



CIB-W62 SYMPOSIUM

Study on the Method for Calculating Water Consumption and Water Uses in Multi-Story Flats

Saburo Murakawa

April 9, ~10, 1985

TOKYO, JAPAN





Dr. Saburo Murakawa

Associate Prof., the Faculty of Eng. Hiroshima Univ.

Saijo-cho Higashihiroshima-shi, Japan

Study on the Method for Calculating Water Consumption
and Water Uses in Multi-Story Flats

Summary

Hunter's method utilizing fixture units has been used as the current design procedure to calculate the size of piping. Nevertheless, we cause several problems such as overload for design of piping in using this method.

Therefore, this paper described the water uses in multi-story flats and suggested a method based on the probability theory for calculating water consumption.

We can estimate the water load with the probability distribution of simultaneous uses of water. The probability distribution is derived theoretically by the queuing theory. At the model given with M/M/S types, Kendall symbol, the probability of simultaneous uses of water is shown as the Erlang formula. Approaching S, the number of fixtures, to infinite, the probability distribution shows the Poisson distribution.

Analysing the water uses of the two multi-story flats, the probability distributions were shown approximately in the Poisson distribution. Therefore, the flow rates in the system equipped with the same and the different types of outlets could be calculated with these probabilities given in the Poisson distribution. These results were shown at small values in comparison with the Hunter's values.

In addition, the relation between loading units and loading curve was shown as a simplified method for the flow rate design of multi-story flats.

Résumé

la méthode de Hunter utilisant des appareils fixes a été utilisée en tant que procédure de conception courante pour calculer la dimension des canalisations. Néanmoins, nous occasionnons plusieurs problèmes tels le surdimensionnement des canalisations en utilisant cette méthode.

Ce document décrit donc l'utilisation de l'eau dans les appartements de bâtiments à plusieurs étages et suggère une méthode basée sur la théorie des probabilités pour calculer la demande en eau.

Nous pouvons estimer la quantité d'eau à l'aide de la densité de probabilité de l'utilisation simultanée d'eau. La densité de probabilité est dérivée de la théorie des files d'attente. Pour le modèle donné par les type M/M/S, selon Kendall, la probabilité d'utilisation simultanée d'eau est donnée par la formule de Erlang. En faisant tendre S, le nombre d'appareils fixes, vers l'infini, la densité de probabilité tend vers une distribution de Poisson.

En analysant l'utilisation d'eau dans les appartements d'un bâtiment de deux étages, les densités de probabilité sont approximativement des distributions de Poisson. Aussi, les taux de débit dans les systèmes équipés d'appareils fixes de même type ou de types différents peut être calculés à l'aide des probabilités données par la distribution de Poisson. Les résultats se sont révélés être des valeurs plus faibles que celles données par la méthode de Hunter.

De plus, la relation entre les appareils de charge et la courbe de charge se révèle être une méthode simplifiée pour le dimensionnement des taux de débit pour les appartements de bâtiments à plusieurs étages.

Zusammenfassung

Als momentane konstruktionsmethode für die Größenordnung der Rohrverlegung wurde das Hunter-Verfahren gewählt, welches auf Installationseinheiten basiert. Trotzdem ergaben sich eine Reihe von Problempunkten, wie zum Beispiel zu der bei dieser Methode zutreffenden Konstruktionsweise zur Rohrverlegung.

Dementsprechend wird in dieser Studie die Wassernutzung in mehrstöckigen Mietshäusern beschrieben, und eine auf Wahrscheinlichkeitsrechnung basierende Methode zur Berechnung des Wasserbedarfs vorgeschlagen.

Die Wasserlast kann mit der Wahrscheinlichkeitsverteilung des gleichzeitigen Wasserverbrauchs berechnet werden. Die Wahrscheinlichkeitsverteilung wird theoretisch von der Warteschlangentheorie abgeleitet. Bei dem mit M/M/S-Typen, Kendall-Symbol gegebenen Modell wird die Wahrscheinlichkeit für gleichzeitigen Wasserverbrauch als Erlang-Formel gezeigt. Mit S, der Nummer an Installationen, gegen Unendlich, zeigt die Wahrscheinlichkeitsverteilung die Poissant-Verteilung.

Bei der Analyse des Wasserverbrauchs für die beiden mehrstöckigen Mietshäuser werden die Wahrscheinlichkeitsverteilungen annähernd in der Poissant-Verteilung gezeigt. Deshalb lassen sich die Fließmengen bei Systemen mit identischen Installationen und bei Systemen mit verschiedenen Installationen mit den in der Poissant-Verteilung gegebenen Wahrscheinlichkeiten errechnen. Diese Ergebnisse zeigen sich im Vergleich mit Hunter-Werten als kleine Werte.

Zusätzlich wurde die Beziehung zwischen Lasteinheit und Lastkurve als vereinfachtes Verfahren für die Fließmengenkonzept eines mehrstöckigen Mietshauses dargelegt.

1. INTRODUCTION

The method by Roy B. Hunter(1) for calculating water consumption has been used for the calculation of pipe sizes. However, it is pointed out that we cause several problems such as over loading for design of piping, using this method. In European countries and U.S.A, the factors of the method by Hunter and new methods are studying(2 - 4). In Japan, there have been some studies in the some cases(5 - 10). Recently, the society of heating, air-conditioning and sanitary engineers of Japan proposed the new method for calculating water consumption in HASS 206-1976(11). However, the new method has some problems and the further studies are necessary for working out those problems.

Therefore, this paper suggests a method based on the probability theory for calculating water consumption and shows the results of calculating water consumption in multi-story flats based on the data. Moreover, the relation between loading units and maximum flow rates in flats is shown as a simple method for calculating water consumption, following the Hunter's Method.

2. THE METHOD FOR CALCULATING WATER CONSUMPTION

2.1 The probability of simultaneous uses

and the procedure for calculating water consumption

We can calculate the water consumption with the probability distribution of simultaneous uses of water derived by analysing the uses of outlets. The procedure for calculating water consumption is as follows;

- 1) Decide the scale of a planning building (the number of occupants, the number of flats and so on)
- 2) Decide the frequency of use and the distribution of the using time in each fixture and water.
- 3) Decide the probability distribution of simultaneous uses of water.
- 4) Calculate the loading of systems consisted of same types or different types of outlets by the probability theory.

The probability distribution is introduced theoretically by the queuing theory(12). If the servers (fixtures) s are arranged in a row line, the probability of the customer's arrival frequency is the Poisson distribution (random arrival) and the service time is the exponential distribution, the probability of the number of customers in the systems can be obtained by solving the equations of a state transition. The probabilities p_n being customers n in the systems are represented by equation (1).

$$\left. \begin{aligned} p_n &= \frac{a^n}{n!} p_0 \quad (0 \leq n \leq s) \\ p_n &= \frac{a^n}{s! s^{n-s}} p_0 \quad (s \leq n) \end{aligned} \right\} \dots\dots(1)$$

where:

$$p_0 = \left[\sum_{n=0}^{s-1} \frac{a^n}{n!} + \frac{a^s}{(s-1)!(s-a)} \right]^{-1} \quad \dots\dots(2)$$

and:

$a = \lambda_f / \mu_f$ (the average number of simultaneous uses of fixtures)

$\rho = a/s$ (utilization factor, $\rho < 1$)

λ_f : average arrival rate ($1/\lambda_f$: average interarrival time)

μ_f : average service rate ($1/\mu_f$: average using time)

Approaching the number of fixtures to infinite, the probability is approximated to the Poisson distribution as follow;

$$p_n = e^{-a} \frac{a^n}{n!} \quad (n \geq 0, a > 0) \quad \dots\dots(3)$$

When all fixtures are occupied, the case which makes users return is called as the loss system. In this case there is the Erlang formula as follow;

$$p_n = \frac{a^n}{n!} / \sum_{n=0}^s \frac{a^n}{n!} \quad (0 \leq n \leq s) \quad \dots\dots(4)$$

When $n=s$, p_s is called the probability of loss, the Erlang formula is established in any distribution of using time.

Therefore, if there are many fixtures used at random, the probability distribution of simultaneous uses of fixtures is approximated to the Poisson distribution shown in equation (3). Furthermore, the probability of outlets r being on from a total of such occupied fixtures n is shown in the binominal distribution $b(r; n, \eta)$. Hence, the probability distribution of simultaneous uses of water P_r is the compound distribution in equation (5) and can be expressed the Poisson distribution which includes the parameter $a\eta$.

$$\begin{aligned} P_r &= \sum_{n=r}^{\infty} p_n b(r; n, \eta) = e^{-a} \eta^r \sum_{n=r}^{\infty} \frac{a^n}{n!} \binom{n}{r} (1-\eta)^{n-r} \\ &= e^{-a\eta} \frac{(a\eta)^r}{r!} \quad \dots\dots(5) \end{aligned}$$

where: η = the mean time of water use / the mean time of fixture use

$a\eta$ = the average number of simultaneous uses of water

Equation (5) is derived from the procedure of customers using water after the arrival at a fixture. However, we can be derived the probability distribution in connection with the occurrence of water use, therefore this thought is applied in this paper.

2.2 A method for calculating water consumption

If the probability distribution of simultaneous uses of water is given, the

maximum loading of system, involving same types of outlets, is calculated by an assumed failure rate. At the group A involved same types of outlets, the probability is formularized in equation(6) in the condition that the random variable X takes the number of simultaneous uses x_{ai} .

$$P_A(X=x_{ai}) = p_A(i) \quad \dots\dots(6)$$

where: $x_{ai}=0,1,2,\dots$ (x_{ai} : discrete variable)

$p_A(i)$: probability function

Therefore, the maximum loading of systems, involving same types of outlets, is derived from the value m_a which satisfies equation (7) with failure rate K_p .

$$\sum_{x_{ai}=m_a+1}^{\infty} P_A(X=x_{ai}) \leq K_p \quad \dots\dots(7)$$

The Maximum flow rate $Q_{A \max}$ in group A is calculated by equation (8) included the average flow rate of outlet q_a in simultaneous uses.

$$Q_{A \max} = m_a q_a \quad \dots\dots(8)$$

In the other systems involved different types of outlets, the flow rate is derived in term of probabilities with the combinations of outlets, using the probability distribution of simultaneous uses in each group.

In above mentioned case, if we express the groups of outlets by A, B, C, ... and the maximum numbers of simultaneous uses by m_a, m_b, m_c, \dots , the probability distribution of simultaneous uses of systems involved different types of outlets $P_r(I)$ is derived by equation (9) with each outlet used independently.

$$P_r(I) = \{P_A(X=x_{ai})\} \{P_B(X=x_{bj})\} \{P_C(X=x_{ck})\} \dots \quad \dots\dots(9)$$

$x_{ai}, x_{bj}, x_{ck}, \dots$ are the numbers of simultaneous uses in group A, B, C, ... and the numbers are discrete independent variables. Therefore, considering the maximum number of simultaneous uses of same types of outlets, the number of the combination derived by $P_r(I)$ is shown by equation (10).

$$M_r = (m_a+1)(m_b+1)(m_c+1)\dots \quad \dots\dots(10)$$

The flow rate is calculated by equation (11) in the probability of equation (9).

$$Q_r(I) = x_{ai}q_a + x_{bj}q_b + x_{ck}q_c + \dots \quad \dots\dots(11)$$

where: q_a, q_b, q_c, \dots are the average flow rate of each outlet in the same manner as the same types above described.

Therefore, the procedure for calculating the maximum flow rate in the system involved different types is as follows;

1) The flow rates calculated by equation (11) are selected stepwise from the minimum value upward.

2) $Q_r(I)$ is used for the selected values.

where: $I = 1, 2, 3, \dots$ and $Q_r(1) = 0$

3) The probability value corresponded to each flow rate is calculated by equation (9), and the values are accumulated.

4) The minimum value n_r is calculated by the accumulated value satisfied equation (12) with critical rate K_r .

5) The flow rate at the minimum value n_r is chosen as the maximum flow rate.

$$1 - \sum_{I=1}^{n_r} P_r(I) \leq K_r \quad (1 \leq n_r \leq M_r) \quad \dots\dots (12)$$

In the above mentioned procedure, there is distinction between failure rate K_r and critical rate K_r for deriving the maximum number of simultaneous uses of system involved same types of outlets and the maximum flow rate of system involved different types of outlets. It is suitable for the both rates to take the range from 0.001 to 0.01 in planning.

The above description was developed by the probability theory. If the average values of the simultaneous uses of water are known in some buildings, the water consumption can be calculated with the approximation to the Poisson distribution.

If there are the frequency distribution of water use, the distribution of water using time and the flow rate distribution of outlets, the flow rate which changes every moment can be calculated by the Simulation method.

3. ANALYSIS OF BASIC DATA FOR CALCULATING WATER CONSUMPTION

3.1 Research of water use in multi-story flats

For collecting of basic data for calculating water consumption, the research for water use was conducted in two multi-story flats, TK and TO.^{Fig. 1} Where, the names are abbreviated. The building scale of TK was one tenement, 4-story house, divided into 24 flats. That of TO was two tenements, 5-story house, divided into 60 flats. Each flat had two rooms and one kitchen-dining in both cases.

The contents of the research were according to the water uses and the amounts of water. The research systems of water and fixture uses are shown in Fig 1. The water using time in each outlet was recorded automatically in the recording room, using the sensor of water use attached to the end of each outlet. The water supply systems for the wash clothes and the WC at TO were recorded by the flow switches installed in pipes. There were five cold water

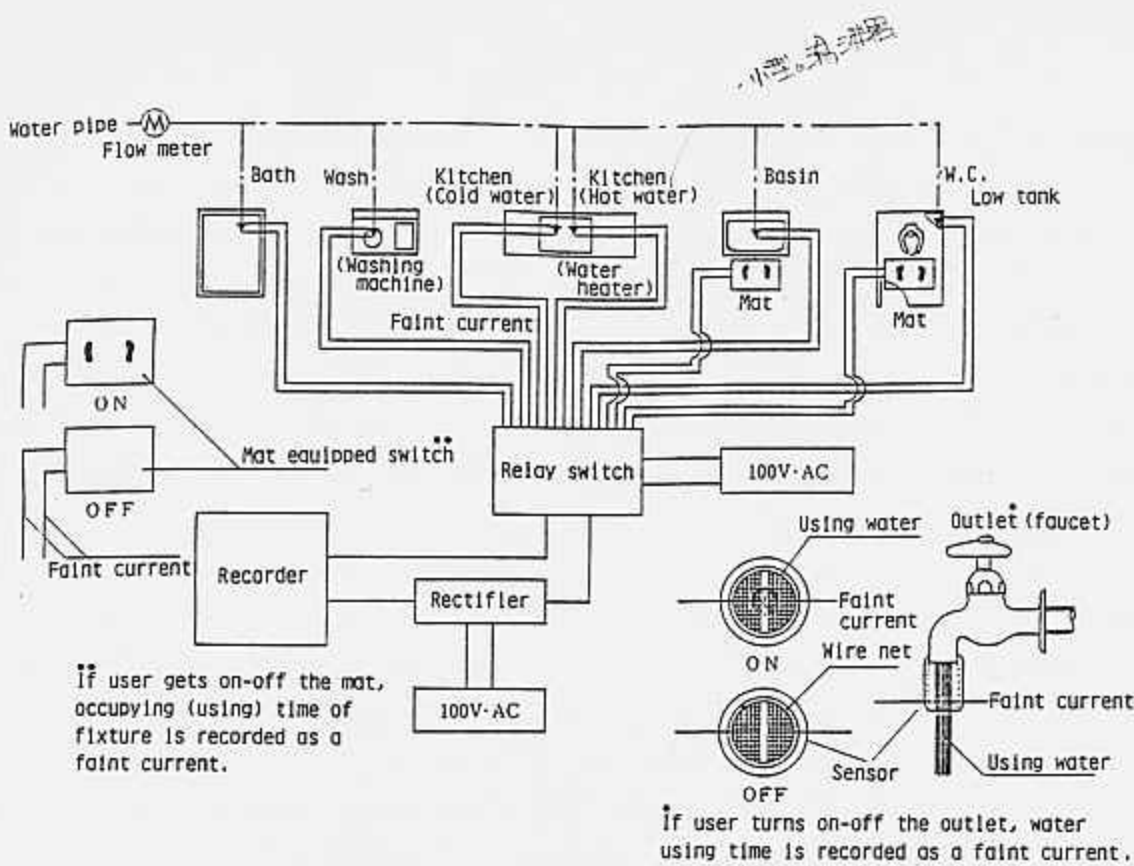
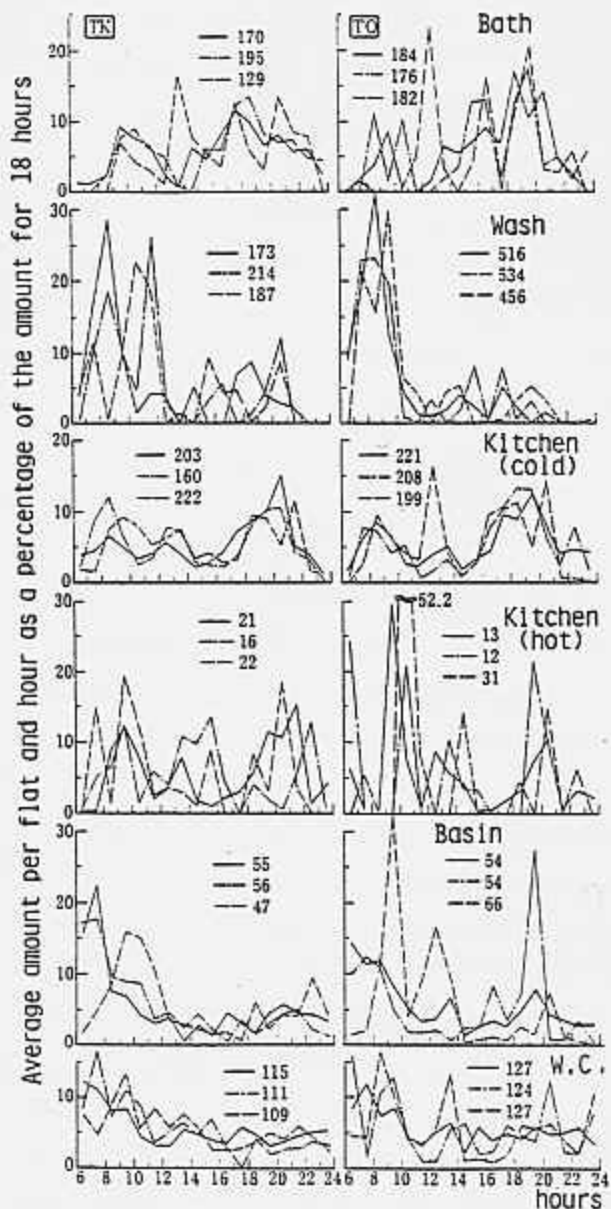


Fig 1. Measurements for using water and fixtures

outlets ; bath, wash basin installed washing machine, kitchen sink , WC and basin, and one hot water outlet; kitchen sink installed instantaneous gas water heater. The amount of water use was recorded by the flow meter of each flat at intervals of 10 minutes from 6:00 to 24:00. 19 flats of TK and 11 flats of T0 were chosen as the subject of this research. The average number of occupants in each flat was 3.45 in TK and 3.54 in T0. In the case of T0, the children age took 0-6, and the babies 0-2 occupied for 70.6 per cent of them ; 17 persons. The research was conducted for the three groups and periods; 17-22 July 1974 on 10 flats of TK, 25-29 July 1974 on the other 9 flats and the former one flat of TK and 23-29 July 1975 on 11 flats of T0.

3.2 The water consumption in each water supply system

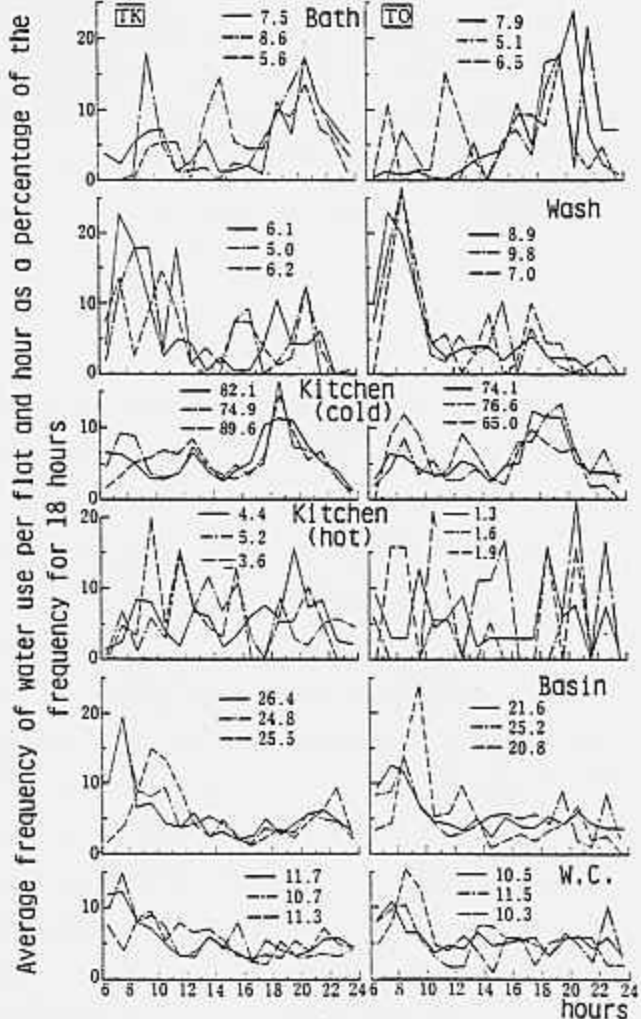
The average amount of water consumption per flat and hour of each type of outlet as a percentage of the amount for 18 hours (from 6:00 to 24:00) is shown in Fig 2 divided in three cases; on Sunday , Saturday and weekday. In those cases there are large variations in some patterns because of limited sample size. However, the character of each pattern can be recognized. Those characters are related to the occupants' life activities in a day. For example, the characters are recognized in the differences between the peak



Note: — Week day — Saturday — Sunday
 The numbers in Figure show average amount consumption from 6:00 to 24:00 h (l/flat · 18 hours)

平均消費水の時間別消費率

Fig 2. Average amount of water consumption



Note: — Week day — Saturday — Sunday
 The numbers in Figure show average frequency of water use from 6:00 to 24:00 h (frequency/flat · 18 hours)

洗濯水の時間別消費率

Fig 3. Average frequency of water use

time occurred on weekday morning and that on Sunday morning at the basin and the WC. About the total water consumption in dwellings, there are commonly the largest peak caused by wash clothes in the morning, and the next peak caused by a kitchen and a bath in the evening.

The amount of water consumption per flat and day of each various water uses is shown for each number of occupants in Table 1. There is a large difference between the two multi-story flats in the case of wash clothes. The difference was caused by the number of babies and the way of wash clothes.

3.3 The frequency of water use

The average frequency of use per flat and hour for each type of outlet as a percentage of the frequency for 18 hours (from 6:00 to 24:00) is shown in Fig 3. The frequency of use at the kitchen is the largest and that of use at the basin is the next. The frequency of use of wash clothes in T0 is about 1.5 times as many as that in TK. The amount of water consumption in T0 is about 3.0 times as much as that in TK. In Fig 6 that gives the average using time of wash clothes per one turned on-off of outlet as mentioned later, the value in T0 is about 1.5 times as long as that in TK. In Fig 7 that gives the average flow rate of wash clothes as mentioned later, the value in T0 is about 1.2 times as large as that in TK. Therefore, the reason that the amount of water consumption at wash clothes in T0 is about 3.0 times as much as that in TK depends on not only the frequency but also the way of wash clothes. The changing pattern of the frequency of water use did not always corresponded to that of the amount of water consumption, and the many differences could be shown at the peak time in the two cases.

The probability distributions of water use are shown in Fig 4 (a), (b) as the examples for the time of high frequency on weekday. The results of the data show that the distribution for each type of outlets is approximated to the Poisson distribution. Hence, the distribution of origination intervals of water use is approximated to the exponential distribution, and we can consider that the water use occurred at random.

3.4 The water using time

The tendency of changing pattern of the water using time is approximated to that of the amount of water consumption shown in Fig 2. The mean water using time for each type of outlets is shown in Table 2. The hourly average water using time of turned on-off of outlet as a ratio of the hourly average using time of that for 18 hours (from 6:00 to 24:00) is shown in Fig 5. In the case of the different purpose of water use in same system, there were re-

Table 1. Amount of water consumption in each system of outlets (l/flat.day)

Number of occupants per flat	Name of flats	Each system of outlets						Sum of each system	Number of flats
		Bath	Wash	Kitchen (cold)	Kitchen (hot)	Basin	WC		
2	TK	164	172	187	2	66	115	706	3
		144*	144*	117*	3*	42*	79*	529*	2*
3	TK	157	154	182	7	42	85	627	5
	TO	161	487	178	27	64	137	1054	6
4	TK	172	200	208	31	55	124	790	12
	TO	179	464	250	0.3	37	93	1023	4
5	TO	277	878	305	13	92	220	1785	1

* These values show the amount of water consumption except one flat which had consumed a great deal of water.

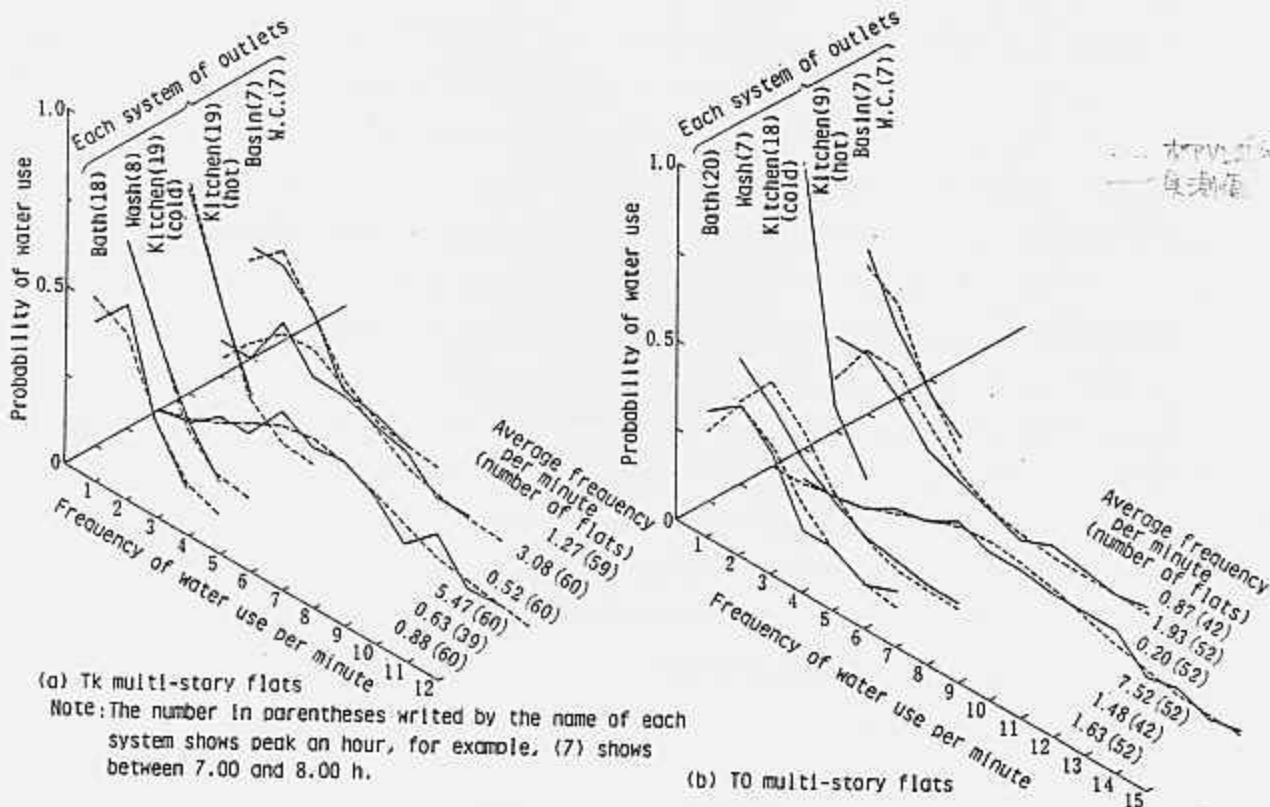


Fig 4. Probability distribution of water use

Table 2. Average water using time (s) per flat in each system of outlets

Each system of outlets	A day of the week	TK multi-story flats				TO multi-story flats			
		6-24	peak an hour			6-24	peak an hour		
		per flat (s/18h)	per flat (s/h)	occured time (h)	peak rate	per flat (s/18h)	per flat (s/h)	occured time (h)	peak rate
Bath	weekday	1102	160	17-18	2.62	1296	227	18-19	3.15
	Saturday	1346	214	17-18	2.85	1621	405	15-16	4.50
	Sunday	719	141	17-18	3.53	1123	264	12-13	4.23
Wash	weekday	1019	306	8- 9	5.41	2189	810	8- 9	6.66
	Saturday	1014	239	8- 9	4.24	2264	641	8- 9	5.10
	Sunday	982	233	10-11	4.26	1698	578	9-10	6.13
Kitchen (cold)	weekday	1702	177	17-18	1.87	1352	165	19-20	2.20
	Saturday	1410	201	8- 9	2.57	1367	179	18-19	2.36
	Sunday	1719	209	21-22	2.19	1119	151	17-18	2.43
Kitchen (hot)	weekday	244	42	21-22	3.09	137	39	9-10	5.12
	Saturday	176	27	9-10	2.76	124	35	6- 7	5.01
	Sunday	225	51	20-21	4.06	284	151	10-11	9.56
Basin	weekday	385	102	7- 8	4.76	377	59	6- 7	2.79
	Saturday	390	81	7- 8	3.73	424	84	19-20	3.57
	Sunday	337	55	10-11	2.96	450	138	9-10	5.54
WC	weekday	914	170	7- 8	3.34	1084	111	7- 8	1.85
	Saturday	667	113	7- 8	3.06	1110	116	8- 9	1.89
	Sunday	789	94	9-10	2.16	1039	164	8- 9	2.84

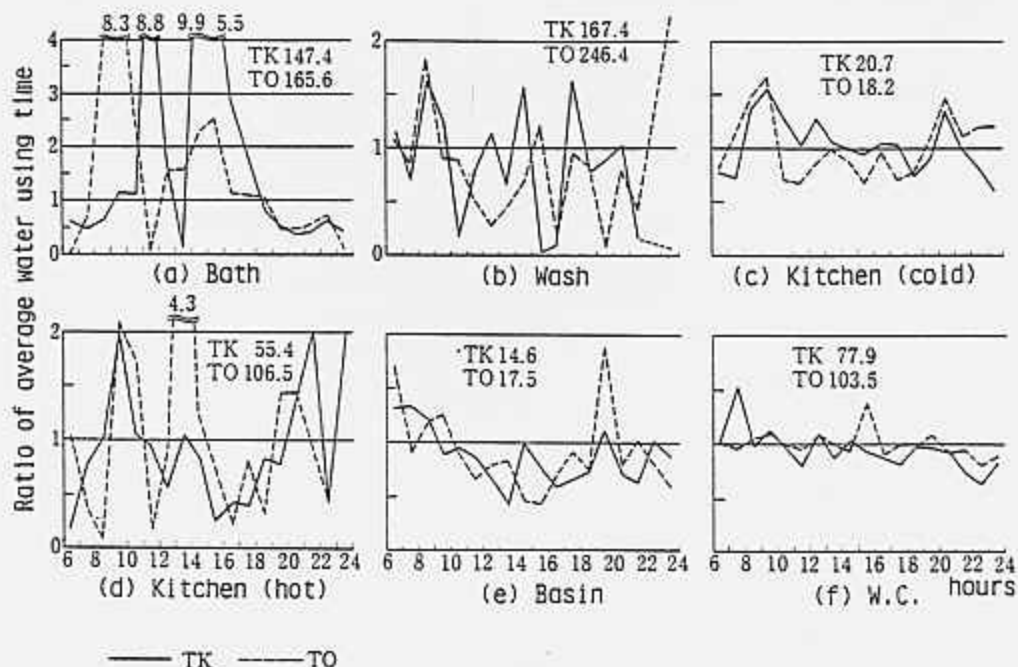
Note peak rate: (Water using time at peak hour) /
(Average using time per hour from 6:00 to 24:00h)

markable differences between the mean water using time. For example, the using time was long at the time of pouring into the bath, clearing the table in the kitchen and washing face at the basin in the morning. The amount of effluent in the WC changes by selected valve, hence, there are no remarkable differences of hourly values in Fig 5. The cumulative frequency distribution of the water using time for turned on-off of outlet is shown in Fig 6. The distributions are approximated to the exponential distribution or the hyper exponential distribution except the case of WC in TO. However, water using time in the time occurred both activities of pouring into a bath and taking a bath is not approximated to the two distributions as shown at the bath in TK. As shown at the WC in TO, if many occupants select the high volume valve, the distribution of water using time is approximated to the Erlang distribution.

3.5 The flow rate of outlet

The flow rate is determined by pressure, pressure loss in pipes, opening of outlets and so on. The user controls the flow rate by the opening of outlet for each purpose.

The histogram of used flow rate as a percentage of total frequencies recorded for 10 days in TK is shown in Fig 7. The average flow rate of each type of TO is in parentheses of Fig 7. In the cases of hot water supplier at



Note: The numbers in Figure show average water using time for turned on-off of outlet from 6:00 to 24:00 h.

Fig 5. Average water using time

the kitchen and low tank at the WC, the flow rates are limited by the character of the equipments, hence, the variances are smaller than the other cases. Furthermore, flow rates are affected by the number of simultaneous uses. Fig 8 shows the histogram of flow rates in each case of the number of simultaneous uses at the wash clothes in TO. The controlled range of flow rate is wide in using one outlet, whereas the range and the flow rate are limited with increasing the number of simultaneous uses.

Therefore, the needed flow rate of each type has to be considered in connection with using function, saving water, user's opinion and so on. With the present studies and researches, the author thinks that the flow rate expected in the maximum number of simultaneous uses is required to satisfy the average

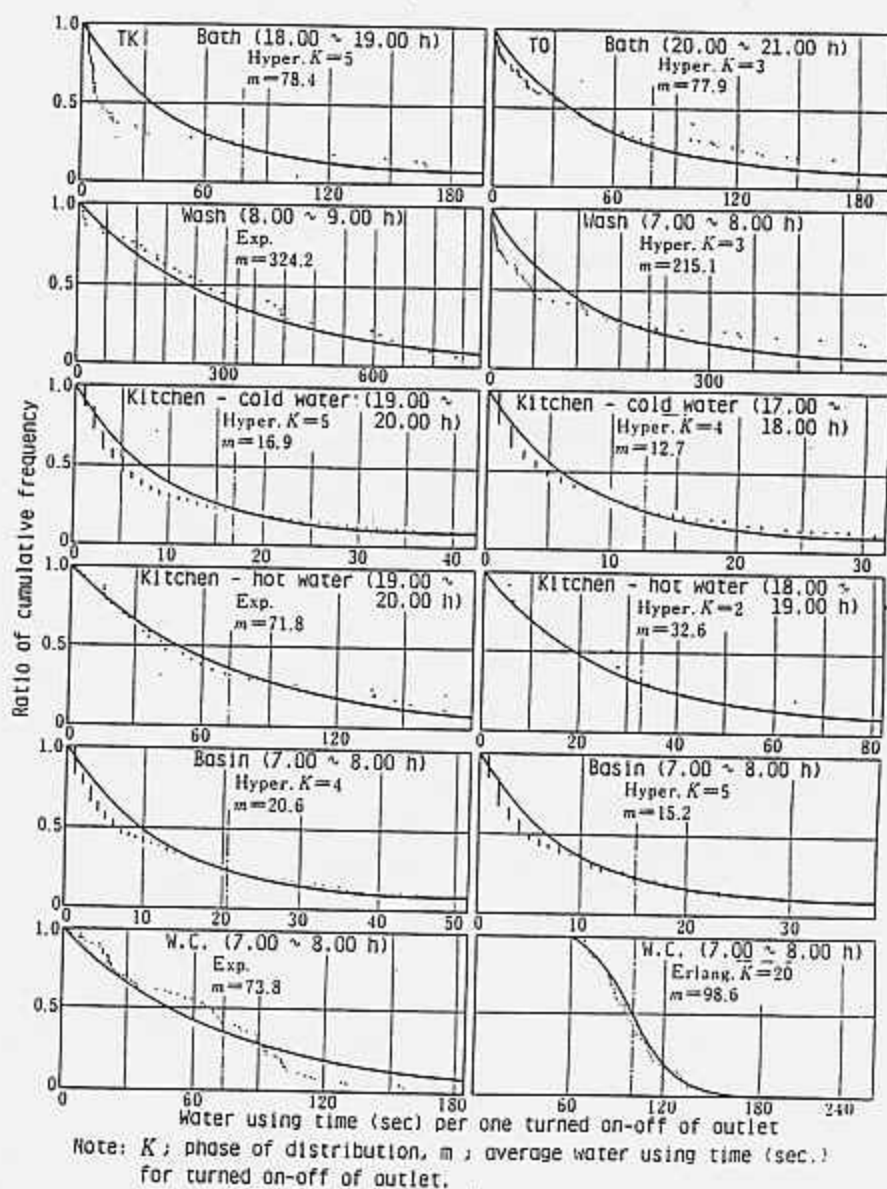


Fig 6. Distribution of water using time

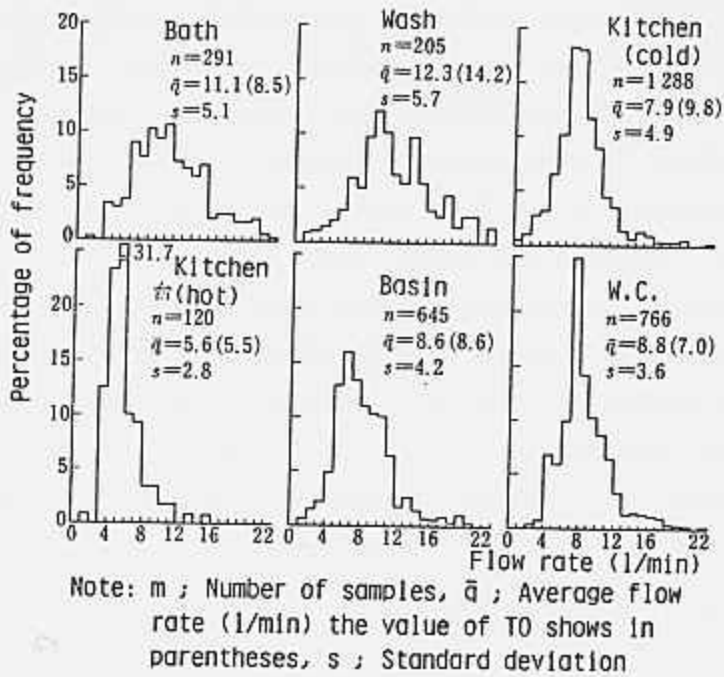


Fig 7. Histogram of flow rates

Case	Number of simultaneous uses	Number of samples	Average flow rate	Standard deviation
(1)	1	308	15.9	4.8
(2)	2	145	27.1	3.9
(3)	3	72	32.4	2.5
(4)	4	40	35.2	1.5
(5)	5	8	37.2	1.0

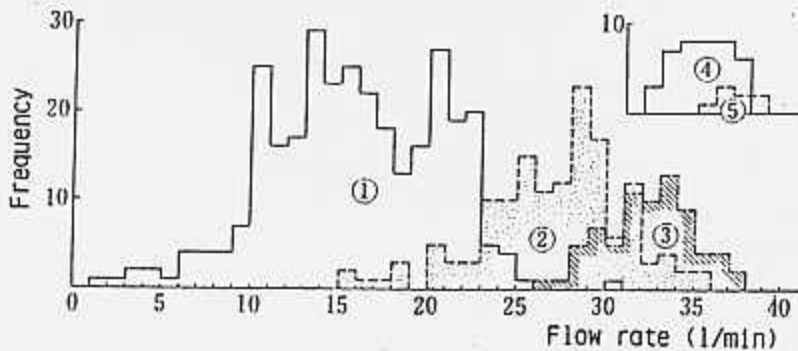


Fig 8. Changes of flow rates by the number of simultaneous uses, wash clothes in TO.

flow rate described in Fig 7 for calculating load.

3.6 The probability distribution of the simultaneous uses of water

Considering the frequency and the using time distribution of water uses, the probability distribution of simultaneous uses of water in peak hour is estimated to be approximated to the Poisson distribution by the queuing theory. The results of recorded data are shown in Fig 9 (a),(b) exemplified on week-day. The distribution in each type is approximated to the Poisson distribution. The hourly average number of simultaneous uses of water per flat is shown in Table 3.

4. ANALYSIS AND CALCULATED RESULTS OF WATER LOADING

4.1 Calculated results by the probability method

The calculated results of water loading are shown on the basis of the probability method and the data of water uses in the multi-story flats above mentioned.

The average numbers of simultaneous uses of water were utilized the values shown in Table 3 and the probability distribution was applied the Poisson distribution on the conditions of calculation. The maximum values were selected for the calculation of each type of same outlet within the values

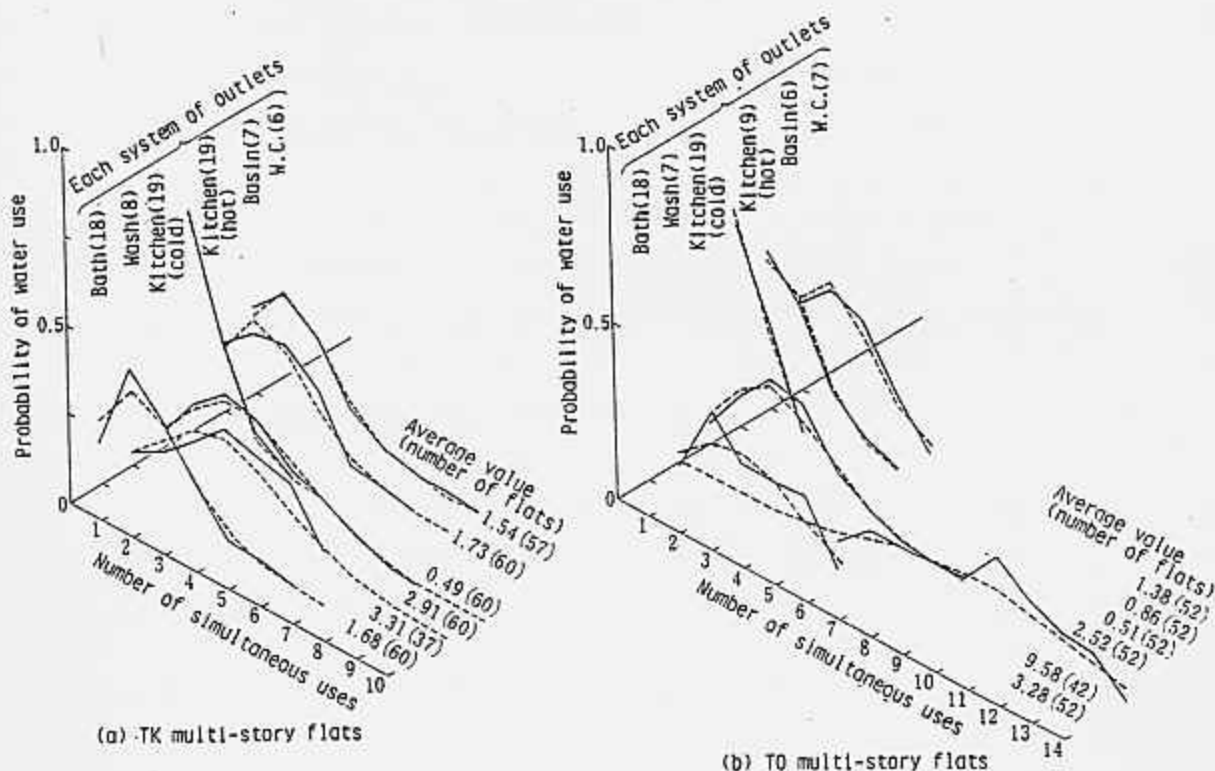


Fig 9. Probability distribution of simultaneous uses of water

Table 3. Average number of simultaneous uses of water

Hours	Name of flats	Each system of outlets					
		Bath	Wash	Kitchen (cold)	Kitchen (hot)	Basin	WC
6 - 7	TK	0.003	0.012	0.031	0.000	0.015	0.027*
	TO	0.000	0.063	0.007	0.002	0.017*	0.026
7 - 8	TK	0.004	0.047	0.026	0.001	0.029*	0.025
	TO	0.001	0.195	0.024	0.000	0.012	0.033*
8 - 9	TK	0.010	0.085*	0.037	0.006	0.009	0.018
	TO	0.010	0.228*	0.028	0.001	0.015	0.022
9 - 10	TK	0.022	0.034	0.022	0.008	0.008	0.017
	TO	0.026	0.061	0.030	0.010*	0.009	0.024
17 - 18	TK	0.036*	0.018	0.036	0.002	0.004	0.012
	TO	0.016	0.036	0.034	0.001	0.004	0.020
18 - 19	TK	0.028	0.024	0.043	0.003	0.002	0.009
	TO	0.063*	0.013	0.035	0.002	0.004	0.014
19 - 20	TK	0.017	0.011	0.048*	0.008	0.005	0.009
	TO	0.028	0.001	0.048*	0.003	0.009	0.022
20 - 21	TK	0.016	0.014	0.047	0.008	0.005	0.009
	TO	0.041	0.011	0.028	0.004	0.005	0.019

* These are the values in peak hours. Peak hour by the kitchen (hot) in TK occurred between 21.00 and 22.00h, and the average number was 0.012.

Table 4. Standard flow rate (l/min) in each system of outlets

	Bath	Wash	Kitchen (cold)	Kitchen (hot)	Basin	WC
As to use more than two outlets	12	13	10	5	10	10
As to use one outlet	20	25	15	6	15	15

given in Table 3. Furthermore, the values between 8:00 and 9:00 were selected for the calculation of the total water consumption involved different types of outlets, for the reason that the maximum amount of water consumption was caused mainly at that time zone. The values of the average flow rate of outlets are shown in Table 4. In Table 4 the values of the upper spaces are selected from the experimental values as the average flow rate to be utilisable at the maximum number of simultaneous uses. The fewer the number of simultaneous uses occurs, the wider the controlled range of flow rate will be. The values of the lower spaces give the flow rate used with the one outlet.

Fig 10 shows the maximum flow rate in each type of same outlets. In this case, the criterion of the failure rate K_f is 0.002. The value of wash clothes in T0 showed the very larger than that in TK. If we make a decision according to the other investigations, it will be suitable to understand that the value in TK is ordinary. Fig 11 shows the maximum flow rate to 100 flats involved the all same and different types of outlets. In this case, the criterion of the critical rate K_c is 0.002. Moreover, the sum of flow rate which was calculated in each type of outlets to 1000 flats on the time between 8:00 and 9:00 is shown in Fig 11. It is clear that the difference between the value which is calculated with the probability of combination in different types of outlets and the total value which is calculated with the probability in each type of outlets. The loading curve in T0 shows large value effected by the wash clothes. In comparison with the values by Hunter's method and Sato's investigation(13), the result of calculation by the probability of combination is simulate approximately to Sato's investigation.

4.2 Calculated result by the easy method utilized loading unit

The method for calculating water consumption by Hunter's Curve is convenience. However, it is clear that the values give the overload for the design of piping size from the above mentioned contents. Nevertheless, the method has valuable contents to be analysed in the process of getting the fixture units. Therefore, in addition to the above mentioned results, new loading units and flow curve are shown nearly the hunter's method.

For determining the loading units in each type of outlets, Fig 10 was utilized. We can consider that the number of outlets is equal to the number of flats in Fig 10, for each of flats equips one outlet of each type. Therefore, the relation between the flow rates and the number of outlets can be gotten. For example, in each flow rate; 0.5, 1.0, 2.0, 3.0 and 5.0 l/s, the ratios of the number of each type of outlets by standardizing the number of basin in TK are shown in Table 5 (where; the number of basin in each flow rate of TK set-

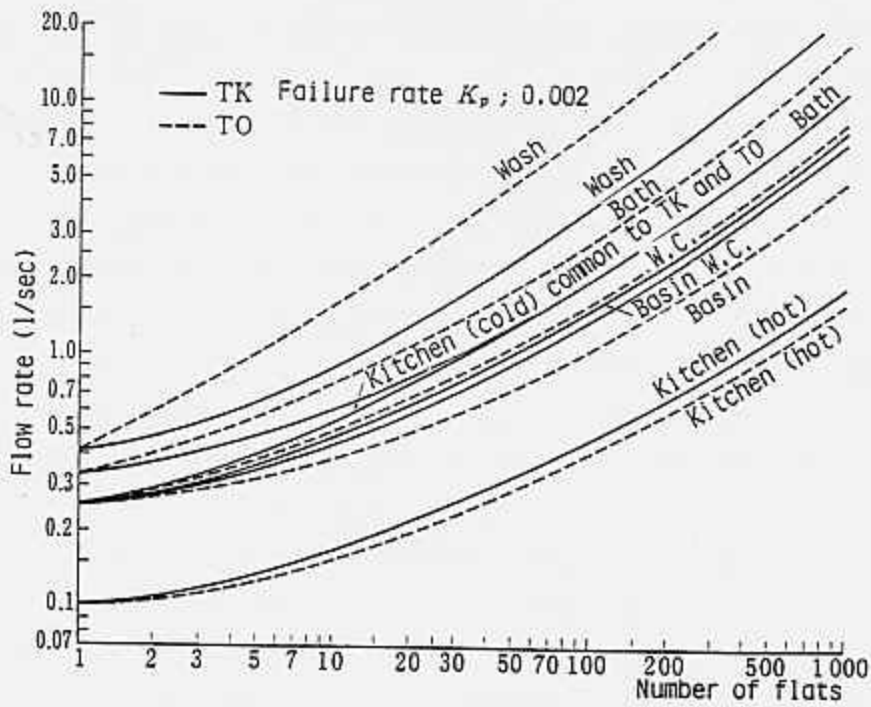


Fig 10. Flow rates in each type of outlets

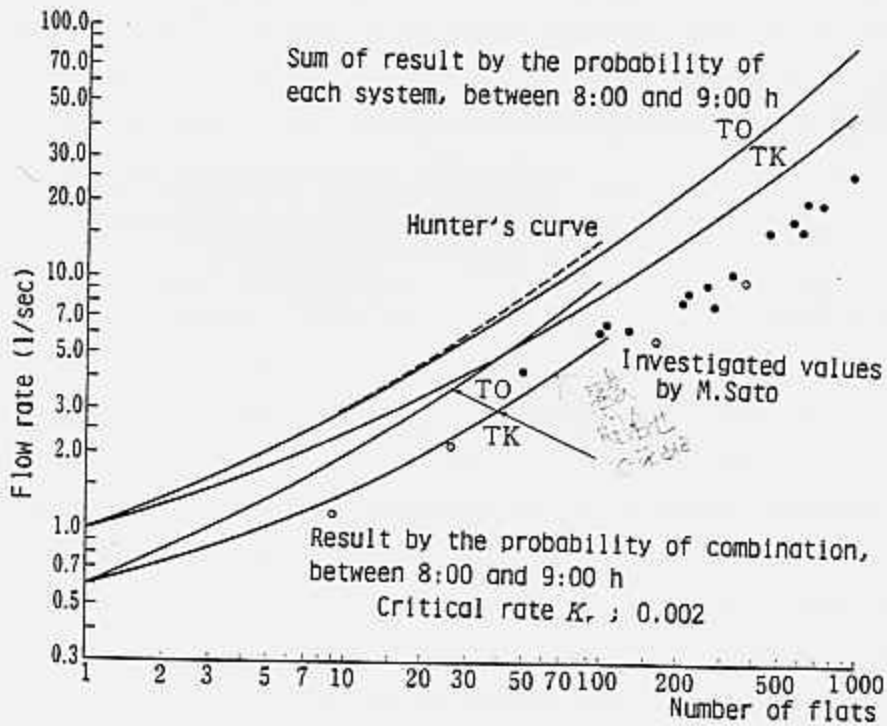


Fig 11. Flow rates involved the same and the different types of outlets

Table 5: Loading units

Flow rate (l/s)	Name of falts	Each system of outlets					
		Bath	Wash	Kitchen (cold)	Kitchen (hot)	Basin	WC*
0.5	TK	2:0	4.6	1.4	0.1	1	0.8
	TO	3.1	8.0	1.4	0.1	0.6	1.2
1.0	TK	1.6	3.9	1.5	0.1	1	0.9
	TO	2.8	10.0	1.5	0.1	0.5	1.1
2.0	TK	1.5	3.9	1.5	0.1	1	0.9
	TO	2.6	10.6	1.5	0.1	0.6	1.1
3.0	TK	1.6	4.0	1.6	0.1	1	0.9
	TO	2.6	10.6	1.6	0.1	0.6	1.1
5.0	TK	1.6	3.9	1.6	0.1	1	0.9
	TO	2.6	10.6	1.6	0.1	0.6	1.1
average	TK	1.7	4.1	1.5	0.1	1	0.9
	TO	2.7	10.0	1.5	0.1	0.6	1.1
loading units		2	4	1.5	0.5	1	1

* Low tank system is equipped at the WC.

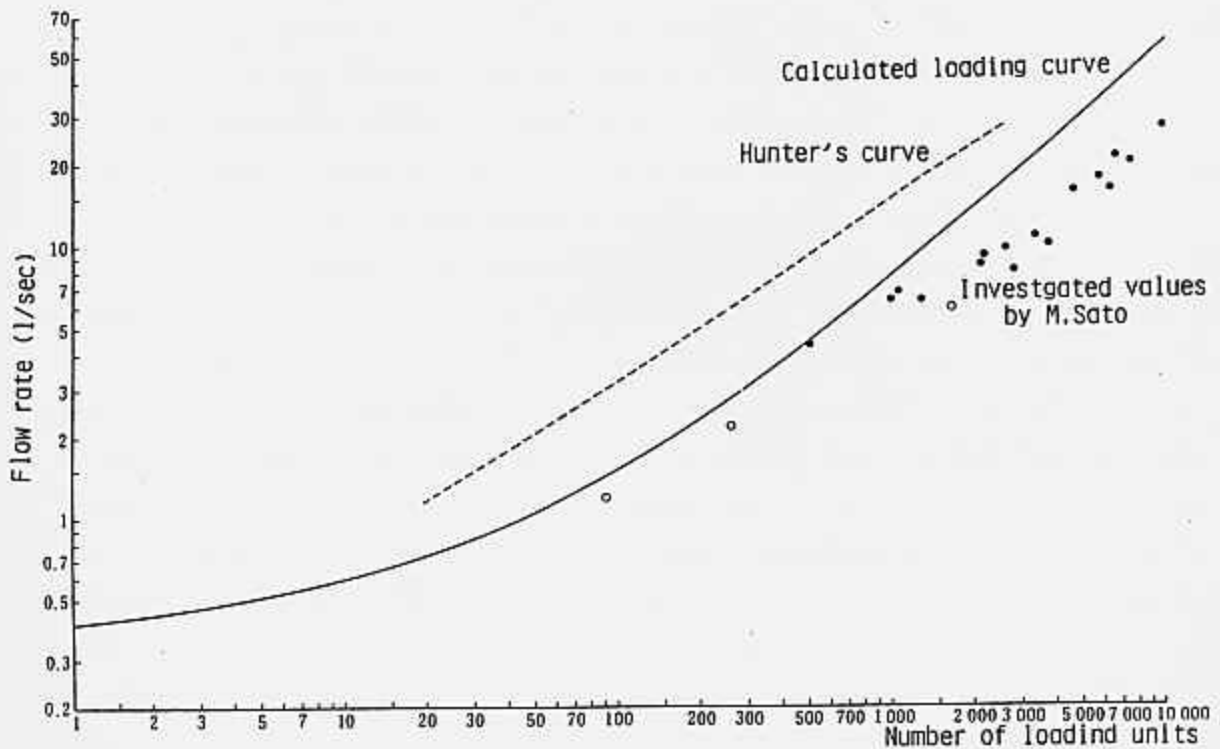


Fig 12. Flow rates based on the number of loading units

ties to unit 1). In this paper the flow rates are settled between 0.5 l/s and 5.0 l/s, however, we can select the flow rate at our pleasure. The values in the same type of outlets are similar in each flow rate, therefore the average values of these for loading unit are shown at the lowest spaces in Table 5. However, the loading unit of wash clothes was calculated from the values of TK because of the values of TO were not considered ordinary. Furthermore, the loading unit of hot water in the kitchen was settled larger than the calculated average values to be utilized not only in summer but also in other seasons.

The relation between the flow rates and the loading units is shown in Fig 12. In Fig 12 the loading curve less than 6 flats was made some changes in the values. To utilize the loading curve is a easy method for the calculation of water consumption. However, the user has to know that the total maximum flow rate calculated in this method on the time between 8:00 and 9:00 gives more than the expected amount, for the loading units are settled from the maximum flow rates in each type of outlets. Nevertheless, the calculated values are half as large as Hunter's values.

5. CONCLUSION

This paper described a method for calculating water consumption for designing a pipe size and the results of analysing the water uses in multi-story flats.

The main conclusions from this study are as follows;

1. The probability distribution of the number of simultaneous uses of water can be derived by the queuing theory with using the data; the intervals between water uses and the distribution of water using time.
2. The amount of water consumption for designing a pipe size can be calculated with the probability distribution of simultaneous uses of water, using a method based on the probability theory.
3. The intervals between water uses can be considered to be occurred at random, and the distribution of water using time can be approximated to the exponential distribution or the hyper exponential distribution by the results of water uses in multi-story. Therefore, the probability distribution of simultaneous uses of water can be approximated to the Poisson distribution.
4. The result of calculating water consumption based on the probability theory using the distribution of simultaneous uses of water is a great deal lower than that of Hunter's method.
5. Considering above mentioned results, the relation between loading units and maximum flow rate was shown as a simplified method.

REFERENCES

1. Roy B. Hunter: Method of Estimating Loads in Plumbing Systems, NBS Building Materials and Structures Report, BMS 65, December 1940.
2. Thomas P. Konen and Wen Yung Chan: An Investigation of the Frequency and Duration of Use Parameter in Sizing Water Distribution Systems, ASPE Research Foundation Report, 102-79, 1979.
3. Wen Yung Chan and Lawrence K. Wang: Reevaluating Hunter's Model for Residential Water Demand, AWWA, August 1980.
4. C. J. D. Webster: An Investigation of the Use of Water Outlets in Multi-Story Flats, CIB Commission W62 Symposium Report, September 1972.
5. Uichi Inoue and Yoshio Inoue: Percent of Simultaneous Usage for Plumbing Fixtures, Transaction of the Architectural Institute of Japan, No. 57 July 1957.
6. Kohsei Okada: Some Problems on the Probability of Simultaneous Usage of Building, Transaction of the Architectural Institute of Japan, No. 57 July 1957
7. Kohsei Okada: A Solution to the Simultaneous Use Problems of Building Equipments and Fixtures, Transaction of the Architectural Institute of Japan, No. 65 June 1960.
8. Fumitoshi Kiya and Saburo Nakayama: Calculation of Water Demand in Office Building, CIB Commission W62 Symposium Report, September 1974.
9. Saburo Murakawa: Investigation of the Method of Calculation of Water Consumption in the Designing of Building Equipments Part 1 - 4, Transaction of the Architectural Institute of Japan, No. 246 August 1976, No. 249 November 1976, No. 250 December 1976, No. 253 March 1977.
10. Saburo Murakawa and Toshihiro Yamate: Investigation of Calculating Method for Flow Rate Design and Water Uses in Multi-Story Flats, Transaction of the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan, No.20 1982.
11. The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan: Heating, Air-Conditioning and Sanitary Standard 206, 1976.
12. Hidenori Morimura and Yoshithugu Ohmae: Applied Queuing Theory, Nikka Giren Shuppansha, April 1975.
13. Mithuo Sato: Investigation of Peak Flow Rate in Multi-Story Flats, Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan, September 1980.
14. Vincent T. Manas: National Plumbing Code Handbook, McGraw-Hill Book Company, Inc., 1957
15. Fumitoshi Kiya and Saburo Murakawa: Design of Loading on Water Supply Equipment, Inoue Shoin, April 1978.