaning faucets). Besides, as its is clear from the above exposition, it was possible to incorporate the reservoir ball valve role.

## 4 Further work

The work continuity refers to a wide application field for the flow-rate trace technique. It can be foresee applications in field measurements to establish water consumption profiles as a powerful tool for water conservation programs; field measurements aiming to establish the consumption parameterisation of great water consumers; field measurements to determine the undermetering in water meters, etc.

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# Study for determining discharge volumes for low flush toilets

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Tesis - Tecnologia de Sistemas em Engenharia

## Abstract

Concerning water availability, Brazil is a privileged country since it has about 15% of the total fresh water in the world. But the south and southeast regions, that are responsible for the major consumption, have only 12 percent of this total. The Federal Government (Ministry of Planning and Budget) launched, in March 1998, the National Plan against waste of water (PNCDA), which contemplates two levels of actuation: meso (water and drainage public systems) and micro (building and communitarian systems). Also in 1998 the Federal Government launched the National Program of Quality and Productivity of residence construction (PBQP-H), whose purpose is going against the construction materials (including building systems components). Inside the PBQP-H, there is the Sectorial Program of vitreous china plumbing fixtures, which has a specific goal concerning water closets (and discharge appliances) in such a way that until 2000 the discharge volume of the toilets that will be manufactured is limited to 9 liters and until 2002 it will be approximately 6 liters. This paper presents the study that has been developed to define the volume that will be used in Brazilian water closets, the functional performance requirements and test methods. The study contemplates laboratory and field investigation. In the laboratory, some tests have been done to define the discharge volumes for Brazilian systems. In the field investigation, the water consumption and the performance of twenty-four low flush water closets have been monitored in low-income houses.

## Keywords

Low flush toilets; water conservation, water closets.

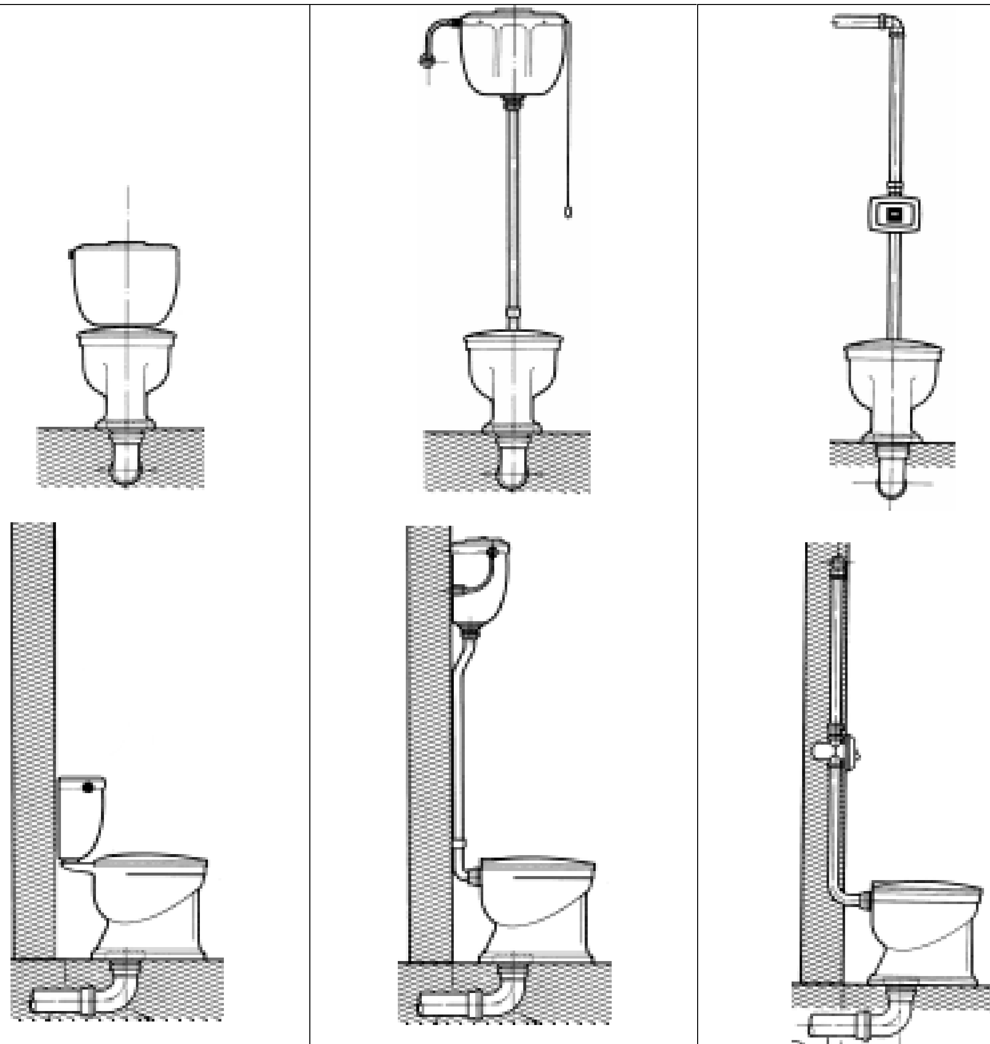
## 1 Introduction

Concerning water availability, Brazil is a privileged country since it has about 15% of the total fresh water in the world. But the south and Southeast regions, that are responsible for the major consumption, have only 12% of this total.
The Federal Government (Ministry of Planning and Budget) launched, in March 1998, the National Plan against waste of water (PNCDA), whose general objective is: "to promote the water rational use for public supply in Brazilian cities, in benefit of public health; environmental sanitation and services efficiency, leading to better productivity of the existent assets and postponing the investments for system expansion" (MPO/SEPURB-PNCDA,1998).
Also in 1998 the Federal Government launched the National Program of Quality and Productivity of residence construction -PBQP-H (MPO/SEPURB-PBQP,1998), whose purpose is going against the non-conformity of the construction materials (including building systems components).Inside the PBQP-H there is the Sectorial Program of vitreous china plumbing fixtures, which has a specific goal concerning toilets (and discharge appliances) in such a way that, until 2000 the discharge volume of the toilets that will be manufactured is limited to 9 liters and, until 2002 it will be approximately 6 liters.
Inserted in this Program, a study has been developed for determining the adequate volume for Brazilian low flush toilets since March 1999.
This paper presents the methodology and preliminary results of this study, which contemplates laboratory and field investigations and had been developed by researchers from two Universities of Sao Paulo State and the vitreous china fixtures manufacturers.

## 2 Laboratory Investigation

In Brazil, there are technical standards to evaluate toilet performance with different types of media (ABNT, 1997a, 1997b). These tests and evaluation criteria are based on ASME (1998) which is currently under examination.
However test procedures are similar in both standards: pressure and flow rates are different, since Brazilian cold water building systems are essentially indirect, with one or more elevated reservoirs.
Also, Brazilian water closets can be supplied with three types of discharge devices: valve, close-coupled and elevated tanks (see Figure 1). Pressure and flow rates for functional performance tests of the toilets are established by discharge devices standards (ABNT, 1991a, 1991b, 1993a, 1993b).
Brazilian standards contemplate the following tests: waste removal (polypropylene balls, toilet paper), surface wash (ink test), water change (dye test), trap seal restoration, seat fouling test, transport test (with polypropylene balls), back pressure resistance of trap seal.
As in the USA, the advent of low flush toilets, with unique and distinct hydraulic (flushing) characteristics, as shown in ILHA; KONEN (2000) mandated change in the methodology for measuring functional performance of these fixtures.
Inserted in this context, a laboratory investigation has been conducted, with help of the Stevens Institute of Technology, Hoboken, NJ, USA, which has developed a series of studies concerning water closets performance evaluation.

Pressure and flow rates used for the tests are shown in Table 1. Laboratory setup is shown in Figure 2.



close-coupled | with elevated tank | valve operated

**Figure 1 - Brazilian water closets.**

**Table 1- Pressures and flow rates used for Brazilian water-closets tests.**

| **WC /flushing device** | **Flow rate (l/s)** | | **Dynamic Pressure (kPa)** | |
|---|---|---|---|---|
| | **(1)** | **(2)** | **(1)** | **(2)** |
| with elevated tank | 0,19 | 0,10 | 60 | 15 |
| Close-coupled | 0,19 | 0,10 | 60 | 20 |
| Valve operated | 1,50 | 1,50 | 100 | 12 |

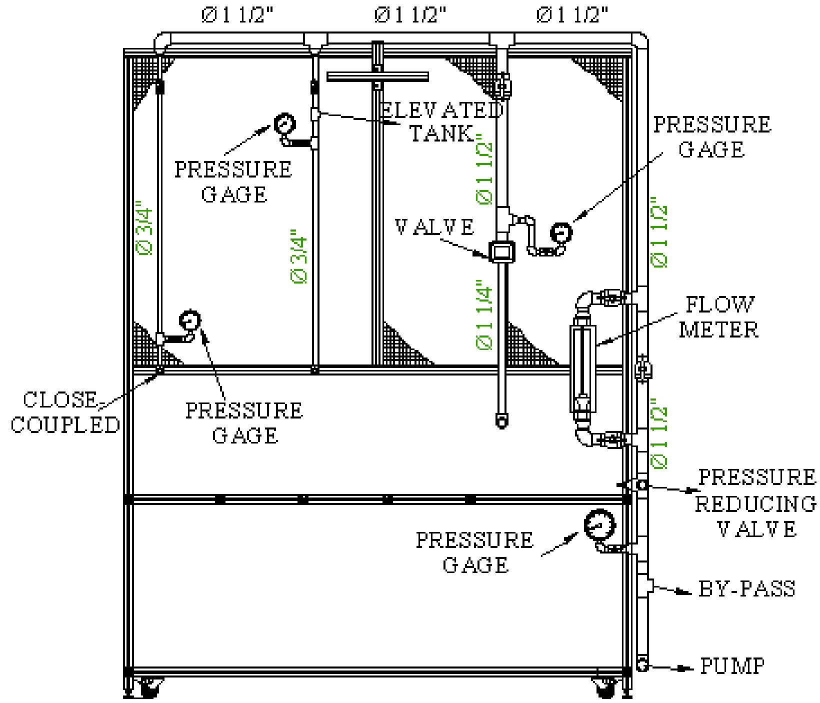



**Figure 2 - Laboratory setup.**

Brazilian low flush toilets have been tested with mixed media with neutrally buoyant wastes (sponges (S) and Kraft paper (P)), based on Stevens Institute experience, which has shown that "polyurethane sponges behave in an acceptable manner and provide a reasonable simulation of waste material. The addition of Kraft paper results in a mixed media even more representative of actual use" (ILHA, KONEN, 2000).
Media characterization and test procedure is explained in the following item.
Also, the following test has been done: waste removal (polypropylene balls) and transport test (sponges and polypropylene balls).

### 2.1 Mixed Media with Neutrally Buoyant Wastes Test

Test Media **Synthetic open cell polyurethane sponges**, white, 20 X 20 (+/-1) X 57 (+/-3) mm having a density of 17 (+/-1.7) kg/m$^3$ when new.
**Kraft anti-tarnish paper**, 7.5 X 6 inches 15 pound, 486 sheets to the ream. Crinkle each of the required number of sheets between the palms of hands to form the required number of balls approximately one (1) to two (2) inches in diameter. Hold the paper balls under the water for three (3) to five (5) seconds to saturate the medium before each test run.
Four units (two close-coupled and two for valve and/or elevated tank) of seven Brazilian manufacturers were tested with the following testing loads: 10S & 6P (Test 1), 15S & 10P (Test 2), 15S & 15P (Test 3), 12S & 10P (Test 4), 7S & 4P (Test 5).
Test 1 was discarded afterwards, since it was considered too light. Test 4, which was established based on results of other tests, was not done with all fixtures.

2.1.1 Procedure
Place the required number of new conditioned sponges in the test bowl and squeeze them under water to remove air, saturating the media. The sponges should be floating with the top of each sponge even with the water surface. Slowly refill the well with

water to ensure a full depth of seal. Drop the paper balls into the well, and flush the unit. The actuator shall be depressed and held for one (1) second. After the flush cycle is completed, count and record the number of sponges and paper balls discharged through the fixture (adapted from STEVENS INSTITUTE OF TECHNOLOGY, 1999).

2.1.2 Results

Criteria for acceptance of the water closets are not yet defined, since field results are being now analyzed and need to be compared with those obtained in the laboratory. Results of four test loads for all types of water closets and discharge devices are shown in Figures 4 to 6. Table 2 shows averages of percentages of total loads extracted in each first flush (the worst of five results was discarded for calculating the averages).

**Table 2 - Percentages of total loads extracted in first flush (four best results).**

| Test | Sponges & Kraft paper | Water Closet / flush device type | | |
|---|---|---|---|---|
| | | with elevated tank | Close-coupled | Valve operated |
| 1 | 10S&6P | 87.5 | 80.6 | 91.3 |
| 2 | 15S&10P | 71.6 | 52.8 | 73.2 |
| 3 | 15S&15P | 61.3 | 35.7 | 63.7 |
| 4 | 12S&10P | 74.5 | --- | 85.0 |

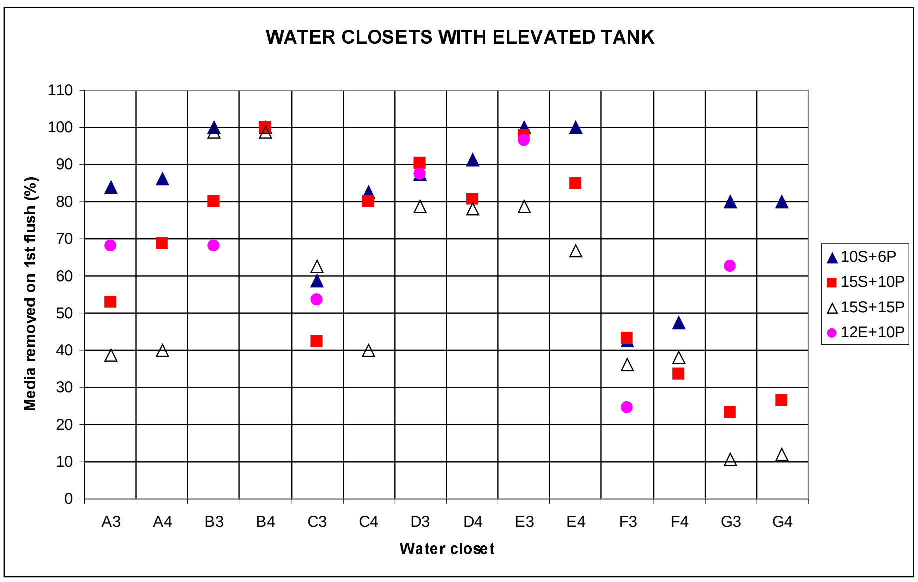



**Figure 3 - Sponges and Kraft paper tests. Water closets with elevated tank.**

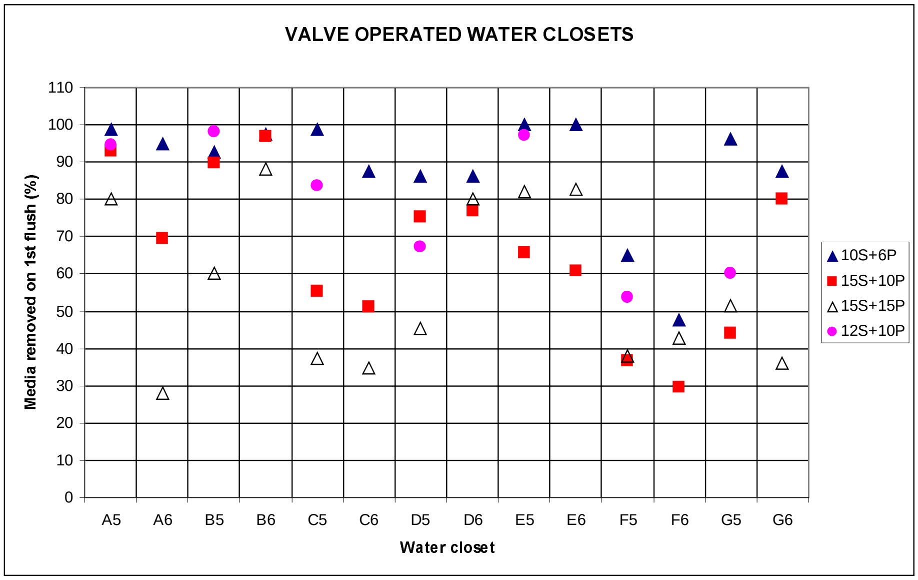



**Figure 4 - Sponges and Kraft paper tests. Valve operated water closets.**

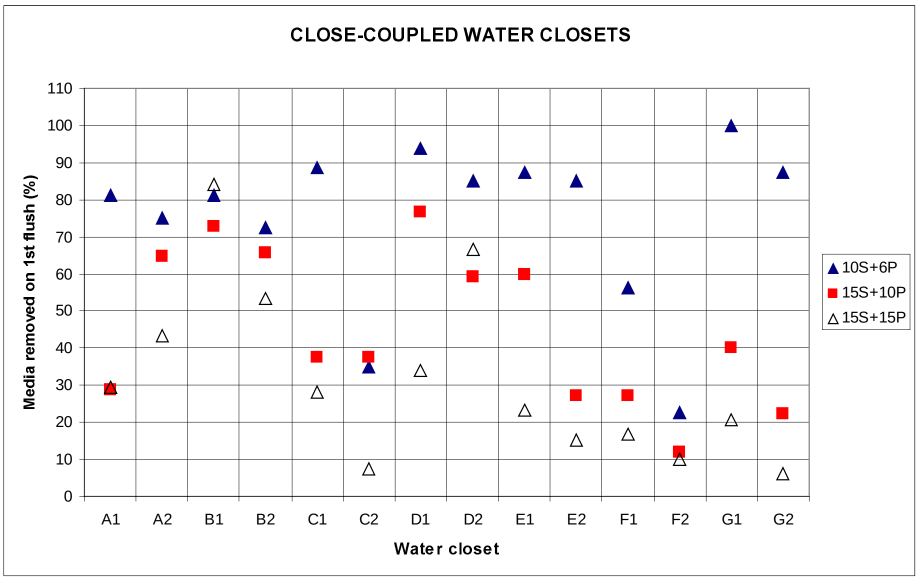



**Figure 5 - Sponges and Kraft paper tests. Close-coupled water closets.**

## 2.2 Polypropylene Balls Test

The procedure of this test is contemplated in ABNT (1997a, 1997b) and it is similar to ASME procedure.

Figure 6 shows results obtained in this test for Brazilian water closets.

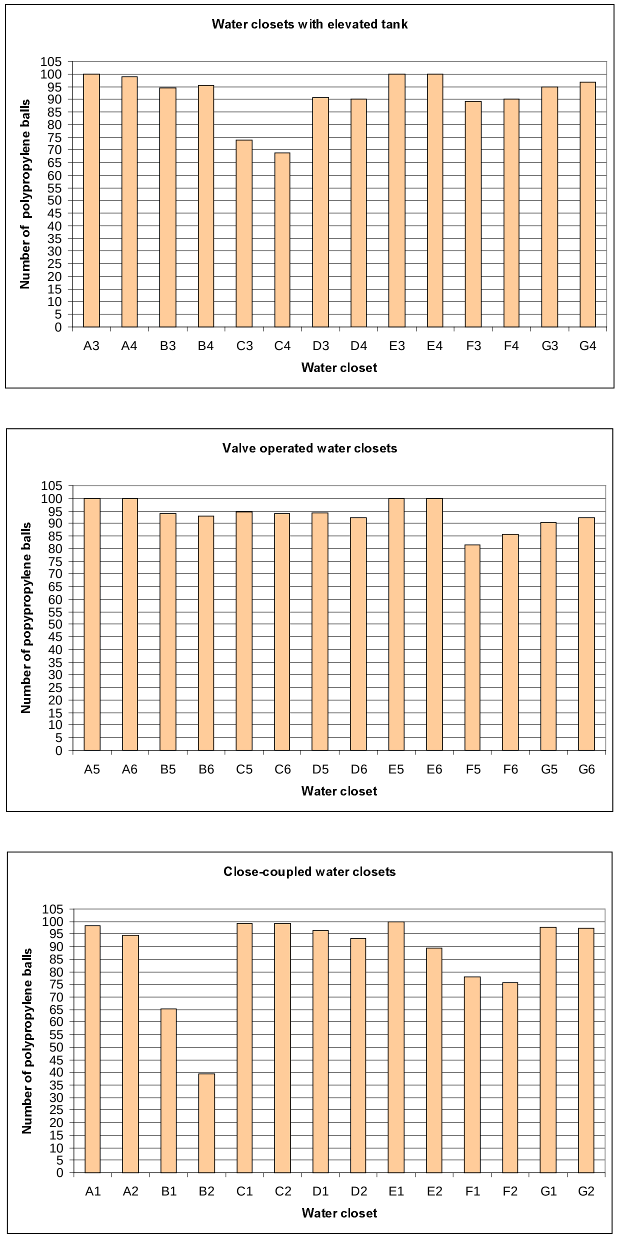



**Figure 6 - Results of Polypropylene Balls Test.**

## 3 Field Investigation

Field investigation was composed by measurement of consumed volume in water closets and total water consumption in brand new low-income houses.

The monitoring was completed in two phases. In the first phase, conventional water closets (9 and 12 liters) were installed in 18 homes and low flush water closets (6 liters) were installed in 6 homes. Total and water closet water consumption was monitored and these data were used to determine the number of single and double flushes, ratio between total and water closet volume and savings.

Phase two contemplated conventional water closets replacement by saver ones in 12 homes. The fixtures models tested in laboratory investigation were the same in the field investigation, but the units were different.
Questionnaire was used for survey users' opinion in both phases.
Figure 7 shows measurement plant outside homes. Two electronic water meters were installed in each home, one for total water consumption and the other for WC consumption. A computer was installed in the construction warehouse.
Inside cold water systems are shown in Figure 8.

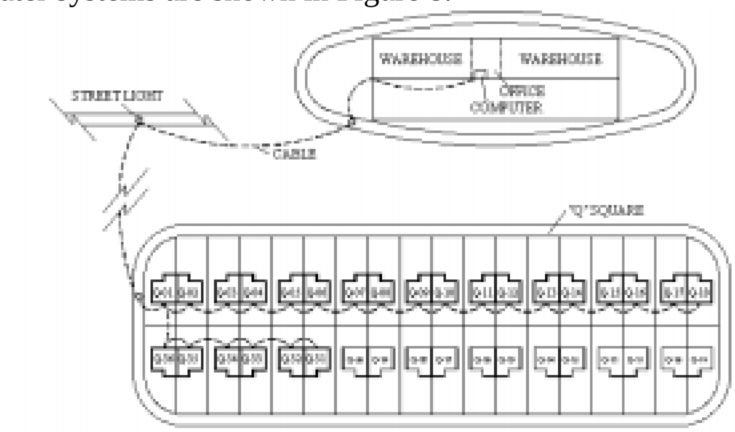



**Figure 7 - Field investigation - Measurement plant.**

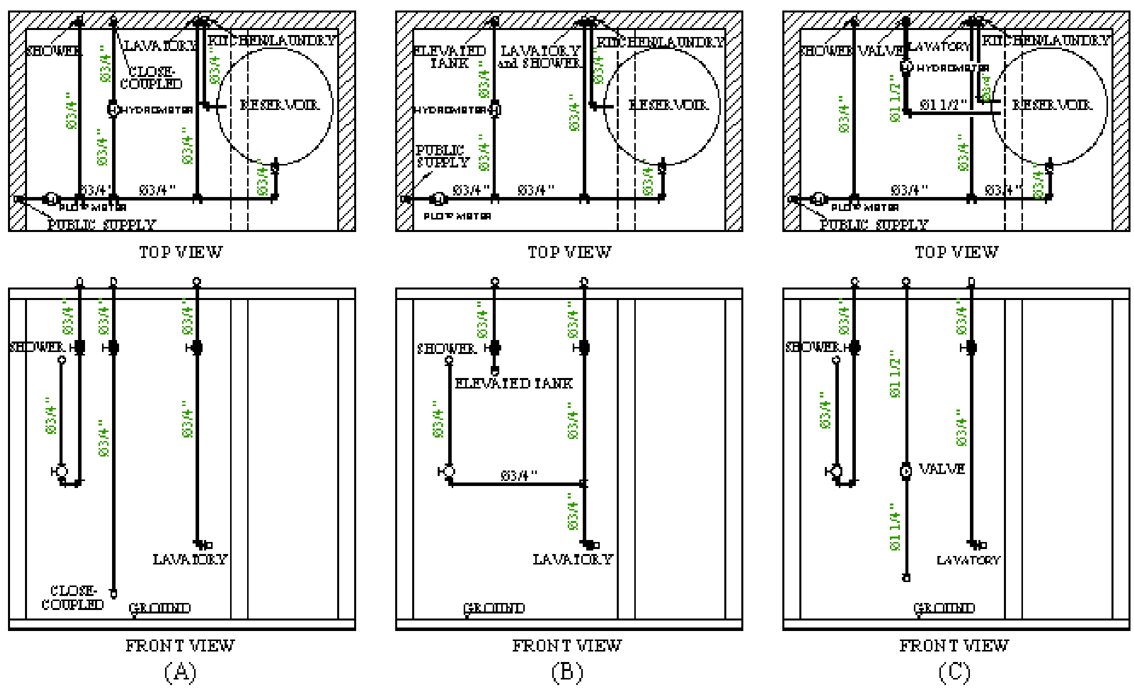



**Figure 8 - Inside cold water systems: (A) close-coupled WC, (B) with elevated tank WC and (C) valve operated WC.**

### 3.1 Results and Analysis

Results of questionnaire application (phases 1 and 2) are shown in Table 3. User's rating on new toilets is shown in Figure 9.
Table 4 shows results of total and WC average water consumption (phases 1 and 2) besides of average number of flushes.

**Table 3- Results of questionnaire application.**

| Home | Phase | WC type | Clogs | | | Needs $2^{nd}$ flush | | | $2^{nd}$ flush aim | | | Stains removal | | | Bad smell inside bathroom | | | Lower trap seal | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N | S | A | N | S | A | Clog | Waste removal | Surface washing | A | N | $2^{nd}$ flush | N | S | A | N | S | A |
| Q-01 | 1 | CC | x | | | x | | | | | | x | | | x | | | x | | |
| | 2 | | | x | | | x | | x | | x | | x | | x | | | x | | |
| Q-02 | 1 | CC | x | | | x | | | | | | x | | | x | | | x | | |
| | 2 | | x | | | | x | | | | x | x | | | x | | | x | | |
| Q-03 | 1 | CC | x | | | | x | | | | x | | | x | | | x | x | | |
| | 2 | | x | | | | x | | | | x | | | x | x | | | x | | |
| Q-05 | 1 | CC | x | | | x | | | | | | x | | | | x | | x | | |
| | 2 | | x | | | x | | | | | | x | | | x | | | x | | |
| Q-06 | 1 | CC | x | | | x | | | | | | x | | | x | | | x | | |
| | 2 | | x | | | x | | | | | | x | | | x | | | x | | |
| Q-07 | 1 | ET | x | | | | x | | | | x | | | x | x | | | x | | |
| | 2 | | x | | | x | | | | | | | | x | x | | | x | | |
| Q-09 | 1 | ET | x | | | x | | | | | | x | | | x | | | x | | |
| | 2 | | x | | | x | | | | | | x | | | x | | | x | | |
| Q-12 | 1 | V | x | | | x | | | | | | x | | | x | | | x | | |
| | 2 | | x | | | x | | | | | | x | | | x | | | x | | |
| Q-34 | 1 | ET | x | | | x | | | | | | x | | | x | | | x | | |
| | 2 | | x | | | | | x | | x | x | | | x | x | | | x | | |

CC - close-coupled WC, ET - WC with elevated tank, V - valve operated WC,
N - never, S - sometimes, A - always
Phase 1 - conventional WC, Phase 2 - low flush WC

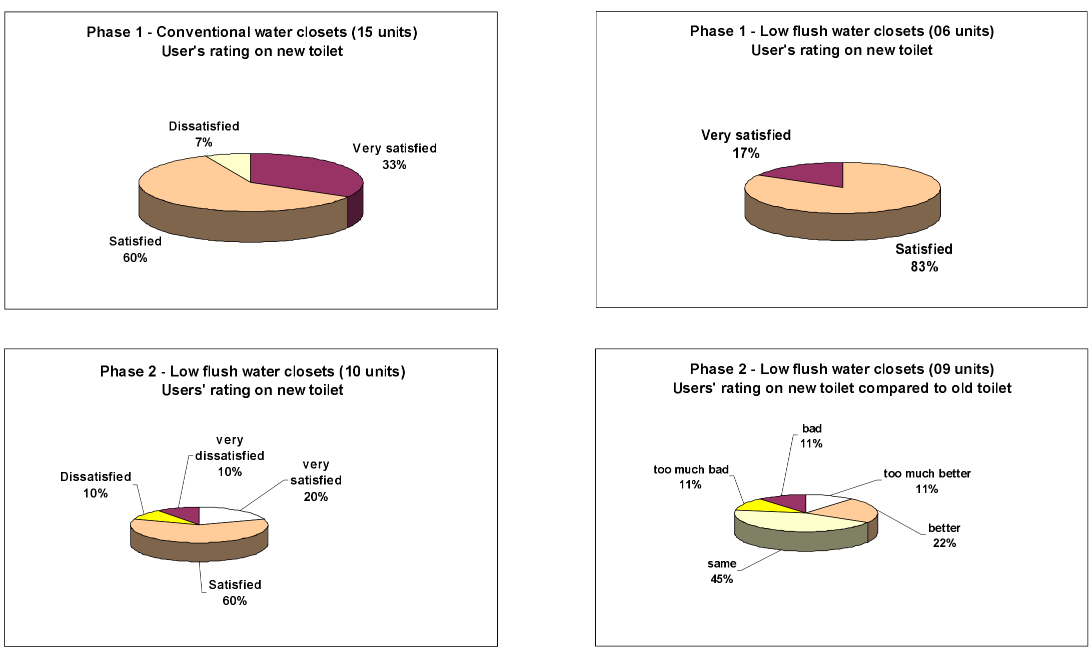



**Figure 9 - Users' rating on new toilets - Phases 1 and 2.**

Questionnaire data analysis indicates that, after water closet change (Phase 2):

- There were clogs only in one home,
- Second flush was related in three homes, basically due to surface washing problems,
- Just two low flush WC were considered dissatisfactory or very dissatisfactory.

For low flush WC installed on Phase 1:

- There were no clogs,
- Approximately 66.7% of the users said second flush is necessary, basically due to surface washing problems,
- Users rating: 83.3% satisfied and 16.7 very dissatisfied.

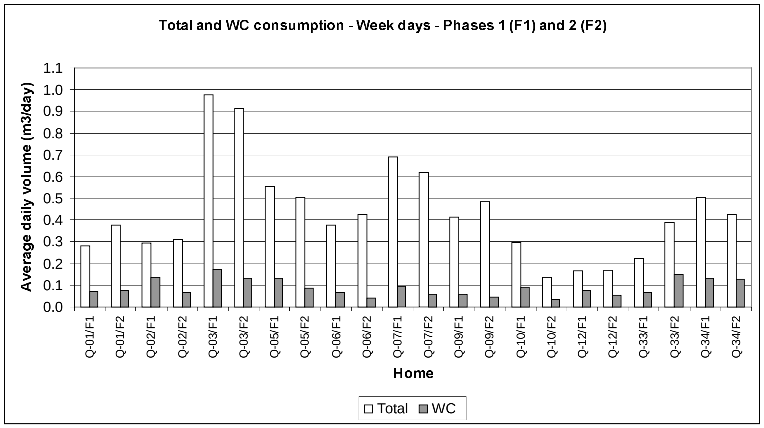
Table 4 shows consumption monitoring data analysis for phases 1 and 2.

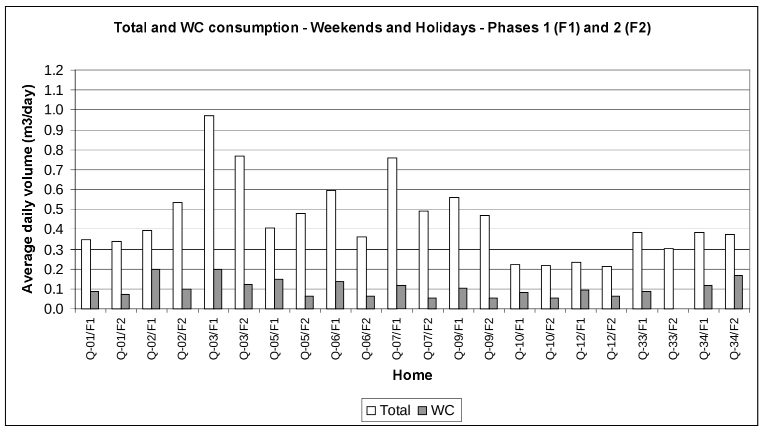
**Table 4 - Monitoring data analysis for low flush toilets.**

| | Phase 1 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Conventional WC 9 and 12 liters | | | | Low flush WC 6 liters | | | |
| | Week days | | Weekends and holidays | | Week days | | Weekends and holidays | |
| | AVG | CV(1) (%) | AVG | CV (%) | AVG | CV (%) | AVG | CV (%) |
| Total water consumption ($m^3$/day) | 0.08 to 0.98 | 22.5 to 85.6 | 0.10 to 0.97 | 25.17 to 65.88 | 0.14 to 0.61 | 21.1 to 65.8 | 0.22 to 0.58 | 23.3 to 80.3 |
| WC water consumption ($m^3$/day) | 0.03 to 0.17 | 15.7 to 68.4 | 0.03 to 0.20 | 23.2 to 65.7 | 0.03 to 0.13 | 23.2 to 75.7 | 0.05 to 0.15 | 18.3 to 100.0 |
| Number of double flushes/day | 0.00 to 3.00 | 58.8 to 336.4 | 0.0 to 3.0 | 63.9 to 299.5 | 0.50 to 1.50 | 89.4 to 131.0 | 0.70 to 2.30 | 81.7 to 123.7 |
| | Low flush WC - phases 1 and 2[(2),(3)] | | | | | | | |
| | Week days | | | | Weekends and holidays | | | |
| | AVG | | CV (%) | | AVG | | CV (%) | |
| Total water consumption ($m^3$/day) | 0.08 to 0.92 | | 17.30 to 171.4 | | 0.20 to 0.77 | | 17.80 to 164.4 | |
| WC water consumption ($m^3$/day) | 0.02 to 0.15 | | 23.10 to 118.00 | | 0.03 to 0.17 | | 21.6 to 68.3 | |
| Number of double flushes/day | 0.20 to 6.70 | | 45.80 to 261.60 | | 0.30 to 3.10 | | 75.0 to 300.0 | |

Notes: (3) CV – coefficient of variation = (standard deviation/average) * 100
(2) These data contemplate low flush WC installed since phase 1 and those installed only in phase 2.
(3) One home was discharged of this analysis, because there was extremely low number of flushes, indicating long periods (days) with no people at home

Figure 10 shows total and water closet consumption for those homes where toilets were changed, from phase 1 to 2 (conventional to low flush WC).



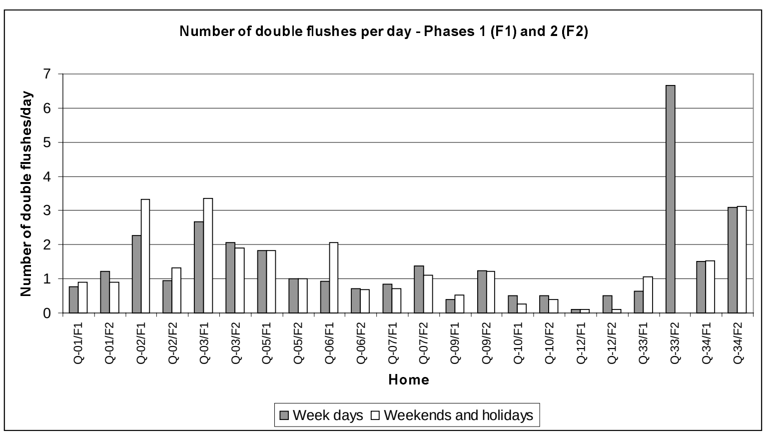




**Figure 10 - Average of total and WC water consumption and average number of double flushes - Phases 1 and 2.**

Water closet daily consumption decreased in 73% of the homes after toilets changing, both for weekdays (18.4 to 61.5%) or weekends and holidays (30.8 to 56.1%).
In two homes, WC consumption stayed the same after toilet changing for weekdays. For weekends and holidays, the water consumption increased about 29.8 % in one home and decreased about 16.8% in another one.
Total daily water consumption increased in 55% of the homes for weekdays (increasing from 2.6 to 42.4%). For the others days, 18% of the homes had higher total water consumption when compared with old toilet (increasing from 15.0 to 26.1%).

For 45% of the homes (weekdays) or 82% (weekends and holidays), total water consumption decreased from 6.2 to 54.5% and from 1.4 to 39.4%, respectively.
The number of double flushes increased in 55% of the homes (weekdays), for different flushing devices. For weekends and holidays, double flushes number increased in 45% of the homes.
Table 5 shows total water consumption and WC consumption ratio for both phases.

**Table 5 - General comparison- Phases 1 e 2.**

| Home | WC type | | WC consumption/total consumption (%) | |
|---|---|---|---|---|
| | **Phase 1** | **Phase2** | **Phase 1** | **Phase 2** |
| Q-01 | Conventional | Low flush | 28.49 | 20.63 |
| Q-02 | Conventional | Low flush | 39.61 | 26.13 |
| Q-03 | Conventional | Low flush | 20.63 | 19.15 |
| Q-04* | Low flush | Low flush | 25.08 | 16.08 |
| Q-05 | Conventional | Low flush | 27.70 | 16.91 |
| Q-06 | Conventional | Low flush | 19.35 | 11.56 |
| Q-07 | Conventional | Low flush | 18.97 | 11.31 |
| Q-09 | Conventional | Low flush | 14.88 | 11.25 |
| Q-10 | Conventional | Low flush | 31.90 | 28.40 |
| Q-11 | Low flush | Low flush | 21.00 | 21.87 |
| Q-12* | Conventional | Low flush | 44.06 | 31.97 |
| Q-14* | Conventional | Conventional | 42.18 | 37.61 |
| Q-15 | Low flush | Low flush | 23.19 | 21.95 |
| Q-16 | Low flush | Low flush | 12.06 | 11.82 |
| Q-18 | Conventional | Conventional | 27.89 | 28.04 |
| Q-34 | Conventional | Low flush | 29.31 | 31.24 |
| Q-35 | Low flush | Low flush | 15.20 | 13.67 |
| Q-36 | Low flush | Low flush | 23.59 | 16.54 |

* These homes have one or more clothes washing machines

It can be shown that WC consumption participation on total water consumption decreased in 80% of the homes where conventional toilets were changed by saver ones. In two homes, where low flush toilets were installed since phase 1, there was great decreasing in this ratio, which may be indicating an adaptation of the user with the toilet.
Finally, the percentage of WC consumption compared with total water consumption was practically the same for 66.7% of the homes.

## 4 Conclusion

Questionnaire data compared with consumption monitoring indicate that when problems are frequent, users know and relate them, when asked. In this case, data from questionnaire and from consumption monitoring are coherent.
However, if the problems are not frequent, users do not say anything and, in this case, consumption monitoring can show double flushes.

Inserted in this context, data from questionnaire always have to be analyzed with criteria and checked by meters.
There were double flushes in 50% of the homes, approximately. However, data analysis indicated total water consumption decrease, since not all flushes contain solid wastes.
Great problems were detected in three homes and it was necessary to change flush volume in one of them and to remove low flow WC in another one. Users of the other one said everything was right, but the monitoring detected problems.
It was detected great variability on number of double flushes, showing problems are not constant.
Finally, water closet and total water consumption ratio was from 14.9 to 49.8%.

## 5 Acknowledgements

The authors thank Professor Thomas P. Konen (Stevens Institute of technology) and the Research Foundation of Sao Paulo State -FAPESP.
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# Sizing a rainwater reservoir to assist toilet flushing

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## Abstract

Rainfall amounts vary over time and space, but the volume of water required for toilet flushing is relatively constant and depends more on the kind of the building and utilities served than on the time of year or location. Using rainfall sequences and toilet flushing demand, one can establish a methodology to examine the relationship of reservoir size for rainfall capture to the reduction of the demand for potable water to satisfy toilet-flushing needs. It is known that mathematical techniques, such as non-linear modeling, can be used to estimate the required storage of the rainfall, but the model described here uses actual local hourly or daily precipitation time series, to examine rainfall harvesting to augment toilet flushing demand. The time series is used to determine how much local precipitation will be available over hydrologically different periods of time. These data together with flushing demand are used to determine the reduction in potable water flushing requirement that results from a specified volume of rainfall storage. Thus, one can determine the best combination of rainfall storage volume and potable water to meet the toilet flushing demand. With the results obtained through this methodology, curves of reservoir volume versus number of toilets assisted can be construct to determine the volume of rainfall water is needed to assist toilet flushing in a particular building. An application of this methodology is proposed for the city of São Paulo to verify the methodology reliability of the system.

## Keywords

Rainwater reservoir; rainfall, storage; toilet flushing, potable water demand, water conservation, water supply

## 1 Introduction

The need of water is rarely the same than the demand. By observing the function of natural lakes, humans have, since long ago, seen the benefits of the storage of water during the wet season to use later during the dry season. According to Myers (1974), collection systems and storage of pluvial waters already existed in the desert of Negev more than 4,000 years ago. During the Roman era, sophisticated systems for harvesting and storing rainwater were constructed. Reservoirs of pluvial waters, which were found at the Mesa Verde National Park region in the United States, was believed to be built by the Anasazis between 750 to 1100 A.D. (Wenger, 1991).

The idea of storing rainwater in reservoirs for later use is discussed by Brooks et al (1991) who describe the application of this practice in Australia in 1948 as well as in Israel and in the USA during the 1930s. Today, collection and storage of rainwater from roofs of houses is commonly practiced in some arid and semi-arid areas. But even in the Caribbean islands, which have significant annual rainfall, storage of rooftop runoff is commonly practiced. And now, the capture and use of rainwater for none potable use in modern cities, like São Paulo, holds promise for decreasing the urban demand for precious fresh water resources.

This paper investigates the feasibility of collecting and storing rainwater for later use to flush toilets. The first step in such a project would be to define where to collect water. In the beginning, many sites could be candidates for “collectors of storm water," and each situation should be analyzed not only from the hydrologic viewpoint but also from the structural, environmental, constructive and economic viewpoints among others. However, while recognizing this, the focus of this paper is on the hydrologic aspects of meeting toilet-flushing demand based on the size of the rainfall collection reservoir.

## 1.1 Background

Normally, reservoirs regularize the available water by regulating flow, either by the supply or the variable consumption (Linsley and Franzini, 1972). Reservoirs can be used for conservation, control or adjustment of the flow. Pluvial water reservoirs to assist toilets flushing collect runoff on rainy days to supply them during the dry days. Therefore, they act as flow regulators since the frequency distribution of the supply (rain) is different from the frequency distribution of the use (toilet flushing).

The different frequency distributions for supply and demand make the determination of the stored volume complicated, but if the objectives are very well known, the analysis of the storage can be made through the mass balance by using the continuity equation.

According to ASCE (1996), the most important physical characteristic of the reservoir is its storage capacity (or volume). The storage capacity determines its ability to deliver a constant supply over a given period of time. However, there is an element of risk that is inherent in meeting this demand, because of the randomness of the supply source (rainfall). Determination of the reservoir volume depends on the risk that the planner wants to assume. Simply stated, the larger the reservoir volume, the lower the risk of not meeting the demand.

The introduction of the risk concept in the reservoir sizing identifies that supply of water, during the reservoir’s useful life, is uncertain and this uncertainty has to be taken into account during the project process. The problem of reservoir sizing can be put in the following way: How much water needs to be stored to meet the demand with a given degree of reliability i.e., the size of the reservoir is dependent on the demand and, the desired reliability of meeting that demand at all times. Of course it is recognized that even a reservoir of infinite volume could not reliably meet the demand if the average demand is greater than the average supply.

## 1.2 Purpose of this work

To determine the volume of the reservoir to store toilet-flushing water, the following data should be known: daily rainfall series at the collection site (or the equation that describes it), water use for toilet flushing (frequency of use and volume per flush) and evaporation data, where it is significant.

Defining a good approach to investigating the use of rainfall to augment potable water supply requires the review of the types and amounts of available information. This review will indicate which methods are better for modeling a particular situation. According to Monks (1987), several methods are available. The methods can be classified in the following way, according to the degree of uncertainty of the problem:

- Methods of complete certainty, where all the required information describing the decision variables and the results are known. For these problems, algebra, calculation and, mathematical programming can be applied.
- Risk and uncertainty methods, which are those where information describing the decision variables or the results are usually probabilistic. Methods used to investigate these problems include statistical analysis, queue theory, mathematical simulation, and heuristics methods among others.
- Methods of extreme uncertainty, where no information is available to evaluate the problem. In this case, the games theory can be used.

In many cases, more than one technique, or methodology, can be used to address an issue such as sizing reservoirs, the subject considered in this work.

This work is determinate, using a one-year time series of the daily pluviometric volumes and a time-constant value for the number of toilet flushings per day to determine the required daily complement of potable water to provide the toilets flushing demand for a 12-liter toilet.

The goal of this work is to allow the planner to investigate the relationship of the volume of a reservoir for rainfall capture, and the resultant reduction in demand for potable water for toilet flushing. The reservoir volume is, in turn, related to the rainwater harvesting area required to assist each user.

## 2 Reservoir Design Methods

Reservoir design methods in general can be classified into four main groups: (Domokos, 1987)

1. Deterministic methods, which use rain data as input data and, the storm series are analyzed by mass curve.
2. Approximate methods based on widespread empiric relationships.
3. Method of stochastic modeling (also well-known as method of probability transition matrix).
4. Analysis systems method, using linear, non-linear or dynamic programming.

The order of the above methods reflects the sequence in which they were developed. Rippl (ASCE, 1996) published the first analysis of the mass curve in 1883, while the approximate methods gained popularity only during the early sixties.

The groups are different from each other; however, inter-relationships exist among them. For example, the methods of the second and of the third groups are frequently used to generate the necessary series of data for the first group.

The first, third and fourth groups are generally appropriate to determine the capacity and the operation rules of reservoirs, while the second is used to determine the reservoir storage capacity, usually by analyzing corresponding pairs of capacity vs. reliability.

The second group of methods, which doesn't require computational work, uses mainly empirical formulas, tables and graphs, which are used in the comparative analyses among a great number of reservoirs. To develop formulas, tables and graphs, the other three methods, particularly the deterministic method, is frequently used to obtain general relationships of the studied area. ). For the analysis of single reservoir, the first two groups of methods have been used while the two more recent groups have been applied for the analysis of a single reservoir as well as for the analysis of the multiples. An algorithm for the solution of the methods of the third group can be found in Shaw (1988

The application of the third and fourth group of methods requires computer use. Therefore, they practically began to be used after the development of computers. Deterministic methods were also enhanced by the technological progress of the computer; this new tool supplied practically limitless possibilities for series generation of data input.

## 2.1 Traditional methods

Historically, mass curve has been the procedure used to determine the volume of reservoirs. The theoretical base of this procedure comes from the following analysis (ASCE, 1996). Consider the total period of time (T), the water that comes in the reservoir to be X(t) and the mass curve I(t):

$$I(T) = \int_0^T X(t)dt \tag{1}$$

where:

I(T) = the cumulative pluviometric volume after a period of time T;

X(t) = i(t)•A;

i(t) = the pluvial intensity at time t, and;

A = the harvesting area.

The evaporation and the precipitation on the reservoir are irrelevant in this case, since the reservoir will be covered. The amount of available water will be I(T). If all water is consumed over the time period at a constant rate, the demand rate $\gamma(t)$ is given by:

$$\gamma(t) = \frac{1}{T} I(T) = \overline{X} \tag{2}$$

The cumulative demand, D(T) over the time period T, for a non-constant instantaneous demand is given by:

$$D(T) = \int_0^T \gamma(t)d(t) \tag{3}$$

For the maximum efficiency of the reservoir during the period of time T, D(T)=I(T); that is to say, all the collected rainfall water will be used to supply the demand of the toilets flushing.

Given a daily precipitation time series X(t), it can be demonstrated that the required storage, $S_R$, to satisfy a constant rate of flow demand is:

$$S_R = \textit{Range of}\,[I(t)\text{-}D(t)] = \max[I(t) - D(t)] + \max[D(t) - I(t)]$$

$$= \max[I(t) - D(t)] - \min[I(t) - D(t)] \tag{4}$$

This is the maximum accumulated value, using the average flow that comes into (and out of) the reservoir.

The method of the curve of residual mass is an extension of the technique of the mass curve with the advantage of having smaller numbers to place in the graph, thus, increasing the precision of the scale of the ordinates. Each value of daily rain is reduced by the medium value over the duration of the study, that is to say, the daily, weekly or monthly average. Tracing a curve of these data versus time is called the *residual curve*. A line is traced going by the two larger successive peaks. The vertical distance from the minimum value between the two previous peaks and the line, will give the required minimum volume to be stored to meet the demand over the same period.

### 2.2 Mathematics programming

To analyze a rainfall harvesting system, the problem can be decomposed into five stages: a) goals definition; b) quantification of the measures for the objectives; c) alternative solutions generation; d) alternatives quantification, and; e) selection of the best alternative. For the choice of the best alternative several techniques have been developed that provides an opportunity to evaluate the behavior of the studied system. These include: linear and non-linear programming, dynamic programming, multi objective analysis, and mathematics-computational simulation, although this last one is not an optimization model.

For the case of satisfying toilet-flushing water demand, the five stages above would be:

a) Goals definition: to assist toilets flushing;
b) Quantitative measures for the objectives: minimization of the consumption of potable water;
c) Alternatives generation: reservoir volume vs. potable water requirement;
d) Alternatives quantification: cost, availability, future situation;
e) Selection of the best alternative: function of *b*, *c* and *d*.

According to BRAGA (1987), the optimization model is sought that maximizes or minimizes the *objective function* $F(X_1, X_2, ..., X_N)$, , where $X_1, X_2, ..., X_N$ is the N *decision variable* of the problem. The objective function is constrained by “m” functions of restriction, $g_i(X_1, X_2, ...,X_N)$, with $i = 1, 2,..., m$, that determine the *viable area* of the decision variables. Thus the optimization problem can be represented as:

Max (or Min) $F(X_1, X_2, ..., X_N)$, (5)

Subject to:

$g_1(X_1, X_2, ...,X_N) > b_1; < b_1; =b_1.$ (6.1)

$g_2(X_1, X_2, ...,X_N) > b_2; < b_2; =b_2.$ (6.2)

$g_m(X_1, X_2, ...,X_N) > b_m; < b_m; =b_m.$ (6.m)

where, $b_i$, $i = 1, 2,..., m$, are the *parameters* of the model.

The groups of decision variables, $X_1, X_2,... ,X_N$ that satisfy equation (6) are called the *viable solutions*. Within the viable solutions is the *optimal solution*, that also satisfies equation (5).

If all the functions are linear (or non-linear), the given groups of the equation set (6) forms a model for linear programming (or non-linear). Then the objective function (5) of a non-linear programming model represents the Markov property, that is, the decision in any stage is function only of the state of the system in that stage. After **m** decisions, the effect of the (N - m) remaining stages on the objective function $F(X_1, X_2, ..., X_N)$, depends only on the process of decision of the (N-m) final decisions. The solution of the problem can be given through dynamic programming.

On the other hand, according to BARBOSA (1997), the traditional approach to the selection of planning alternatives in water resources --which involves the allocation of water using technical-economic analysis, especially through benefit-cost analysis-- has been giving way to an approach that considers multiple objectives. Although this approach requires more information is slower to implementation, it is an irreversible international tendency, representing progress in the evolution of societies impelled by the understanding with relationship to environmental and social problems. An undertaking is multi-objective when it addresses several objectives simultaneously such as: economic efficiency, conservation of natural resources, attendance to the purpose, environmental quality, etc. The objectives are translated into programs such as: maximization of liquid benefits, minimization of environmental impact, and minimization of risks. The benefits that can be obtained with the use of the rainwater in the buildings include, the savings in cost resulting from reduced use of potable water for toilet flushing, reduction of the amount of rain water in urban drainage, with subsequent reduction in flooding or need for flood control facilities. However, the goal of this study was to obtain a *simplified and practical tool* to determine the required storm water storage volume, through linear or non-linear programming.

**2.3 Failure rate and reliability:**

The reliability of the reservoirs can be represented as:

$$R = f_R[X(t),d(t),S) \qquad (7)$$

where:

R = reliability;

X(t) = time series of input flow (rainfall) into the system;

d(t) = time series of demand;

S = storage volume of the reservoir.

Here, the direct objective is usually the determination of the function R=R(S), satisfying the demand series, d(t). Using the mass curve, the problem is solved through graphs, where it can be observed as the reservoir of given capacity transforms the series X(t) to an outflow time series $y_{S_i}(t)$. Then the values of $R_{S_i}$ are determined by mean of the computed series $y_{S_i}(t)$. Using stochastic methods, the R(S) relationship is computed directly from input flow distribution series, without simulating the operation of the reservoir.

According to McMahon (1993) several definitions are given for the probability of "failure" of a reservoir. A common definition of "failure" in theoretical analyses is the relationship between the time that the reservoir is empty, "$n_f$" and the total time in the period of the analysis, "n", ie.:

$$F_f = \frac{n_f}{n} \qquad (8)$$

But this definition is not realistic because the reservoir is prevented from becoming empty by placing some restrictions on the outflow.

The better definition for the failure is:

$$F_r = \frac{n_r}{n} \qquad (9)$$

where "$n_r$" is the time that the reservoir only partially supplies the demand. "$F_r$" is then the proportion of total time that the restrictions are imposed.

Either $F_f$ neither $F_r$ are a percent of the time that reservoir cannot meet the demand. They are not probabilities in the strict sense, once they are expressed as the percent of the failure time over a certain period of time.

Reliability is a term used to represent the proportion of the time in that the reservoir *can* meet the demand. It is the complement of the failure and is calculated as:

$$R_f = 1 - F_f \qquad \text{and,} \qquad R_r = 1 - F_r \tag{10}$$

## 3 Applied Methodology

An important consideration of the rainwater harvesting project is the relationship of the reservoir size to the requirement for potable water to make up flushing water demand deficits (Ree et al., 1971). Unless the reservoir will be very large (and consequently very expensive) so that it can supply the flushing demand throughout the entire drought period, the dependence on the supply of potable water can be projected.

To determine the volume of the reservoir and the need for potable water to supply the flushing demand, the following methodology was developed:

a) Choose a daily precipitation time series for 12 years with at least 10 complete years;
b) For the period of record compute the average precipitation for each day of the year;
c) Compute the flushing demand as Demand = number of toilet uses * volume per flush;
d) Assume constant flushing demand for each day of the month;
e) Calculate the rainfall harvesting area necessary to satisfy the toilet flushing demand every day, keeping extra water in storage for times when rainfall is less that demand. The obtained result is the minimum harvesting area per toilet, so that potable water not needed. The calculation was made using the Excel® spreadsheet and, programming of macros using the internal routines of mathematical programming contained in the spreadsheet for problem optimization;
f) With the minimum harvesting area determined, the volume available for toilet flushing each day was calculated;
g) To supply the first day, it was verified that water remained from the last day of the previous month, otherwise the deficit was made up with potable water until the daily demand was satisfied (for the first day of operation of the project, the supply is the same to the demand for that day);
h) The daily volume of potable water required to meet the toilet flushing demand was calculated for cases where the harvesting area was equal at 90%, 70%, 50%, 30% and 10% of the minimum harvesting area;
i) For the various sizes of harvesting areas defined above, the monthly consumption of the potable water, the economy obtained with the use of the pluvial waters, the failure and the reliability of the reservoir, and the minimum volume of the reservoir for each user was calculated.

With the results above, the planner can determine the required reservoir volume, as a function of the number of users and of the available area for harvesting.

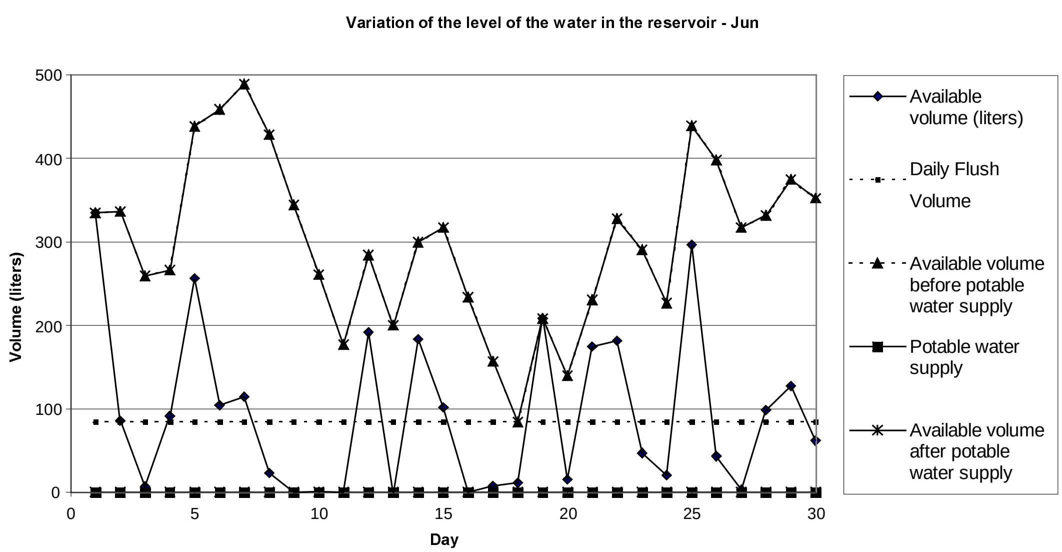
If the available harvesting area and the number of uses by users are known, the spreadsheet will calculate the minimum reservoir volume, the potable water necessary, obtained economy, reliability and failure of the reservoir.

## 4 Application of Metho d

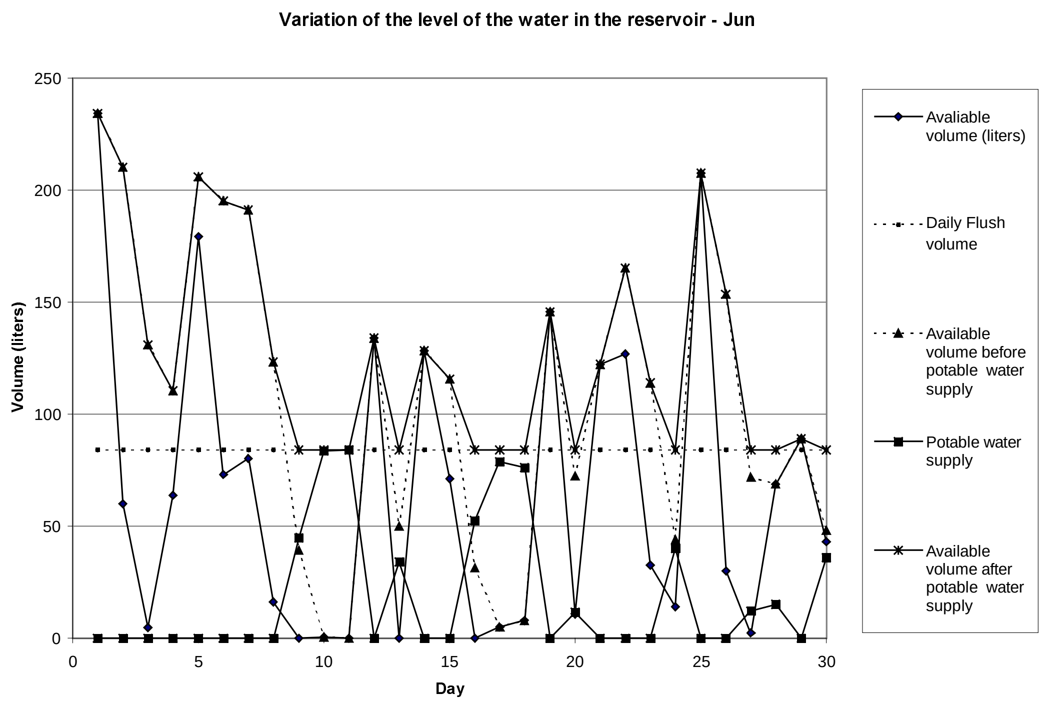
To demonstrate the applied methodology, an application was made using the precipitation time series for the month of June, in the Água Branca, Tietê upper basin for São Paulo city, Brazil. The nonexistent data were not considered for the average calculation.

The results obtained for this month are shown in the graphs (1), (2), (3) and (4). Graph 1 shows, and smallest harvesting area, the daily flushing volume (for 7 uses a day, of a 12 liter toilet), potable water needs, volume in the reservoir just considering the rainwater, volumes in the reservoir before and after the augmenting the rainfall supply with potable water.

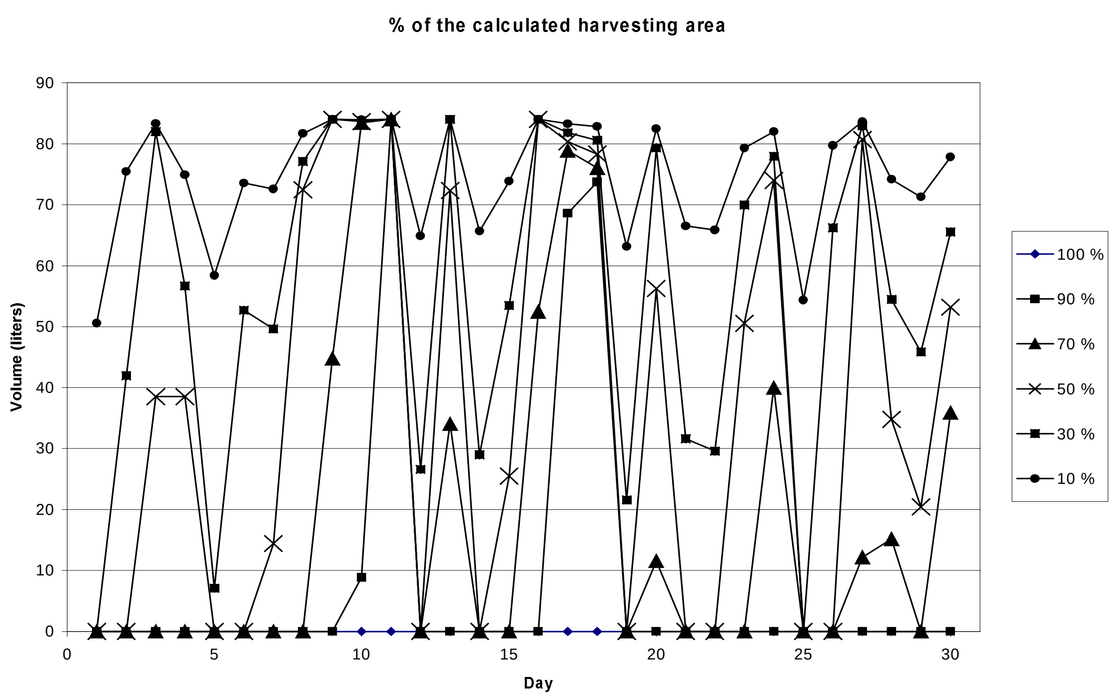
Graph 2 shows the same as the graph 1, but the harvesting area is reduced to 70% of the minimum area; Graph 3 shows the potable water supply for different sizes of harvesting areas; Graph 4 shows the reliability change in response to increasing the area for harvesting rainfall; and Graph 5 shows the reservoir volume vs. required potable water to supply the flushing demand for the month of June.



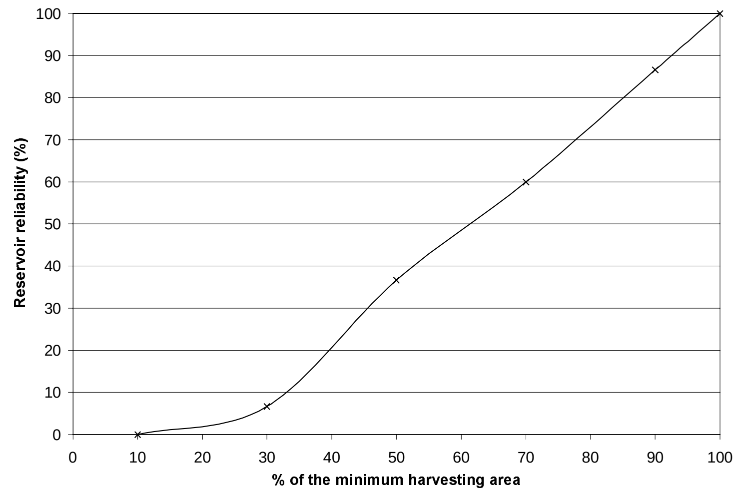

**Graph 1 - Variation of the level of the water in the reservoir with smallest harvesting area.**



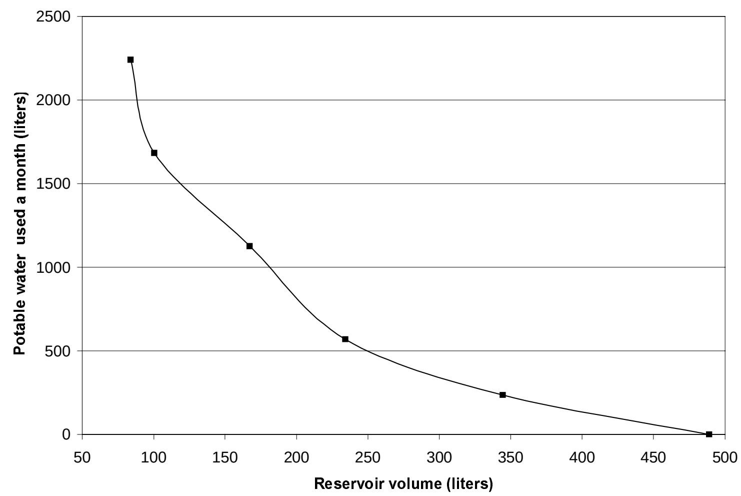

**Graph 2 - Variation of the level of the water in the reservoir with collection area the same to 70% of the minimum area.**




**Graph 3 – Required supply of potable water for the different size collection areas.**




**Graph 4 - % of the minimum harvesting area vs. reliability.**




**Graph 5 – Reservoir volume vs. required potable water.**

For this situation, the following results are obtained and shown below in the table:

**Table 1 - Results obtained for 7 uses a day, for user**

| % Of the minimum collection area | Potable water used a month (liters) | Reservoir minimum volume (liters) | Obtained economy | | Reliability (%) | Failure (%) |
|---|---|---|---|---|---|---|
| | | | (liters) | (%) | | |
| 10 0 | 0.00 | 489.03 | 2520.00 | 100 | 100 | 0 |
| 90 | 235.20 | 344.56 | 2284.80 | 90.67 | 86.67 | 13.33 |
| 70 | 568.34 | 234.21 | 1951.66 | 77.45 | 60.00 | 40.00 |
| 50 | 1125.96 | 167.29 | 1394.04 | 55.32 | 36.67 | 63.33 |
| 30 | 1683.57 | 100.37 | 846.43 | 33.19 | 6.67 | 93.33 |
| 10 | 2241.19 | 84.00 | 278.81 | 11.06 | 0.00 | 100.00 |

## 5 Conclusions

With the described methodology, it is possible to determine the reservoir volume for rainfall harvesting for any place where the daily precipitation time series the number of uses a day by user (or toilet flushing demand) are known.

Graphs 1, 2 and 3 can be compared to determine the different amounts of potable water supply that are required to meet the flushing demand for harvesting areas of various sizes. The variation in behavior over the month can also be observed, and the appropriate harvesting area size can be selected to assure the desired readiness for meeting the flushing demand with potable water.

Graph 4 shows that a minimum harvest area of 30 percent is required to have any significant increase in reliability. Conversely, the failure rate is more than 90% until the harvesting area exceeds 30%, after that reliability increases linearly with increase in harvesting area, and failure also decreases linearly with increase in harvesting area.

Graph 5 shows that the *knee of the curve* to be about 250 liters, which means that it, may not be cost-effective to build a larger tank. If we build the tank of 250 liters, we will reduce the potable water requirement from 2520 liters/month to 450 liters/month (a reduction of 2070 liters/month) but if we add another 250 liters to the tank (i.e. double its size) the additional savings in potable water demand is only 450 liters/month (450 - 0). This plot shows the economics of building various size reservoirs, and helps to determine the optimal size (and percent collection area) to use for most cost-effective use of rainwater for toilet flushing.

Using the spreadsheet and its optimization macros; it is possible to calculate the harvesting area, the volume of the reservoir and the volume of potable water exactly to satisfy the flushing demand during the period.

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# Development of Rainwater Soakway in the Building Boundary

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**ABSTRACT**

Environmental problems have always constituted serious problem. Environmental conservation included water resources is primarily concerned globally, systematic and planned action. One of the efforts to related it, is environmental friendly of drainage system development, with hoping can give as alternative solution for water resources conservation.

Water is very important as natural resources to be reserved its existence, such as rain water without a channel would filled to groundwater and not or would happened a bigger disaster, such as flood. It will disturb the environmental healthy, but it as the side if the entire water be flowed to the rivers or sea, it would be a very ironical condition, whereby water would be disposed uselessly but the other side, the resources of ground water more decrease or become be scarcity which is felt so badly especially in the dry season.

To improve the efforts that could decreased or anticipated water run off about 90 % and also to be preserved as ground water supply that is very needed, naturally " Available Water " with " Rain Water Soakway development", beside the cost of production will be lower, the technology which is used will be quite simple, both of rain water soakway with or without porous wall.

The other advantages of implementation this rain water soakway are :

1. to prevent land subsidence, sea water intrusion and increasing ground water supply which can prevent plant dehydration in the dry season.
2. to reduce dimension of drainage channel so investment cost will be low.
3. to reduce contamination so environmental healthy will be better.

# CHAPTER I : INTRODUCTION

## 1.1. Basic Concept

Water is very important natural resources to be reserved its existence, such as a rain water without channel would filled and not or would happened a bigger disaster, such as flood, it will so disturb the environmental healthy, but it at the side if the entire water be flowed to the rivers or sea that would be a very ironical condition, whereby water would be waste uselessly but the other side the resources of ground water more decreased which is felt so bad especially in the dry season.

To improve the efforts that could decreased or anticipated water run off about 90 % and also to be preserved the ground water supply that is very needed, naturally "Available Water" with "Rain Water Soakway development", beside the cost production will be lower, the technology which is used will be quite simple.

## 1.2. Purpose and Objective

### 1.2.1. Purpose

To improve the society ability in implementation of the development of rain water soakway in the building boundary.

### 1.2.2. Objective

To recognize the matters that is needed to be taken note of and the procedures, to arrange the planning of the development of rain water soakway in the building boundary.

## 1.3. Basic Law and Regulation

Basic legislation and program policy which are used as a base to popularize rain water soakway in Indonesia as follows :

1. Indonesian Constitution (UU-RI) No.23/1997 ; section 10 on Environment Management, whereby it is said firmly :
   - To realize, improve, develop and increase : The awareness the decision making right and responsibility of the society, in environment management, and the partnership between society, private sector and government in the effort to preserve "**support capacity**" and "**storage capacity**" of the environment.

- To develop and implement Environment Management National Policy to guarantee the preservation of support capacity and storage capacity of the environment.
- To make use and develop the friendly environmental technology.
- To supply the environment information and publican to the society.

2. Program policy and environment management activity which are focused to the rehabilitation of environment damage.
3. Policy and targets of department of settlement and region development such as : infrastructures and public facilities that is continued and environmental oriented.
4. Regional Regulation Implementation
5. Indonesian National Standard

## CHAPTER II : REQUIREMENTS FOR BUILDING OF RAIN WATER SOAKWAY

### 2.1. Building Requirement

Building requirement that is needed to be compiled are as follows :

1. Rain water soakway is made in the permeability of soil and landslide resistance.
2. Rain water soakway must be free from waste contamination.
3. The water that is fill into rain water soakway is rain water.
4. For the region with bad environment sanitation, rain water soakway only contains the water from roof and be distributed with water gutter.
5. Considering the hydrogeology, geology and hydrology aspect.

### 2.2. Dimension

Dimension of rain water soakway are as follows :

1. Shape and size of rain water soakway is square or circle.
2. Minimum size of cross sectional side or diameter is 0,8 m.
3. Maximum size of cross sectional side or diameter is 1,4 m.
4. Size of influent pipe is 100 mm.
5. Size of over flow pipe is 100 mm.
6. Maximum size of depth can be seen in table 1.

TABLE 1

DEPTH SIZE AND CONSTRUCTION TYPE

| DEPTH | CONSTRUCTION TYPE |
|---|---|
| Maximum 1,5 m | I |
| Maximum 3,0 m | II |
| Maximum of ground water table | IIIa, IIIb, IIIc |

**2.3. Building Material**

Building material that be used for rain water construction can be chosen from the list which is inserted in table 2 bellow :

TABLE 2

THE ALTERNATIVE OF BUILDING MATERIAL USAGE FOR RAIN WATER SOAKWAY CONSTRUCTION

| COMPONENT/BUILDING MATERIAL | SOAKWAY COVER | UPPER PART OF SOAKWAY WALL | LOWER PART OF SOAKWAY WALL | SOAKWAY CONTAINED MATERIAL |
|---|---|---|---|---|
| Ironed Concrete Plate, H = 10 cm, 1 PC : 2 S : 3 gravel | * | | | |
| Unironed Concrete Plate, h = 10 cm, 1 PC : 2 S : 3 Gravel | * | | | |
| Soil and Plastic Heaps d > 15 cm | * | | | |
| Ferrocement | | * | | |
| Brick Construction, Concrete Block 1 PC : 5 S, Size ½ Thick Of Terracotta | | * | * | |
| Porous and nonporous Ironed Concrete | | * | * | |
| River Stones, Size 20 cm | | | | * |
| Debrise of Brick, Size ¼ Thick of Brick | | | | * |
| Palm Fibers | | * | * | |

### 2.4. Building Construction

Building construction of rain water soakway consists of several type construction inserted in example figure as follows :

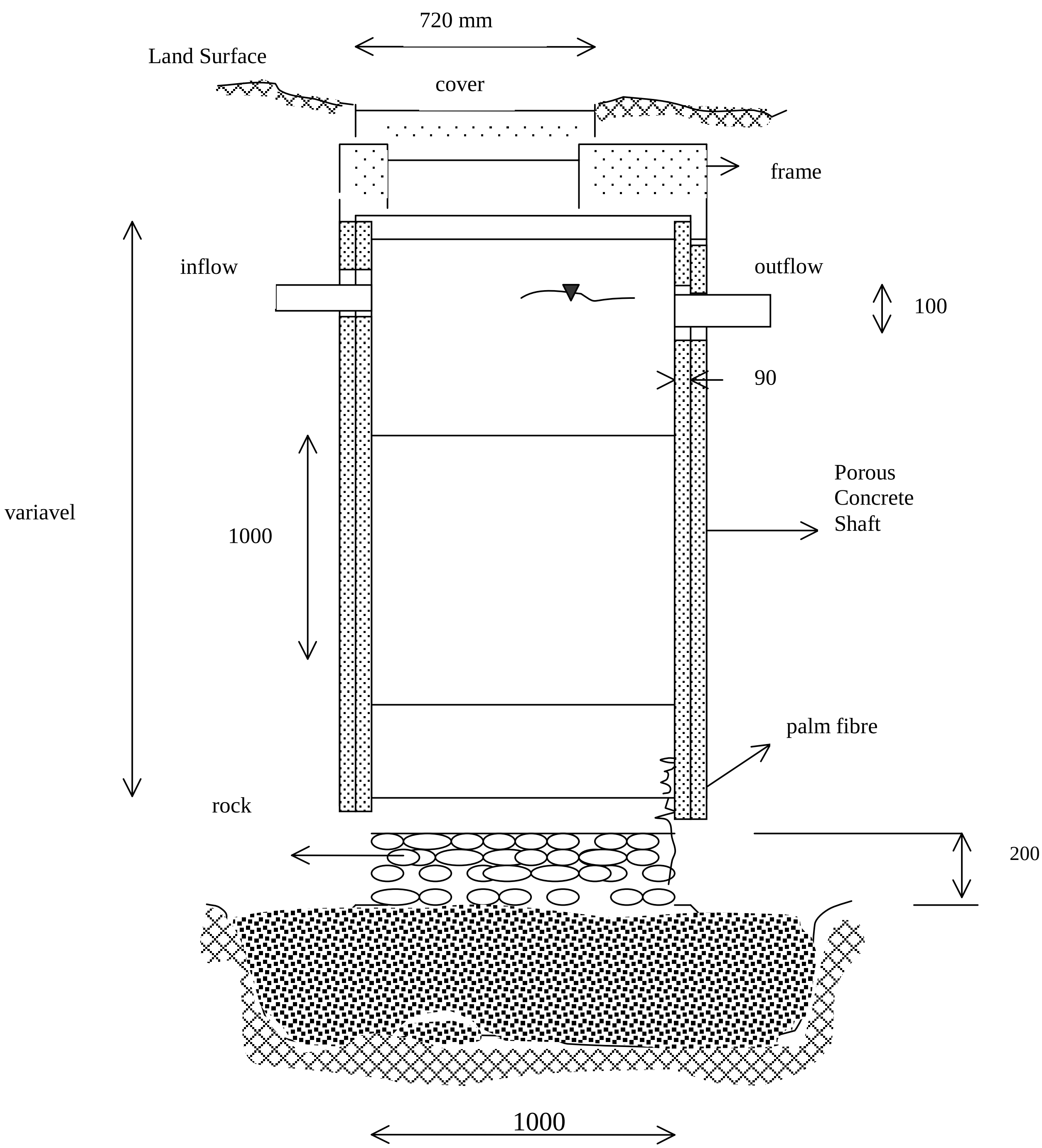



FIGURE 1

RAIN WATER SOAKWAY

## 2.5. Selection of Location

### 2.5.1. Condition of Water Table

Rain water soakway is made at the starting point of flow area that can be decided by measure the depth of the ground water table to land surface, at around of the soakway in rainy season.

### 2.5.2. Permeability of Soil

Permeability of soil that can be used for soakway divided into 3 (three) classes as follows :

1. Permeability of medium soil (loam, 2,0 – 6,5 cm/hour)
2. Permeability of rather fast soil ( refined sand, 6,5 – 12,5 cm/hour)
3. Permeability of fast soil ( raw sand, more than 12,5 cm/hour)

### 2.5.3. Distance Between Building

Rain water soakway that is placed in yard with distance condition to septic tank, absorption area of septic tank/pit latrine/waste water disposal, clean water and the other rain water soakway, can be seen in table 3.

TABLE 3

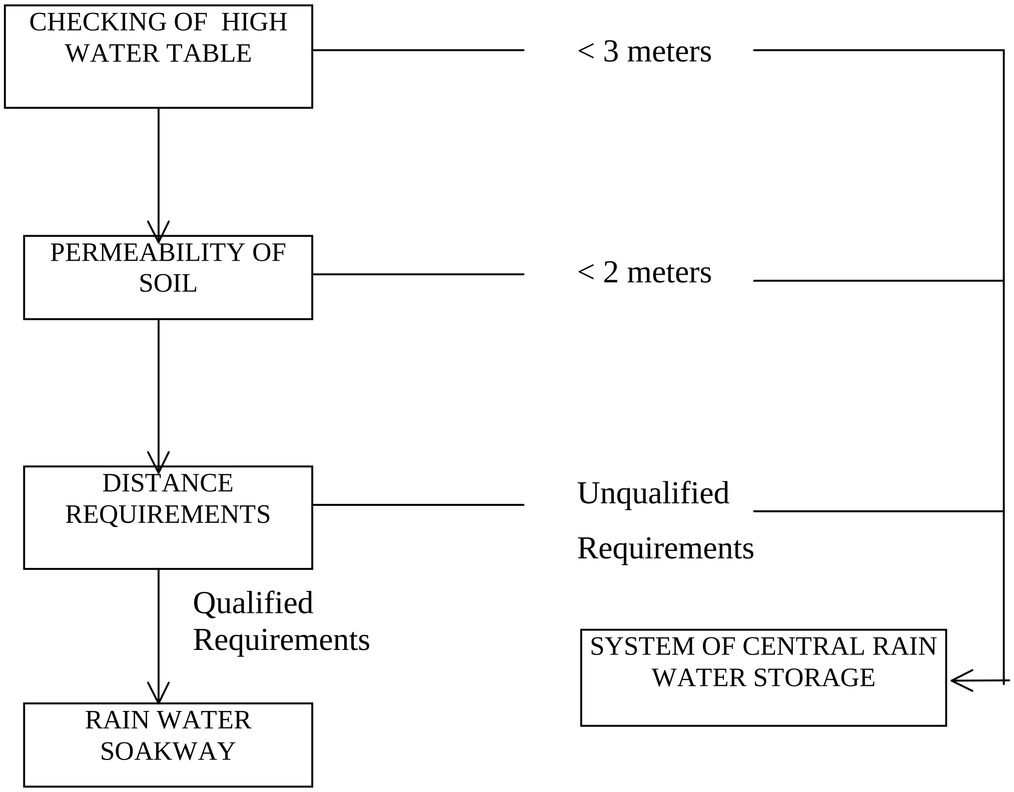
MINIMUM DISTANCE OF RAIN WATER SOAKWAY TO BUILDING

| NO. | BUILDING TYPE | DISTANCE FROM SOAKWAY (m) |
|---|---|---|
| 1 | Septic Tank | 2 |
| 2 | Septic Tank Absorption, Pit latrine, Waste Water Disposal, Solid Waste Disposal | 5 |
| 3 | Rain Water Soakway/Clean Water Deep Well | 2 |

Note : distance is measured from side to side

### 2.5.4. Procedure Aplication of Rain Water Soakway

The procedure that must be attention in rain water soakway construction are as follows :




## 2.6. DETERMINATION OF RAIN WATER SOAKWAY TOTAL

Determination of rain water soakway total in yard base on maximum rainfall, soil permeability and area of receptable plane, with formula :

a. For rain water soakway with the side part of well is permeable

$$H = \frac{D . I . A_{receptable\ \ area} - D . k . A_{soakway}}{A_{soakway}}$$

b. For rain water soakway with the side part of soakway is impermeable

$$H = \frac{D.\ I\ .\ A_{receptable\quad area} - D\ .\ k\ .\ A_{soakway}}{A_{soakway} + D\ .\ k\ .L}$$

Whereby :

I = Rain Intensity (m/hour)

$A_{rp}$ = Area of Rain Receptable ($m^2$), could be shaped : house roof and/or hardened land surface

K = Soil Permeability (m/hour)

L = Length of Cross Sectional Soakway

D = Rain Duration (hour)

H = Height of Soakway (m)

The result of rain water soakway total solution, can be seen in table 4 and 5.

## 2.7. Inspection

Rain water soakway needs to inspect periodically, every 6 (six) month a time to guarantee the continuity of soakway operation.

The checking which is needed to be done is :

1. influent current ;
2. controller basin ;
3. soakway condition.

# The Comparison between Plastic and Traditional Inspection Chambers under Labor Productivity Evaluation

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## Abstract

This paper discusses labor productivity for the execution of inspection chambers for sewer systems. There were collected 211 data points in a daily basis during the execution of inspections, manufactured with plastic materials and also with traditional materials (mortar, brick, and rings of concrete). It was developed a methodology for collecting data in site and for processing these data. The results represent a solid base of data (collected in a sewer system implemented in Brazil, in 1998) that can be used to compare productivity between installing traditional and plastic inspection chambers.

## Keywords

Inspection Chamber; Labor Productivity

## 1 Introduction

Sewer System is very important for population health and environmental preservation. So that it is necessary to reduce costs of implementation, maintenance and operation, allowing that more people can be linked to the sewer system. For this cost reduction, it will be necessary to develop new technologies and new concepts of design. Related to technology, the use of plastic for sewer system is an alternative that is being implemented in Brazilian Construction, using all the accessories and pipes in plastic.

This research discusses the implementation of inspection chambers, comparing plastic technologies and traditional ones, in terms of productivity. This labor productivity was measured during the execution of a sewer system using these two different technologies. The plastic technology uses plastic pipes and all accessories are also made of plastic. For the traditional technology, inspection chamber is made of traditional construction material like bricks; rings of concrete and pipes are made of ceramic or concrete.

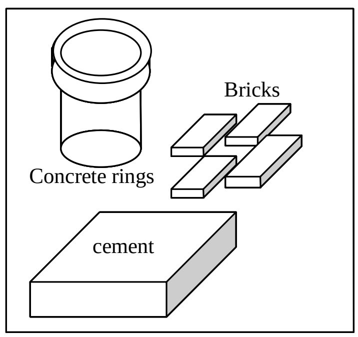


**Figure 1: Materials used in the construction of inspection chamber**

The study uses a database gathered from construction sites. A partnership between CEDIPLAC (Centro de Desenvolvimento e Documentação da Indústria do Plástico para a Construção Civil) and CAESB (Cia. de Água e Esgotos de Brasília) that is a public sewer company, made the data collection possible. Two geographic areas were studied; the first one is called Recanto das Emas and the other one, Riacho Fundo II. Both of them are located in Brasília, Brazil.

For this research, it was necessary to develop a methodology to quantify the labor productivity, which was composed of collecting site data and also processing them through tables that were specially developed for it. The result is presented using tables that show productivity data for each type of material and for various diameters, analyzing the advantages for the use of plastic inspection chambers.

# 2 Inspection Chamber for Sewer System

## 2.1 Definition

Most Inspection Chambers or Manholes are circular in shape and must allow the system inspection and cleaning. Inspection Chamber should be placed at all changes in sewer grade, pipe size, or alignment; at all intersections; at the end of each line; and at distances no greater than 100 m for sewer pipes with a diameter equal or superior of 150mm. For diameter equal to100 mm, it should be adopted distances between 40 and 50 m. Figure 2 shows the sewer system parts as they were considered by this research.

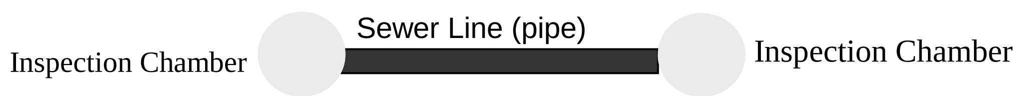


**Figure 2 – Schematic of inspection and sewer pipe**

## 2.2 Traditional Inspection

### 2.2.1 Types of Inspection Chambers

There are different types of inspection chambers, as showed in Figures 3 and 4. Figure 3 shows an inspection called in Brazil “PV-Poço de Visita” which has an irregular shape, because there’s a difference between the upper section and the bottom one. In figure 3, there is also another inspection chamber called in Brazil TIL (“Tubo de Inspeção e Limpeza”), which has a uniform section, with no eccentric slab. PV and also TIL are traditional inspection chambers often used in sewer systems with traditional methodology. Terminal Cleanout (called in Brazil TL) is another inspection chamber, less used than the other ones (Figure 4). TL is just used in the beginning of sewage to allow the introduction of maintenance equipment. Inspection Chambers (CI) are used in the entrance of each house that is linked in the network.(as showed in Figure 3)

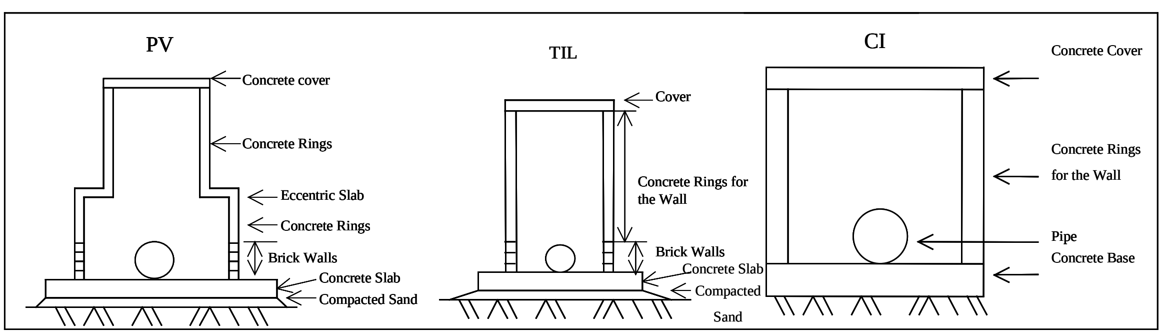


**Figure 3 – Schematic of Traditional Inspection Chambers (PV, TIL and CI)**

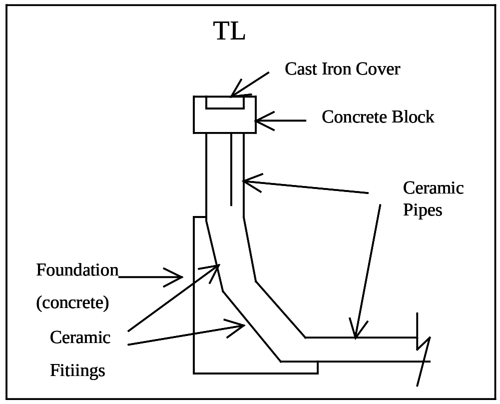


**Figure 4 – Schematic of Terminal Cleanout**

### 2.2.2 Installation

PVs are made at the site using construction materials like bricks, precast concrete rings, reinforced concrete slabs, ceramic pipes and fittings, concrete, cement, sand, and others by Alem Sobrinho and Tsutyja (1999). As presented in Figure 3, the following parts compose an inspection chamber:

1. Compacted sand for the base;
2. Foundation using reinforced concrete slab;
3. Bricks for the wall;
4. Precast concrete rings for the bottom part of the “body”;
5. Eccentric slab;
6. Concrete rings in the 600mm diameter for the upper wall, forming the access;
7. Covered generally is made of Reinforced Concrete or Cast Iron, and this last one is used in places where you have traffic;

When the PV or TIL is located in places with high water table, it is necessary to waterproof their external and internal surface.

The TL is made using ceramic pipes and fittings, with concrete foundation and it is necessary to embrace the ceramic fittings with concrete to assure the stability.

Traditional inspection chamber production demands more labor and also uses heavier equipment to transport components like precast concrete rings and prefabricated reinforced concrete slabs.

Because of these facts, the productivity for installing traditional inspection chambers is worse than for plastic one (that implies just an assemblage).

## 2.3 Plastic Inspection Chamber

### 2.3.1 Types of Plastic Inspection Chambers

In Brazil, there are two types of inspection chambers; the first one is the Radial Inspection Chamber, which is used with pipes in a diameter between 100 and 300 mm. These inspection chambers are used as an alternative to the traditional inspection chambers (PV and TIL).

It generally has circular shape and is composed by the following parts:

1 – Cover
2 – Inspection Pipe
3 – Body
4 - Base

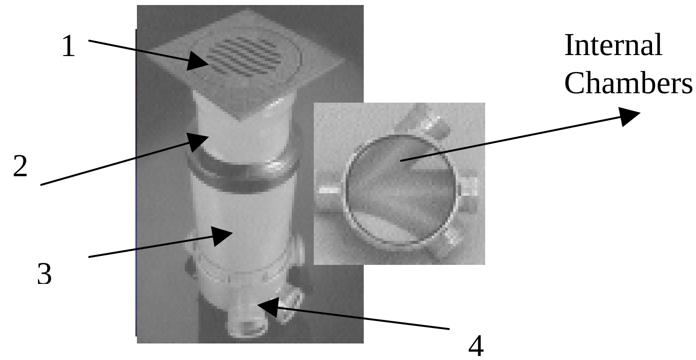


**Figure 5: Detail of an inspection chamber**

It is designed to resist the efforts caused by traffic. Generally made of Polyethylene (PE), this kind of inspection chamber has inside chambers that are important to direct the sewage. For connecting pipes in the chambers, it is necessary to use gaskets.

Its size and shape make possible the installation of it without using concrete for fixing it. When water table is high, it should be necessary to use concrete for the assurance of stability.

Another advantage is that internal surface is very smooth, allowing the perfect flowing for sewage and also avoiding points of accumulation. Internal shape was designed to facilitate operations of cleaning and inspection. (Figure 5).

In Figure 6, there is also an inspection chamber that is used to collect the sewage from the houses or buildings in substitution of traditional inspection made of concrete or brick.

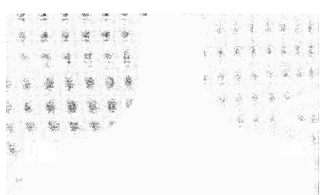

**Figure 6: Service Connection (for sanitary sewer)**

### 2.3.2 Installation of Plastic Inspection Chamber

Because of plastic inspection chamber is industrially manufactured, the installation is just an assemblage, involving generally two people that are capable to do all the steps for installing it. The steps are similar to the traditional techniques, i.e., once the trench is opened; it is just to lay the Inspection and then, cover it with soil. If sometimes the water table is high, it can be necessary to concrete the inspection in its base to assure the stability.

There is also a reduction of material loss and an improvement of labor productivity when compared with traditional technologies. The quality is guaranteed because it is the manufacturer's responsibility, reducing the interference of labor in that way.
In figure 7 it is possible to see an installation of a plastic inspection chamber in a sewer system.

**Figure 7: Installation of Radial Plastic Inspection Chamber**

## 3 Labor productivity in the installation of inspection chambers

Labor productivity study was done aiming to get information about the reality of sewer systems production, which are built with lots of interference.

In terms of productivity in a Traditional Sewer System, the installation of an inspection chamber is a very critical part of the execution once it involves several construction activities, such as the base (foundation), the concrete slabs and also the laying of concrete rings. According to several authors, when comparing labor productivity data, the installation of plastic inspection chamber presents better productivity rates than the installation of traditional ones.

### 3.1 Definition and Method used in this research

Productivity is the efficiency in transforming **labor** (effort) into a finished service ("results"). In the case of inspection chamber, effort is measured in terms of demanded work hours and the number of installed inspection chambers quantified the result. The work hours result from the multiplication of the number of workers involved in the service by the worked hours. The concepts that are described here are discussed by Souza (1996).

For determining productivity in the installation of plastic inspection chambers, there were developed a methodology of collecting data and also processing it, considering just the inspection instead of all the system. Sewer system was considered in parts (as said before), and the productivity of all system was also measured, but it is not included in this paper.

A specific person that was hired just to do this job, using tables in the site and also taking notes about any extraordinary events had registered the data collected in a daily basis. After collecting data, they were reconciliated in order to assure the validity of these results. Data were then processed and the results were analyzed.

Table 1 was used to help site collection; Table 2 was useful to calculate labor productivity rates.

| Table 1: Collecting Data for inspection Chamber Installation | | | | | | |
|---|---|---|---|---|---|---|
| Identification of Sewer Line | | | | | | |
| Characteristic | Number of Inspection | | | | | |
| | Type of Inspection | | | | | |
| | Material | | | | | |
| Team Work | | | | | | |
| Hours | | | | | | |
| Work Hours (Wh) | | | | | | |
| Total Wh | | | | | | |
| Extraordinary Events | | | | | | |

**Table 1 – Collecting services data for inspection chamber installation**

| Table 2: Processed Data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Constructor:** | | | | | | | | | |
| Place | Type Of System | Period of Collected Data | Type Of Inspection | Material | Diameter in mm | Depth in m | Work Hour Wh | Quantity of Inspection(unit) | Wh/unit |
| | | | | | | | | | |
| | | | | | | | | | |

**Table 2 – Processing collected data in site**

## 4 Case and Results

The characteristics for the studied place are: plane topography; the soil has good mechanical resistance and the streets are not paved with asphalt.

The amount of plastic inspection chamber researched was 1.242 units. Part of this amount, 1068 units, were used for sewer systems with a diameter of 100 mm while174 units represented inspections for sewer systems with diameters varying between 150 mm and 300mm

The researched amount of Traditional Inspection Chamber was 81 units. Part of this amount, 63 units, were used for sewer systems with a diameter of 100 mm while18 units represented inspections for sewer systems with diameters varying between 150 mm and 300mm.

## 5 Results and Comments

The results represent the mean value of productivity for different diameters and types of inspections. The work hours included delay and rework. Table 3 presents a summary of plastic inspection productivity figures. It shows that there is almost no variability in comparing the rates for different diameters of plastic inspections.

| Type of Inspection | Diameter mm | Mean Value of Depth (H in mm) | Work hours (Wh) | Quantity of IC* (unit) | Wh/unit |
|---|---|---|---|---|---|
| Radial IC* | 100 | 0,70 to 1,75 | 223,59 | 1068 | 0,21 |
| Radial IC* | 150 to 300 | 1,20 to 1,98 | 47,83 | 174 | 0,27 |
| **Radial IC*** | **100 to 300** | **0,70 to 1,98** | **271,42** | **1242** | **0,25** |

*IC=Inspection Chamber

**Table 3 – Plastic Inspection Chamber Productivity**

Table 4 presents the mean value of labor productivity for traditional inspection chambers. As showed in this table, there are great differences if comparing different diameters. For CI the mean value for productivity is 0,42 Wh/unit while for TIL the unit rate reached 8,72 Wh/unit. For PV mean value of productivity was 12,13 Wh/unit.

| Type of Inspection | Diameter mm | Mean Value of Depth (H in mm) | Work hours (Wh) | Quantity of IC* (unit) | Wh/unit |
|---|---|---|---|---|---|
| CI | 100 | 0,40 to 0,77 | 9,16 | 22 | 0,42 |
| TIL | 100 | 0,59 to 1,20 | 357,36 | 41 | 8,72 |
| PV | 150 to 400 | 1,37 to 1,90 | 218,34 | 18 | 12,13 |

**Table 4: Traditional Inspection Chamber Productivity**

Table 5 presents the improvement of productivity when comparing results from both types of inspections: Plastic and Traditional. In this table, it is possible to evaluate the advantage in using Plastic Inspection Chambers for diameters between 150 mm and 300 mm. The demanded effort to assemble one (1) Traditional Inspection Chambers (T) is the same as for assembling forty-five (45) Plastic Inspection Chambers (P).

| Place installed Inspection Chamber | Diameter (mm) | Technology (material) | Productivity (Wh/unit) | Relation between quantity of Inspections Traditional x Plastic |
|---|---|---|---|---|
| Sewer House connection | 100 | Plastic | 0,21 | 1T=2 P |
| | | Traditional | 0,42 | |
| Public sewer system | 100 | Plastic | 0,21 | 1T=40 P |
| | | Traditional | 8,72 | |
| Public sewer system | 150 to 300 | Plastic | 0,27 | 1T=45 P |

**Table 5: Improvement of productivity using Plastic Technology**

*Where T=Traditional and P=Plastic

## 6 Conclusion

With the results presented in table 5, it was possible to conclude that labor productivity for inspection chambers depends on the technology involved. Plastic Technology demands less labor, reducing costs. The figures showed in this paper can help managing a sewer system implementation.

It was possible to see that the differences do exist when comparing materials, not diameters. Besides, Plastic Technology has a better quality because all of its components are industrially manufactured by Ilha and Teixeira (1997). Also, Traditional Technology depends on the combination of labor involved in the execution and also on the quality of different components.

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# *CONFORMANCE ASSESSMENT APPLICATIONS for RECOGNITION of PLUMBING PRODUCT APPROVALS*

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## Abstract

Harmonization of regulatory requirements through application of conformity assurance procedures in regulated product acceptance is discussed. Conformity assessment procedures include inspection and testing, product certification, quality system registration, and laboratory accreditation. Manufactured plumbing products are usually regulated by legal requirements through adoption of plumbing codes and reference to national plumbing standards for assuring performance for health, safety and code provisions for installed building systems. Introduction of legal requirements from conformity procedures was established for regulatory requirements applied to plumbing product approvals in the state of Oregon, United States. Reference to international guides for conformity applications to recognized plumbing standards and code organization requirements could be useful as a model under international mutual recognition arrangements for regulatory sectors that would contribute to elimination of trade barriers. The Oregon regulation demonstrates that combining conformity assessment methods is feasible and practical when applied to regulatory actions. That model eliminates selective control for approved plumbing product listing(s) with costly duplicative testing and provides for expanding commercial product applications. Legislative mandates for legally required applications must apply to implement regulatory sector applications.

## Keywords:

Conformity Assessment, Plumbing Products, Regulatory Approval, State Plumbing Regulations

**Foreword**

Excerpt from Plumbing Manufacturers Institute draft submittal to case study for Building Regulatory Process of National Conference on States for Building Codes and Standards (NCBCS) [1] for adoption of Oregon model across the United States:

> "…current conformity assessment systems are becoming more fragmented and more and more sectored and local conformity assessment programs are created.….. The conformity assessment problems of the plumbing industry are shared by virtually every industry sector. ..
>
> ….proposed plumbing product approval model {*based upon Oregon State regulation* [2]} would improve the environment in which plumbing industry operates by reducing unnecessary duplication and complexity in conformity assessment requirements. …"

## Introduction

The importance of conformity assurance and assessment practices applied in trade and commerce for product performance from standards and/or legal metrology requirements are recognized as essential for facilitating international trade for products and services throughout the world [3]. Elimination of trade barriers from the burden of duplicative testing requirements, certifications and other prerequisites that do not address legitimate regulatory concerns, consumer needs, or market demands, has become a significant international concern. There exist a great variety of different stages of technical development in plumbing standards and codes and confusion is further added from a wide variety of approvals applied from legally binding regulatory provisions in many countries.

The importance of standards, metrology with conformity procedures to facilitating international trade has a long history. Adoption of common water conservation requirements for reduced volumetric water consumption and flow rates for plumbing fixtures in many countries has recently resulted from recognition of limited available water resources, escalating costs, and waste water treatment limitations for allowable environmentally safe discharges.

Further economic benefits in international trade can be accelerated if harmonized fixture requirements and test methods in performance standards are to the same acceptable performance levels. Harmonized regulatory requirements can eliminate diverse product performance differences, and through conformity assurance techniques, including assessing laboratory competence for testing evaluations to performance prescribed levels (set in standards for fixtures and systems) that will result in elimination of trade barriers.

Expanding applications of conformity methods is increasingly important to acceptance of advances in plumbing technology. Introduction of electromagnetic sensors with chip/circuitry interfaces to computer applications for devices for water and energy conservation. Those are increasingly applied to plumbing systems as a part of control management in heavily utilized facilities. Those elements/controls are already in synchronization with many types of automated building facility systems that include "energy managed smart house" technology. Such impacts provide increased commercial trade opportunities for plumbing products and those components do not involve heavy and large volume shipments of fixtures.

Significantly, practical installations of high-technology products now permit growth opportunities in plumbing trade without fixture costs for shipments. Unless regulatory citations in legal authorizations by governing bodies are adopted for regulatory purposes the applications of conformity practices and assessment cannot be enforced. Mutual recognition arrangements (mra's) provide an essential step to reduce barriers in trade and commerce. Legal regulatory requirements become necessary under the authorization systems mandated through national legislative proceedings.

Differences in product performance approvals occur within countries due to intra-national provincial and/or special considerations granted (large communities or counties/provinces for special selections) for differences in locally applied plumbing standards. Also, approval requirements and procedures differ where product acceptance is based upon competitive code bodies that maintain selective approved product lists. Such practices impede broad product acceptance in jurisdictions despite the fact that nationally accepted test criteria and product performance standard requirements have been successfully demonstrated.

Differences also result from plumbing standards development methods and tests applied for acceptance criteria. Developments may be directly under governmental direction and authorities, whereas in other regional arrangements standards are developed by private sector organizations where influence or special interest cannot be eliminated in setting adequacy requirements in the standards.

Functional specifications for performance, health and safety compliance requirements are usually cited by requirements referenced to standards or specific mandatory regulatory specifications. Countries adopt legal controls on trade for sales of products and may apply restrictive applicable standards. It becomes necessary that demonstration verification to required levels of performance depend upon reliable test data. However, significant differences occur since there are usually no requirements for sufficient and necessary measurement assurance that corresponds to those from legal metrology (where technical fundamentals are established and prescribed by most nations as signatories to international treaty arrangement [4]). Practices in plumbing product acceptance methods allow considerable variation from many procedures employed or at times none exist; examples procedures include self-declarations, manufacturer's quality systems registration, product certification, or test data, sometimes with requirements that include laboratory accreditation. Requirements established with conformity assurance processes need regulatory statutes that stipulate requirements for testing and product certification with reliable data development through established legal authorizations governing trade and commerce in non-voluntary sectors.

## Conformity Assessment

*Conformity assessment* is the comprehensive term for measures taken by manufacturers, their customers, regulatory authorities, and independent, third parties to assess conformity to standards" [3, 5]. Conformity assessment procedures assure required characteristics are fulfilled consistently from distinctive specifications for reliable and maintained systems. The procedures can include one or more of the following:

| CONFORMITY ASSESSMENT PROCEDURES | |
|---|---|
| Sampling and testing | Inspection |
| Personnel, products, services certifications | Process, system assessment, registration |
| Accreditation of competence by third party(s) | Recognition of capability for accreditation program |

Various national and international publications include one or more of the above elements for standards, guides, and recommendations. To assure confidence in conformity assessment processes several recognized means exist to demonstrate fulfillment of requirements; briefly they consist of the following:

| TYPES OF CONFORMITY ASSESSMENT | | |
|---|---|---|
| **First Party, or Manufacturers Declaration** – Confidence from capability/integrity/ Reputation | Process for Product/Service/System to meet one or more standards fulfilled by self-determination or declaration | Basis from assurance of Quality Control System, or Testing/Inspection audits as Authorized |
| **Second Party** Buyer requires/verifies products meet standard(s) depending on purchaser's needs | Process for Product/Service/System to meet one or more standards fulfilled by contractual requirement for other evaluation/determination | Variable depending on buyers reference(s), standards and specifications |
| **Third Party** Validation of producers claim(s) from competent third party (no control of involved parties) to products and meet standard(s) | Evaluation process for Product/Service/System by independent source to referenced standards fulfilled by external independent requirement evaluation/determination | Independent and non-affiliated with confidence for certifications from test data and inspections to referenced standards and specifications |

## Terminology and Meaning

Recognition of internationally accepted definitions for terminology customarily applied for international purposes is ISO/IEC Guide 2 (see ISO list, next page); those of greatest interest here are (vocabulary definitions):

> *Conformity Assessment* is a comprehensive term for measures taken by manufacturers, their customers, regulatory authorities, and independent third parties to assess conformity to relevant standards. Conformity assessment procedures ensure that products, processes and services meet certain characteristics in a consistent manner and include inspection, testing, certification, quality and environmental management system registration, and accreditation activities.
>
> *Testing* as the action of carrying out one or more technical operations or tests to determine the characteristics of a given product, process or service according to a specified technical procedure or test method.

*Inspection* as conformity evaluation by observation and judgment accompanied as appropriate by measurement, testing or gauging.

*Certification* as a procedure by which a third party gives written assurance that a product, process or service conforms to specified requirements. Certification is distinguished from testing by three key features:

1. Certification always measures a product, process or service against one or more specific standards, whether mandatory or voluntary. Testing, by contrast, does not necessarily measure against any specific standard;
2. Certification is always performed by a third party, independent of either the supplier or the purchaser;
3. Certification results in a formal statement of conformity, a certificate that can be used by the manufacturer to show compliance with regulations, meet purchasing specifications, and enhance the product's marketability.

*Product Certification* as the process of providing assurance that a product conforms to a standard or specification. It encompasses many different levels of complexity and expense, depending on the characteristics of the product and the degree of need for confidence in the product's conformity to standards.

*Quality System Registration* (sometimes referred to as "quality system certification") as the assessment and periodic audit of the adequacy of a supplier's quality management system by a third party, known as a registrar, against quality management standards such as the ISO 9000 series. Quality system registration does not imply product quality or conformity to any given set of requirements. It only guarantees that a product is made consistently to a certain quality level set by the manufacturer.

*Laboratory Accreditation* as the process that determines whether a laboratory is capable of performing specified test methods and procedures correctly to the level of accuracy required for a given specification. It does not ensure that the laboratory competently and consistently conducts the tests. Furthermore, laboratory accreditation provides assurance about the capability of a laboratory only within the scope or areas for which accreditation was granted.

## Mutual Recognition Arrangements

Increased recognition for implementation of international guides has gained credibility in worldwide commerce [see, Agreement on Mutual Recognition Between the United States of America and the European Community", (1997); {website}www.mac.doc.gov/mra/mra.htm] in arrangements for establishment of Mutual Recognition Agreements (MRA's) or mutual recognition arrangements (mra's) [3]. Information on multilateral issues covered by existing arrangements in MRA's concerning the scope of many related issues for trade facilitation can be downloaded from the 'web' from the European Commission (http//europa.eu.int/comm/trade). There, it is indicated that non-tariff barriers to trade can range up to 10% of overall product costs (higher for less developed countries) so that actions for simplification through harmonized procedures for coordinated approach to trade facilitation is necessary; the World Trade Organization (WTO) agreed to address such problems.

Particular interest amongst proposed solutions for elimination of trade barriers is the "wider adoption of harmonized international standards used in the trade transaction". Therefore, the adoption of guides that have been broadly accepted for conformity assessment procedures to regulatory provisions for reducing plumbing product barriers to trade and increase commercial exchanges can be anticipated to be worthwhile. Examples of organizations that have applied the recognized international guides as acceptable methods into the signatory requirements are Asian Pacific Laboratory Accreditation Conference (APLAC), European Cooperation for Accreditation (EA).

The following partial list indicates the range guides and standards published by the International Organization for Standards (Copyright © ISO, 2000).

## ISO LIST OF GUIDES - (Partial)

ISO/IEC Guide 2:1996 Standardization and related activities -- General vocabulary
ISO/IEC Guide 7:1994 Guidelines for drafting of standards suitable for use for conformity assessment
ISO/IEC Guide 15:1977 ISO/IEC code of principles on "reference to standards"
ISO/IEC Guide 21:1999 Adoption of International Standards as regional or national standards
ISO/IEC Guide 22:1996 General criteria for supplier's declaration of conformity
ISO/IEC Guide 23:1982 Methods of indicating conformity with standards for third-party certification systems
ISO Guide 27:1983 Guidelines for corrective action to be taken by a certification body in the event of misuse of its mark of conformity
ISO/IEC Guide 28:1982 General rules for a model third-party certification system for products
ISO Guide 30:1992 Terms and definitions used in connection with reference materials
ISO Guide 31:1981 Contents of certificates of reference materials
ISO Guide 32:1997 Calibration in analytical chemistry and use of certified reference materials
ISO Guide 33:1989 Uses of certified reference materials
ISO Guide 34:2000 General requirements for the competence of reference material producers (available in English only)
ISO Guide 35:1989 Certification of reference materials -- General and statistical principles
ISO/IEC Guide 43-1:1997 Proficiency testing by interlaboratory comparisons -- Part 1: Development and operation of proficiency testing schemes
ISO/IEC Guide 43-2:1997 Proficiency testing by interlaboratory comparisons -- Part 2: Selection
and use of proficiency testing schemes by laboratory accreditation bodies
ISO/IEC Guide 46:1985 Comparative testing of consumer products and related services
ISO Guide 47:1986 Presentation of translations of ISO publications
ISO/IEC Guide 51:1999 Safety aspects -- Guidelines for their inclusion in standards
ISO/IEC Guide 53:1988 An approach to the utilization of a supplier's quality system in third party product certification
ISO/IEC Guide 58:1993 Calibration and testing laboratory accreditation systems – General requirements for operation and recognition
ISO/IEC Guide 59:1994 Code of good practice for standardization
ISO/IEC Guide 60:1994 ISO/IEC Code of good practice for conformity assessment
ISO/IEC Guide 61:1996 General requirements for assessment and accreditation of certification/registration bodies
ISO/IEC Guide 62:1996 General requirements for bodies operating assessment and

certification/registration of quality systems
ISO Guide 64:1997 Guide for the inclusion of environmental aspects in product standards
ISO/IEC Guide 65:1996 General requirements for bodies operating product certification systems

ISO/IEC 17025:1999 General requirements for the competence of testing and calibration laboratories

## Conformity Assessment Applications

In figure 1 various conformity assessment methods are shown that have applications for the voluntary sector in trade practices for products and services. From the common basis of mutual arrangements or international Mutual Recognition Agreements (MRA's) by selection of one or more linked paths several may emerge. Each linked path (the vertically oriented connected lines) include primary elements from a conformity assurance selection. Each set of linked lines have been applied (selective occasion) as a separately applied 'tool' required for assurance in applications to products and services for trade and commerce in voluntary sector applications to manufactured goods. Such selectively chosen arrangement(s) and practice(s) can be adequate when the lesser limitations or lower priority for specifications can be applied as necessary provisions that do not require intensive actions from proficiency, laboratory testing competence and meticulous measurements.

The linked lines (from bottom to top) in figure 1 from the MRA's box trace paths for conformity practices which are applied that assures confidence in each of the methods shown. For example, following Quality Systems (links) assures oversight through an independent body established for registration of suppliers/producers (quality systems implementation of ISO 9000 series documents). The registration assures confidence for special qualifications in the product or service that must be achieved as integral elements necessary to maintain continuous manufacturer adherence for quality that insures replication of the products/components.

Countries that adopt any one of the conformity procedures for acceptance lessens barriers and confusion for products in trade and commerce. Restrictive oversight requirements are simplified and reduced for acceptance into markets usually with user cost benefits. Governmental distinctions that occur for voluntary sector(s) can be provided through trade rules without excessive restrictive legal regulations or without detailed specifications (or standards) to achieve needs or set limitations for introduction of products/services. In regulatory situations details become an important aspect for acceptance practices that need to have uniformity that does not impeded trade in applications from rules. Reduction of trade barriers results from implementation in voluntary sectors where less severely constraining factors occur for technically comprehensive requirements.

Singular methods do not provide product assurance and confidence for competence in testing necessary for regulated products or delivering services. Single conformity assessment practices are not sufficiently comprehensive to have application to provisions for product acceptance in regulatory sectors. The combination of several elements of discrete conformity assessment practices becomes necessary to establish sufficiently adequate controls for assurance and confidence from practices applied to regulatory sectors as a basis for international arrangements. Regulated products in trade arrangements for acceptance requires assurance and confidence from several practices. They must encompass provisions for technical depths of verified assurances that includes primary factors as inspection, competence for test data developed from accredited laboratory that assure measurement reliability and accuracy (based on traceable national reference standards) and product certification. No one process can apply for regulatory purposes applied in trade; several conformity procedures become essential.

### Conformity Assessment Perspectives

Conformity assessment infrastructure in the Western Hemisphere (Free Trade Area of the Americas {FTAA}) [6] illustrated the variety of methods applied. The study considered four elements from conformity assurance; those were inspection and testing, product certification, quality system registration, and laboratory accreditation. Selected tables from the report are attached.

Indications from the report showed widely varying methods implemented and demonstrated infrastructure differences for practices while in some instances no methods existed. Details from the applied requirements indicate extensive differences in national practices and applications for implementation from conformity assessment practices. Those with extensive applications were also more involved with organizations that related to other activities for standards development and their implementation method. Other analyses of national issues for differing conformity assessment systems implementation that can be applicable to regional mutual recognition arrangements or applied in a global network needs to be made. Differences can become more readily identified from understanding the specific details leading to other options that may be considered. Introduction of the elements from the Oregon model could become a basic building block for applications. The adoption would contribute to achievement toward the goal of reducing and/or eliminating trade barriers resulting from the widely different plumbing product methods applied in many countries.

## Applying Conformity Assurance

Regulated product requirements from combinations of elements adopted from conformity assessment methods became a basis for the legal establishment in Oregon of a framework infrastructure. The purpose was to eliminate existing shortcomings identified from practices in place. The regulatory scope and format of the regulation provides a basis for considerations that can apply to all essential details in other legislatively mandated regulatory requirements applicable to other products. Indications concerning implementation of the model legislation will be forthcoming from its impact evaluation in future years.

To apply the model as a suggested format requires clarity in the objective(s) and purpose(s) so that details can be structured in the regulatory actions with complete and necessary requirements. Assurance and confidence in technical performance evaluations and the continuity for sustained evaluation methods {beyond only applications of statistical product(s) sampling} is accomplished in the adopted measures from certification methods and referenced to guides and standards procedures. An essential component applied to regulatory product approval(s) must be inclusion of effective enforcement.


**LADDER for NECESSARY PROCEDURES**

Principal elements were considered in identifying needs for the new applications from the revised Oregon regulations. The features considered basic to the development are shown in the sketch. At the time the existing methods were beyond state control in important identified aspects and elimination of variables from the new procedures were important.

New regulations were to assure uniformity from adopted international and national reference guides and standards for objective independent third party support to be established. Inconsistent applications in acceptance criteria had allowed substitution of drawings instead of actual test data in accord (from test standards) and recurring payments by manufacturers for listings would no longer occur. Clarity for approvals would result from labeling and marking requirements. The state office responsibility for plumbing product approvals in Oregon would be in place and field approvals could not occur from new procedures. Individual evaluations by plumbing inspectors in field jurisdictions would not occur.

Prior product acceptance practices, previously based on the product approval listings established by plumbing code organizations, would no longer be applied. Those lists were established by plumbing code sponsor organizations. Intrastate practices varied at local jurisdiction levels due to "individual expertise, with determination from opinions", that may or may not have had validity. Such occurrences were experienced whether or not product approvals had a common basis from testing criteria or test evaluations required in national standards, or other allowable state practices. The local jurisdiction acceptance from the marking and labeling of products would become mandatory. Product acceptance from uniformly required performance testing would assure applications based on national plumbing standards criteria for approvals of manufactured products.

The simplified 'ladder' illustration shows how implementation may be viewed from the new regulation for plumbing product approvals. The adopted measures established the necessary linkages built on reliance from each step of the regulatory approach and applied to each of the specific functions. Confidence follows from legally set requirements that prescribe qualifications to be followed. As a result the newly established Oregon regulations would provide uniformity for all jurisdictions in the state for uniform acceptance of plumbing products.

Enforcement of the regulation then became essential to the effort so that the common basis for acceptance would not be circumvented.

Assurance from laboratory accreditation for test data results from assurance for testing competency for proficiency in test measurements backed by requirements for traceable calibration confirmation to national reference standards (and/or uncertainty of measurements) [7, 8]. Testing capability can be readily determined from specific test methods with the listed accreditation scope. Important elements for conformance methods recognized were:

- Laboratory requirement of independence assures confidence beyond testing competency. Laboratory certificates of accreditation include scopes of accreditation for test methods listed for specific recognition.
- Laboratory assessment evaluations are conducted periodically by independent technical experts in on-site visits.
- Product certification provides validation of performance criteria established in the state listing of referenced standards that are required for utilization plumbing products [9].

Quality systems registration as a separate distinct requirement was not applied directly. Such systems are recognized to provide for essential management quality practices to assure replication of products but does not assure test performance data certainty from standard test methods. Control of manufactured products is made by manufacturers through registration based upon assessments by registrar organizations to evaluate quality system practices. In the new regulation quality system registration can be a requirement for approval procedures can be allowed at the discretion of a special deputy approval provision for limited products.

Recognition of limitations and/or differences that result in conformity assessment has previously been noted [3].

> *"Certain forms of conformity assessment, some more rigorous than others, may be invoked... Those include sampling, inspection, product testing, product certification, personnel certification, accreditation of testing and calibration laboratories, management system registration, (for ISO 9000 and 14,000) and recognition programs"*.

## Oregon Effort Completed

Lack of objective independence for plumbing product approval practices for listings (developed from plumbing code sponsorship) was to be made completely free of potential narrow interest control. Principal shortcomings could be traced to inadequate controls for objectivity in methods that were beyond state authority to regulate. Approval evaluations had varied widely; at times test data substitution could occur from only product plan reviews. The absence of test data resulted in no assurance or confidence that product standards were the factual basis for acceptance.

Conditions existed which required manufacturers to have duplicated product test approvals for acceptance in various state jurisdictions where different codes were in place (possibly from early historical needs and evolution of private plumbing code sponsors). Despite reference by code organizations to the same national standards for test requirements performance variations were not uncommon; that reflected different techniques of test validation methods applied, and lack of competency recognition of selected test laboratories. Competitive plumbing codes showed different products as acceptable from plumbing manufacturers according to their own approval listings.

The necessary elements in the ‘ladder for necessary procedures’ were implemented in a new regulation. Initially, the draft state efforts were to carry out specific functions for adoption of conformity assurance in actions undertaken by state personnel. The final regulation established that private independent organizations were to conduct those tasks in support roles that fulfilled the approval processes cited. Product identification labels display or visible markings were stipulated as required for acceptance of products.

From the early recognition applications of conformity assessment methods were to become necessary in order to achieve the new required requirements for regulatory purposes. Four potential techniques considered were:

■ inspection and testing; ■ product certification;

■ laboratory accreditation; ■ quality system registration.

Those conformity procedures provide reliable evaluations from third party sources to achieve elimination of uncertainty in practices, or departures from listed national product standards requirements and acceptance criteria with confidence established from testing.

### Initial Draft

Initial draft provisions adopted conformity assessment practices that would deeply involve state employees in evaluations that would result in costly assessment activities for onsite assessor evaluation activities.  To achieve proficient performance in those activities costly training would be required and experience gained before achieving proficient expertise. That provision was to provide independence for the objective purposes previously not applied in product approval practices. The price for objectivity was high for the process to set required staff capabilities at a competence level for conducting assessments in compliance with conformity assessment practices. The planning never lost confidence derived from conformity assessment practices through objective evaluations.

Application of the steps in the ladder of requirements for product approvals became evident to assure field and local jurisdictions would not make discretionary decisions for products. The new practices would establish a common application basis throughout the state for plumbing products based on product approvals from national standards. The legally established approved mode of operation control would be at the state capital office would exclude arbitrary decisions. Appropriate marking and labeling would be unequivocally applied for presenting information by a clearly observable display for inspection at local levels.

## Oregon State Solution

Further regulation for a comprehensive recognition process development was based upon the draft and encouraged through NIST in cooperation with the Plumbing Manufactures Institute (PMI) and with other interested representatives of the plumbing community. To assist and guide in revision of Oregon draft plumbing regulations the cooperation of the Office of Standard Services (OSS) at the National Institute of Standards and Technology (NIST) was requested. NIST assembled staff with trade and engineering specialized backgrounds for presentations and discussions at meetings. Review of the proposed draft plan was made with personnel assistance and provided submittals in written commentary and recommendations.

State endeavors to directly undertake the involved procedures from conformity assurance would duplicate already existing organization activities that were in place for the same purposes. Those functions were already functional and operated by existing private sector programs, and also by selected public bodies in government; several were particularly established that actively conducted program evaluations specifically for conformity assurance with independent expert assessor that conducted periodic on-site evaluations.

Since the draft document was inclusive of necessary elements from conformity practices the analysis indicated that the basis was sufficiently comprehensive and avoided duplications. Redundancy was unnecessary since all necessary aspects for maintaining assurance from independent evaluations. Periodic reviews would be maintained in accord with international guides for testing competency; product certification and inspection provided in methods for accomplishment to desired goals. The final step for product identification(s) from labeling, and/or marking, as the method for displaying satisfactory performance from test evaluation acceptance criteria established necessary assurance and confidence from the steps performed in the prescribed measures. For the regulation and practice with conformity assessment procedures to be effective the necessity for enforcement was also required and made inclusive through the regulatory mandates (subject to Oregon legislative processes).

The state office agreed that required objectives for assurance based on recognized third party independent organization participation achievement for compliance responsibility to guides and standards would be purposeful. Confidence in those special capabilities to conduct necessary services conducted with staff and specialist assessors for services was acceptable for application in final revisions to the proposed regulation led to the final adoption.

Lesser budgetary impacts resulted from the final state regulation with different implementation methods from the initial draft. The cost-effective implementation of rules that draws upon established independent organizations to implement conformity assurance methods provided budget benefits as compared to the initial draft document. Introduction of established independent organizations as the entities to conduct detailed functions from conformity assurance techniques provided the basis for reliance which would not require duplication to achieve assured objective(s) implementation of rules from recognized guides.

## The Established Rule

The final regulation adopted appears in the Oregon Administrative Rules 1998 Compilation, Division 770 [2]. Extracts of principal elements under the section headings follow:

***Purpose*** – Approval procedures for plumbing product testing laboratories and product certification systems. No plumbing product may be sold unless in conformance with approved standards by an approved testing laboratory. Listed by Board approval body. Approval exemptions by special deputies,

***Definitions*** **-** Adopted (mostly) from international references

***Composting toilet Rules*** – Installation, construction and permits for site control established that allow only aerobic system decomposition of wastes and also the disposal of resulting humus.

***Approval of Testing Laboratories*** – 1. Test data acceptance only from approved laboratory accreditation programs that apply requirements of ISO Guide 25:1990 (obsolete document now replaced by ISO 17025:1999) for competence. Testing laboratory approvals require a Certificate of Accreditation for listed specific test methods from accrediting organizations. 2. Only accrediting organizations that meet ISO Guide 58:1993 (*currently being rewritten*) and maintain active certifications for testing laboratories with specific test methods in scopes of accreditation listed. 3. Testing laboratory accreditation organizations approved are (a) National Voluntary Laboratory Accreditation Program (NVLAP), and (b) Oregon Electrical and Elevator Board. Others may apply for recognition.

***Standards of Approval for Bodies Operating Product Certification Systems* - *Operation*** for the purpose of providing written assurances that plumbing products conform to specific product standards approved by the Board shall be required to show compliance with ISO/TEC Guide 65:1996 or ANSI Z34.1: 1993. Product certifiers shall provide one copy of product directory or listing for conformance.

***Applications Procedures*** - 1. Testing laboratory(s) approval for product conformance testing to the approved standards shall submit application to Chief Plumbing Inspector with Certificate of Accreditation from an approved laboratory accreditation program organization. 2. Laboratory accrediting organizations seeking approval to issue Certificates of Accreditation shall submit application with evidence of compliance to requirements of ISO/IEC Guide 58:1993. 3. Approvals for certifying organizations require application to the Chief Plumbing Inspector that documents evidence of compliance with requirements of ISO/IEC Guide 65: 1996 or ANSI Z34.1: 1993. 4. Approvals for the foregoing organizations conducting their respective indicated functions shall be for an indefinite period and contingent upon properly maintaining compliance with the approval requirements. 5. Written denials of applications shall be provided; submittals of revisions by applicants may be made for applications without prejudice.

***Revocation of Approval*** - 1. Failure to comply with any of the approval requirements (in the rules) by any of the referred to organizations may be cause for revocation of approvals. 2. Notice of intent to revoke approval shall be given with thirty days allowance for response, and review of Board's decision, as provided for in Oregon statutes. Denial of appeal shall be stayed pending outcome of an appeal unless immediate threat to health and public safety exists(s).

***Change in Status*** **–** Changes in of any recognized approval accreditation or certification system status shall be provided within 30 days.

***Product Certification by Special Deputies*** – 1. Approval for plumbing products through the Chief Plumbing Inspector may be made provided if: a. No more than three products are intended; b. No more than two manufacturers and the requester for certification does not intend further special deputy certification of the product for sale in Oregon; c. Product not offered for sale in Oregon for more than two times over any two year period s following inspection approval. 2. "Three similar products" includes custom assemblies for same purpose.

***Submission of Plumbing Products for Approval by Special Deputy*** - Sample of the product(s) submitted for approval shall be made or site-specific location provided for review. Necessary supplemental information necessary for evaluation related to approval shall be provided.

***Fees and Procedures*** – 1. Payments are required for product approval fee at $40 per hour for special inspections and payments shall be provided for special added evaluations by submitter. 2. Payments shall be made in advance of inspection including that for estimated costs; deposits not required for fee shall be refunded upon request.

***Special Deputy Certification Procedures*** – 1. Determination(s) shall be made by special deputy inspector of product(s) to meet Board adopted minimum health and safety standards by: a) Examination of product and components for compliance to application and installation; b) Reviewing assembly of all components in correct utilization(s); c) Reviewing code compliance; d) "Production type" testing required where applicable under Board adopted product safety standard. 2. Product attached certification label by special deputy inspector or certification label is authorized. 3. Special deputy examination actions for certification of production line products is authorized for standards conformance and production control processes. Authorization is given for special deputy to permit attached labels for products approved under quality control production and allows periodic visits to manufacturing facility on conformance to approved quality control plan. Continued certifications of approved production line products shall be conditioned on conformance to special deputy original approvals.

***Certification Marks and Product Standards Identification*** – Listed products must be identifiable either on the product or documentation enclosed in packaging. If with packaging required inclusion is: 1) Certified product picture, image or drawing; 2) Registered marks of certifier; 3) Product specifications and standards for certification with adoption dates; 4) Manufacturer and model number identifier; 5) Origin location of manufacturing plant; 6) Labeling information required as listed in Board approved standards.

***Status of Existing Approved Plumbing Products*** – Approved plumbing products as of October 1, 1997 shall be reviewed against these rule provisions. Notification notice for revocation of approval provides 30 days for response with judicial review available with stay of action pending appeal unless of immediate thereat to health and safety.

***Approved Plumbing Product Standards and Specifications*** – Board approved applicable standards and specifications are referenced as listed.

**Applications Commentary**

Acceptance of products by direct application of certification under ISO 9000 quality registration was not adopted in this regulatory program. Quality registration for products does not achieve all necessary assurances to provide reliably accurate test data that results from laboratory accreditation. There is a need for necessary criteria for product acceptance (…tell nothing about technical competence or ability to provide reliable and accurate test data ….") (10). However, Special Deputy Certification Procedures that permits discretionary option for temporary product acceptance in limit period approvals; if desired, that quality criteria could be applied after manufacturer site inspection. That limited application decision only achieves the certification purpose for products under allowed limit rules.

The completed regulatory requirements provide confidence that independent sources can provide an objective basis for evaluation of each function through adopted conformity assurance methods according to international guides and/or national standards. Uniform practices for plumbing products through eliminated product approval listings from industry related sources. The goal for statewide uniformity by acceptance of labeled products practically eliminates conflict of interest situations by applying independent sources for implementing the regulation.

Mutual recognition arrangements for requirements need to have necessary only essential elements from conformity assurance methods applications that include independence in conducting detailed assessments from evaluation services; those that provide depths of objectivity were used in the Rule for:

**(a)** Inspection and Testing - Approval of Testing Laboratories

**(b)** Product Certification - Standards of Approval for Bodies Operating Product Certification Systems

**(c)** Certification marks - Certification Marks and Product Standards Identification

**(d)** Laboratory Accreditation.-Approval of Testing Laboratories; and potentially implied

**(e)** System Registration -(ISO 9000 Series) Special Deputy Certification Procedures.

For regulatory programs it is essential to have compliance with specifications that assure competence for developing test data from laboratories subject to independent evaluations that affirm product performance set in standards criteria. In all cases listing of designated plumbing test standards must be specific. Plumbing product standards and specifications approved by the Oregon Board are referenced [9]. Referenced documents are established and published by national (ANSI, ASTM, ASME) or international organization (ISO). The strict qualifications for independent objectivity in the selections assure confidence and trust in the result.

The purpose of laboratory accreditation programs assures competence of laboratories through evaluations by independent expert assessors in the programs [see "International Laboratory Accreditation Cooperation Why use an accredited laboratory", ILAC (1998) {at website} www.ilac.org]. The Oregon test laboratory accreditation requirement only recognizes NVLAP because of independence from conflict of interests. That selection recognizes objectivity because all operations require functions to be in accord with U.S. government practices; operations are fully described, see Handbook 150 [7], based on international requirements of Guide 58. NVLAP accredited laboratories need to satisfy requirements of ISO Guide 25 (now replaced by ISO 17025) for all testing and calibration accreditation programs. The specific plumbing accreditation program in Commercial Products Handbook [8] is unique and is a public document. The plumbing program scope of accreditation lists only test methods for which the laboratory has achieved satisfactory evaluation for competency recognition by on-site assessment supported by quality systems applied to testing in order to receive a Certificate of Accreditation.

## Standards

International acceptance methods for plumbing products require collaborative efforts to develop common technical test requirements in performance standards. Viable approaches require performance test parameters applicable to differing practices in nationally accepted standards. An analogy from legal metrology may apply. Recommendations (i.e., standards) are accepted by nations that are treaty signatories to the International Organization of Legal Metrology (OIML) [4]. Committees from national organizations serve as Secretariats and bring participants from worldwide member nations together for setting requirements and approval.

In other efforts plumbing developments from working groups in bilateral and trilateral North American efforts (Canada, Mexico, United States; North American Free Trade Act Bilateral Treaty). Those have demonstrated satisfactory resolutions from international cooperation for needs based upon differences recognized for national water supply conditions that can be applied to phrase precisely requirements in common standards.

The Appendix lists organizations in the Western Hemisphere (6) that conduct related activities in standards and conformance developments. A significant examples of common activity are the trade simplifications and European Norms as regional standards that have been promulgated for member nations of the European Union.

## Conclusions

The Oregon model provides the setting of a legal mandate for plumbing product approvals in a form for infrastructure and requirements from detailed conformity assurance practices. Identified organizations provide the primary purpose for independent objective decisions without partiality. The conditions achieved from recognition for adherence to stipulated criteria and functions evaluated through independent oversight requirements and assessor evaluations conform to requirements based upon international guides and standards. Independence from influences and affiliations is assured to provide objective evaluations and certifications based on international guides for compliance.

Consideration of that model in applications to trade and commerce can introduce benefits from established product standards applied to commerce and trade issues. The model system provides interested parties with the structure for determining recognition of qualifications of conformity participants with assurance based on knowledge and implementation practices. Acceptance of conformity assurance to practical procedures can ensure uniform compliance from regulations with confidence for validity of procedures and elimination of duplication for trade requirements.

In plumbing practices the introduction of modern techno-devices for functions in automated buildings with integrated systems for energy management and water conservation has introduced new trade opportunities. Additional efforts for revisions in building codes and standards that effect health and safety must be undertaken.

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# Trade / Conformity Assessment

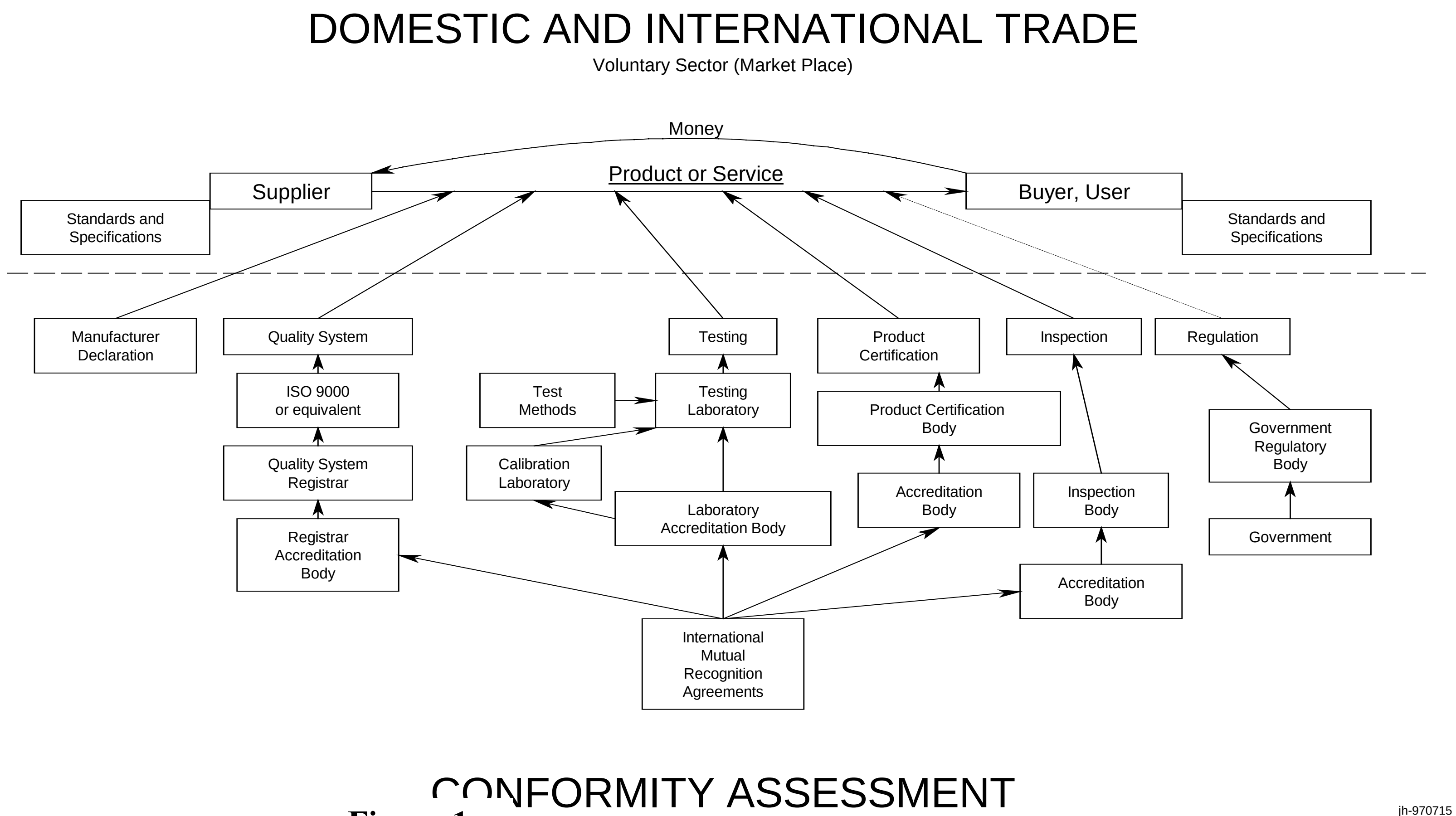


**Figure 1**

## FTAA Countries Conformity Assessment Infrastructure

| Country | Inspection & Testing | Product Certification | Quality System Registration | Laboratory Accreditation |
|---|---|---|---|---|
| **Antigua & Barbuda** | The Antigua and Barbuda Bureau of Standards will conduct inspection and testing. However, it does not have any testing facilities yet. Efforts are being made to acquire the facilities, equipment and training to support local industry needs, principally in the areas of food, clothing, automotive and building materials. Often the testing facilities of the Bureau of Standards of Trinidad and Tobago and Jamaica are used. Also the Ministry of Agriculture does some limited testing in the food sector. Usually inspection and testing results issued by other countries are accepted. | The Antigua and Barbuda Bureau of Standards is the official body for product certification. Sixty percent of the national Gross Domestic Product comes from tourism. A program to certify hotels is in progress. Other product certification programs to support local cottage industries such as food processing, clothing, brewery, distillery are being considered. In general, product certification results from other countries are accepted in the country. | The Antigua and Barbuda Bureau of Standards is the official national body for quality system registration. The sectors of importance are the hospitality industry and manufacturing industry. In general, quality systems registrations/certifications from other countries are accepted in the country.<br>The company in the Cable and Wireless sector has received the ISO 9002 registration. | Presently Antigua and Barbuda does not have a national laboratory accreditation program. |
| **Honduras** | There are seven (7) inspection and testing bodies, five (5) in the public sector and two (2) mixed bodies (drugs and meats). The Department of Standards and Metrology, part of the Secretariat for Industry and Commerce (SIC), is authorized to issue and enforce compliance of the official quality standards, and as set forth in the consumer protection law, it receives advisory services and assistance from the Inter-institutional Commission for Standardization. Generally speaking, testing inspections from other countries are accepted in the Honduran market. | Currently, there is no national agency for product certification. The origin of national products is certified by SIC through the center for export processing of the General Directorate of Business Management (CENTREX); meats are certified at the Secretariat for Agriculture and Livestock (SAG) authorized by the fitosanitary law. The Metrology Law should be passed soon. The regulations in this law involve mandatory and voluntary standardization activities, inspection, verification of technical quality, certification of products and systems and accreditation. In addition, Honduras is considering the creation of an Institute of Metrology and Quality (INMECA) which will support the implementation of the aforementioned law. | SIC has the power but does not have the structure to issue the results of certification of quality systems. However, private companies in Honduras have been certified/accredited by other accredited international organizations. Honduras accepts certifications from other countries for commercial purposes that operate in the non-regulated field. | Presently Honduras does not have a national laboratory accreditation program. In the public sector, the Health Secretariat accredits its laboratories through the Food Control Laboratory.<br>In the private sector, Red Technical Services functions as the accrediting agency for Texaco Laboratories. |

| Country | Inspection & Testing | Product Certification | Quality System Registration | Laboratory Accreditation |
|---|---|---|---|---|
| **México** | Each government department is responsible for verifying and monitoring compliance with the standards they issue. In cases related with the interests of the public in general, monitoring of compliance with the Official Mexican Standards is the responsibility of the Government's Public Prosecutor's Office for Consumer Affairs (PROFECO). For imported goods subject to the Mexican Official Standards regarding their entry into the country, verification and monitoring is the responsibility of the General Customs Office, part of the Tax Administration Service of the Department of the Treasury and Public Credit. The tests indicated in the Official Mexican Standards are carried out by testing laboratories accredited by the Mexican Accreditation Agency, A.C. (EMA). The results are presented before verification units (VU), also accredited by the EMA. The VU's issue the report verifying compliance with the applicable standard. This report makes it possible to import the product in question. | In México, the body responsible for product certification is the Mexican Accreditation Agency, A.C. (EMA). EMA is a civil association to which all Government departments have delegated the responsibility of deciding the technical competency of the certification bodies. In addition, the certification bodies must obtain approval from the body that issues the corresponding Official Mexican Standards. The DGN, General Directorate of Standards, certifies products in accordance with Mexican National Standards, for which SECOFI is responsible through the verification units (UV's). SECOFI has accredited approximately five certification bodies from the private sector such as ANCE, NYCE, IMNC, NORMEX, CRT. These bodies have been accredited to handle specific voluntary standards and under which they can issue certificates for the relevant products. For more details go to SECOFI's web page (www.secofi.gob.mx) or (www.secofi.gob.mx/dgn8.html).<br><br>Accreditation and follow-up responsibility was transferred from the DGN to EMA in 1999. The DGN maintains its role as monitor of these bodies. | The entity responsible for the Accreditation of the bodies that register Quality Systems is the Mexican Accreditation Agency (EMA). The bodies previously accredited by the DGN will be accredited by the EMA in 1999.<br><br>The DGN has accredited four bodies whose activity is the certification/registration of quality assurance systems. They are: one international body, the SGS of México, and three national bodies, IMNC, CALMECAC and NORMEX.<br><br>Currently, México has more than 192 corporations that have obtained ISO 9000 certification. | The DGN has accredited over 398 testing laboratories through the National Accreditation System for Testing Laboratories (SINALP), It has also accredited more than 79 calibration laboratories in 139 measurement areas.<br><br>Accreditations issued by SINALP will become EMA accreditations in 1999. EMA will continue with the function of determining the technical ability of the testing and calibration laboratories in addition to performing periodic reviews of the same. The various departments that issue the Official Mexican Standards will determine whether to accept or reject the validity of the results from the laboratories whose technical capacity has been recognized by EMA. This determination shall be made concurrently with the evaluation of the technical capacity of the laboratory in question or subsequently. |

| Country | Inspection & Testing | Product Certification | Quality System Registration | Laboratory Accreditation |
|---|---|---|---|---|
| **Saint Kitts and Nevis** | No information. | No information. | No information. | No information. |
| **Nicaragua** | Nicaragua has approximately 8 public institutions, 5 private entities and 15 academic bodies that perform inspections and testing in accordance with each subject. For example, in the public sector operations are carried out by the Department of Health (food and pharmaceuticals), Department of Agriculture and Livestock (meat, chicken, seafood, agricultural products, agrochemicals), Department of Construction and Transportation (Construction materials) and the Department of Natural Resources (Environment). | There is no national agency in Nicaragua for product certification other than the Government Departments named under Inspection and Testing.<br><br>Currently, Nicaragua is setting up the Nicaragua Integrated Quality System (SICAN) which includes, among others, a national system of Technical and Quality Standards. There is a coordinating commission, three technical committees and several work groups within this system where the subject of product certification will be developed appropriately. | Currently, Nicaragua does not have a national agency to register or certify quality systems. However, Nicaragua is in the process of establishing the Nicaragua Integrated Quality System, SICAN, which will include the National Accreditation System which will oversee the system Certification Bodies.<br><br>Nicaragua has one company that holds ISO 9000 certification issued by SGS of Nicaragua. | Currently, there is no national laboratory accreditation system, however, under SICAN, a National Accreditation Office would be created. This office will establish a Network of Accredited Laboratories. |

# APPENDIX

Excerpts from […] are presented for information and acronyms frequently applied in conformity assessment discussions**.**

**c. Explanatory Notes**

1. The **International Laboratory Accreditation Cooperation** (ILAC) is an international cooperation among 44 laboratory accreditation schemes operated throughout the world. ILAC is a forum for the development of laboratory accreditation practices and procedures, the promotion of laboratory accreditation as a trade facilitation tool, the assistance of developing accreditation systems, and the recognition of competent test facilities around the world. ILAC also provides advice and assistance to countries that are in the process of developing their own laboratory accreditation systems.
2. The **International Accreditation Forum** (IAF) is an organization of accreditors of certifiers, association of certifiers and internationally oriented trade associations. The purpose of IAF is to share experiences in carrying out accreditation and certifications in the use of ISO/IEC guides. IAF also seeks to establish the equivalence of the programs of its members that are accreditors.

3. The **Interamerican Accreditation Cooperation** (IAAC) is a regional organization of accreditation bodies from the American countries whose main purpose is to harmonize accreditation procedures and reach multilateral recognition of conformity assessment systems. IAAC accreditation includes product certification, personnel certification, quality and environmental systems registration and laboratory accreditation. IAAC supports the development of accreditation systems in any member country seeking to set one up and in compliance with the appropriate ISO/IEC international guides.
Note that the members of ILAC, IAF or IAAC are accreditation bodies and **not** countries. There may be more than one accreditation body per economy that are represented in these international bodies.

**d Explanatory Notes**

Mmbership in the World Trade Organization (WTO); also if a country has submitted an implementation statement, established an enquiry point or signed the Code of Good Practice (Annex 3).

**Implementation Statement**
Each WTO Member must notify Members of the measures in existence or taken to ensure the implementation and administration of the Agreement and of any subsequent changes to them (Article 15.2). The statement must include:

1. All relevant laws, regulations, administrative orders, and other relevant documentation that ensures that the provisions of the Agreement are being applied;
2. The names of the publications where technical regulations, standards and conformity assessment procedures are published;
3. The expected length of time for the presentation of written comments on technical regulations, standards or conformity assessment procedures;
4. The name and address of the Enquiry Points established under Article 10.

**Enquiry Point**
As a complement to the obligation to notify, each WTO Member must set up a national enquiry point. The enquiry point is a focal point where other WTO Members can request and obtain information and documentation on: (a) Member's technical regulations; (b) standards and conformity assessment procedures, whether impending or adopted; (c) participation in bilateral or multilateral standard-related agreements, regional standardizing bodies and conformity assessment systems (Article 10).

Enquiry points can be governmental bodies or be assigned to private agencies. There may be more than one enquiry point per country, but they must coordinate with one another and provide complete information to interested parties. The obligation to set up enquiry points is important for countries wishing to acquire information from other Members on foreign regulations and standards affecting products in which they have a trade interest.

**Code of Good Practice**

The Code of Good Practice for the Preparation, Adoption and Application of Standards defines disciplines for central government, local government, non-governmental and regional standards bodies developing voluntary standards. The Code is recommended for adoption by all of these standards bodies; however, central government standards bodies must accept and comply with the provisions of the Code. A standards body wishing to adhere to or withdraw from the Code has to notify its acceptance of or withdrawal from the Code using the appropriate notification. Standards bodies that have accepted the Code must report their work program at least twice a year and where details of this program can be obtained. Notifications have to be sent either directly to the ISO/IEC Information Center in Geneva, or to the national member of ISO/IEC.

**Table 1: Membership to International and Regional Standards Bodies**

| Country | National Standards Body | Type | Membership | | |
|---|---|---|---|---|---|
| | | | ISO | ISONET | COPANT |
| **Antigua & Barbuda** | **ABBS** | **Gov** | | | |
| **Argentina** | **IRAM** | **Prv** | • | • | • |
| **The Bahamas** | **Agriculture Dept.**<br>**Env. Health Dept.** | **Gov** | | | |
| **Barbados** | **BNSI** | **Mix** | •(C) | • | • |
| **Belize** | **BBS** | | | | |
| **Bolivia** | **IBNORCA** | **Prv** | •(C) | | • |
| **Brasil** | **ABNT** | **Prv** | • | • | • |
| **Canada** | **SCC** | **Mix** | • | • | • |
| **Chile** | **INN** | **Prv** | • | • | • |
| **Colombia** | **ICONTEC** | **Prv** | • | • | • |
| **Costa Rica** | **INTECO** | **Mix** | • | • | • |
| **Dominica** | **None** | | | | |
| **Ecuador** | **INEN** | **Gov** | • | • | |
| **El Salvador** | **CONACYT** | **Gov** | •(C) | | • |
| **Grenada** | **GDBS** | **Gov** | •(S) | | • |
| **Guatemala** | **COGUANOR** | **Mix** | •(C) | | • |
| **Guyana** | **GNBS** | **Gov** | •(S) | | • |
| **Häiti** | **None** | | | | |
| **Honduras** | **DNM-SIC** | **Gov** | | | |
| **Jamaica** | **JBS** | **Gov** | • | • | • |
| **México** | **DGN** | **Gov** | • | • | • |
| **Nicaragua** | **DGCT** | **Gov** | •(C) | | |
| **Panamá** | **DGNTI** | **Gov** | • | • | • |
| **Paraguay** | **INTN** | **Gov** | •(C) | | • |
| **Perú** | **INDECOPI** | **Gov** | •(C) | | • |
| **República Dominicana** | **DIGENOR** | **Gov** | •(S) | | • |
| **Saint Lucia** | **SLBS** | **Gov** | •(S) | | |
| **St Kitts & Nevis** | **Ni** | | | | |
| **St Vincent & Grenadines** | **Ni** | | | | |
| **Suriname** | **None** | | | | |
| **Trinidad &Tobago** | **TTBS** | **Mix** | • | • | • |
| **United States** | **ANSI*** | **Prv** | • | • | • |
| **Uruguay** | **UNIT** | **Prv** | • | | • |
| **Venezuela** | **FONDONORMA** | **Prv** | • | • | • |

(C) = Correspondent Member (S) = Subscriber Member * See explanatory note 2

• = Yes Blank = No ni = no information

## e. Explanatory Notes

1. Acronyms for the National Standards Bodies (NSB) of the FTAA countries and full names
2. The United States does not have an official NSB. The **American National Standards Institute** (ANSI) is a federation of private sector standards developers and is the U.S. representative to the ISO. Not all the standards developers in the United States belong to ANSI, nor are they obligated to do so.
3. The **International Organization for Standardization** (ISO) is a private international organization dedicated to voluntary standardization. Its membership consists of recognized national standards bodies from 129 countries. Membership in ISO is by the National Standards Body listed in column 2.
4. The **ISO Information Network** (ISONET) links the information centers of the ISO members into a coherent information system. ISONET is an agreement between standards bodies to combine their efforts in order to make information on standards, technical regulations and related matters readily available whenever it is required. Column 5 lists the ISO members that are members of ISONET.

The **Panamerican Standards Commission** (COPANT) is a regional standards organization that develops or harmonizes regional standards where appropriate and coordinates regional positions and representation to the ISO. Membership in COPANT is by the National Standards Body listed in column

## f. Explanatory Notes

1. Unlike the ISO and COPANT, membership in ITU or IEC is not necessarily by the National Standards Body. The **International Telecommunications Union** (ITU) is a treaty organization that develops standards in the telecommunication and services industries. Membership in ITU is comprised of government representatives from 185 countries. In the United States, the Department of State coordinates representation.
2. The **International Electrotechnical Commission** (IEC) develops standards for electrical and electronic engineering products and devices. Membership in IEC is by the presidents of the national committees of 60 countries. The U.S. National Committee to the IEC is housed at ANSI.

**Codex Alimentarius Commission** (Food Code in Latin) is a subsidiary of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO). The Codex system was set up to facilitate trade in food while protecting consumer's health and ensuring fair practices in food trade. Codex is the compilation of all the Standards, Codes of Practice, Guidelines and Recommendations of the Codes Alimentarius Commission and of government reactions to these. To be comprehensive, Codex was included in this document since many FTTA countries have economies which are largely based on the export of food products.

## g. Explanatory Notes

1. **The International Organization of Legal Metrology** (OIML) is an intergovernmental treaty organization whose membership includes Member States (countries which participate actively in technical activities) and Corresponding Members (countries which join OIML as observers). OIML promotes global harmonization of legal metrology procedures and provides metrological guidelines for the elaboration of national and regional requirements concerning the manufacture and use of measuring instruments for legal metrology applications.
2. The **Bureau International des Poids et Mesures** (BIPM) (International Bureau of Weights and Measures) ensures world-wide uniformity of measurements and their traceability to the International System of Units. It does this with the authority of the Convention of the Metre, a diplomatic treaty among forty-eight nations. It operates through a series of Consultative Committees whose members are the national metrology laboratories of the nations that have signed the treaty.
3. **The Interamerican Metrology System** (SIM) brings together the National Metrology Laboratories of the FTAA countries. The goal of SIM is to promote international and regional cooperation throughout the Americas, in order to contribute to the improvement of activities in the domain of scientific, industrial and legal metrology. The region is divided into five subregions, which are Noramet, Camet, Carimet, Andimet, and Suramet. Column 4 lists the relevant subregion for each country.
4. The **International Laboratory Accreditation Cooperation** (ILAC) is an international cooperation among 44 laboratory accreditation schemes operated throughout the world. ILAC is a forum for the

development of laboratory accreditation practices and procedures, the promotion of laboratory accreditation as a trade facilitation tool, the assistance of developing accreditation systems, and the recognition of competent test facilities around the world. ILAC also provides advice and assistance to countries that are in the process of developing their own laboratory accreditation systems.

5. The **International Accreditation Forum** (IAF) is an organization of accreditors of certifiers, association of certifiers and internationally oriented trade associations. The purpose of IAF is to share experiences in carrying out accreditation and certifications in the use of ISO/IEC guides. IAF also seeks to establish the equivalence of the programs of its members that are accreditors.
6. The **Interamerican Accreditation Cooperation** (IAAC) is a regional organization of accreditation bodies from the American countries whose main purpose is to harmonize accreditation procedures and reach multilateral recognition of conformity assessment systems. IAAC accreditation includes product certification, personnel certification, quality and environmental systems registration and laboratory accreditation. IAAC supports the development of accreditation systems in any member country seeking to set one up and in compliance with the appropriate ISO/IEC international guides.
7. Note that the members of ILAC, IAF or IAAC are accreditation bodies and **not** countries. There may be more than one accreditation body per economy that are represented in these international bodies.

**Table 1: WTO Membership and Selected Obligations**

| Country | WTO | Implementation Statement (15.2) | Enquiry Point | Code of Good Practice Annex 3 |
|---|---|---|---|---|
| Antigua &Barbuda | • | | ♦ | |
| Argentina | • | • | • | • |
| The Bahamas | | | | |
| Barbados | • | • | • | • |
| Belize | • | | ♦ | |
| Bolivia | • | • | • | |
| Brasil | • | • | • | • |
| Canada | • | • | • | |
| Chile | • | • | • | • |
| Colombia | • | • | • | • |
| Costa Rica | • | | • | • |
| Dominica | • | | ♦ | |
| Ecuador | • | | • | • |
| El Salvador | • | | • | • |
| Grenada | • | | | • |
| Guatemala | • | | ♦ | |
| Guyana | • | | ♦ | • |
| Häiti | • | | | |
| Honduras | • | • | • | |
| Jamaica | • | | • | • |
| México | • | • | • | • |
| Nicaragua | • | | ♦ | |
| Panamá | • | • | ♦ | • |
| Paraguay | • | | ♦ | |
| Perú | • | • | • | • |
| República Dominicana | • | | • | • |
| St. Kitts & Nevis | • | | | |
| Saint Lucia | • | • | • | |
| St. Vincent & Grenadines | • | | | |
| Suriname | • | | | |
| Trinidad &Tobago | • | • | • | • |
| United States | • | • | • | • |
| Uruguay | • | | • | • |
| Venezuela | • | | ♦ | • |

• = Yes; Blank = No ♦ = Sanitary and Phytosanitary Enquiry Point only

**Table 3: Membership to other International Standards Bodies**

| *Country* | Membership | | |
|---|---|---|---|
| | ITU | IEC | CODEX |
| Antigua & Barbuda | | | • |
| Argentina | • | | • |
| The Bahamas | • | | |
| Barbados | • | | • |
| Belize | • | | • |
| Bolivia | • | | • |
| Brasil | • | • | • |
| Canada | • | • | • |
| Chile | • | | • |
| Colombia | • | •(P) | • |
| Costa Rica | • | | • |
| Dominica | | | • |
| Ecuador | • | | • |
| El Salvador | • | | • |
| Grenada | • | | • |
| Guatemala | • | | • |
| Guyana | • | | • |
| Häiti | • | | • |
| Honduras | • | | • |
| Jamaica | • | | • |
| México | • | • | • |
| Nicaragua | • | | • |
| Panamá | • | | • |
| Paraguay | • | | • |
| Perú | • | | • |
| República Dominicana | • | | • |
| Saint Lucia | | | • |
| St Kitts & Nevis | | | • |
| St Vincent & Grenadines | | | |
| Suriname | • | | • |
| Trinidad &Tobago | • | | • |
| United States | • | • | • |
| Uruguay | • | •(P) | • |
| Venezuela | • | | • |

(P) = Pre-associate Member • = Yes Blank = No

# Trends and latest developments in the use of PE and PP pipe systems for buildings water supply and sewage


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## Abstract

In Europe, polyethylene (PE) and polypropylene (PP) plastics have been used increasingly and with an excellent track record for piping systems inside and around buildings over the past 40 years. Most commonly used are crosslinked PE and specially stabilised PP-R for hot water applications, flexible PE compounds for house connection water and gas pipes and, more recently, high impact strength and stiffness PP-B for sewage. A high level of quality and installation efficiency has been developed over the years through improved raw materials and a clear system approach (raw materials, pipes, fittings, installation procedures, training). This level is safeguarded by CEN, ISO as well as local standards and regulations. In future, the use of PE and PP is expected to continue its strong growth due mainly to the excellent material properties and increasing acceptance among installers, architects, authorities and house owners. Borealis as world-wide the leading supplier and developer of PE and PP raw materials for these applications, now see this trend spreading rapidly into other areas such as China, South America, the Middle East and the USA. This paper gives an overview of the PO systems commonly used for the different applications as well as the relevant technical advantages and limitations, standardisation, track records and future trends for each.

## Keywords

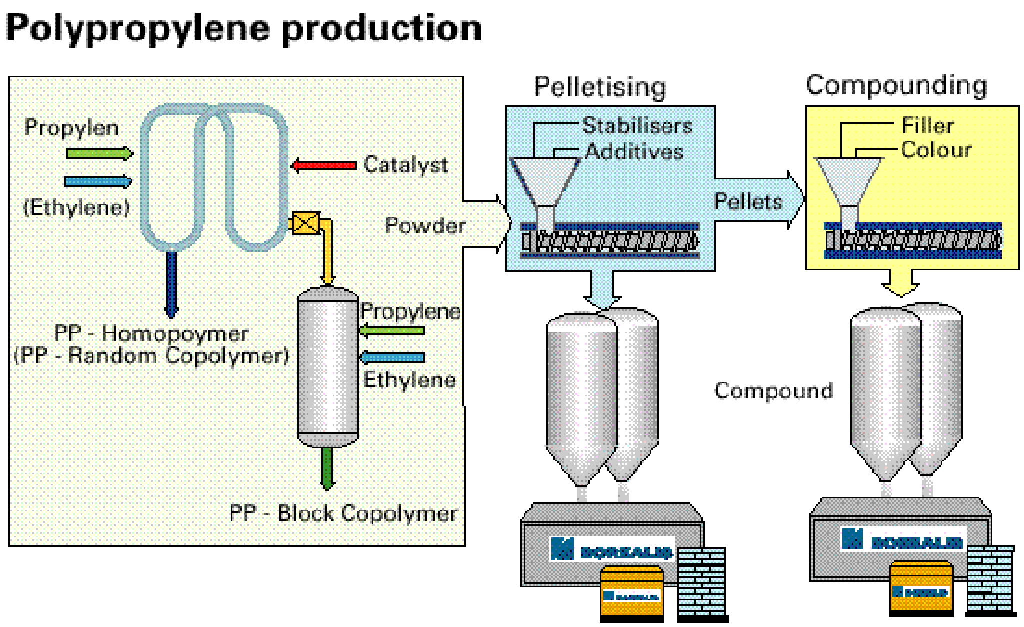
PE and PP pipe systems; building sanitary and heating systems; sewage and waste water

## 1 Contents

## 2 What are polyolefins and how are they used for pipe

The most common polyolefins (PO), polyethylene (PE) and polypropylene (PP), are produced by polymerising ethylene or propylene gas in the presence of a catalyst at moderate temperatures and pressures. The monomers are built into a range of molecular weights during polymerisation and by using modern catalysts, different comonomers and polymerisation techniques (such as the two reactor Borstar® process), molecular weight distribution and molecular configuration can be carefully controlled. For all pressure pipe and some non pressure pipe application, ready made PE or PP compounds - produced as illustrated for PP in Figure 1 - are offered to the pipe and fitting producers for quality, accountability and cost reasons.

**Figure 1 – Production of ready made polypropylene pipe compounds**




As pipe and fitting materials, polyolefins have built up an excellent track record for over 40 years. Properties such as flexibility, non corrosiveness, light weight, weldability and cost competitiveness, have made users aware of the advantages and possibilities polyolefin pipes offer compared to other pipe materials. Furthermore the polyolefin pipe industry has demonstrated excellent innovation in designing raw materials and pipe systems for specific applications. Borealis, being the leading supplier of polyolefin pipe compounds, has participated in this development and is now leading the way into the future with an extensive product portfolio to highlight the benefits of polyolefins as piping materials.

The European plastic pipe market of around 2,5 million tons is today basically equally divided between poly vinyl chloride (PVC) and polyolefins, but polypropylene and polyethylene have over the past 10 years been demonstrating 3-4 times higher growth rates than PVC.

## 3 Types of polyolefins used in buildings pipe applications

Of the 1,2 million tons total market for polyolefin pipes in Europe, around 8 % found its use in building hot water applications and another 12% in drainage or sewage applications. If you look around typical modern European houses, you would commonly find pipes and fittings made of 4 different types of polyolefins: high density polyethylene (HDPE), cross linked polyethylene (PEX), polypropylene random copolymer (PP-R), and polypropylene block copolymer (PP-B).
It is important to realise that these materials have very different properties and have been designed and documented to fulfil the requirements of different applications. Especially important here is the application temperature for the designed service life of typically 50 years.

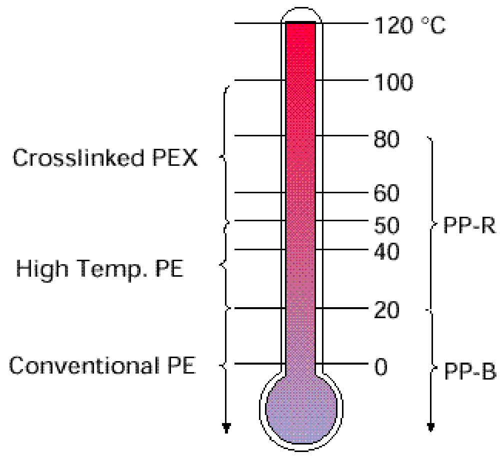
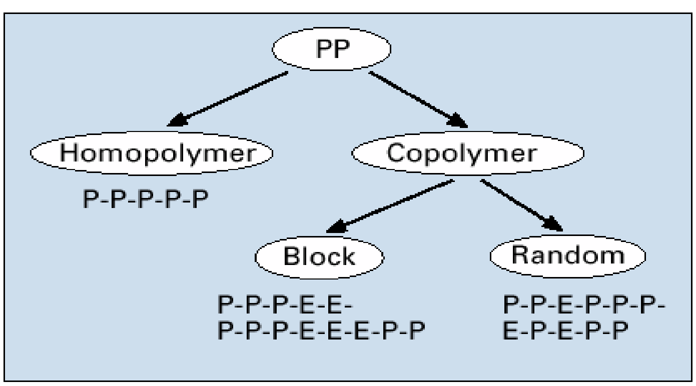



**Figure 2 – Application temperatures of different polyolefin plastics**

From Figure 2 it can be seen that un-crosslinked PE is suitable for gas and cold water applications (in a specially heat stabilised version for up to 50 °C).
Cross-linking the PE chains by chemical or physical process (PEX) greatly increases the long term temperature resistance, notch resistance and memory effect making these materials suitable for hot water applications.
**Figure 3 –Different types of polypropylene**




Polypropylene homopolymer, PP-H is made by polymerising propylene and by introducing ethylene as a comonomer, polypropylene copolymer, PP-C can be produced. The ethylene can be introduced in blocks and with a higher percentage for what is classified as a “block copolymer”, PP-B or at random and more dispersed for a “random copolymer”, PP-R (Figure 3).
PP-R, the most recent development, has been further improved to obtain the best long term heat stability, slow crack growth resistance performance and welding performance. This material is used for hot and cold water sanitary systems and heating pipes.

PP-B is typically used for non-pressure applications such as sewage, profiles and cable conduits, where the long term pressure resistance is not critical and cold temperature impact strength and suitability for compounding with fillers are more important.
PP-H shows superior resistance to certain chemicals and is therefore preferred for sheet, filter plates, pipes and fittings in industry application. It also has the greatest stiffness and short term mechanical strength but a lower impact strength at cold temperatures (around 0°C).

# 4 Illustration of common polyolefin pipe systems

## 4.1 Hot and cold water supply

In 1997 roughly 1,6 billion meters of sanitary and heating pipes were installed in east and west Europe alone. According to a German study, KWD, 36% of this was plastic based, mostly PEX or PP-R (Table 1).

| Material | Million meters installed Europe 1997 | Connection |
|---|---|---|
| Copper | 706 (44 %) | Weld & press |
| Galvanised steel | 309 (19 %) | Weld & thread |
| Stainless steel | 14 (1 %) | Press |
| PE-X | 302 (19 %) | Press & shrink fit |
| PP-R | 147 (9 %) | Weld |
| PE-X/Al | 65 (4 % | Press |
| PB | 44 (3 %) | Weld/press |
| PVC-C | 18 (1 %) | Glue |
| **Total** | **1606** | |

**Table 1 – Raw materials used for sanitary and heating pipes in Europe**

Market growth trends, for example in a very large and competitive buildings market like Germany, demonstrate clearly that the acceptance of plastic systems among installers, architects, authorities and house owners is increasing (Figure 4). It is interesting to note that solely plastic systems profited from the building boom after the German reunification.

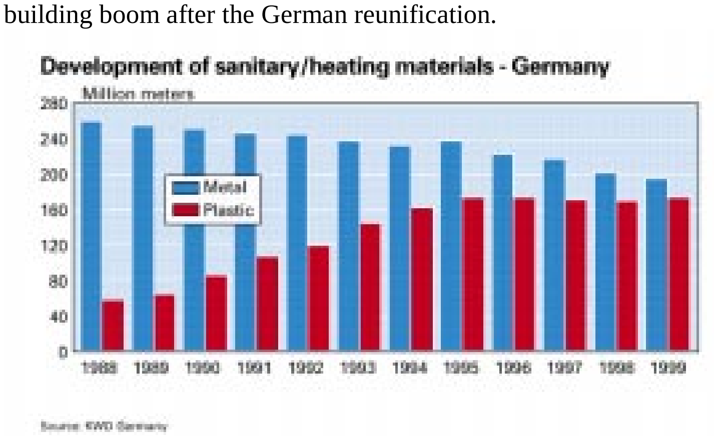



**Figure 4 – Gain in market share of plastic systems in Germany**

In countries with a large use of traditional galvanised steel pipes and the big corrosion problems associated with this, the substitution with mainly PP-R has been particularly dramatic. Turkey (Figure 5), Italy, Argentina, East Europe and most recently China are good examples of this. The success of PP-R has globally documented itself by the rapid market growth to today 60 ktons since its introduction for heating and plumbing in Germany more than 15 years ago.

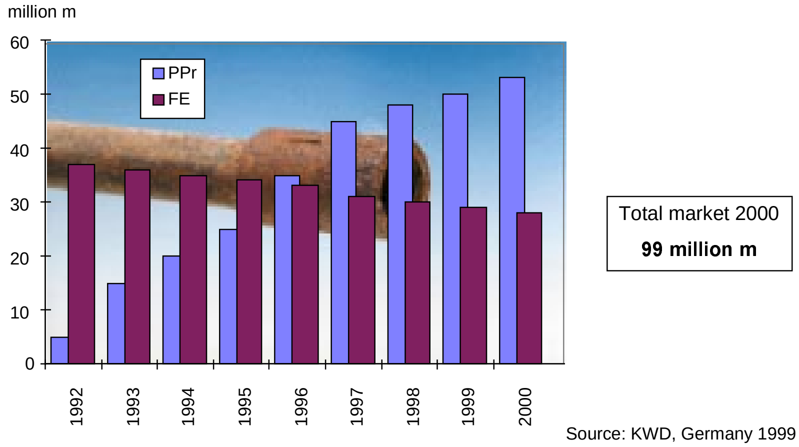



**Figure 5 –Growth of PP-R vs. galvanised steel sanitary systems in Turkey**

For sanitary systems, different installation techniques are used taking advantage of the material properties. PP-R systems are installed in traditional straight lengths with socket welded fittings (Figure 6) and are typically dimensioned as SDR 6. PEX systems are installed as flexible SDR 7,4 lengths or as a stiff, bendable multi-layer aluminium constructions (Figure 7). Both types of constructions are jointed with press or shrink fit fittings, as PEX can not easily be welded but has excellent memory shrinkage properties.

**Figure 6 – PP-R drinking water installation**

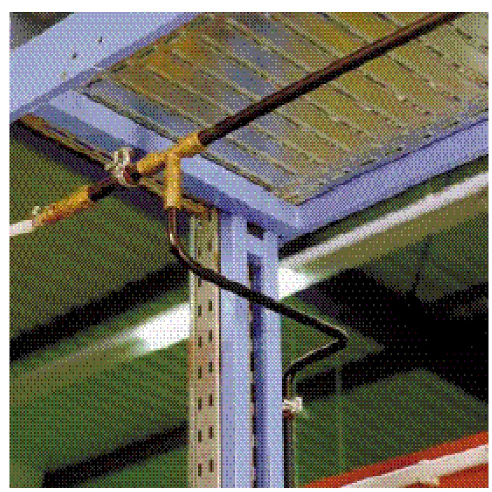


**Figure 7 – Multi-layer PEX/Aluminium pipes**

## 4.2 Under floor and radiator heating

Due to their high temperature resistance, PP-R and PEX pipes are also suitable for radiator connections (Figure 8).

**Figure 8 – PP-R systems for radiator connections**

Polyolefin pipes have good flexibility making them easy to bend and install for floor heating application (Figure 9).

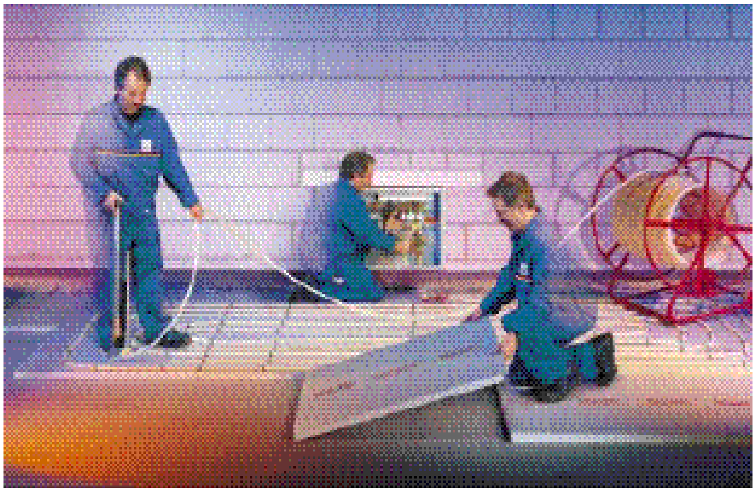


**Figure 9 – PEX for floor heating systems**

## 4.3 Wall heating and cooling

An innovative application is the heating and cooling mats for air conditioning in buildings without the disadvantages of circulating air. In addition to the flexibility, the excellent and safe weldability at the many joints makes PP-R the best material choice.

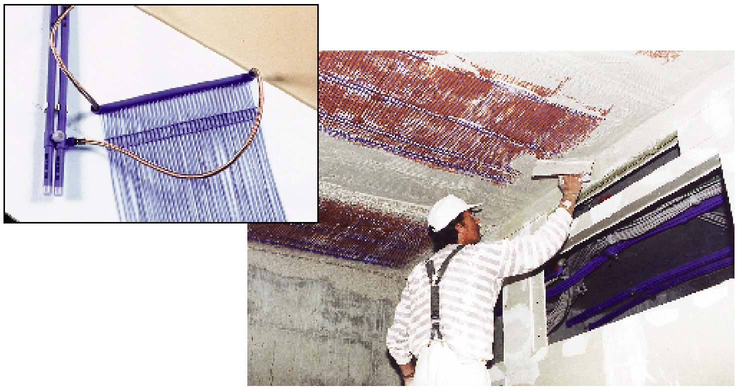


**Figure 10: Cooling and heating mats for air conditioning**

**4.4 Indoor and outdoor sewage and waste water**

According to a CDC study published in 2000, plastic systems have at least 90% share of the indoor soil and waste water systems market in most European countries. This is due to their non corrosiveness, ease of installation and cost competitiveness. The only weak aspect is that noise can be a problem in flushing systems, especially in high buildings. Low noise polypropylene pipe compounds and insulation system solutions have been developed to meet the renewed threat from cast iron pipes on the market.

From Figure 11 it can be seen that the soil and waste water application is dominated by PVC. While the PVC market has a matured, however, and growth rates have been stagnating since 1994, the market for PP-B systems has expanded at a rate of 8%.

Advantages of PP-B systems are their good impact strength and form stability in resisting to hot waste water from washing and dishwasher machines (up to 97 °C containing detergents).

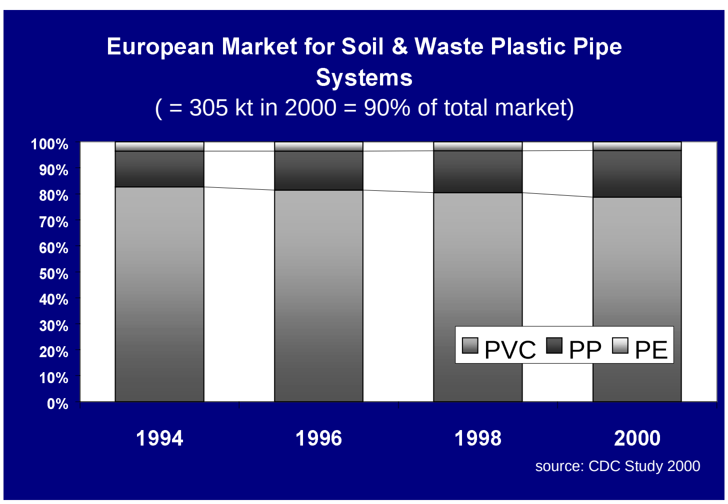



**Figure 11: European market for soil & waste plastic pipe systems**

For outdoor sewage applications, pipe stiffness and in many climates cold temperature impact strength are especially important. Also, corrugated constructions are very common as they offer improved stiffness with less material (Figure 12). Recently, Borealis has very successfully introduced to the market a new PP-B with greatly improved stiffness and impact strength especially designed for this application. In Sweden, for example, the use of PP sewage pipes has exploded from just 6% in 1997 to over 25% in 1999.

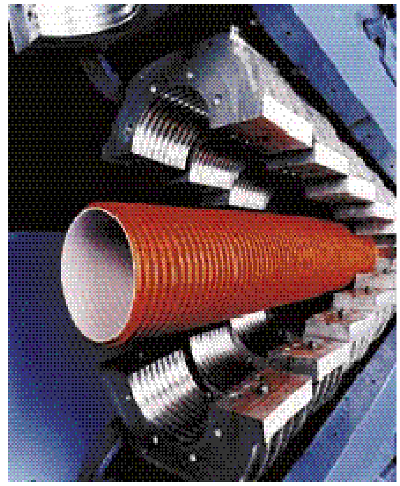


**Figure 12: PP systems for sewage applications**

# 5 System quality requirements and standardisation

## 5.1 The systems approach

Polyolefins have established their position for all indoor pipe applications from sanitary to cable conduits. A key success factor for all plastic pipes has been the systems approach. A system typically includes pipes, all fittings and valves, auxiliary installation materials, installation procedures and in most cases a raw material specification. Advantages of the system approach are the complete availability of compatible parts and the clear approval and liability. Many systems suppliers also provide a corresponding guarantee. Furthermore, the accumulation of know-how and experience by the system supplier leads to excellent training facilities and continuous optimisation of the speed and ease of installation.

## 5.2 Quality requirements of the system

A good example to illustrate system quality requirements is that of sanitary installations. Here the tricky requirement combination of drinking water neutrality and lifetime of 50 years at 60 - 70 °C pressure application must be met.

For the former, the recipe of the raw material must be according to national and European positive lists and additionally authorities, for instance in Germany, France, Holland and Scandinavia require formalised taste and odour testing of some raw materials and of the final products (Figure 13).

**Figure 13 - Steps of taste and odour control of the raw material and pipe**

For the latter, it is best practice to use long term pressure testing and standardised extrapolation methods to statistically demonstrate that the elevated temperature lifetime of one raw material or modified type of pipe. More than 400 pipes made of Borealis RA130E - for example - have been tested in different environments (water/water and water/air) at 6 temperatures between 20 ºC and 120 ºC over a period of more than three years. As quality control some points of this extrapolation are regularly cross checked with pipes or welded testing trees (Figure 14).

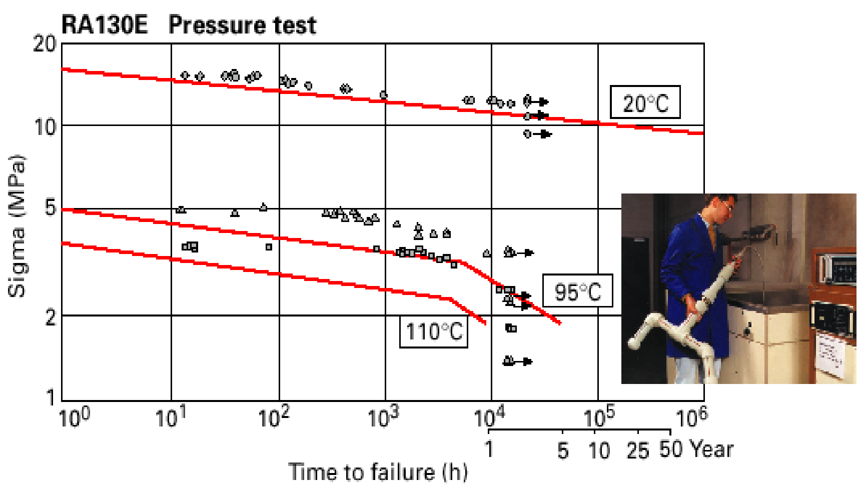



**Figure 14 - Pressure testing of PP-R raw materials and systems**

Over time, the weakest link in a piping system is often the jointing technology. In sanitary systems this is especially critical due to the severe pressure and temperature changes when the taps are turned on and off. To offer durable connections, different raw materials require different techniques, such as welding, pressing, threading, shrink fit and gluing. In any case, it has to be secured that pipes and fittings fit together in terms of dimensioning and design. To check this, a specific test equipment has been developed as described in Figure 15. The thermal cycling test is carried out under pressure on a sample system consisting of typical fittings and jointing techniques. The temperature of the water running through this system is changing over 5000 cycles every 15 minutes very quickly from 20 ºC to 95 ºC. This test simulates quite well what happens in the field during some years of operation.

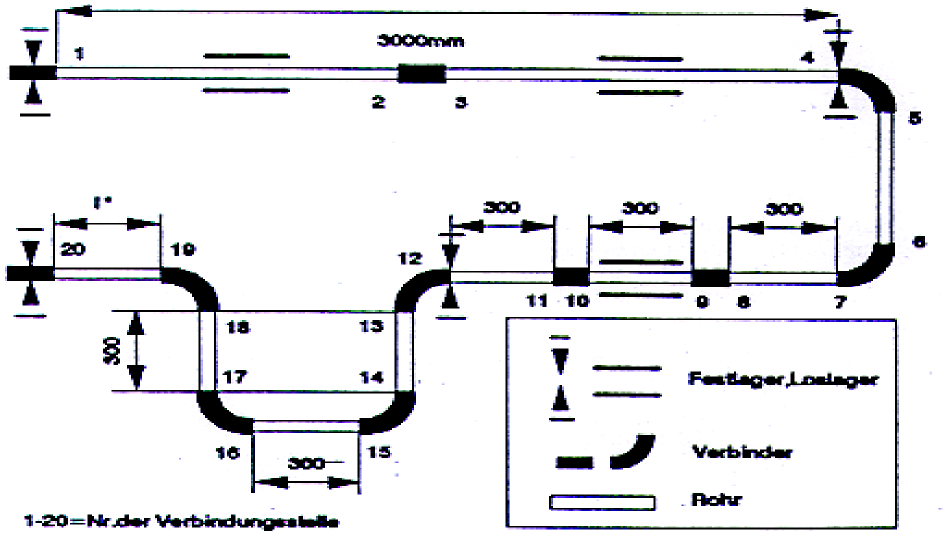



**Figure 15 - Temperature cycle test for jointed systems according to EN 12293**

### 5.3 Enforcing these quality requirements through standardisation

The high requirements placed on indoor plastic pipe systems are standardised and enforced to different degrees by a very large network of national standards, international EN and ISO standards, local legislation rules, authority guidelines, quality marks and end user specifications. For example, hot and cold water systems are described by ISO/DIS 15874 for PP-R, ISO/DIS 15875 for PE-X, ISO/DIS 15876 for PB and ISO/DIS 15877 for PVC-C and PP waste water systems by prEN 1451-1. Even once these draft standards are implemented, non-government authorities such as the DVGW in Germany plan to continue to give their quality marks based on their own working documents DVGW W 534, W 542 and W 544. In most cases, national standards world-wide are building on the ISO, CEN or European national standards and guidelines.

Besides representing good business for quality labs and test institutes, experience has shown that a network of high requirements ensure that - in the countries where they are enforced - only thoroughly developed, high quality raw materials are used in best practice conversion to well designed systems.

## 6 Environmental impact

Today, environmental impact is an important consideration for the construction engineer or architect when planning building projects. Generally, polyolefin plastics have shown excellent life cycle analysis results and this is especially the case for high performance pipe polymers designed and documented to last more than 50 years.

With respect to environmental impact an in depth study was carried out by Professor Dr. Helmut Käufer at the Technical University of Berlin. Using the "VENOB" technique he compared energy requirements as well as impact on the ground, air and water in the production, transport and installation of steel, copper and several plastic systems. The basis for comparison was a 16 living unit house with central warm water supply and installations according to DIN 1988 part 3. Figure 16 clearly demonstrates that plastic systems offer the most environmentally friendly solution.

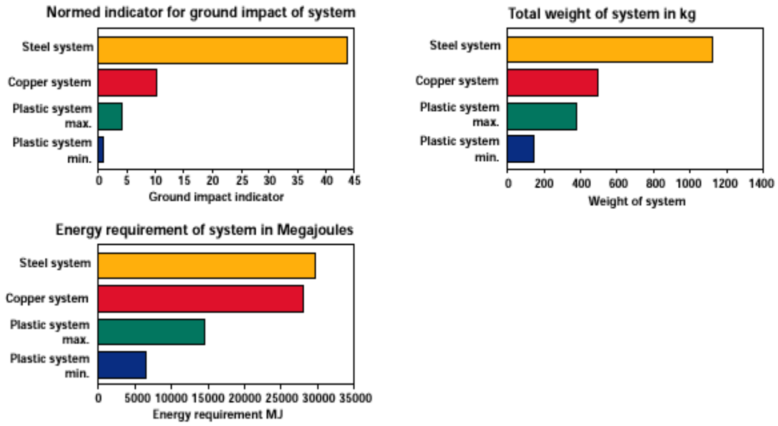
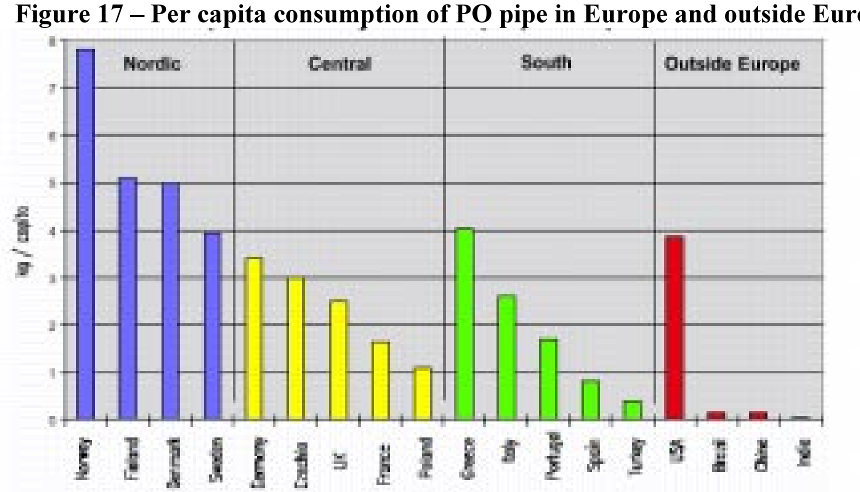



**Figure 16 - Environmental impact of different plumbing systems**

## 7 Conclusions and outlook for the future

We have seen a very strong growth of polyolefin pipe systems in sanitary, heating, soil and waste water, electrical conduits, water and gas house connection, and buried sewage applications in Europe and increasingly global. Polyolefins have built up an impressive track record over more than 25 years for hot water and even 40 years for cold water applications and now represent a very sucessful alternative to more traditional piping materials. To sustain this growth, it remains critical to have a very high level of requirements and formalise these through corresponding standards and specifications.

**Figure 17 – Per capita consumption of PO pipe in Europe and outside Europe**




If we compare the PO pipe trends in Europe with those in different countries around the world, we can see many similarities with some time delay. We have already seen many examples of European polyolefin solutions being adopted and adapted globally and also of new applications being developed. The currently very low PO pipe per capita consumption in for example Brazil, China and India 17 further illustrates the excellent growth potential for PO pipe solutions outside Europe.

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# The process of regulation – a UK policy maker's view

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## Abstract

This paper explains the framework by which technically robust recommendations are considered by Government. It examines the different non-technical factors that need to be assessed, as well as the process by which regulations are delivered in practice. This process is exemplified by the Water Supply (Water Fittings) Regulations 1999[1], which prevent the waste, misuse, undue consumption and contamination of public water supplies in England and Wales. One important aspect of these Regulations is the WC Suite Performance Specification, which will introduce a number of significant changes to WCs from 1 January 2001. This paper largely focuses on just one change that this Specification will introduce, namely that non-siphonic flushing mechanisms[2] will be permitted in the UK for the first time since the early 1900s. In particular, why is it that sound technical verification that over their lifetimes, high quality drop valves have a performance equivalent to siphons may not necessarily result in a change in Government policy? Clearly, the context in which these Regulations were developed is the UK's legal, political and environmental situation. Nonetheless, this process ought to be instructive as to the complex considerations that have to be made by governments generally.

## Keywords

Regulation; WC; flushing mechanism; environment

## 1. Purpose of regulations

In developing and delivering its policy objectives, the Government has a number of different tools at its disposal. The issue is really one of influencing people's behaviour in the most effective way. This can be achieved in a variety of ways, including financial incentives or disincentives (such as grants or taxation), voluntary schemes, education or regulation. Evidently, each of these approaches will have different implications with

[1] From now on referred to as the Water Fittings Regulations.
[2] The term 'siphonic flushing mechanism' is used in this paper to describe the mechanism that delivers flush water from the cistern to the WC bowl. Non-siphonic mechanisms include drop valves with or without a pressurised cistern.

respect to cost, impact and outcome achieved. For example, to change behaviour through education would tend to require a sustained campaign probably using a variety of media. The outcomes of this approach may be uncertain. On the other hand, regulation, with appropriate enforcement provisions, would require a far greater input of resources and administration, but would be likely to deliver faster more comprehensive changes. However, this approach risks introducing anomalies and greater, more sudden costs to those affected.

The approach chosen by the Government in a given situation will depend on numerous factors. Significantly, however, it must be recognised that any Government action to influence behaviour does affect peoples' lives and often livelihoods, so the approach taken must be justified. Clearly, the necessity of having a certain policy or law in place, or the severity of the consequences of these not being in place, will play a significant role in determining the approach adopted. For example, imposing regulations would seem proportionate in order to protect health and safety; tax incentives would seem more suitable to encourage personal savings; whereas information and education would seem more appropriate to encourage the use of recycled paper. Often a mixture of these is essential, for example a fine for littering but because this is very hard to enforce there is also supporting education. It is clear that at each level, different degrees of Government involvement would be justifiable.

With respect to preventing the contamination of drinking water, there were a number of drivers for regulation. Primarily, the quality of drinking water is a matter of essential public health, making it crucial to regulate and relatively straightforward to justify this approach.

In terms of preventing the waste and undue consumption of water, more than 80% of domestic customers in the UK are not metered and so there is no direct financial incentive to save water or use it efficiently. Without imposing water meters on all customers, with the inherent costs this would involve, this context effectively rules out any fiscal measures to encourage water efficiency. Influencing behaviour can be effective, but takes time, so regulation was necessary to establish minimum standards of water efficiency.

Domestic water use in the UK accounts for about 60% of all potable (drinking) water used, of which about one third is used to flush WCs. Clearly this makes WCs a prime target for any water conservation activity. The Water Byelaws, which preceded the Water Fittings Regulations, introduced a maximum flush volume of 7.5 litres in 1993; before that the maximum was 9.5 litres and was historically much higher. Clearly, an effective, low-flush solution would bring the potential of saving a large volume of water.

Just as background, Water Byelaws had existed in England and Wales since the mid-1800s. These were produced and enforced regionally by the public Water Authorities which were set up in 1984. The Byelaws set prescriptive requirements for the performance and quality of water fittings to prevent the waste, misuse, undue consumption and contamination of public water supplies. However, following the privatisation of the Water Industry in 1989, the regional application was no longer acceptable, it caused anomalies and there was a desire for a uniform national approach to enforcement. The Water Fittings Regulations were introduced to address these concerns and to enable the Government to regain responsibility at national level for the safety and quality of public water supplies and fittings.

## 2. Flushing mechanism argument within wider context

Under the Water Byelaws only siphonic flushing mechanisms for WCs were permitted. The siphonic flushing mechanism was invented in the UK in around 1850. The great advantage of the siphon is that it cannot leak and so is incapable of wasting water through the outlet to the WC pan. However, for some time there was a concern that siphons could reduce the potential for people to save water (and, if metered, money) because their flushing performance seemed to deteriorate at low volumes. There was also a strong argument that the requirement for siphonic flushing mechanisms unjustifiably preserved a protected market in the UK, which was an increasingly unsustainable position in a single European market.

While the original debate centred on the performance of siphons against non-siphonic mechanisms, and principally enduring leak tightness, this became much broader. In addition to exploring the maximum flush volume reduction that could be achieved and the introduction of dual flush, the debate extended further to cover the quality of inlet valves, pan clearance, drainline carry, etc. The issue had now became one of whole suite performance, especially the different aspects of flush performance at lower volumes. This became an opportunity to develop a world class standard for WC suite performance. This paper will focus on the debate surrounding the choice of flushing mechanism.

## 3. Technological arguments and their limitations

In addition to the growing case against the siphon requirement, valve technology, especially in terms of materials and endurance, had developed considerably. Research was available that demonstrated that the durability and leak tightness of high quality valve products were now equivalent to that of the siphon. Valve technology also facilitated other beneficial applications such as dual flush, hands-free operation and better performance at lower volumes because of the different flush profile achieved.

The technical case for allowing the introduction of flushing mechanisms other than the siphon was strong and it may be that for some this was where the argument ended, as a point of principle. However, while on technical grounds this may appear to be a fairly clear-cut decision, the concept of removing the siphonic requirement was a highly contentious and controversial issue in the UK. For the Government, there were a number of other non-technical issues that needed further consideration.

Upon exploring these other issues, it soon becomes evident that what appears to be a straightforward decision can in practice be extremely complex. During the process of developing regulations the Government is presented with a variety of conflicting opinions, about technical issues as well as the more subjective concerns about change. In the development of the WC Specification, the issues that arose included the European legal framework, concerns about the impact on UK businesses and employment, environmental considerations, de-regulation initiatives, public opinion and the practicalities of implementation. Each of these presented factors that either advocated change or pressed to retain the siphon requirement, some of which were more conclusive than others. The paper takes each of these in turn and explains their relevance.

## 4. Legal framework

The free movement of goods is central to achieving an open market for business in Europe. In 1985, European Community Ministers agreed on a "New Approach to Technical Harmonisation and Standards" to fulfil this objective. New Approach Directives (that is Community Law) establish the essential requirements that must be met before products can be lawfully sold anywhere in the European Community. European harmonised standards provide the detailed technical information enabling manufacturers to meet these essential requirements. The development of harmonised European Standards for sanitary appliances, such as that for WC pans with integral trap (EN 997), brought the proposed UK requirements into a wider continental debate. The Water Fittings Regulations needed to reflect the UK's commitment to these wider single market initiatives.

As a Member State of the European Union, the UK no longer acts in isolation with regard to technical regulations. Accordingly there were a number of European drivers shaping the Regulations. The Construction Products Directive (CPD) seeks to remove existing technical barriers to trade within the European Economic Area (EEA) as part of the move to complete the Single Market. The intention of the CPD is to replace existing national standards and technical approvals with a single set of European-wide "technical specifications" for construction products. In addition, the Standards and Technical Regulations Directive 98/34/EC exists to prevent Member States establishing new technical barriers to trade.

The Water Byelaws were based on prescription, of which the siphonic flushing requirement is a good example. A new framework was required which was capable of accommodating technical improvements and new products. Where these products were of an equivalent or better quality to siphons, it would have become increasingly difficult to legally sustain their exclusion from the UK. Perhaps it would have only been a matter of time before a legal challenge was mounted on this trade restriction, as manufacturers of valve products were keen to exploit the UK market.

## 5. Environment

There was also the environmental imperative to conserve water. Although the common perception is that it always rains in the UK, there is actually quite a diverse water resource position. Some areas, particularly in the South and East, are water scarce, whilst other areas have a more plentiful supply of water. Environmental sensitivities were heightened by droughts in the early and mid 1990s. As well as these concerns from recent experience, climate change forecasts predict more extreme weather events, for example rising temperatures and shorter, sharper showers, which are less useful for re-charging water supplies. Partly due to this, demand is predicted to rise, especially at peak times and for agricultural use. Social changes compound the problem as trends towards greater affluence and a greater number of smaller occupancy households also increase demand.

In 1997 a new Government was elected, the first change in 18 years. Water issues were prominent because of the Labour Party's scepticism over privatisation, which crystallised over the much-publicised high levels of leakage from water company mains. The new administration called a Water Summit in May 1997 to explore how these issues could be addressed. The outcome was a '10 Point Plan' that included measures to improve water company performance and service, as well as commitments to alleviate the pressure on water resources. The Water Fittings Regulations were developed within this context of heightened attention to water conservation.

As explained previously, the fact that WCs account for 30% of domestic water usage presented a compelling argument for examining opportunities to reduce flush volumes. In addition, with increasing domestic metering, water usage and associated costs are becoming more of a social issue especially for lower income households.

## 6. Employment

A legitimate concern of Government is the impact of regulations on UK industry and businesses. However, this is far from a simple calculation. While it is usually clear where jobs could be at risk it is not always as clear where the advantages to industry, and in new employment opportunities, may be. For example, while UK manufacturers opposed the move to open up the market to non-siphonic flushing mechanisms, some UK companies already produced high quality non-siphonic devices for overseas markets even though they were prohibited in the UK. Furthermore, as a member of the Single Market, the Government should be concerned with the impacts of its decisions across that whole area. Clearly, this will be a far more complex consideration than for the UK situation alone. However, for European manufacturers the opening of the UK market to non-siphonic mechanisms was seen as a far more positive step.

## 7. General development in regulatory frameworks

General developments in the regulatory framework also influenced the decision making process. The Government is keen to deregulate, i.e. to lessen the regulatory burden on businesses. In particular, technically prescriptive regulations can impose an unjustified financial burden and stifle innovation, so the Government is keen to move away from this approach towards performance- or output-based regulation.

This change in emphasis is evident in the move from the prescriptive Water Byelaws to the Water Fittings Regulations. The Regulations are performance based and so provide a framework for innovation and best practice. They establish the minimum standards that water fittings must achieve, but not how to achieve them. In contrast, the prescriptive nature of the Water Byelaws meant that they needed regular reviewing and updating to reflect changing technology. By maintaining the siphonic requirement they discouraged innovation in this area (at least for the UK market) and prohibited the use of 'new' products. To have retained this requirement with the new Regulations would have been wholly inconsistent, and would have required considerable justification.

## 8. Public opinion

A further important consideration for Government is that of public opinion. As directly elected representatives Ministers are answerable to the public and therefore are always conscious of a duty to reflect the public's concerns. Although it may be hard for you to imagine, the decision to remove the siphonic requirement caused a great deal of controversy. The public debate was not so much concerned with the relative technical merits of siphons compared to valves, but centred on far more emotive topics such as UK employment, tradition, water conservation and European Commission interference.

When the siphonic requirement was being considered, a number of MPs sought to convince Ministers to reject the proposal. They were particularly concerned about the impact this change would have on UK industry and in particular on firms in their constituencies. These concerns were presented to the Government mainly through correspondence and in meetings, but were also voiced in a Parliamentary debate in July 1997.

In June 1998 the tabloid press picked up on the decision to allow flushing devices other than 'the good old British siphon'. This was used to portray interference by the European Commission who were trying to lower UK standards, and in this way tried to raise Europhobic sensitivities over the changes. It also attempted to raise concerns about the effect of introducing valves on water conservation grounds by suggesting that, unlike siphons, all valves will leak.

## 9. Practicalities

Once the decision is taken to regulate, there are numerous practicalities that need to be worked out. For example, when the law changes it is essential that this is communicated clearly to the people who will be most affected. Their involvement and commitment should increase the chances of the regulations realising their full potential. Without adequate understanding of how and why changes are being made, there is an increased danger that regulations will not be followed. Therefore, the implementation of regulations tends to be about compromise by turning the idealistic into the realistic, both legally and politically.

### 10.1 Point of sale enforcement

One very practical difficulty with introducing the Water Fittings Regulations is that they are only legally enforceable at the point of installation. It is not illegal, therefore, to buy or sell non-compliant products but only to actually install them. Clearly this makes the requirements of the Regulations hard to enforce, especially with the proliferation of home improvement stores. This lack of point of sale enforcement is due to the original primary legislation (Water Act 1989) and so is not easily rectified. Amending or introducing primary legislation, i.e. Acts of Parliament, takes on average three years from inception to completion, whereas for secondary legislation, e.g. the Water Fittings Regulations, this takes about one year. Constraints such as this (i.e. further from the ideal) had to be factored into the solution, which involved education and compromise.

The Construction Products Directive also comes to bear on this issue. Once fully implemented this will enable enforcement at the point of sale for products covered by harmonised European Standards. However, as these standards are still being developed for water fittings this enforcement regime is still a long way from realisation. Although this ought to improve compliance with the Regulations in the longer term, it does cause complications now. For example, to introduce point of sale enforcement in the UK for the Water Fittings Regulations now would risk prematurely restricting the market, bearing in mind that harmonised standards would take precedence once they became available.

**10.2 Transition period**

When the WC Specification is introduced it will bring about significant and beneficial changes to WCs, including the removal of the siphonic requirement. While it was desirable to bring about these changes with minimum delay, it was also important that the maximum benefits of the Specification would be realised. The compromise reached was that of delaying its introduction until 1 January 2001. However, not all parties were in favour of such a transition period. In particular, manufacturers of valve products felt this continuation of a barrier to trade to be unjustifiable. The transition period had to be defended to the European Commission on the grounds of the environment.

This 18-month transition period would allow time for manufacturers to develop their products and have them tested against the Specification. It would also allow time for the education of those in the supply chain, designers, specifiers and plumbers about the changing requirements. Significant effort from the Government, Water Industry and others has been devoted to educating these parties about the requirements of the Water Fittings Regulations. It was essential to have this opportunity to engage with and educate all stakeholders, in order to reduce the likelihood of the new requirements causing confusion. This was intended to benefit the environment by preventing the sale and installation of poor quality flushing devices. Failure to influence in this way would risk bringing the WC Specification into disrepute, as well as jeopardising the overall aim of water conservation. However, in a largely cost-driven market, it remains to be seen whether consumers will be able to, or want to, differentiate between legal and cheaper illegal products.

**10.3 Approved contractors**

Another route for encouraging compliance with the Water Fittings Regulations is through improving standards in the plumbing industry. The Regulations introduce the concept of Approved Contractor Schemes, which form part of a wider Government initiative to improve standards in the construction industry. These schemes are voluntary, but provide tangible benefits to competent plumbers as well as to consumers. Approved plumbers are exempt from some of the administrative requirements of the Regulations and can use their approved status as a marketing tool. Consumers benefit primarily from being able to easily identify a good quality plumber and through insurance on work carried out. They can also be confident that work has been carried out in accordance with the Regulations.

## 10.Role of an Advisory Committee

The UK has a history of technical experts sitting on committees to advise Government. They are not paid for this service, but membership is generally sought after because of the responsibility and respect it brings. Involving key stakeholders in this way brings valuable expertise that Government does not have internally into developing regulations.

Invariably on advisory committees, some members are allied to commercial interests by virtue of background, employment or affiliation to professional organisations. Indeed, to possess the required level of technical expertise, candidates would have inevitably had long histories within their field. While for some this may raise the issue of how impartial these committees are, in reality this is not a concern. Members of advisory committees represent themselves as experts, not their respective organisations. Membership of such a committee brings with it the responsibility to act impartially, which is taken seriously. In addition, by ensuring that a good blend of backgrounds and interests are represented, these committees deliver balanced, well thought out proposals.

To develop the Water Fittings Regulations, the Water Regulations Advisory Committee (WRAC) was appointed in 1996. The remit of WRAC was 'to advise the Secretary of State for the Environment on the requirements for plumbing installations and fittings to be included in Water Regulations made under the powers in section 74 of the Water Industry Act 1991 and on other technical matters connected with the regulations'. The Committee was made up of manufacturers, representatives from the water and plumbing industries, academics, researchers, standards organisations, etc. The work of WRAC included reviewing the existing Water Byelaws requirements, establishing equivalent performance-based requirements and also, most relevantly, updating the Byelaws to reflect new technology.

## 11.Role of consultation

Whenever the Government proposes to change or introduce regulations there is a requirement to consult the public and particularly those who will be most affected. The main purpose of public consultation is to improve the proposals being made. The wider involvement of stakeholders should ensure that proposals are soundly based on evidence, take account of the views and experience of those affected by them, and that innovative and creative options are considered.  This process also acts to provide external scrutiny of the advisory committee's advice.

Consultation exercises invariably result in technical criticism as well as legitimate other concerns being raised.  While it is important to obtain the views of everyone likely to be affected by the changes, this presents a considerable challenge - how to reconcile the large amount of conflicting opinion and evidence that is gathered in response?  Furthermore, how ought technical rights and wrongs to be balanced against more subjective concerns about employment or the environment?  This is one area where the expertise of an advisory committee is invaluable.  A more thorough understanding of the technical issues enables better judgements to be made on these.  It also provides an experienced forum at which to consider the more subjective concerns raised about the consequences of adopting a certain technical approach.

Consultation responses are carefully and open-mindedly analysed, the results of which are made publicly available along with an account of the different views expressed and rationale behind the final decision.  Responses will generally reveal possible new approaches; further evidence on the impact of those canvassed; an indication of levels of support among particular groups for various proposals.  However, analysing responses is never a matter of counting votes.  Different levels of importance will be attached to the views of certain groups, for example particular attention is given to the views of representative bodies, such as trade associations and other organisations representing groups particularly affected.  Eventually, however, it is for Ministers to assess the arguments and evidence presented and to reach a decision in the public interest.

Another part of the process of developing regulations requires a Regulatory Impact Assessment to be produced.  These documents explain the issue that has produced the need for regulation and compares this approach with other options, probably including non-regulatory measures that might be considered.  Assessing the relative risks, costs and benefits, who will be affected and why non-regulatory action would be inadequate is meant to ensure that proposals are proportional and appropriate to the situation.  In this way, RIAs can also assist the public debate as they tend to identify and quantify some of the concerns raised by the consultation exercise, such as the impacts on competitiveness.

The Water Fittings Regulations, along with their Regulatory Impact Assessment, went out to public consultation in July 1998.  Sanitaryware manufacturers were also specifically consulted about the proposed changes to WCs in March 1999.  Together these consultations produced about 120 detailed responses from the whole range of stakeholders.  While the comments received represented a great amount of experience and expertise, they also demonstrated considerable disagreement about the best way to proceed.

## 12.Role of Government

The role of Government in the regulatory process is to consider, decide and ultimately to act. However, "Government" is a collective term including Ministers and their civil servants who each have distinct roles. Ministers decide and are answerable, while civil servants exist to advise Ministers. It is important to remain impartial and dispassionate in assessing arguments, although some assessments will be subjective. Significantly, Ministers may weight the factors outlined above differently to others because of their unique position in the political spectrum.

## 13. Assessing the success of the outcomes of this political process

Measuring the success of regulations will never be a simple exercise. For one thing, it is impossible to be sure what would have happened had a different approach been taken, or if the situation were left unchanged. Alternatively, an outcome may be compared to the projected benefits of the theoretical conclusions of research, but it is not necessarily evident that these would have been achieved in reality.

The WC Specification will not be introduced until January 2001, so to a large degree its success remains to be seen. Assessment of success will also be complex because this means different things to the different parties involved in the process. To the Government, the success of the WC Specification, and in particular removing the siphonic requirement, will be concerned with water conservation. However, this will not be easy to quantify, especially at a national level. Even if in coming years water consumption fell considerably, it would not necessarily be clear whether this could be attributed to this development or to other factors. To UK sanitaryware manufacturers, success will also be about their ability to adapt to the changing demands of a competitive market. The wider success of the Water Fittings Regulations should also be viewed in terms of their implementation and transition from the requirements of the Water Byelaws.

## 14. Conclusion

The UK made the decision to accept non-siphonic flushing mechanisms much later than other countries. Evidently this has influenced the debate because of concerns about the impact on manufacturers primarily or extensively involved in the domestic market adapting to new requirements. These concerns were heightened by the threat from overseas manufacturers who have been producing high quality valve products for many years.

However, this 'delay' also allowed the UK Government to learn from experience elsewhere. For example, experiences with low quality valve products in some parts of the United States[3] have led to this technology being discredited. While originally installed to reduce water consumption, valves that leaked or could be easily adjusted by

[3] From an article by Brian Brittsan, President of Water Management Services Inc, in the Environment Agency's Demand Management Bulletin, August 1999: 'Fixing the leak in demand management programme'

consumers resulted in high repair and maintenance costs, as well as the water conservation aims not being realised. These unfortunate experiences were taken into account in the development of the UK's high performance specification for WC suites.

Co-operation in the regulatory process is crucial, both for Government and stakeholders. It is important for all parties to engage in early debate, both to discuss the 'correct' technical outcome, but also to prepare for the consequences of the Government's decision. A co-operative approach also enables better decision making, as it helps to clarify and resolve subjective issues and quantify objective ones. It should also enable those affected to recognise early indications of the Government's policy. With respect to the decision to remove the siphonic requirement, a Press Release in December 1996 signalled the Government's intention four years before this was brought to reality.

## 15.Summary

This paper has sought to explain how an apparently self-evident statement, "over their lifetimes, high quality drop valves have a performance equivalent to siphons" may not necessarily result in a change in Government policy. In addition to the technical justifications, the Government also has to consider the impact of changing legislation on all stakeholders. They also need to operate within the constraints of existing commitments. None of these factors are as straightforward as an initial thought may suggest.

# An Investigation Study on Renewal of Plumbing Fixture in A Super-High-Rise Office Building

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## Abstract

This paper describes results of investigation and analysis about renewal construction of plumbing fixture facilities in an office building, and aims to present the fixed-quantity data( such as the decrease of water consumption) and the water-saving technique in the case of installing " water-saving toilet system". Following the renewal construction of plumbing fixture facilities in a 29-storeyed super-high-rise office building, we have investigated the effect of installing " water-saving toilet system" as the water-saving technique of flushing water, and report the outline here. The building used in this study was built in 1986, and it is located in the center of Tokyo. Furthermore, the questionnaire result about the feeling of use in a water closet booth is also explained.

In addition, "water-saving toilet system" consists of water closet, urinal, and washbasin. Each plumbing fixture is water-saving compared with the conventional one.

## Keywords

Super-High-Rise Office Building; Renewal of the Plumbing Fixture; water-saving toilet system; water consumption

## 1 .Contents

In recent years, there are demands for water-saving from the view point of earth environment preservation problem. In the United States, the regulation for water saving is constructed in all states. The motion which promotes water-saving is also active in Japan along with the Environment Agency, the Ministry of Construction, the Ministry of Health and Welfare, etc. On the other hand, as for office buildings, office building stock demand is in increase tendency in a center part of Tokyo, especially after collapse of the Bubble Corporate Finance (around 1991), it has shifted to the time of STOCK from SCRAP & BUILD. Therefore, demand for renewal construction of the equipment has also increased rapidly. (Table 1.)

Therefore, recently, there also caused a demand of water preservation from the environmental point of view, and water-saving techniques about toilet flushing have been actively examined and performed, for example, use of reclaimed water, etc.

This paper describes results of investigation and analysis about renewal construction of plumbing fixture facilities in an office building, and aims to present the fixed-quantity data( such as the decrease of water consumption) and the water-saving technique in the case of installing " water-saving toilet system". Following the renewal construction of plumbing fixture facilities of a 29-storeyed super-high-rise office building, we have investigated the effect of installing " water-saving toilet system" as the water-saving technique of flushing water, and report the outline here. The building used in this study was built in 1986, and it is located in the center of Tokyo. Furthermore, the questionnaire result about the feeling of use in a water closet booth is also explained.

**Table 1- Office Building Stock (the 23 wards in Tokyo)**

| Year | Office Building Stock( stocked buildings which 16 to 25 years has passed after construction ) |
|---|---|
| 1995 | About 1600[ha] |
| 2010(Anticipation) | About 2700[ha] |

*The office building stock sum total in 23 wards in Tokyo in 1995: about 7000[ha]

## 2 .Investigation outline

### 2.1 Building specification

The outline of the building for investigation is shown in Table 2.

**Table 2- Building equipment**

| | |
|---|---|
| Building | Location: Shinjuku Ward, Tokyo, Japan<br>Building scale: 29 floors, four lower ground floors<br>(Offices:26847.59m$^2$, Stores:1780.32 m$^2$)<br>Total floor area: 52,310 m$^2$<br>After [ construction ] 13 years<br>Measurement place: The 17th floor Gentlemen's Lavatory and Ladies' Lavatory (Fig.1)<br>The number of persons on the 17th floor: 35 men, 25 women<br>Average age: 50 years old( men ), 36 years old( women )<br>Working hours: From 9:00 a.m. to 5:00 p.m.<br>( Saturday, Sunday, and a public holiday are day off) |

### 2.2 A measurement item and a method

The measured contents are the amount of water supply to the plumbing fixture system (water closets, urinals, washbasins) installed in each gentlemen's lavatory and ladies' lavatory.

A measuring method is as follows.
Pulse output electronic water meters are installed in the five points ( 1 to 5 ) of water supply vertical pipes in PS and get to each plumbing fixture, as shown in Fig.1.
The measured data are transmitted from the water meters to a personal computer every 0.1 seconds.
After that, we can grasp water consumption of each plumbing fixture by analyzing data with an original program.

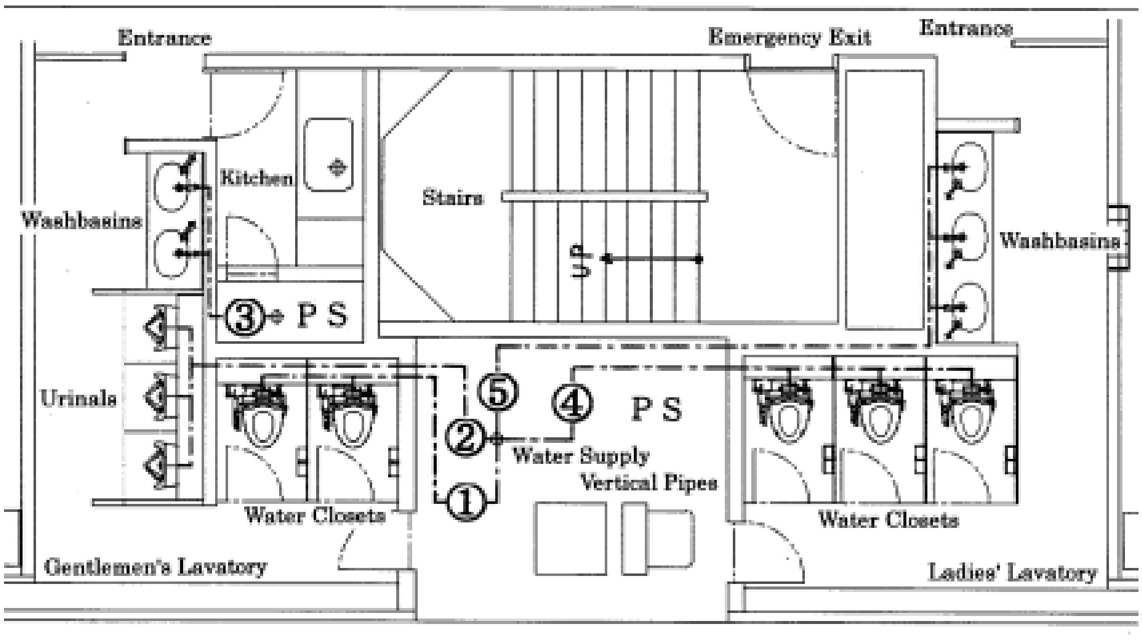


**Figure 1. Toilet plane view**

**2.3 Plumbing fixtures**

The specification of each plumbing fixture installed before and after replacement and the investigation term are shown in Table 3.

**Table 3- The plumbing fixture equipment of before and after replacement and investigation term**

| | Before replacement (amount of flushing water) | After replacement (amount of flushing water) *water-saving toilet system | The rate of water-saving of fixture |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Water closets*1 | C454PV<br>(standard 13[L/flush])<br>(Actual measurement<br>14.3[L/flush]:gentlemen's side 2 pieces,<br>11.4[L/flush]:ladies' side 3 pieces) | C743PV<br>(standard 7[L/flush])<br>(Actual measurement<br>7.0[L/flush]:gentlemen's and ladies' side) | Gentlemen's side: 51.0%<br>Ladies' side: 38.6% |
| Urinals*2<br>( With an automatic flushing sensor ) | U370<br>(standard 4[L/flush])<br>(Actual measurement<br>2.7[L/flush]:gentlemen's side 3 pieces) | UFS520CE<br>(standard 1-2[L/flush])<br>(Actual measurement<br>1.0-2.0[L/flush] :gentlemen's side 3 pieces) | 25.9% or more |
| Washbasins | 2 valve mixture faucet<br>(gentlemen's side 2 pieces, ladies' side 3 pieces) | Hot-and-cold-water mixture automatic faucet<br>(gentlemen's side2 pieces, ladies' side 3 pieces) | - |
| Investigation term | 14 weekdays during 1998.10.26-1998.11.14 | 32 weekdays during 1999.01.26-1999.02.24 | - |

*1 Flushing sound effects generating equipments are attached to closet seat of the ladies' water closets after replacement.
*2 In the urinal after replacement, since there is a fuzzy-control function, the amount of flushing water of the urinals are changed between 1[L] to 2[L].

### 2.4 Questionnaire outline

The questionnaire was performed at the end of each investigation term for the purpose of getting hold of the features of the behaviors and backing of the measurement data. The questions are about the behaviors which relate to the water consumption, for example, about "brushing teeth", "using flushing sound effects generating equipment".

## 3 .Result and consideration

### 3.1 Comparison of amount of water consumption per day before replacement and value of bibliography

The amount of water consumption which one person uses per day is shown in Table 4 about every plumbing fixture. The measured value of this investigation is indicated in the column of A, the value of reference 7) is indicated in the column of B, and the value of reference 8) is indicated in the column of C.

First, since the value of B is arranged about each plumbing fixture for gentlemen's lavatory and ladies' lavatory, it can be compared with the value of this paper. The value of gentlemen's water closet is in agreement with the maximum of B. Moreover, the value of ladies' washbasin is approximated to the average value of B.

However, about the urinal, A(6.7 [L]) is about half of B(12.0±1.0 [L]). The cause of the difference is that there is a difference in the amount of flushing water between A and B. The amount of flushing water of A is 2.7 [L/time] and the value of B is 5.0 [L/time]. Therefore, replacing the amount of flushing water 2.7 of A[L/time] with 5.0 [L/time], and multiply it by the number of times of one day use surveyed in this paper, since it becomes 12.4 [L] and the average value of B is close, what is depended on the difference in an instrument the amount of flushing water will be presumed.

Next, A is compared with C regarding the sum total value of amount of water consumption. As for A(13.5+12.4+2.6=)28.5[L] and B 31.0[L], there is little difference. When each value of ladies' water closet of A, B, and C is compared, the amount of water used in A is about 15 [L] more than B and C. (When it converts into the number of times of flushing valve operation, it is for about 1 time.) Although this becomes clear by the result of a below-mentioned questionnaire and actual measurement, it is considered to have originated in the number of times of flushing valve operation per person is large.

As mentioned above, comparing the result of this investigation with the result of previous investigation, although some difference will be found by the influence of the difference of investigation years, a term, and a use plumbing fixture etc., it can be considered that rough value is practically equal. Therefore, these results of an investigation shall be used on a real design level as basic data considering its flexibility and we used it for checking the water-saving effect after replacement.

**Table 4- The amount of water consumption which one person uses per day before replacement. (Weekday) [L/(day*person)]**

| Reference name | | A. This paper | [*3]B. Reference[7)] | C. Reference[8)] |
|---|---|---|---|---|
| Announcement year | | 1999.4 | 1980.8 | 1998.8 |
| Gentle men's | Water closets | 13.5 | 9.0±4.5 | 31.0 |
| | Urinals | 6.7(2.7[L/time]) ↓ 12.4(5.0[L/time Conversion) | 12.0±1.0 | |
| | Washbasins | 2.6 | 4.5±0.3 | |
| Ladies' | Water closets | 89.5 | 70.7±5.5 | 74.8 |
| | washbasins | 6.7 | 6.5±0.7 | |

*3 The amount of flushing water using urinal: 5.0[L/time],
the amount of flushing water using water closet: 15.0[L/time]

### 3.2 The plumbing fixture use situation of before and after replacement

The change of water consumption during investigation term is shown in Fig.2. The change of water consumption during a day is shown in Fig.3.

The variation shown in Fig.2 will be altogether settled into the width, if the width of 2sigma (sigma is standard deviation) is taken around an average. Therefore, the number of staff work on the floor is almost changeless before and after replacement. So the fixed staff uses the plumbing fixtures every day, and it is considered that it is almost changeless in a use situation.

Amount of water consumption has decreased in Fig.3 by installation of the water-saving type plumbing fixture. However, the use situation which considering average value as the index, and the generating time of a peak are similar. Therefore, the big change use situation before and after replacement is presumed not to be produced.

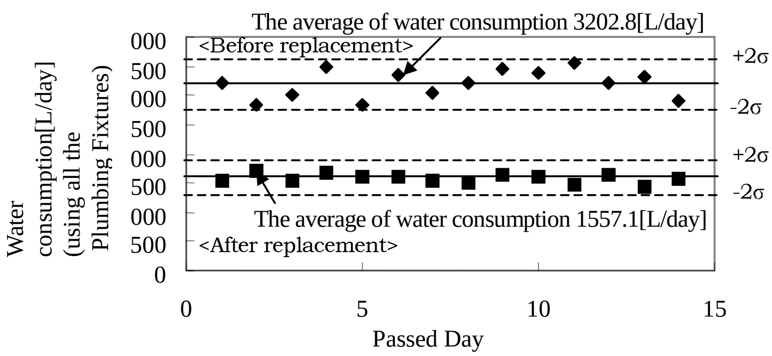


**Figure 2 – The change of water consumption during investigation term**

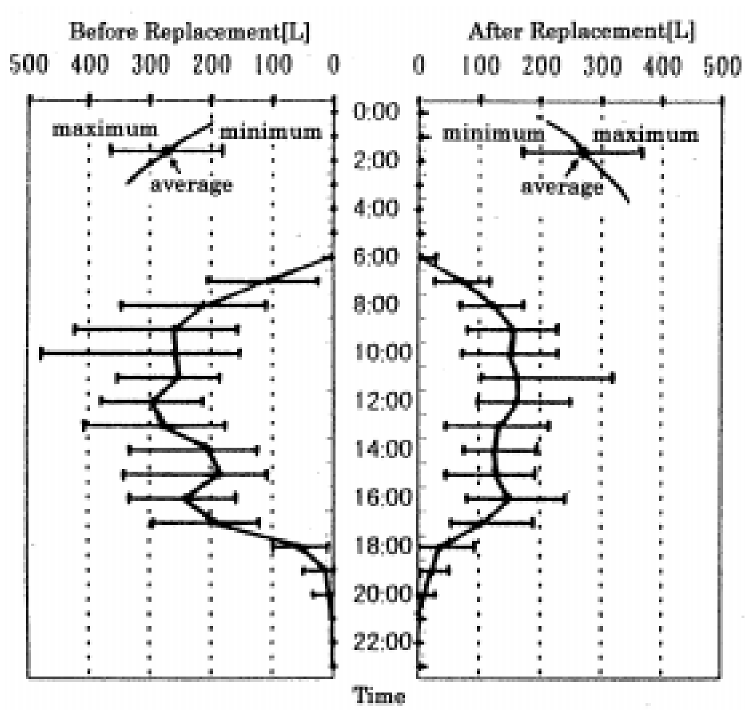


**Figure 3 – The amount of water consumption about each before and after replacement used by time**

### 3.3 The curtailment effect of the amount of water consumption of the plumbing fixture about before and after replacement

The amount of water consumption per day the plumbing fixture about before and after replacement is shown in Fig.5. By replacing plumbing fixture equipment, it turns out that about 52% of water consumption was reduced by all the fixtures.

Including a questionnaire result the reduction effect of amount of water consumption is considered and explained below.

**Table 5- The amount of water consumption per day about before and after replacement[L/day]**

| | Water Closet | | Urinal | Washbasin | | Sum total |
|---|---|---|---|---|---|---|
| | Gentlemen's | Ladies' | | Gentlemen's | Ladies' | |
| Before replacement | 471.9 | 2236.8 | 236.1 | 90.1 | 167.9 | 3202.8 |
| After replacement | 215.3 | 917.7 | 182.5 | 71.1 | 140.9 | 1527.5 |
| The amount of water-saving | 256.6 | 1319.1 | 53.6 | 19.0 | 27.0 | 1675.3 |
| The rate of water-saving | 54.4% | 59.0% | 22.7% | 21.1% | 16.1% | 52.3% |

#### 3.3.1 Water closet

Table 5 shows the following. Of all plumbing fixtures, The water-saving effect using water closet in a ladies' lavatory is the largest and is about 59%. The next is about 54% using water closet in a gentlemen's lavatory. The rate of water-saving of each fixture is about 51%(7.3[L]/14.3[L]=51%) for gentlemen's, and about 39%(4.4[L]/11.4[L]=39% for ladies' from Table 3. With a gentlemen's water closet, the rate of water-saving measured actually shown in Table 5 and the rate of flushing water-saving of each fixtures are mostly same. However, with the ladies' water closet, the rate of water-saving is 20% more than the rate of flushing water-saving. It can be considered that the factor is the effect of flushing sound effects generating equipment.

According to the questionnaire result, 90% of the ladies has answered that "a flushing water is carried out in order to remove excretion sound and smell", with the idea of "Shame" or "Manners". Moreover, 95% of the ladies has answered "I use flushing sound-effects generating equipment" after flushing sound-effects generating equipment installation. Therefore, using flushing sound-effects generating equipment was checked qualitatively here.

The number of times of flushing valve operation measured in a booth of a ladies' water closets is shown in Table 6. From the table, it is able to check that the number of times of flushing valve operation per using a booth had decreased about 0.8 times by installing flushing sound effects generating equipment. Therefore, it has checked using flushing sound-effects generating equipment also quantitatively. Converting this result into amount of water, the water of about 15 [L] can be reduced for every 1 water closet booth use, and the water-saving effect is large.

**Table 6- The flushing sound-effects generating equipment use effect (Weekday average)**

| | *4The number of times of flushing valve operation per one ladies' water closet booth use [Times/(booth)] | The number of times of the flushing valve operation [Times/Day] | *5The number of times of lady water closet booth use [Times/Day] |
|---|---|---|---|
| **Before replacement** | 2.29 | 195.86 | 85.6 |
| **After replacement** | 1.53 | 131.10 | 85.6 |

*4 Value which divided the number of times of flushing valve operation by the number of times of water closet booth use.
*5 The number of times of ladies' water closet booth use after replacement is diverted. (Since the number of times of use of the ladies' water closet booth before and after replacement can regard almost the same).

**3.3.2Washbasin**

From Table 5, by changing two-valve mixture faucet of washbasins into automatic faucets, a gentlemen's side caused about 21% of water-saving, and a ladies' side caused about 16% of water-saving.
In order to check the effect of an automatic faucet, carrying out a questionnaire, there was reply of "becoming easy to use washbasin" from 70% of a gentlemen, and 62% of ladies. As for the reason, it was mainly "without faucet operation there is no waterdrop scattering", "it is clean because of uncontacting", etc.
Water consumption by time about gentlemen's washbasin is shown in Fig.4, and Water consumption by time about ladies' washbasin is shown in Fig.5. It can be found that a ladies' washbasins are intensively used around (at the time of a lunch break) 12 o'clock (Fig.5). It is considered that the feature that the custom to brush their teeth has been fixed to the ladies in an office, because the questionnaire result about brushing teeth shows that 90% of the ladies (15% of the gentlemen) have answered "I brush my teeth after lunch".
On the other hand, while these effects became clear, there were following a few opinions about brushing teeth. "It becomes an automatic faucet and is hard coming to collect water in a glass", "the temperature control of water became impossible", etc. Therefore, the knowledge which will be a good reference for plumbing fixture installation to an office building in the future was acquired.

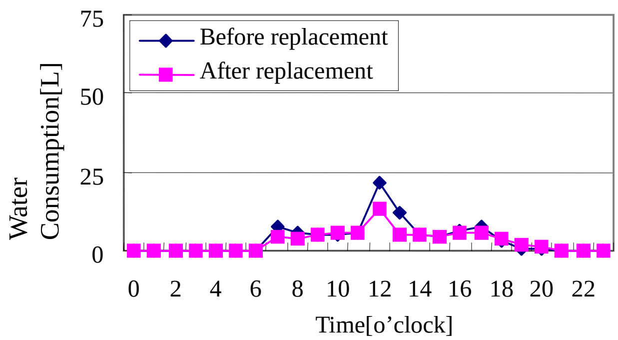


**Figure4. Change of water consumption about washbasin in gentlemen's lavatory**

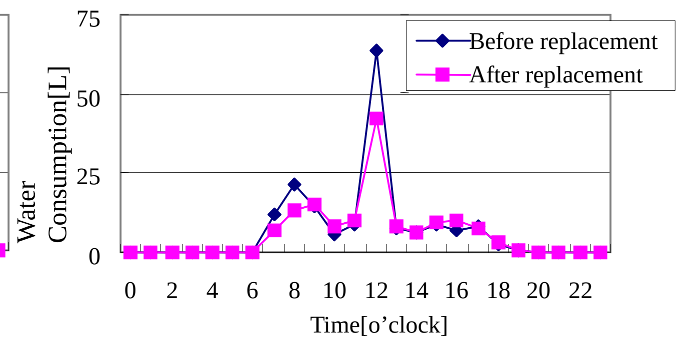


**Figure5. Change of water consumption about washbasin in ladies' lavatory**

**3.3.3 Urinal**

In the original trial calculation, the rate of water-saving of urinals expected at least 50% or more. It is because the standard flushing water before replacement is 4.0 [L/flush], and the standard flushing water after replacement is 1.0-2.0 [L/flush](with fuzzy-control function). However, as a result of measuring, as shown in Table5, the rate of water saving was as small as about 23%. It can be considered because of the followings: "The actual measurement of the flushing water before replacement was very small value (2.0 [L/flush]).", "Since the operating frequency after replacement was low, though it has fuzzy control, almost all flushing water were 2.0 [L/flush]."

## 4 .Conclusion

With regard to the renewal construction of plumbing fixture facilities in an office building,we have investigated the effect of installing " water-saving toilet system". Furthermore, the questionnaire result about the feeling of use in a water closet booth is also obtained. The main points of the investigation study results are as follows.

(1)The use situation of plumbing fixtures in the office building has been grasped and the water-saving effect have been explained quantitatively in the case of installing " water-saving toilet system ", and high reduction( about 52%) of water consumption was pointed out.

(2) "Water-saving toilet system" was proposed, and the validity of the system has been explained.

(3)It has grasped that the water consumption by ladies' water closet accounts for large percentage of the total consumption, and its water-saving effect was the largest of all plumbing fixtures.

(4)There wasn't sufficient quantitive data about the effect of the flushing sound effects generating equipment so far, but this investigation clarified the effect by the precious data, and qualitative information such as questionnaire results was also obtained.

(5)From the results of an investigation about the washbasins, it has confirmed that brushing teeth after lunch was established as a custom of ladies' daily life in the office.

We also examine the water-saving effect to plumbing system, for example, reduction of loads on water supply pipes or drainage pipes, etc.

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# Plumbing Systems Rationalization

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## Abstract

The article presents research about actually solutions to set cold water, hot water and sanitary plumbing systems inside buildings and the importance of researches to adequate those solutions to the performance requirements.

## Keywords

Civil Construction, Plumbing Systems, Cold and Hot Water Plumbing Systems, Drainage Plumbing Systems, Quality in the Civil Construction

## 1 Introduction

The productivity improvement solutions that are being used for the rationalization of Plumbing Systems needs, at the same time, to assist to the users' performance requirements, that are: stability, safety on fire, safety in use, tightness, acoustic comfort, visual comfort, tactile comfort, antropodinamic comfort, hygiene, adequated spaces for specific uses, durability, economy and environmental conservation. Naturally those requirements are linked to inherent human being needs, although some are linked to uses and regional habits.

The rationalization begins in the stage of global planning of the enterprise and it continues in the project and execution stages of the systems.

In the stage of global planning it is fundamental the definition of the constructive system to be adopted: it is defined if conventional structural system will be used (pillar, slab, beam) in reinforced concrete; system in metallic structure; system in structural masonry; etc. It is defined the masonry system that will be used. For each one of those systems it is necessary to choose among several options of solutions for the spaces that will shelter the components of the Plumbing Systems.

On the project stage, sanitary fixtures and fittings location is fundamental condition to get a rationalized system. The amount of the components, the disposition and the necessary space to a good maintenance should be very well studied.

A meticulous study of solutions is made in sequence for the chosen constructive system.

On the execution stage, a good production project, that can include the execution of "hydraulic kits", makes it necessary to complete the rationalization cycle.

## 2 Rationalization

### 2.1 Solutions in use

Actually, in Brazil, to locate cold and hot water plumbing (pipes, fittings, accessories, etc.) it has been worked in two preferential ways:

a. The main vertical plumbing is located inside of shafts and the horizontal ones inside of masonry. The vertical shafts are already used broadly, being used the solution less and less of tearing the wall to accommodate this plumbing. This solution is used in constructive system in reinforced concrete (with the horizontal plumbing being located inside ceramic bricks masonry by tearing them), as in structural masonry (that had special blocks to accommodate horizontal pipes) and "dry-wall" with the accommodation of the horizontal pipes inside of the emptiness of the own wall (Figure 01).
b. The main vertical plumbing is located inside of shafts and the horizontal ones inside of the inferior false roof. This solution has been used in structural masonry and dry-wall (Figure 02).
c. The main vertical plumbing are located inside of shafts and the horizontal ones inside of horizontal shafts, that is, spaces especially created for this purpose (Figure 03).

For sanitary drainage system it has been using the following solutions:

a. The main vertical plumbing is located inside of shafts and the horizontal ones inside of the inferior false roof.
d. The main vertical plumbing are located inside of shafts and the horizontal ones inside of horizontal shafts, that is, spaces especially created for this purpose (Figure 03).

European companies defend the system denominated "pre-wall" that has the concept of the minimum interference of the plumbing with the building sub-systems (Figure 04). That results in plumbing placed in front of the walls and closed inside of furniture that compose the sanitary room. According to the manufacturers, this system makes simpler, more flexible, cheaper and faster constructed buildings, trying to satisfy characteristics of the current demands (Westfal, 1996). In that system the concept is used of "equipping instead of to embed and to set up instead of installing ". It also argues that this system type decreases the conflict with the structural system. It is noticed, therefore, decrease of the useful space what is compensated by the rational use of that furniture.

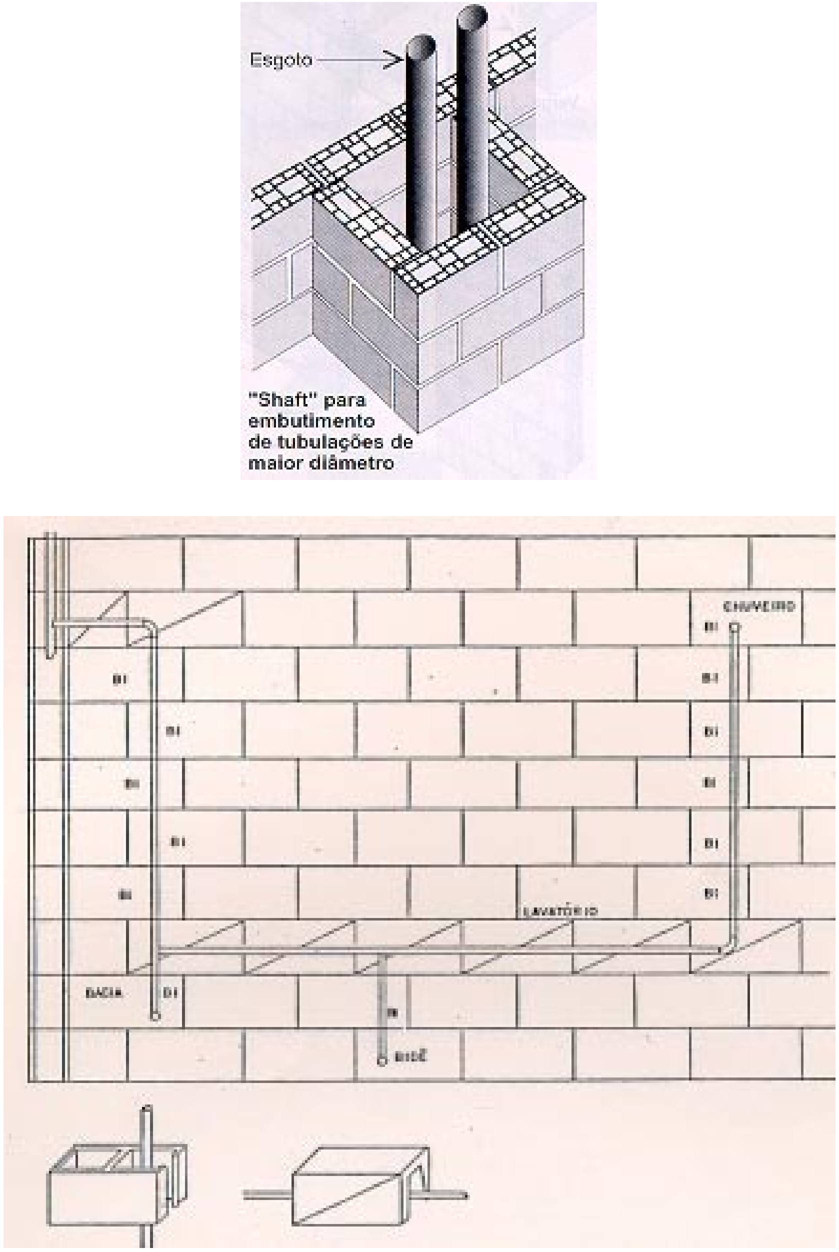



**Figure 01: Vertical pipes shafts and horizontal pipes inside of the masonry (structural masonry). (Lanna, 1997)**

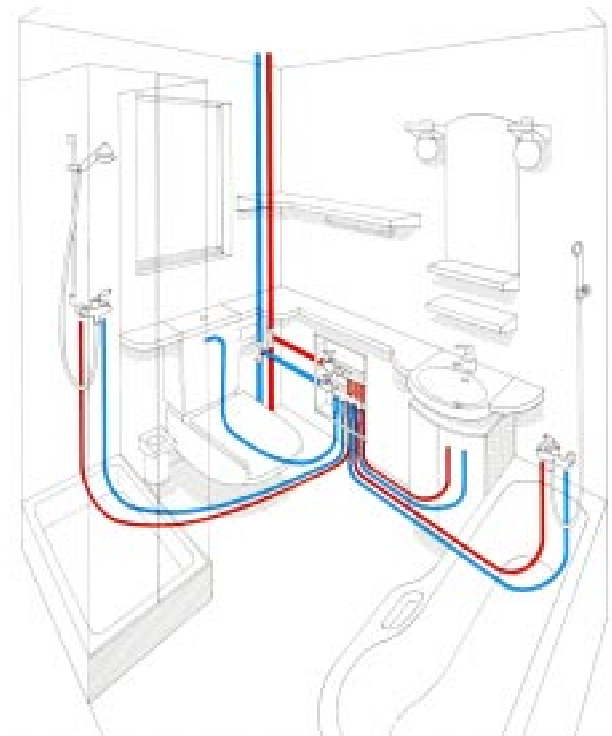


**Figure 02: Vertical pipes shafts and horizontal ones inside of the inferior false floor. (PEX pipe tubes manufacturer catalog)**

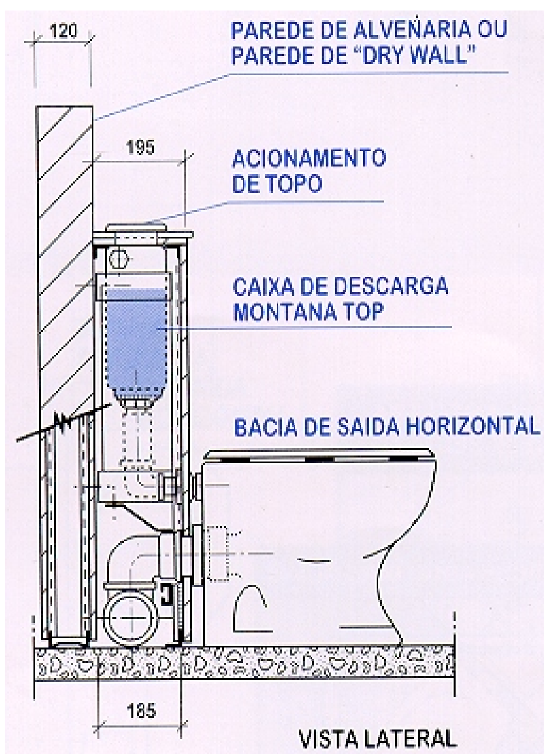
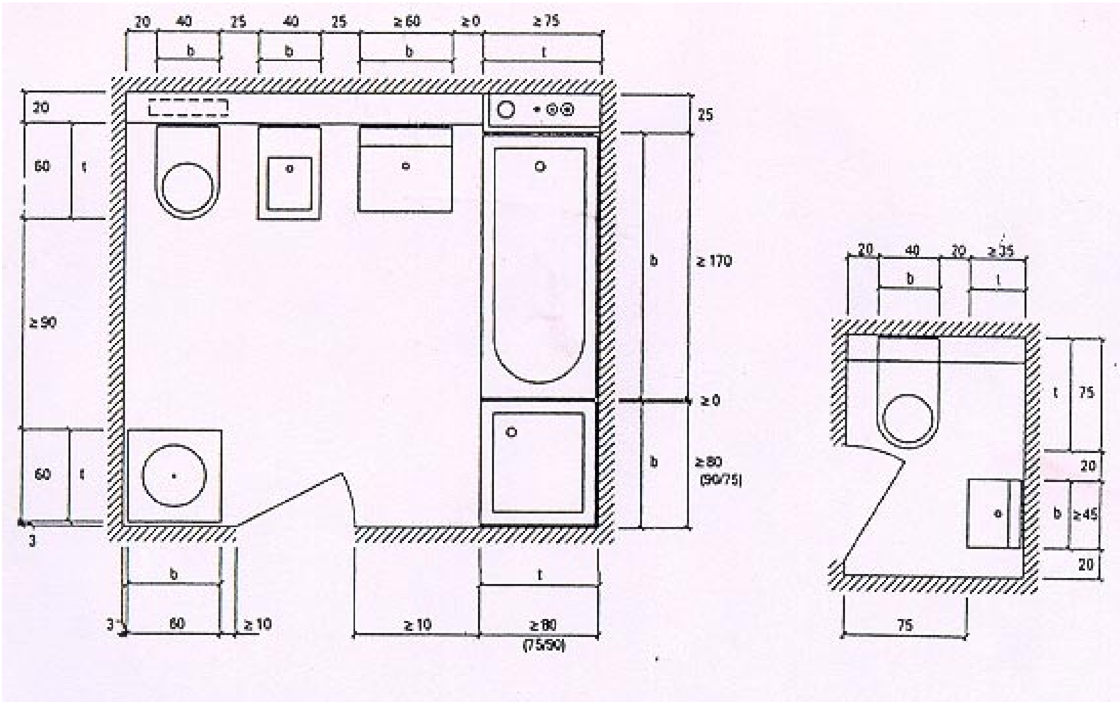



**Figure 03: Shaft created to shelter horizontal pipes. (Wysling, 2000)**



Planning example bathroom / WC with pre-wall installation according to DIN 18022 (dimensions in cm)

**Figure 04: "Pre-wall" system example. (Westfal 1996)**

Some experiences were already executed with systems using ready hydraulic walls, that is, walls set up previously already to the execution with the pipes inserted. Those concrete walls with the inserted pipes presented problems of leaks in junctions in researches done in habitational groups.

Ready bathrooms, that is, complete bathroom being installed on pre-prepared floor, were adopted in an experimental way on the 13th floor of a hotel in the city of São Paulo. The bathrooms were imported from an Italian company and they were manufactured with walls of 4 cm in pre-fabricated plates of concrete with 40 MPa. The bathroom-containers were hoisted to the pavement-type and moved until the fixation point with the equipment aid on wheels. The slabs were previously depressed on the bathroom location during the concrete work. The units arrived to the pavement-type with all the accessories and internal finishes, of the roof to the floor (Kiss, 1999).

This solution is used in Japan where we can choose the most convenient bathroom through catalogs (Figure 05).

In the execution stage the concept of "hydraulic kit" is already being used with some frequency.

## 2.2 Performance requirements

Plumbing systems performance requirements are listed in Table 01. Those requirements need to be respected by the solutions that are being introduced for the rationalization under feather of we come to witness future pathologies.

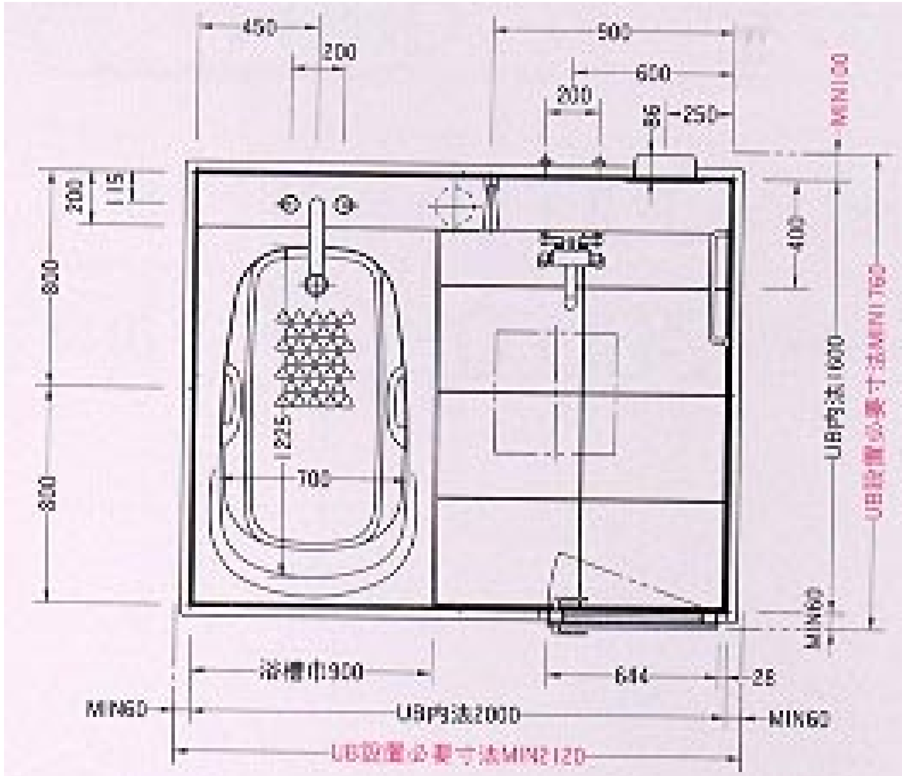



**Figure 05: Ready bathroom example. (Manufacturer catalog)**

It was noticed in plumbing systems studies made on constructions in use, that pathologies generated in solutions used for the rationalization of those systems exist. Among them: leaks generated from differential movements in junctions of pre-executed walls; accessibility lack for maintenance; insufficient internal spaces; noises in vertical shafts; lack of components in the market to substitute components specifically created for certain constructive systems; etc.

## 3 Conclusions

From this study we can conclude that the concern with Plumbing Systems and its real insert in the productive process of the building is in improvement process. Rationalized solutions have been used to increase the productivity in the execution and to decrease the interference with other sub-systems.

But it is also noticed that those existent solutions in the market need to be analyzed under plumbing systems performance requirements. It is necessary the creation of performance criteria to analyze rationalization solutions with parameters of the up-to-date users' satisfaction.

Those solutions should look for to reach the following general concepts:

- Not to interfere with the other building sub-system performance requirements.

- Look for the largest possible independence of the structural sub-system and of the masonry.
- To promote global access for maintenance.
- Look for the largest possible independence among the stages of construction.

**Table 01: Plumbing systems performance requirements**

| PERFORMANCE REQUIREMENTS | |
|---|---|
| stability | Referring requirements to the user's need that the plumbing systems components don't reach a state rupture limit, excessive deformation or loss of stability caused by the normal use of the same ones, for accidental impacts or not, for stress, etc. as well as that the same ones don't cause in another sub-systems of the construction or in the environment, the same state. |
| safety on fire | Referring requirements to the user's need that the plumbing systems components limit the risk of a fire beginning inside of the building. That is function of the sanity equipment safety and of the reaction properties to the fire of the materials that form the other components of the plumbing. Besides limiting the risk of a fire beginning, the components should limit the propagation of the fire, of the smoke and of gases toxicant maybe generated during a fire. |
| safety in use | Referring requirements to the users' need that the plumbing systems components don't cause lesions when they are being used (to burn, to cut, shocks, tumbles, etc.). |
| tightness | Referring requirements to the user's need that plumbing systems doesn't transmit humidity to the construction through leaks, bad operation, etc., and that promote tightness of the components to the reception of dusts and solid materials. |
| acoustic comfort | Referring requirements to the user's need that plumbing systems doesn't produce noises with unacceptable sound level to the atmosphere in that are inserted, to surrounding and to neighboring constructions. |
| visual comfort | Referring requirements to the user's need that the sanitary rooms and components are of pleasant aspect. They are requirements of high psychological factor. |
| tactile comfort | Referring requirements to the user's need that the surfaces that he will have direct contact they don't have excessive roughness, be not sharp, viscous, warm, humid or wet. |
| antropodynamic comfort | Referring requirements to the user's need that the plumbing systems physical characteristics (form, height, dimensions, etc.) are adapted to the objectives they are created for, not causing uncomfortable positions, excessive efforts, non-balanced efforts, etc. during the use. |

**Table 01: Plumbing systems performance requirements (continuation)**

| | |
|---|---|
| hygiene | Referring requirements to the user's need that water supply is convenient for his/her personal hygiene, that this water is collected and moved away in safe way to his/her health, that prevention exists against the physical and biological water contamination, that easiness of cleaning of his/her body exists, of the sanitary rooms and of the own plumbing system. |
| adequability of spaces for specific uses | Referring requirements to the users' need that the dimensions of the sanitary rooms are appropriate to the components inside them and to its use and that it must be sufficient sanitary rooms and components to use. |
| durability | Referring requirements to the user's need that plumbing systems maintains the foreseen performance during its useful life. |
| economy | Referring requirements to the user's need that the global cost of plumbing systems is compatible to the readiness of its financial resources. The global cost is understood as the sum of the initial, operation, maintenance and replacement costs. |
| environmental conservation | Referring requirements to the user's need that plumbing systems preserves the natural resources. |

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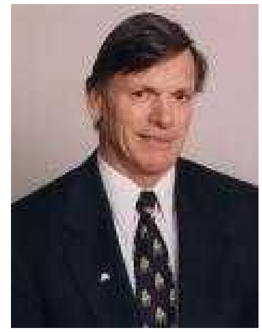
# A Case for Global Regulation : Perspectives for the Future from the World Plumbing Council



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## Abstract

When humanity was showing the first tentative signs of urbanisation, the advent of community water sanitation infrastructures brought untold benefits for human health. Now, with a world population beyond 6 billion and urbanisation continuing as a driving force, the World Plumbing Council believes it is time once again, for visionary action. Change is necessary in many aspects of humanity's resource use but none of these is more critical than water. With current practices, there simply is not enough fresh water to maintain human health and progress to any degree of justice or environmental sustainability. Rhetoric, however is just that. Only action begets action, so the World Plumbing Council has been asking what changes are necessary and how can these be achieved. Based on the unique experiences, expertise and situations of our member nations, we have concluded that an industry driven global approach to regulation must be an essential component of any long term perspective to the way human beings, use, manage and most importantly share, the all too finite resources of water on Earth.

## Introduction

As I speak here today, the mother of a poor family in Lima is paying a street vendor the equivalent of at least US$3 per cubic metre for water with which to drink, cook and wash. Water she will have to carry home herself, as tens of millions of other women world-wide will do today. Further down the road another mother, not poor at all, turns on the tap in her kitchen, only paying one twentieth of the amount per cubic metre for water on hand 24 hours a day. In the slums of Port-au-Prince, water costs will take around 20% of a family's income this week (Water Aid website, 2000). Meanwhile, in my home of Western Australia, water typically costs less than 1% of a far more generous household income and people use it accordingly, despite the fact that our city dams are less than a quarter full.

My name is Stuart Henry. It is my honour to be Vice Chairman of the World Plumbing Council and to represent them here today. We believe the plumbing industry has a central role to play in protecting the natural environment and human health by providing safe, fresh water and proper sanitation, as well as proper management care, reuse and conservation of resources.

Our vision is a united world plumbing industry safeguarding the environment and the health of nations for all. It is a big job but we are in good company. The World Water Commission Vision document and conference in The Hague earlier this year is a perfect example of the ground-breaking work on water that can and must be achieved. The World Plumbing Council's mission is to help the global plumbing industry of today and tomorrow make the greatest possible contribution to establishing a sustainable, equitable future of human water use.

Plumbing is an integral part of human history. Ever since the first sewers were built in Iraq in 5000 BC, the first sanitary systems were constructed in India around 2500 BC and much later when the Romans built their famous aqueducts, plumbing has had a remarkably enabling and ennobling effect on human endeavour and progress. The two major trends of the 20$^{th}$ century, population growth and urbanisation, coupled with increasing globalisation as we move into the 21$^{st}$ century, poses, some real challenges to our global communities in ensuring the integrity of plumbing systems. Whatever the technology, locality or culture involved - quality water supply and safe wastewater management are constant fundamentals of healthy human society and both the built and natural environments. Technology may change, and cultures may evolve but this fact of life will not. To live together in the world, humans need plumbing.

Currently the practice of plumbing regulation around the world is fragmented or non-existent. Many countries have systems of best practice plumbing regulation, others are working towards them and yet others are struggling to navigate their way through local challenges of economics, politics and disadvantage. In particular, there are many variations of approach to the issue of regulation. The differences have enormous implications for human rights, economic equality and international relations. At the World Plumbing Council, we believe a framework for a global regulatory system is an essential step towards minimising this variation and providing true water security. This paper will outline the arguments for such regulatory framework but I want to preface my comments by making it clear that I will not be arguing that regulation is a panacea or stand-alone solution. For such a complex challenge the only way forward is a wide-ranging, complementary set of strategies. What I <u>will</u> argue is that comprehensive plumbing regulation should be an integral part of any action we take. It must become an entrenched, dynamic and cooperative part of how we build and manage built environments in all parts of the world. This needs to happen in the context of real change in our approach to water, others and ourselves.

## The Plumbing Context

Water is a substance unlike any other and all life on Earth depends on its unique chemistry. As far as we know, liquid water is very rare in the cosmos, yet it is the most common of all the substances on our own planet, where there is enough to cover Earth in an unbroken sea more than 2.5 km deep. But this very perception of abundance has misled us sadly. Fresh water accounts for only 2.5 % of the world's total supply and most of this is frozen in glaciers and polar ice caps. Of the remaining 1.6-1.7%, one fifth is currently too remote for practical access and three fifths arrives and leaves in patterns we cannot harness such as monsoons and floods. Just eight hundredths of one percent of all the water on earth is suitable for human use (World Water Council, 2000). This means in six large pitchers of the Earth's water, only one single drop can ever be for us.

When the Romans were constructing their first aqueducts, human population was less than 3% of what it is today. Yet we have the same amount of water to drink, wash, cook and grow food. The global per capita water consumption has increased constantly with demand rising for industry, irrigation, recreation and to support ever-rising lifestyle aspirations of communities everywhere.

More than 31 of the world's countries currently grapple with a "chronic" water shortage. Another 17 nations are expected to be added to the list over the next 25 years (Black, 1994). Most of these will be developing nations whose resources are already deeply committed while in the developed world we have hardly set a good example. In a time where borders are changing and globalisation is remaking the world order, we plumbers are working with the most global resource and issue of them all - water.

## What do we mean by regulation?

So what is regulation, why do we need it and how can it be achieved? When I talk of regulation, I mean a well-established and clearly understood system which sets and maintains minimum standards of installer competence and product manufacture underpinned by law. Many people are wary and struggle to get past a preconceived idea that regulation is protectionist in its intent and its practice, as well as complex and unwieldy. I want to make it very clear that this is not the sort of regulation I am talking about. Not some sort of "closed shop" where an industry protects its own interests by restricting the number of licensees allowed, nor any sort of system that works against competition. Such approaches would be unacceptable in most, if not all of the developed nations and immoral in most of the developing ones. They would also actually work against the goals of regulation which I will outline shortly.

But many people may wonder, if the world plumbing community is not looking for protectionist regulation, then why are we looking for regulation at all? The primary goal is to protect public health and safety, and in so doing the environment. That is the bedrock upon which regulation stands and, in this regard, plumbing is no different to medicine. The competence of doctors and the manufacture and dispensing of drugs are regulated.

Like medicine, few in plumbing think regulation will make their life easier. It can be structured in such a way to minimise the burden but a burden it will remain. Despite this, most plumbers, like doctors still argue for regulation on the basis of its long-term benefits for the entire community. Naturally the plumbing industry would benefit from such a system, but this would be only indirectly and in the long term, as the community regard for plumbers gains strength and, eventually there is increasing demand among young people to enter the field. This can only be in the interest of all people, as ours is a profession making a significant contribution to the proper functioning of modern society.

The regulation I am advocating here today is self-regulation, open to all. It would be industry and consumer driven as opposed to control by the State but, to be effective, needs to be underpinned by law. As with comparable structures of statutory self-regulation to make it work requires the participation of all interest groups and stakeholders, including:

1. Consumers - who must be aware of the regulation, motivated to support it and be able to have input in general terms and specifically about service providers.

2. Plumbing Operatives - for whom regulation protects the integrity of their license to operate, and the reputation of their field in the community.

3. Regulators - who have the responsibility of ensuring the quality of work provided and products used – today and in the future.

4. Government – who, I would argue, need to support plumbing industry regulation as a public health and environmental issue –at both national and local levels. This involves providing direction and the simplest, strongest legislative structure possible.

5. Water Service Providers – the organisations responsible for the complex infrastructure of water supply and sanitation. Historically these were almost always publicly owned but the worldwide trends of globalisation and privatization mean that in many nations these utilities are now privately owned or at least corporatized, albeit within a government regulatory system.

To be effective, regulation would also need to reflect very clearly and strongly four key characteristics:

1. Clearly focused on each community's specific needs
2. Public Health
3. Environmental responsibility
4. Industry Management (Statutory Self-Regulation)

The goals of such a regulatory system would need to be unambiguous and wide ranging, such as:

Overarching Goals:

- To improve human health by facilitating long term security of high quality water supply and sanitation for all the people of the world.
- To protect the natural environment.

Key Objectives:

- To facilitate appropriate plumbing skills training in all global communities
- To encourage production of high-quality plumbing products
- To increase efficiency of water use
- To minimise the human impact on the hydrological cycle
- To facilitate community education, knowledge and therefore empowerment

The structure of a regulatory framework is perhaps the most potentially contentious issue. The World Plumbing Council, among other groups, believes that to achieve these goals, regulation must be structured in a three-tier framework: service providers, products and operatives. I agree with others from within the plumbing community, that each level of a regulatory system needs to be overseen by an independent, industry focused board.

It is all too often the case that governments are willing to exercise regulatory control at one level (typically the utilities) but not at one or both of the other levels. I would argue that ensuring quality of infrastructure is necessary but by itself only a half measure. Security in the quality of access and delivery are critical – which means regulating products and plumbers, too. Only an integrated framework which is strong in all three tiers can actually deliver the goals of protection for public health and the environment. In the current international atmosphere of increasing globalisation, we would argue that an inclusive, collaborative approach between nations, not just within them, is needed.

1. Regulation of Service Provision

The first tier is at the water service provider or utility level and regulation here aims to guarantee quality and reliability of infrastructure and basic supply. Virtually all governments recognise the need for this type of regulation in managing water resources. Work at this level needs to focus on developing consistency between nation states.

2. Regulation of Product Certification

The second tier focuses on guaranteeing the quality of the products used in plumbing systems. This typically relies on agreed standards (such as the ISO system) and/or codes against which products are tested. Assessment is carried out in laboratory and manufacturing settings and there is usually a badging system under which acceptable products are “licensed” to carry an endorsement mark.

Many countries, such as the United Kingdom, have well developed product certification systems, some have loosely structured or optional systems and some have no regulation at this level at all. Work needs to focus on establishing an internationally recognized system which gives equal priority to environmental responsibility and public health while promoting cost-efficiency, reliability and longevity.

3. Regulation of Plumbing Operation
As this is the least understood and least recognized level of plumbing regulation, I will discuss it in more depth. In my view, and that of many others, regulation of plumbing operatives would involve four key components:

- Licensing (assessed against competency standards, with levels built into the structure)
- Certificates of Compliance and self-certification
- Performance Audits (5% of certified work)
- Enforcement as required

As well as these, the roles of the industry board responsible for operative regulation must include regular review of standards and codes and supply of information to industry and the community, underpinned by industry focused training. This training is a critical strategy, I believe, in maintaining and sharing the benefits of emerging technology and knowledge. At an International Plumbing Conference in 1996, Mike Kefford, Commissioner, Plumbing Industry Commission, Victoria, Australia drew a distinction between a plumber claiming 20 years of experience yet really having one year of experience 20 times. This may not have been a problem a generation ago but a plumber operating this way today is not working effectively for him or herself, the customers or the community.

## Why Regulate?

The World Plumbing Council believes the main value of regulation lies in its power to facilitate change. Establishing an effective regulatory framework would not only facilitate this change now, but in the long term it would allow the global plumbing industry to be flexible in the way it serves the future needs of the environment and the human community.

Let’s consider some of the things that good statutory self-regulation would facilitate:

- Effective delegation of responsibility to industry, rather than the State, without compromising standards or creating further inequity.

- Greater access to cost-effective water supply and sanitation for the billions currently disadvantaged.

- Increasing consistency of water use between communities and nations.

- Community-level training for many plumbing roles to enable communities to be self-reliant. (The UK charity Water Aid has had many successes with this sort of program, as have we in Western Australia.)

- Sharing of technology and expertise between local and national communities.

- Frameworks for finding compromise and shared solutions between competing water claims.

- Greater use of water-efficiency technology. This is critical as efficiency initiatives already increase available supply at 25-50% of the cost of new infrastructure.

- Decision making which respects and reflects the shared nature of the human relationship with water, and the dynamic, far-reaching effect our water-related activities can have on the health of the environment.

- Continual improvement and upskilling in the plumbing industry, resulting in better community service. This offers particular benefit in disadvantaged communities which would otherwise not be reached by developments in technology or expertise.

- Community and public education towards sound understanding of water resource management issues.

- And ultimately … greater water security for coming generations.

## A Case in Point

I'd like to look at an example now and make a point about the currently emerging technologies of grey-water re-use and single residential unit sanitation systems. These have enormous potential to radically change the way we manage water in our communities. As these become better developed and accepted over the coming few years, they will offer great benefits through significant efficiencies over current technologies.

Much of the reason that billions of people still live without access to sanitation is that large scale sewerage systems are extraordinarily expensive to establish, particularly in existing built environments or remote locations. In cash-poor countries it has often been hard to muster the huge political will necessary to provide sewerage systems to the large numbers of largely disempowered people in rural or marginal urban areas. Grey-water re-use and single residential-unit sanitation systems are widely expected to supercede the current sewerage systems entirely within a matter of years. This means we could avoid this problem altogether as the alternatives are low cost, flexible and able to provided incrementally. They could also minimise the need for expensive external expertise and facilitate the spending of funds where they are most needed, rather than in large bureaucracies.

But neither grey-water re-use nor single residential unit sanitation technologies will be safe and effective if installed in an unregulated manner. Training, auditing, compliance and maintenance will not be difficult but they will all be essential if we are to avoid substituting a new problem for an old one.

This applies equally to the developed as to the developing world. We must be able to ensure that all systems, products and operatives are delivering the safety and environmental responsibility needed in order to benefit from these or other new technologies. Regulation is, quite simply, the only way to do this.

## Business as Usual

So now that we have covered some of the important gains which would be facilitated by well conceived and well managed global plumbing regulation, in contrast let's consider what we are risking if we continue without it. This is "business as usual" approach which the Water and Sanitation Supply Collaborative Council unequivocally describes as damaging, unjustifiable and unsustainable (Water and Sanitation Supply Collaborative Council, 2000). It will lead to:

- Construction of plumbing systems which are inefficient, unsafe and environmentally irresponsible. This will only perpetuate and reinforce the current problems.

- Chronic problems in human health. The list on this is staggering. It starts with diarrhoeal disease and moves through more than 50 water borne fatal or debilitating bacterial and parasitic infections such as river blindness. Beyond these is the spectre of pandemics. Poorly conceived water systems raise the risk of frighteningly rapid spread of emerging, high-mortality disease.

- Incalculable loss of human potential through the death of many and the need of many more to devote enormous amounts of time and energy to merely obtaining the water to survive. This will have the greatest effect on those already experiencing economic and social disadvantage, especially women (World Health Organisation, 2000)

- Continuation and likely increase of the current gross inequity in water use worldwide. The good news is that progress is possible and has been made. The Water and Sanitation Supply Collaborative Council (WSSCC) points out that in the last 20 years, over 2.4 billion people have gained access to water supply. But 1 billion more of the world's poorest people are still waiting for it. The picture is less rosy on sanitation - 600 million have gained access but 3 billion are still waiting (Water and Sanitation Supply Collaborative Council, 2000).

- Further degradation and contamination of the world hydrological cycle, much of it irreparable. Groundwater, wetland and catchment pollution are already major problems – nearly all the world's fresh water bodies are contaminated to some degree by agricultural runoff, sewage, industrial waste and the like. Many are literally disappearing.

- Increasing discord between groups of people at local, national and worryingly, at international level. Many of the world's most arid and drought-prone areas are also zones of political and cultural tensions. The governments in these areas have, to date, mostly managed to prevent water exacerbating the tension. Rising populations, however, brings rising risk of hostility over water use.

## Conclusion

Today, while we talk at this symposium, 10 000 human beings will lose their lives to diarrhoeal disease. Most of them will be children and each of their deaths is preventable. The time to be daunted by obstacles is well past. The longer we wait, the tougher the job will become. Currently 2.8 billion people deserve our immediate progress on what has already become a world crisis in water supply and sanitation – and threatens to become even worse.

For developed and developing nations alike – clear, practical action makes perfect economic, environmental, sociological, public health, political and social justice sense. This is why the World Plumbing Council is advocating the soonest possible global adoption of an enabling framework, laying the foundation for the plumbing standards and regulations of the future. Enforceable codes which are flexible enough to focus on local community needs and resources – not distant preconceptions.

Such measures have an essential role to play in the immediate improvement in life expectancy for millions of people in the developing world each year. They will contribute towards an increase in worldwide protection against pandemics of disease and towards protecting and improving the state of the natural environment for generations to come.

10 000 people a day are worth any and all efforts to revolutionize the way we, use, protect and most importantly share, the all too finite resources of water on Earth.

I thank you for your time, and look forward to our efforts.

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