SUMMARY OF MATHEMATICAL MODELS FOR THE DESIGN OF WATER DISTRIBUTION SYSTEMS WITHIN BUILDINGS

Summary

This paper presents a survey of mathematical models determining the design flowrate of water distribution systems design (hot and cold), developed by researchers specific of this segment.

The papers presented in the CIB-W62 Seminar of 1972 held in England about the theme "Water demand in Buildings" were taken into account as reference for the begining of this task. Afterwards, other models, directly linked to this matter (instantaneous flows) presented on the subsequent CIB-W62 Seminars were taken into account. An numerical example was developed based on these surveyed models.

Another survey, resulting of questionnaires, sent to CIB-W62 members of several countries indicated which models are being employed nowadays by the plumbing engineers of each respective country in the design of building services.

Finally the paper discusses the requirements of a design model focusing on the need for flexibility and openness thereby providing the engineer with needed freedom to design systems satisfying the wide varying characteristics of buildings.

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SUMMARY OF MATHEMATICAL MODELS FOR THE DESIGN OF WATER DISTRIBUTION SYSTEMS WITHIN BUILDINGS

1. INTRODUCTION

The evolution of the procedures of systems design concerning building services area must consider some main aspects :

. the quality to be obtained, considering:

- the intrinsic performance of a system / subsystem and its components;
- cost and time involved in the implementation of a system / subsystem;

. the adjustment of the procedures aiming at the integration among countries, proclaimed in several continents.

The above quoted aspects can not be analysed either dissociatedly and hermetically . The concept of systems quality lies on the user's satisfaction which is a crucial point (performance / cost / time) which can not be reached unless the different cultural, social and economic aspects related to civil construction strongly influenced by regional and policital characteristics can be fulfilled.

Lately, the effort towards integration of countries in organized and united comunites has been intensified. The EEC - European Economic Community, the "new created" NAFTA with countries of the North American Continent and the MERCOSUL - with countries of the South American Continent are active examples of this growing world tendency. Evidently, the harmonization of technical specifications and design procedures are very important because they can hasten the integration process and mobilize several work groups. In the case of CEN, specifically, some of the CIB-W62 members have participated intensively and some of the technical themes have been discussed in our seminars.

The central point of the harmonization process lies upon how specifications and procedures could be suggested when considering the quality concept, together with the ability of attaining the spectrum of diversities found in several countries, or even in several regions of the same country in order to constitute a unified community. It is observed that the harmonization of procedures /

specifications have been restrained, in some cases, to an addition of documents of different origins, giving source to either a wide range of varieties, or a list of conceptual and even universal performance requirements giving each country / region the choice to define its own specific criteria.

Concerning the adoption of a mathematical model in order to determine the design flow rate to dimension the water supply pipe system, its suitability must be taken into account.

The suitabilbity of a model as a design procedure is attached to the quality of the obtained results and consequently to the capacity of representing and considering the user's and the building characteristics where the distribution system is being inserted.

Thus, the designation of mathematical models to determine the design flow rate aiming at harmonizing this design procedure to a unified community shall warrant the fulfillment of the existing diversity. It can be acquired through the employement of each country's specific model or through open models where each country / region could adopt its own input parameters.

More important is the recognition of a correct model which can result to changing technology. The plumbing industry has been, and continue, to experience change brought on by a substantial effort to conserve water through reduced flow rates at fixtures and reduced volumes for fixtures such as water closets, clothes washers and dishwashers.

Twenty years ago, the first CIB-W62 Symposium was held in the United Kingdom with the theme "Water Demand in Buildings". Eight technical papers were presented evenly divided in presenting field data and mathematical models including simulation techniques. Since then, researchers around the world have continued efforts to resolve the complex pattern of water use in buildings of all types. At the 1991 meeting of the CIB-W62 Commission in Brussels, it was decided to undertake a survey of the countries actively engaged in this methodologies at the 1992 symposium in Washington D.C..

It is presented, as follows, a brief review of the mathematical models, developed to determine the design flow rate in water supply systems and some comments about the evolution of these models.

2. MODELS TO DETERMINE THE DESIGN FLOW RATES - CIB-W62

Papers presented at the first CIB-W62 seminar, held in England 1972, had its main theme "Water demand in buildings". The paper entitled "Demands for water in buildings - the background to current research" W. Carson classifies data concerning water demand into two different types : water consumption data and a water flow data. Each type is directly associated to definition of different parts of water supply system, according to table proposed by Carson in [1].

	Water consumption data	Water flow rate data
Cold Water and Total Water	Service mains	Distribution pipework
	storage tanks (high and low level)	
	Pumps for raising water to high levels	
	Water charges, running costs of pumps	
Hot Water	Storage Capacity of calorifiers	Distribution pipework
	Heating capacity of calorifiers and hence capacity of boiler plant and primary heat distribution system where present	Rating of instantaneous heaters and hence capacity of boiler plant and primary heat distribution system where present
	fuel costs	

Table - Facilities and cost factors relevant to data on water consumption and flow rate by W. Carson.

The purpose of this paper is related, mainly, to the models determining the design flow rates related to water flow data, according to Carson's classification. Therefore these models are meant to dimension hot and cold water distribution system's pipes and specify the instantaneous water heater capacity.

Roy B. Hunter (USA) [2] [3] study about this subject is classical. He developed a method to determine the design flow rates based on the binomial distribution of probabilities. The probability that **r** or more fixtures will be open simultaneously in a group of **n** fixtures ($n \geq r$) is given by:

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

where:

p is the probability of one fixture to be opened.

Hunter's model considers the **failure factor**, representing that the system can fail for one time unit of a fixed number of time units (τ). So:

$$P(x \geq r) < \frac{1}{\tau} = \varepsilon$$

Then, Hunter built curves, based either on the fixture probabilities (p_i) and on the definition of the failure factor ($\varepsilon = 0{,}01$), and related these curves to the number of fixtures in simultaneous use and resulting flow; later on he suggested a standardization of the fixtures by means of "fixture units" associated to each type. The "fixture units" of the fixtures connected downstream to the section are summed and the design flow rate was obtained in the curve suggested by Hunter that relates fixture units x design flow rate

Rydberg (1945) like Hunter, following paths foreseen by Jonsson, in Sweden, laid the theoretical basis for the analytical formula which came to be used in Scandinavia. In this formula the design flow rate is given by:

$$q = a + b + c$$

where **a** is the standard flow of a given fixture (the greatest), **b** is the mean flow of the others fixtures and **c** is the risk term which considers the random variation of the flow of the others fixtures, using binomial and Poisson probability distributions. The formula as used today for dimensioning supply pipes in Scandinavian countries is presented as follows:

$$q = \underbrace{q_1}_{a} + \underbrace{\theta (Q - q_1)}_{b} + \underbrace{A \sqrt{q_m \theta} \sqrt{Q - q_1}}_{c} \ (l/s)$$

where:

- q_1 - standard flow of the largest water fixture (l/s);
- q_m - mean value of the water flow from each fixture(l/s);
- θ - probability that q_m is used during a peak period;
- **Q** - sum of standard flow of the fixtures connected to the (l/s);
- **A** - parameter considering the failure factor.

These two methods, Hunter and Rydberg (Swedish) can be considered as being the first based on probabilistic support . Other methods,which had been developed till then and even now indicated in the standards of several countries employ procedures simplifying real situations and estimate design flow rates by summing flows or "units" of all the fixtures on the system and multiplying this by a simultaneous factor **f** ($f \leq 1$), or by using empirical formulas. In CIB-W62 Seminar - 1979 W. Carson [4] classified these methods as "Deterministic Models" in his paper "From averages to time series" . In the same paper Carson classifies the models into two other groups : Probabilistic Models and Simulation Models.

There will be presented models that can be grouped in the above classification as probabilistic or simulation and which are related to the determination of design flow rate. Consequently, studies in the CIB-W62 Seminars, from 1972 to this day were taken into account. These models will be presented by its proponents indication.

WEBSTER (UK)

Probabilistic methods employing the binomial probabilistic distribution are suitable for groups of homogenic fixture, that is groups of fixtures of the same type.

The model suggested by Webster, in 1972, is based on the use of the **generalized binomial** distribution function, which includes group of different types of fixtures.

Consider n_1 fixtures of the type **1** served by a section, n_2 of the type **2**, ... n_i of the type **i**. Consider, yet, that r_1 fixtures of the type **1**, r_2 of the type **2**, ..., r_i of the type **i** are simultaneously opened. The binomial probability distribution, regarding statistical independence, can be employed as follows:

$$P_{r1}^{n1} = \binom{n1}{r1} P_1^{r1} (1 - p_1)^{n1 - r1}$$

$$\vdots$$

$$P_{ri} = \binom{ni}{ri} P_i^{ri} (1 - p_i)^{ni - ri}$$

where:

$p_1 \ldots p_i$ - probability of one fixture of type **1**, ..., i to be open.

The probability that only r_1 fixtures of the type **1**, ..., ri of the type i are opened simultaneously, regarding the statistical independence is expressed by:

$$P_{r1,\ldots,ri} = \prod_{x=1}^{i} P_{rx}^{nx}$$

Knowing the unitary flow rates related to each type of fixture we have:

$$Q_{r1,\ldots,ri} = \sum_{x=1}^{i} r_x q_x$$

Thus, the probability distribution can be built, associated to the flow rates Q_{r1}, ... r_i, and to the probabilities $P_{r1,\ldots,ri}$, and can determine the design flow rate (Q_d) once the desirable failure factor (ε) is already determined, using the following expression:

$$P\,(Q_{r1,\ldots,ri} \geq Q_d) \leq \varepsilon$$

The practical application of this method is made through computer aid to calculate the possible pairs of $Q_{r1,\ldots,ri} / P_{r1,\ldots,ri}$

COURTNEY (UK)

Courtney [6] presented a paper in the CIB-W62 Seminar utilizing the Monte Carlo method. This method was employed to generate at random not only fixtures opened but also unitary flow rates aiming at the analysis of the performance of a specific building services installation which was also employed in Webster's studies.

Later Courtney [ ] suggested a probabilistic model to determine design flow rate, aiming at the utilization of different types of fixtures, in dwellings, employing the multinomial probability distribution function

Suppose that in a given rest room, supplied by a pipe, m different flows $Q_1, \ldots, Q_m$ ($Q_i \neq 0$) may occur with associated probabilities $p_0, p_1, \ldots, p_m$, during the peak period. Then, the probability that **n** rest rooms supplied by the pipe, x_0 be with null flow, x_1 with flow Q_1, ..., X_m with flow Q_m, can be calculated by the **multinomial** distribution:

$$P\,(x0, x1, \ldots, xm) = \frac{p_0^{x0}\ p_1^{x1}, \ldots, p_m^{xm}}{x_0!\ x_1!, \ldots, x_m!}$$

where:

$x_0 + x_1 + , \ldots, x_m = n$

$p_0 + p_1 + , \ldots, p_m = 1$

and

$$Q_{x0, ..., xm} = \sum_{i=x_0}^{x_m} x_i Q_i$$

Consequently, like in Webster's model, the probability distribution of $Q_{x0, ..., xm}$ can be built with associated probabilities $P(x_0, ..., x_m)$ and the design flow rate Q_d can be determined once the failure factor (ε) had already been determined

KIYA (JAPAN)

In 1974 Prof. Kiya presented [7] a simulation model. This model is carried on the Monte Carlo Simulation by computer for the mathematical model of using plumbing fixtures and considering the water usage.

There is obtained throughIn this method a fluctuation curve representative of the volume of water supply relative to time. Then the volume at the peak load can be analysed and results will provide necessary materials for designing facilities. The procedure of calculations comprises:

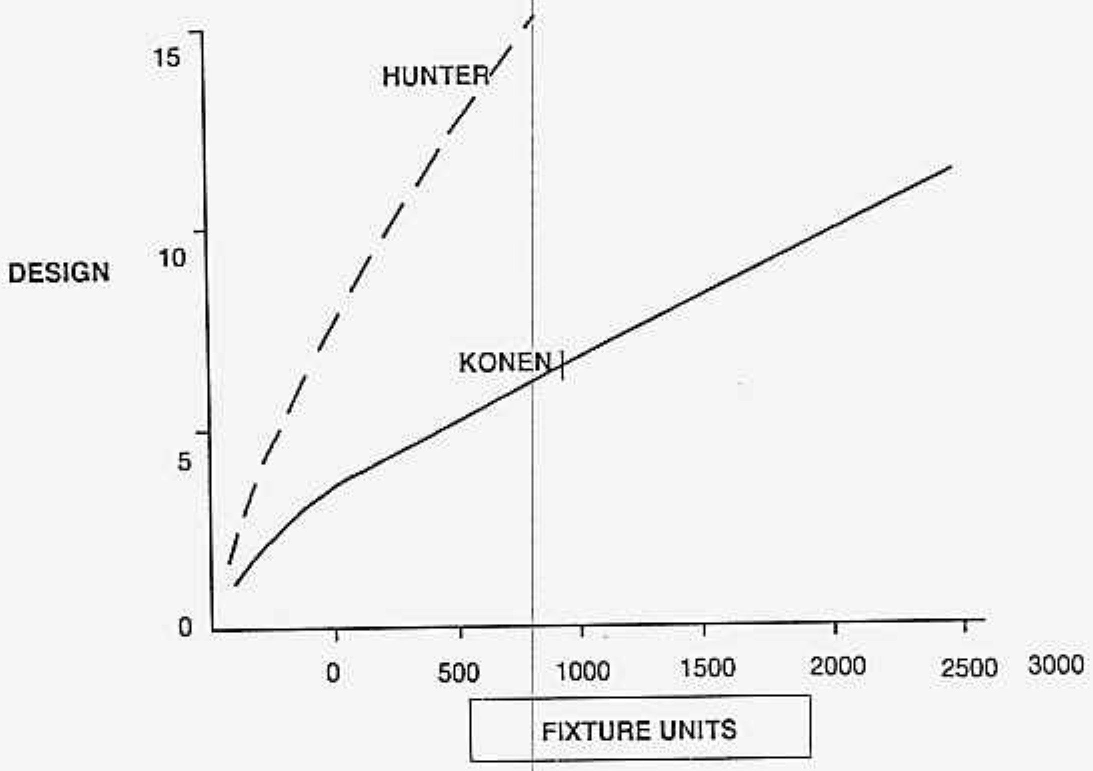
- to check the simultaneous use of fixtures after conducting repetitive simulations of the state by which fixtures are used;
- to calculate how many fixtures are properly needed;
- to check usage of fixture and water;
- to seek the characteristics of the volume of water delivered from the fixtures by means of experiments (flush valve and wash basin varying the pressure)
- to draw a flow curve in accordance with the experimental results and the state of water usage checked so far;
- to compute the momentary water volume after simulating the flow curve with the state of use of fixtures;
- to compute the total volume of water supply in the entire building by adding together the water volumes consumed by different kinds of fixtures.

The method presented by Prof. Kiya was initially developed for office buildings, but can be extended to other types of buildings.

KONEN (USA)

Using the same principles of the probabilistic formulation developed by Hunter, Konen [8] suggested in 1980 , new values for the unitary fixtures imputed to fixtures, in relation to the results collected from the field . He also proposed a new curve relating the design flow rate with the sum of the unitary fixtures attended by the considered section. Konen named this model "Modified Hunter".

The Figure below presents a graph of both curves: "Modified Hunter" and the one proposed by Konen.



In 1984 Konen [9] presented another proposition for the values of the parameters of the unitary fixtures which substitute the graph curve above by the following expressions below:

for a group of fixtures made of WC and flush tank:

$$10 < P < 10.000$$

$$Q_D = \frac{1}{15,85} \left(3,54 .10^{-10} P^3 - 1,166 .10^{-5} P^2 \; 0,1263 P + 10,9\right)$$

for a group of fixtures made of WC and flush valve:

$$5 < P < 1.000$$

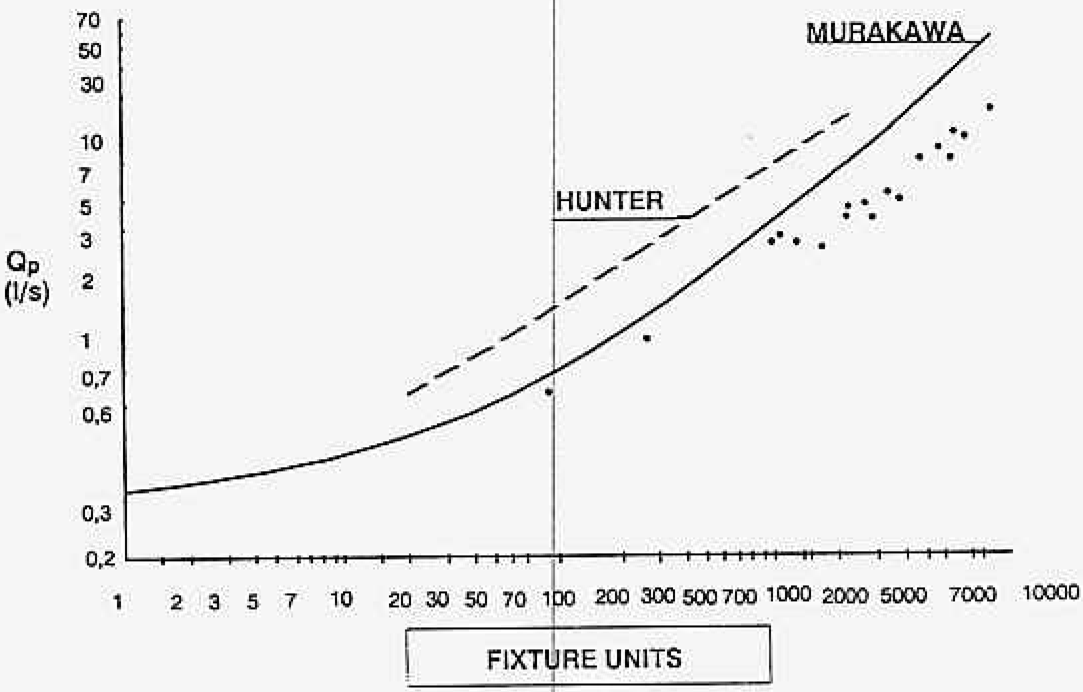
$$Q_D = \frac{1}{15,85} \left(15 + 11,50 \log P + 8,50 \log^2 P\right)$$

where

P - sum of units / unitary fixtures of fixtures.

MURAKAWA (JAPAN)

In 1985 Murakawa [10] presented a method to determine the design flow rates based on field data supported by the Poisson's probability distribution function which derives from the Queueing Theory and took into account a large number of fixtures.



Murakawa's method like that of Hunter and Konen , suggested fixture units in the case of dwellings in relation to several types of fixtures, as well as curve to get the design flow rate in relation to the sum of the fixtures units served by the section. The Figure above presents the curve proposed by Murakawa.

The suggested mathematical equation related to the Poisson's distribution is the following:

$$P_r^n = \frac{e^{-a\eta}\,(a\,\eta)^r}{r!}$$

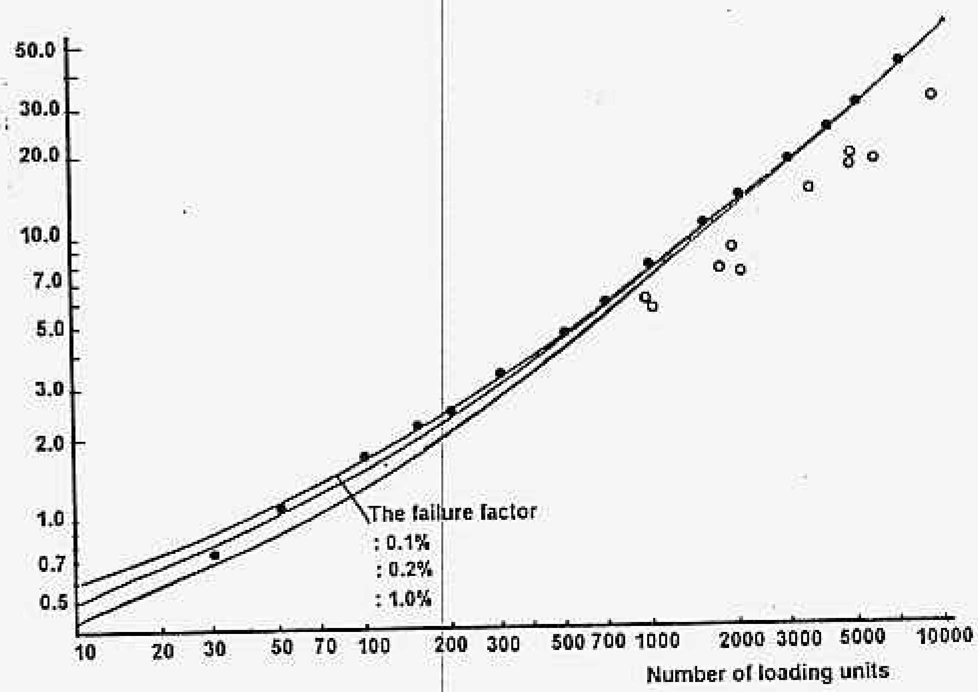
where:

- **a** - mean number of fixtures in service (utilization by users);
- η - ratio between mean time of discharge duration and occupancy time of the fixture while the fixture is in service.

The Poisson distribution and the binomial distribution can in certain situations be considered to be approximately equal. For large values of **n** and small values of **np** = **a**η the binomial distribution can be re-expressed to give Poisson's formula:

$$p_r^n = \binom{n}{r} \left(\frac{a\eta}{n}\right)^r \left(1 - \frac{a\eta}{n}\right)^{n-r} = \frac{e^{-a\eta}(a_\eta)^r}{r!}$$

In CIB-W62 Seminar - 1989 Murakawa et alli [11] presented a study showing water flow oscilations related to the definition of several time intervals and reached significative results. In the same paper he compared Murakawa's model (Poisson's distribution) to the simulation model, both applied in dwellings. Observing the curves shown in the graph below there can be noted a slight difference between the results of the two models.



GONÇALVES / GRAÇA (BRAZIL)

In 1987 [12] the authors presented a mathematical open model enabling the designer to define the input parameters of the model. Intervenient variables occuring in the water flows of the water supply systems are grouped as follows:

- intensity of utilization of the group of plumbing fixtures;
- unitary flow rate of each fixture.

The intensity of utilization depends on the following variables:

- discharge duration of a plumbing fixture denoted by **t**;
- time interval between start or end of consecutive discharges of a plumbing fixture denoted by **T**; **T** depends on the number of uses "per capita" during the peak period (**u**), on the population attended by the sanitary area (**p**), on the number of fixtures available to the population (**Na**) and on the considered peak period (**tp**);
- number of fixtures installed downstream form the considered section, denoted by **n.**

The unitary flow rate of a specific type of a fixture is denoted by **q**.

The authors took into account the random variables **t** and **T** [(μ_t, σ_t) and (μ_T, σ_T)] which was represented by probability density function of Erlang type or exponential. The random variable **q** (μ_q, σ_q) represented by probability density function of Gamma type. Thus, the μ and σ parameters of these variables can be obtained through 3 known point estimate or through field survey

So, the design flow rate can be expressed as follows:

$$Q = \sum_i r_i q_i$$

where:

r_i - number of appliances of type **i** in simultaneous use:

$r_i \overset{d}{=} B - B\,(a_i, b_i, n_i)$ - **Beta-Binomial distribution**

a,b depend on μ_p, σ_q ;where:

$q = t/T$ and these parameters depend on μ_t , σ_t μ_T and σ_T ;

q_i - unitary flow rate of the fixture type **i.**

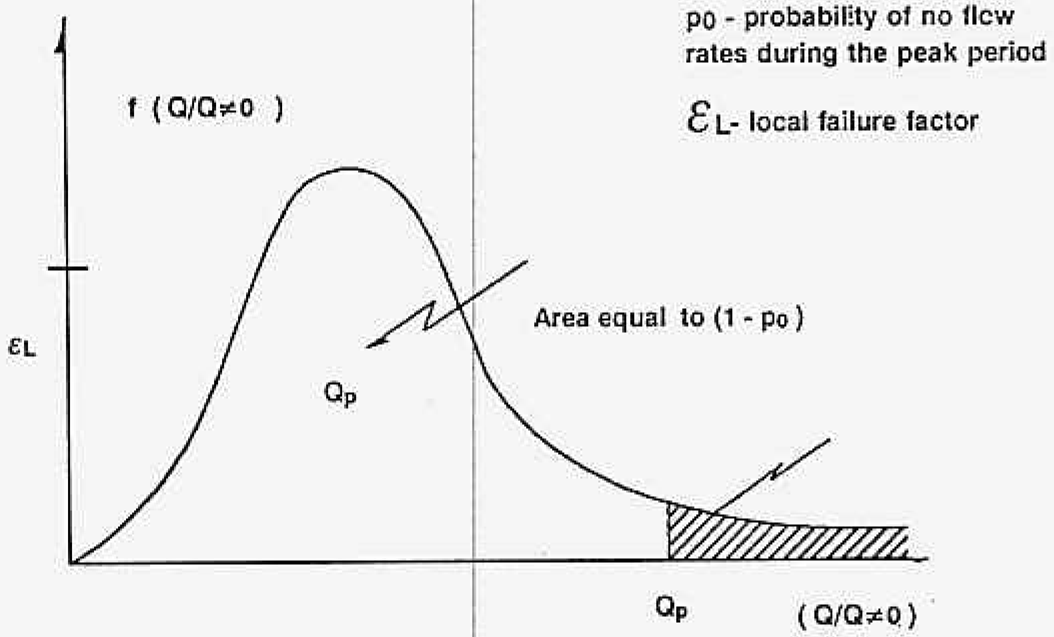
In this way μ_Q and σ_Q can be determined and by transformation, so can $\mu_{Q/Q\neq 0}$, and $\sigma_{Q/Q\neq 0}$, where the variable **Q/Q≠0** represents the non null flows.

The probability density function considered to the **Q/Q≠ 0** variable is of Gamma type:

$$f(Q/Q\neq 0) = \frac{\lambda_Q^{r_Q}}{\Gamma_{(r_Q)}} (Q/Q \neq 0)^{r_Q - 1} e^{Q(Q/Q\neq 0)}$$

when

$$\lambda_Q > 0 \text{ and } r_Q > 0;$$



Therefore, considering the failure factor (global and local) and the Johnston approximation, in order to obtain **z**, the design flow rate Q_p can be obtained by:

$$Q_P = {}_{Q/Q=0} + z\ {}_{Q/Q=0}$$

The authors developed a simulation software to evaluate the results of the proposed model applying routines from the IMSL - International, Mathematical & Statistical Library, of generation of random data.

In 1988 [13] a model which applied the Queueing Theory (M/M/C model) was presented. This model, through the performance criteria, enabled to determine the necessary number of plumbing fixtures and the random variable **T** in order to calculate the design flow rate.

HOLMBERG (SWEDEN)

Holmberg (1981) investigated the Scandinavian dimensioning formula, already presented in this paper. He proposed the following expression for the calculation of the q_m value:

$$q_m = \frac{G_1 q_{n1} \ldots\ldots + G_n q_{nn}}{\sum G}$$

where:

G_i - the coefficient for weighing the relative utilization time (probability) of the open fixture **i** and

q_{ni} - the mean flow from the fixture referred to G_i.

Holmberg also proposed that the first term q_1, inthe Scandinavian formula should be changed to $2q_m$. In the NKB (Nordic Committee on Building Regulations) publication n° 48E (1983)the change from q_1 to $2q_m$ was adopted, and the formula was transformed in:

$$q = 2q_m + \theta (Q - 2q_m) + A \sqrt{q_m \theta} \sqrt{Q - 2q_m}$$

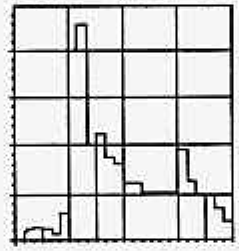
In 1987, Holmberg [14] presented a simulation model to obtain hot and cold water design flow rate, water volume and energy consumption in dwellings.

The model's philosophy is based on the concept of a computer which records measurements and supplies information to a process computer so that the latter can produce an image of the system. Stochastic observation of the state of the system are made during predetermined discrete intervals of time (1 second). For each interval, the status (on / off) are checked for each fixture in the system. In the case of an on-status, an event chain is formed, in which the next step is to determine the magnitude of the flow.

The model takes its values from two variables of state. One gives the probability of an outflow occurring (step 1) and the other gives the magnitude of the particular flow (step 2). See following figure:

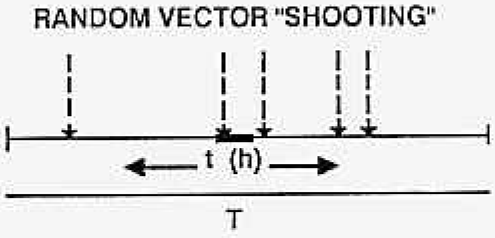
The frequency of the flows used, obtained by simulation, is stored in a long vector. Every possible flow has its position on the vector. Then it is possible to obtain the flow frequency distribution and, consequently, the design flow rate can be determined.

$p(h) = t(h) / T(h)$



$h = 1, 2, ..., 24$

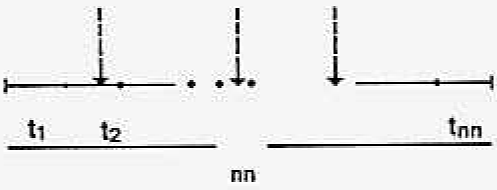
STEP 1



nn

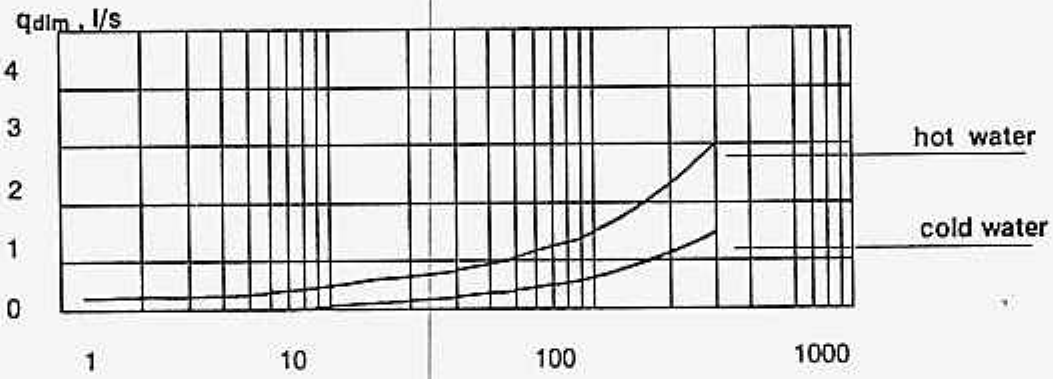
STEP 2

$q_i = 0{,}01,\ 0{,}02,\ ...,\ 0{,}nn$



$t_1 \rightarrow q_1,\ t_2 \rightarrow q_2, ..., t_n \rightarrow q_{nn}$

The author presents a graph of design flow rate x number of rest rooms when water temperature is 45^{o}C.



A numerical application of some of the presented models is shown.

3. NUMERICALAPPLICATION OF THE MODEL TO DETERMINE DESIGN FLOW RATE

A numerical application was developed in order to better visualize how the design flow rate values, obtained through different models, are presented when applied to similar design situations. The following types of uses were considered:

- low congestion use - dwelling building;
- medium congestion use - office building;
- high congestion use - intercity bus terminal.

The scheme and data for each different situation of utilization are presented in Appendix 1.

The mathematical models. presented in item 2 of this paper, which are employed in this numeric example are:

Webster;

Courtney;

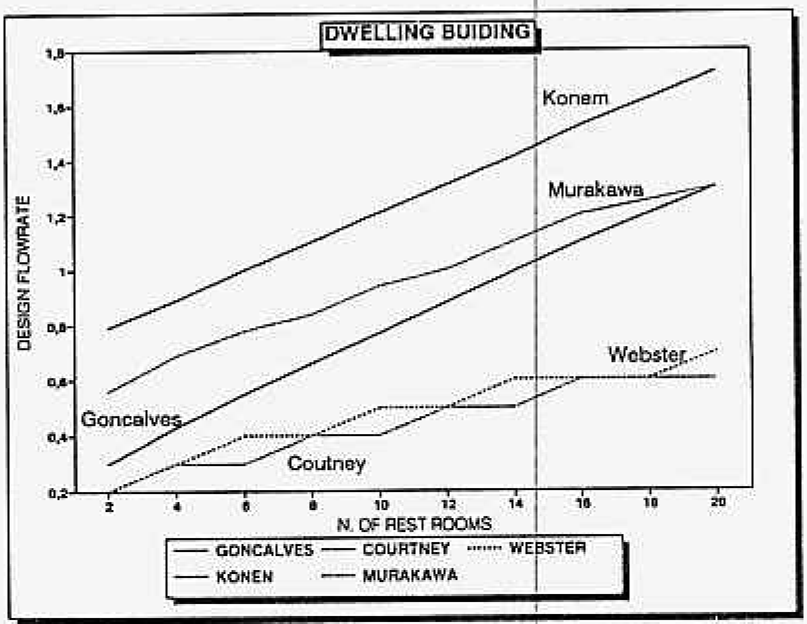
Konen;

Murakawa;

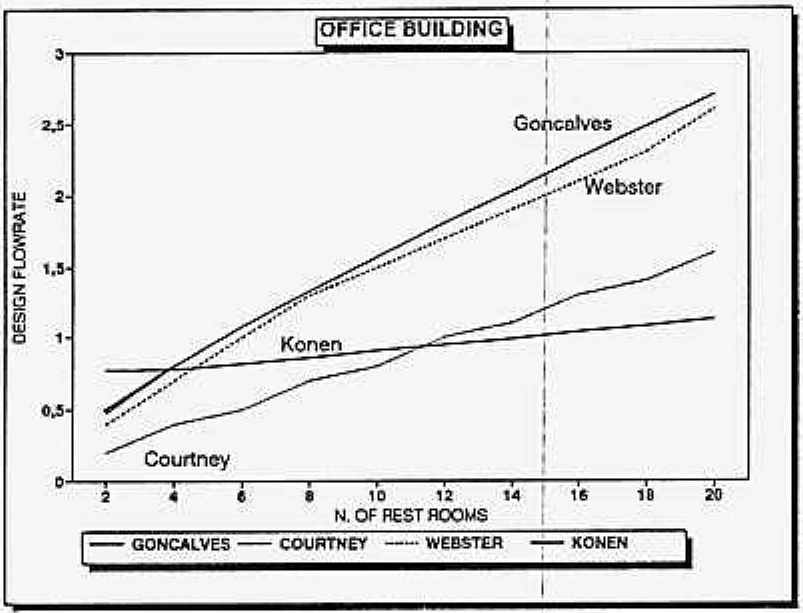
Gonçalves / Graça.

A specific software was developed by the engineers Marina S. O. Ilha and Alexandre Derani of Escola Politécnica da Universidade de São Paulo in order to employ these referred models to the suggested design situation. This software enabled the ellaboration of the following curves now presented:

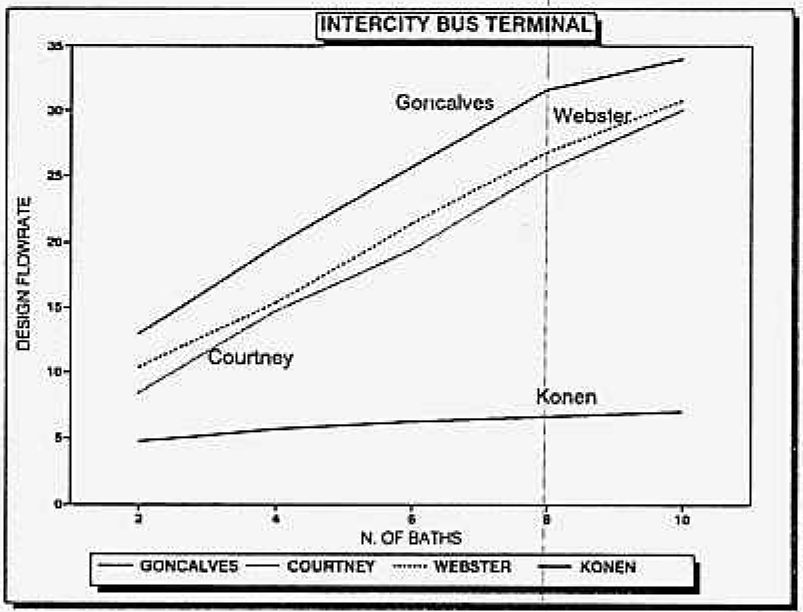
- **Dwelling building:**



- **Office building:**



- **Intercity bus terminal building**



The variation of the design flow rate values obtained through the different models is significant. In the case of dwellings the range of results varies vary between 0,7*l*/s and 1,7*l*/s for the section serving 20 rest rooms. In the case of office buildings the range of results varies between 1,13*l*/s and 2,70*l*/s, for the same number of rest rooms. Finally, in the case of the intercity bus terminal buildings the range of result varies between 6*l*/s and 26 *l*/s for the section serving 6 rest rooms.

4. SURVEY OF THE MOST COMMONLY USED MODELS TO DETERMINE DESIGN FLOW RATES

To determine the design flow rate in water distribution systems a survey of the models was carried out. This was made by means of questionnaires sent to some of the CIB-W62 members of several countries. The main purpose of this survey was to obtain a view of the models commonly used in some countries, and find out what extent the results of the models studied in chapter 3 had been incorporated in technical standardization and in normal system design procedures. The support given by the colleagues, sending back information, is registered here in special:

- V. Abrantes -	Universidade do Porto -	PORTUGAL
- A. Deb -	Central Building Research INstitute -	INDIA
- S. Holmberg -	National INstitute of Occupational Health -	SWEDEN
- F.S.Jorgensen -	SBI - Danish Building Research Institute -	DENMARK
- F. Kiya -	Tokyo Institute of TEchnology -	JAPAN
- J. Määttä -	VTT Technical Research Centre of Finland -	FINLAND
- S. Murakawa -	Hiroshima University -	JAPAN.
- E. Olsson -	The Swedish Building Standard Institution -	SWEDEN
- I. Silberstein -	The Standards Institution of Israel -	ISRAEL
- D. Trinkler -	Institute für Bautechnik -	GERMANY

The more usual methods obtained by both this survey and by bibiliographic investigation were grouped in the following way:

- methods based on Hunter's model;
- methods based on Rydberg's model;
- methods relating design flow rates to the sum of unitary flow rates (or fixture units) through expressions (or curves).

A large number of countries employ Hunter's probabilistic method. Some changes and some adequations in the input parameters (fixture units) were carried out as time went by but the method maintained its mathematical formulation to determine the design flow rate. Among the countries that employ this method it can be mentioned: USA, the U.K , Japan, India, etc.

The Scandinavian countries employ methods based on Rydberg's model (presented in chapter 2 of this paper). This group of methods includes some alterations in the initial mathematical formulation as a consequence of the results obtained in Holmberg's proposition (1981), according to publication n° 48E of NKB, of August 1983.

A variety of methods can be found in the third group. Some of them will be mentioned thereafter.

The method employed in Germany and indicated by DIN Standard 1988 (Teil 3) - "Codes of Practice for Drinking Water Installation: Determination of the diameters" considers the basic formula:

$$Q_p = a\,(\sum n_i\, q_i)^b + c$$

where:

- Q_p - design flow rate of a considered section, in *l*/s;
- $\sum n_i\, q_i$ - sum of unitary flow rates of all the plumbing fixtures;
- q_i - design flow rate of a fixture **i**, in *l*/s;
- n_i - number of fixtures of type **i**;
- **a, b, c** - coefficients depending on the type of considered building.

The following table presents the values of **a**, **b** and **c** coefficients according to the ranges of $\sum n_i\, q_i$, to the individual values of q_i and to the type of building; the values represent the lowest limit of the flow rates for $\sum n_i\, q_i$.

Type of Building	$d \le \sum n_i\, q_i \le 20$ l/s								$\sum n_i\, q_i > 20$ l/s		
	$q_i \ge 0{,}5$ l/s				$q_i < 0{,}5$ l/s						
	a	b	c	d	a	b	c	d	a	b	c
Residences	1,7	0,21	-0,70	1,0	0,682	0,45	-0,14	1,0	1,7	0,21	-0,70
Offices	1,7	0,21	-0,70	1,0	0,682	0,45	-0,14	1,0	0,4	0,54	0,48
Hotels	1,0	0,366	-	1,0	0,698	0,50	-0,12	0,1	1,08	0,50	-1,83
Shop. Centers	1,0	0,366	-	1,0	0,698	0,50	-0,12	0,1	4,3	0,27	-6,65
Hospitals	1,0	0,366	-	1,0	0,698	0,50	-0,12	0,1	0,25	0,65	1,25
Schools	4,4	0,27	-3,41	1,5	4,4	0,27	-3,41	1,5	-22,5	-0,5	11,5

The method employed in France and indicated in the Standard DTU-60.11 (October/88) , presented in the CIB-W62 Seminar of 1989 by Mr. Mambourg considers the following expression:

and

$$Q_p = x \sum n_i q_i$$

$$x = \frac{0{,}8}{(\sum n_i - 1)^{0{,}5}}$$

where:

x - flow factor to determine design flow rate;

The method employed in Portugal and indicated in the "Regulamento Geral de Distribuição de Água e de Drenagem de Águas Residuais" considers curves relating to the sum of the flow rates of the served fixtures ($\sum n_i q_i$) and the design flow rate (Q_p), mainly for residential buildings. The curves presented in this paper were represented by the following expressions:

. to $0 < \sum n_i q_i \leq 3$ l/s, without flush valves:

$$Q_p = 0{,}5548 \, (\sum n_i q_i)^{0{,}4958} \quad [R^2 = 0{,}9994]$$

. to 3 l/s $< \sum n_i q_i \leq 44$ l/s, without flush valves:

$$Q_p = 0{,}5244 \, (\sum n_i q_i)^{0{,}5462} \quad [R^2 = 0{,}9992]$$

. to 44 l/s $< \sum n_i q_i \leq 500$ l/s, without flush valves:

$$Q_p = 0{,}2023 \, (\sum n_i q_i)^{0{,}7982} \quad [R^2 = 0{,}9996]$$

The method employed in Brazil, and indicated in the Standard NBR-5626 - "Instalações Prediais de Água Fria" - ABNT, considers the following expression:

$$Q_p = 0{,}3 \sqrt{\sum n_i q_i}$$

where:

p_i - is the fixture unit associated to the fixture type i;

In this square root method the fixture unit of each fixture is determined by the relation between the unitary flow rate of the fixture and the reference flow rate. The reference flow is equal to 0,3l/s.

Appart from the methods grouped in the 3 different types the SHASE of Japan (Society of Heating, Air-Conditionig and Sanitary Engineers of Japan) presents a combined probabilistic method, described in the HASS206 - Plumbing Code document. This method uses the combinned probability for sanitary fixtures and water usage. The equations of combinned probability are provided by using some variables and parameters such as number of fixtures, utilization factor and duration factor of water usage. The equations are presented as follows:

$$Q_{max} = Y_{max}\,(F.U.)$$

and

$$Y_{max} = c\rho\eta + b\sqrt{c\rho\eta} + \Delta$$

where:

- Q_{max} - design load;
- Y_{max} - maximum number of simultaneous use of water;
- **F.U.** - fixture unit;
- **C** - number of fixtures;
- ρ - utilization factor;
- η - duration fator of water usage;
- **b**,Δ - parameters.

In this method, the value Q_{max} is calculated for each type of appliance, subsequently the maximum load in the group of different sanitary appliances and the half load of the others appliances in the group is summed up. According to Prof. Kiya, who described it briefly in the questionnaire, this method is rarely used in Japan. Dr. Murakawa presents the SHASE Code HASS-206 method in this 1992 Cib-W62 Seminar.

As can be observed in this chapter, the studied models of the last two decades, developed by the researchers, have not been fully incorporated as an usual design procedures of dimensioning water supply systems within buldings.

5. COMMENTS ABOUT THE REQUIREMENTS OF A MODEL FOR THE DESIGN FLOW RATES DETERMINATION

This final part of the paper presents for further discussion (Panel Discussion on Models) some considerations about the requirements of a design model focusing on the need for feasability and openness thereby providing the engineer with needed freedom to design systems satisfying the widely variyng characteristic of buildings.

Input parameters

The most direct relationship between the user and the water supply system within building occurs when he is performing activities related to the use of water and sanitary fixture systems.. Therefore the flow rates in the system depend basically on the following factors:

. Users activities:

- depend on the type of building: dwellings, schools, hospitals, offices;
- depend on the user's characteristics that are determined by physiological, regional, cultural, social and climatic factors.

. Building characteristics:

- population (quantity and distribution);
- spacial organization.

. Characteristics of the group of sanitary fixtures:

- depend on the type of the fixture;
- number of fixtures available.

Thus, the water flow rates in the system network result from the combination of the above factors.

Consequently, to calculate the design flow rates, the input parameters of a model must represent quantitatively the qualitative factors considered above.

Hence, the plumbing engineer would have to fix a set of input parameters representing the user's activities, the building characteristics and the group of fixtures for each specific design situation.

Fundamentally these parameters should enable the designer to evaluate the suitability of the numeric values of these parameters for the referred design situation.

As an example, the following input parameters which represent the above mentioned factors can be considered:

. temporal - peak period (T_p);

. set of parameters related to each type of fixture and established during the peak period;

$$s(i) \rightarrow [ti, Ti, ni, qi]$$

where

s(i) - set of input parameters that represent a fixture of the **i** type, during the peak period;

t_i - discharge duration of the fixture type **i**;

T_i - time interval between consecutive discharges of fixtures type **i**:

n_i - number of fixtures (type i) installed downstream from the considered section;

q_i - unitary flow rate of the fixture type **i**.

In the table below, the depending relationships between the factors affecting the flow rates and the intervenient variables (input parameters) are presented. The model must consider the randomability of the parameters **ti**, T_i and q_i.

FACTORS	VARIABLES	INPUT PARAMETERS			
		t	T	n	q
Users activities	Type of building	D	D	IN	D
	Users characteristic	D	D	IN	D
Building characteristics	Population	IN	D	IN	IN
	Spacial organization	IN	D	IN	IN
Characteristics of group of sanitary appliances	Appliance function	D	D	IN	D
	Number of appliances	IN	D	D	IN
		rv	rv	dv	rv

where:

D - depend;

IN - independ;

rv - random variable;

dv - deterministic variable.

Therefore each design situation will comprise a set of specific input parameters related to each type of fixture.

It must be stressed that there is a need for field data survey (numeric values) enabling the determination of input parameters to several types of use, mainly the values of t_i and q_i. Specifically in the case of the T_i parameter the model could consider other direct variables to be surveyed enabling the utilization of the Queueing Theory Models.

Thus, the harmonization of the results of the field survey, so far carried out, grant to the building services design professional important supporting data. There stand out in this chapter the studies developed in Japan and in the United States. New field survey could be carried out employing the same methodologic basis, aiming at repetitivity of results to similar design situations.

System Performance - Failure Factors

The randomability of the intervenient variables (input parameters) in the determination of design flow rates is a factor of fundamental importance to be considered in the model.

In order that the design flow rates be defined, the performance factors suitable to the design system determined by the plumbing engineer must be taken into consideration. In the majority of the studied models the performance factors are defined as failure factors, related to the various sections of the network, as follows:

$$P(q_i \geq Q_D^i) \leq \varepsilon$$

where:

Q_D^i - design flow rate of the section i;

Q_i - flow of the section i;

ε - failure factor of the section i;

The question raised is: Which failure factors must be taken into consideration ?

This matter was discussed in the 1972 CIB-W62 Seminar. As W. Carson mentioned "The users of the water are not, however, interested in the probability of failure of sections of the distribution system; they are intersted only, in the probability of an outlet failing to deliver water at the requisite rate". The determination of the failure factors ε, considering the failure factors of the system as a whole is difficult to model once the flow rates of the several sections depend on the network.

A solution for this problem may be to verify if the minimal admissible pressure is met in the various fixtures of the system considering the values of the failure factors in the section of the network.

Suitability

A model to determine the design flow rates in water supply systems within buildings, when aiming at its suitability, must consider the following:

- the quality of the results obtained through its application, comparing them with studies / simulations carried out; in this sense, it is important to establish suitable accurate degrees of the model considering both, the indefinition of some design conditions and the fact that the flow rates vary in a continuous manner while the diameters of the pipes vary discretly.
- the practicity of the model, observing time and cost spent to obtain the results; some models can cause excessive time of processing and consequently high costs, even when modern computing facilities, available to small design companies, are employed.

These comments about the requirements of models to determine design flow rates in water supply systems within buildings, try to give support to the discussions about the theme.

It is important to consider that an appropriate model must have a general character in relation to the intervenient variables but must also have a specific character in relation to the particular features of each design situation.

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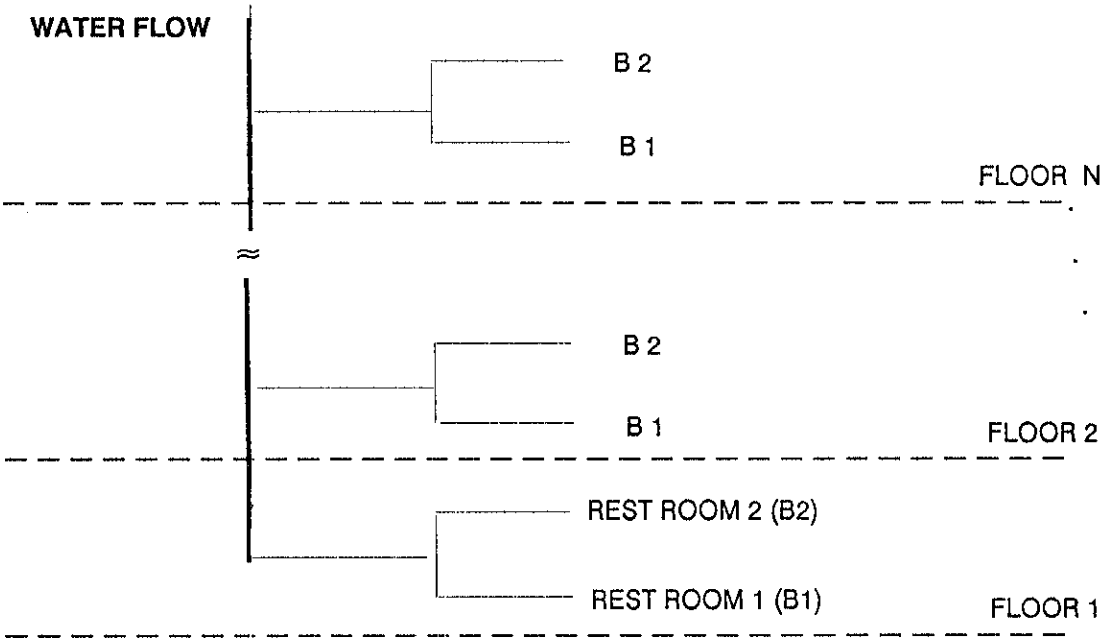
APPENDIX 1

Numerical applications
Scheme and data

BUILDING TYPE 1 - DWELLING BUILDINGS

1 Scheme:



2. Data

- **Each apartment -** 3 Rest rooms;
  2 Rest rooms (B1 and B2)
- **Each rest room-** 1 shower;
  1 wash basin;
  1 WC with flush tank.
- **Duration of the peak period - Tp** = 1 hour.
- **Fixture data:**

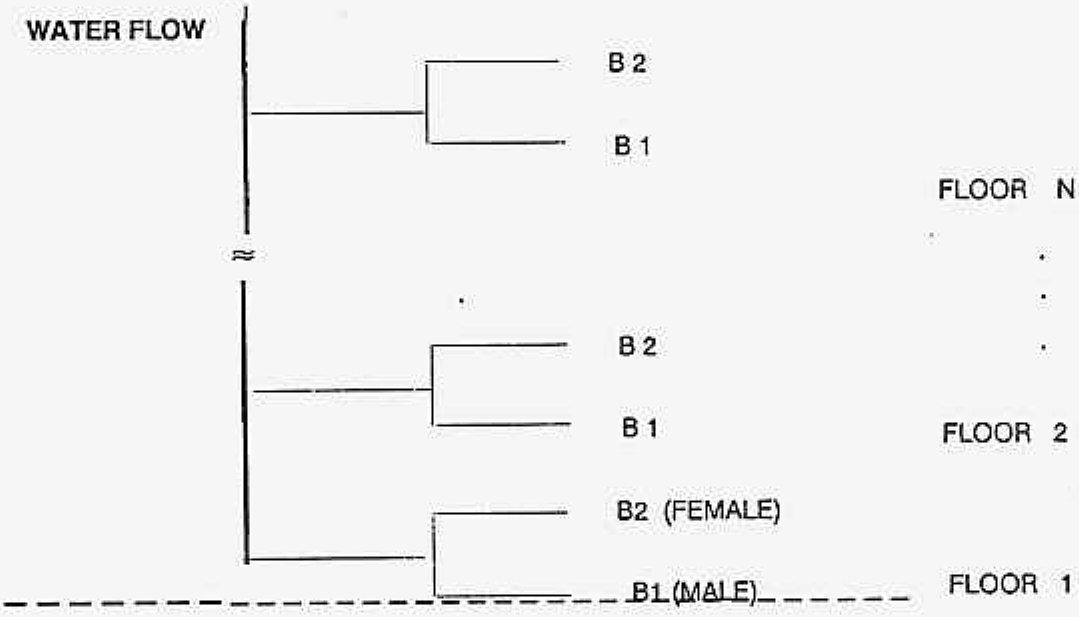
- Shower - SH
  Wash basin - WB
  Water closet - WC

Water flowrate (*l*/s) - q
Discharge duration (s) - t
Number of uses per person - u
Medium value - μ
Standard deviation value- σ

		SH		WB		WC	
	unit	μ	σ	μ	σ	μ	σ
q	l/s	0.106	0.02	0.092	0.06	0.15	0.01
t	s	465	260	32	25	87	0
u	-	0.75	0.29	0.83	0.50	1	0,36

BUILDING TYPE 2 - OFFICE BUILDINGS

1 Scheme:



2. Data

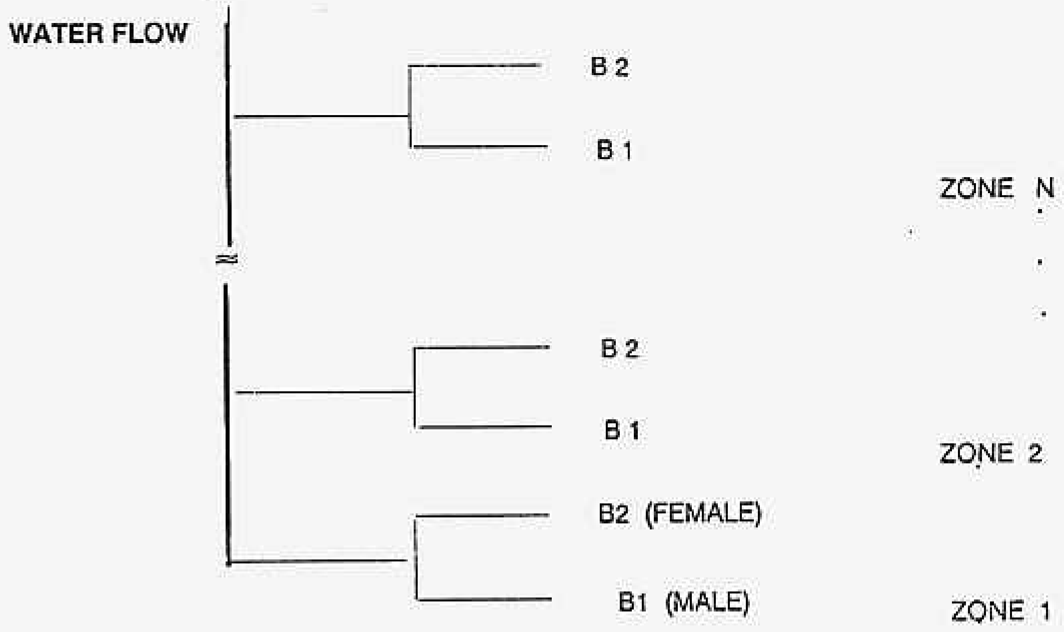
- **Number of people using the rest room** - female = 20, (10); - male = 40, (20).
- **Each rest room**
  - female: - 1 wash basin; - 1 WC with flush tank.
  - male: - 1 wash basin; - 1 WC with flush tank.
- **Duration of the peak period - Tp** = 2 hours.
- **Fixture data:**

Shower -	SH	Water flowrate (l/s) -	q
Wash basin -	WB	Discharge duration (s) -	t
Water closet -	WC	Number of uses per person -	u
		Medium value -	μ
		Standard deviation value -	σ

		MALE (40 people)				FEMALE (20 people)			
		WB		WC		WB		WC	
	unit	μ	σ	μ	σ	μ	s	μ	σ
q	l/s	0,092	0,06	0,15	0,01	0,092	0,06	0.15	0.01
t	s	32	5	87	0	32	5	87	0
u	-	1	0.36	1	0.36	1,5	0,4	1,5	0,4

BUILDING TYPE 3 INTERCITY BUS TERMINAL BUILDING

1 Scheme:



2. Data

- **Male rest room -** 10 WC with flush valve;
  10 wash basin.
  number of people (peak period) = 300
- **Female rest room-** 10 WC with flush valve;
  1 wash basin;
  number of people (peak period) = 400.
- **Duration of the peak period - Tp** = 1 hour.
- Fixture data:

Wash basin - WB
Water closet- WC

Water flowrate (l/s)- q
Discharge duration (s)- t
Number of uses per person- u
Medium value- μ
Standard deviation value - σ

		MALE				FEMALE			
		WB		WC		WB		WC	
	unit	μ	σ	μ	σ	μ	σ	μ	σ
q	l/s	0.092	0.06	1.96	0.10	0.092	0,06	1,96	0.10
t	s	32	5	8	1	40	10	8	1
u	-	1	0.2	1	0.2	1	0,2	1	0,2