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CALCULATION METHODS FOR DESIGN OF FLOW RATES AND PEAK FLOW-RATES IN PIPES FOR WATER INSTALLATIONS INSIDE BUILDINGS

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Abstract: *Taking into consideration all facts (climate changes, droughts, rising of the sea level and urbanization) we decided to concentrate on a wide range of storm water management methods and grey water reuse that will contribute to significant cost savings in potable water and sustainable design. In this article we will present our results of volume flow measurements in installations inside buildings and peak flow-rates in installations inside buildings. It is focused on peak flow-rates in separate water installations which supply WC-cisterns, WC and urinals flush valves. The design flow rates set by the different methods are generally higher than the measured peak flow rates. It will therefore be necessary to carry out another measurement and the calculation method.*

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K e y w o r d s: design flow-rate; peak flow rate; draw-off flow-rate; simultaneous use; measurements;

1 INTRODUCTION

Facilities are a great opportunity for water conservation and water use efficiency. There are numerous retrofits available for the water-using equipment and fixtures within the building complex. Developing a water use profile often leads to short payback periods for retrofits.

It is important to calculate properly design flow rates of supply pipes for the dimensioning water installations inside buildings. There are used various calculation methods in different countries. These methods are based on probability theory or measurements of the peak flow rates in the pipeline. Both methods may be mutually combined that allows to complete missing information or comparison of the results.

2 METHODS FOR CALCULATION OF DESIGN FLOW RATE IN SUPPLY PIPES FOR WATER INSTALLATIONS INSIDE BUILDINGS

An important quantity for determination of design flow rate is draw-off flow-rate called in the Slovak and Czech Republic „nominal flow rate“. Comparing design flow rates in accordance with the standards and to the values measured by authors is referred to in Table 1. Another important indication is the simultaneous use of taps which is different in various types of buildings. It is possible to determine calculated design flow rates in supply pipes of installations inside buildings with the knowledge of draw-off flow rate and the simultaneous use of taps. Methods of calculation for design flow rate shall be based on probability theory and/or the measurements of peak flow rates in the pipeline. There is a simplified method for the certain calculation methods, such as [1] taps (draw-off points) characterised by loading units (LU).the policy makers of an organization to decide about the investments in IT. There can be two possibilities.

2.1 METHOD BASED ON PROBABILITY THEORY

Real A calculation method of design flow rate based on probability theory was dealt with by Roy B. Hunter in the US, who published it in the year 1940 [6]. The result of calculations was the total number of taps, which are used simultaneously and depends on:

- the total number of taps (fixtures) supplied by a particular pipe;
- the average duration of flow for a given kind of fixture for one use;
- the average time between successive operations of any given fixture of a particular kind.

On the basis of fixtures (taps), which are used simultaneously and the flow rate Hunter estimated weight in pipe flow-rate expressed in FU (fixture units). Hunter took into account less simultaneous use of fixtures, which was started up in residential buildings caused by their location in bathrooms used as a general rule by one person only, by setting FU value for bathroom group composed of such as water closet, washbasin and bath or shower head. The FU value for bathroom group is equal to total of FU fixtures, which are in it and divided by two. Later FU values were re-evaluated and adjusted [7].

2.2 METHOD BASED ON MEASUREMENTS

The method based on the measurements of peak flow rates from the year 1989 is used in Germany. This method consists in the systematic measurement of flow rates in the different buildings (residential buildings, office buildings, hotels, schools, etc.). The measured peak flow rates in the buildings with different number of fixtures drawn in the graph are then doing curve, which expresses dependency of design flow rate on total flow rate (Figure 1). The curves were adjusted [2] in the recent revision of the German standards.

Draw-off point	**Draw-off flow-rate Q_A (l/s)in accordance with various standards and measurements**							
	EN 806-3 [1]		DIN 1988-300 [2]		STN 73 6655 [3]	ČSN 75 5455 [4]	Measurement of draw-off flow rate	Notes on measurements
	Only cold or hot	Loading units LU	Only cold or hot	Draw-off flow rate				
WC-cistern	0,10	1	0,13	0,13	0,10	0,15	0,05 to 0,15	--
Washbasin DN 15	0,10	1	0,07	0,14	0,20	0,20	0,10 to 0,14	--
Domestic kitchen sink DN 15	0,20	2	0,07	0,14	0,20	0,20	0,20	running sink
Bath domestic DN 15	0,40	4	0,15	0,30	0,30	0,30	0,40	--
Shower head DN 15	0,20	2	0,15	0,30	0,20	0,20	0,20	--
Urinal flush valve DN 15	0,30	3	0,30	0,30	0,15 to 0,25	0,15 to 0,30	0,15 to 0,30	In accordance with product norms
WC flush valve DN 20	1,50	15	1,00	1,00	1,20	1,20	1,0 to 1,3	In accordance with product norms [5]

Table 1. Comparison of draw-off flow rates in accordance with various standards and measurements your title here.

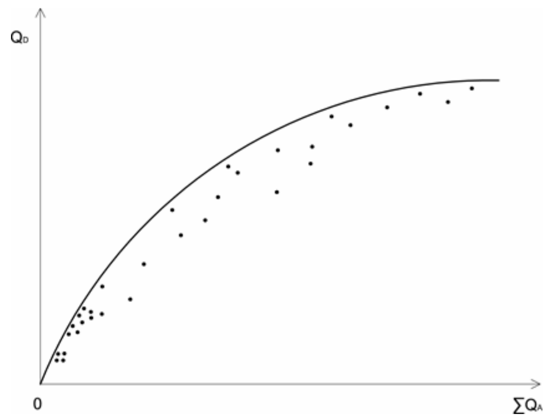

Fig.1 Dependency curve of design flow-rate QD on total flow-rate ∑QA in accordance with measurements of peak flow rate highlighted by dot.

Dependency curves of design flow-rate on total flow-rate have the equation:

$$QD = a \cdot (\sum QA)b - c \qquad (1)$$

Where QD is design flow-rate (l/s);

QA – draw-off flow-rate (l/s);

a, b, c – the constants dependent on the type of buildings.

The constants a, b, c have values specified in Table 1 and processed in accordance with [2].

Type of building	**Constants**		
	a	***b***	***c***
Residential houses	1,48	0,19	0,94
Hotels	0,70	0,48	0,13
Schools or office buildings	0,91	0,31	0,38

Table 2. Constants a, b, c for various buildings

2.3 METHOD IN ACCORDANCE WITH THE SLOVAK AND CZECH STANDARDS

The method of determining design flow-rate in accordance with the Slovak [3] and the Czech Standard [4] was introduced in the early 60´s of the 20th century in the former Czechoslovakia, and after certain adaptations it is still used in Slovakia and in the Czech Republic. This is the method of calculation, which is based on the measurements and analyses obtained by empirical and static methods and experience. Relation (2) is based on the method published in the [8].
The method used in Slovakia and in the Czech Republic is simple by calculated dependency of design flow rate on the number of taps (draw-off points) with certain values of draw-off flow rates. The pipes of uniform installations with dimensioned design flow rates, and set out in accordance with this method always safeguarded faultless water supply and the experience of using this method was good.

Design flow rate QD (l/s) in supply pipes shall be determined in accordance with relations:

a) for family houses, residential houses, administrative buildings, the individual stores (with equal collection of water only for personal hygiene of employees and cleaning) and sanitary facilities for a hotel room

$$Q_D = \sqrt{\sum_{i=1}^{m} \left(Q_{Ai}^{2} \cdot n_i \right)} \qquad (2)$$

b) for the other buildings with a predominantly equal collection of water, such as hotels, restaurants, commercial houses and day nurseries according to the Slovak standards [3]

$$Q_D = \sum_{i=1}^{m} Q_{Ai} \cdot \sqrt{n_i} \qquad (3)$$

c) for the other buildings with a predominantly equal collection of water, such as hotels, restaurants, commercial houses and day nurseries according to the Czech standards [4] (the adjustment of the previous relation (3))

$$Q_D = \sum_{i=1}^{m} f_i \cdot Q_{Ai} \cdot \sqrt{n_i} \qquad (4)$$

d) for building or group fixtures, for which the mass and the one about use of taps (draw-off points) are predicted, for example sanitary facilities, industrial plants, public spa

$$Q_D = \sum_{i=1}^{m} \varphi_i \cdot Q_{Ai} \cdot n_i \qquad (5)$$

Where:

QA - draw-off flow-rate (l/s) according to the table 1;
f - coefficient of flow rate according to the table 3;
φ - coefficient of simultaneous water collection according to the table 3;
n - the number of draw-off points of the same type;
m - the number of the types of draw-off points.

Draw-off point	**Coefficient of draw-off point 1**		Coefficient of simultaneous water collection φ
	For one draw-off point	**For two or more draw-off points**	
WC-cistern	0,7	0,7 2)	0,2 až 0,3
Washbasin, handbasin, wash through	0,65	1	0,8
urinal with siphonic action	1	0,75	0,2
WC flush valve DN 20	0,85	0,85	0,1
Shower head	1	1	1
1) For not given draw-off points $f = 1$ 2) Only for pipes supplying WC-cisterns $f = 1$			

Table 3. Coefficients of draw-off point and coefficients of simultaneous water collection.

Design flow-rate determined in accordance with relations (3) and (4) is given by the total of sub-design flow-rates for the various types of draw-off points. From the comparison between the (2) relation and (3) and (4) it is evident that, determining the design flow-rate for draw-off points of the same type and with coefficient of flow rate f = 1, the value of design flow rates referred to in relations (3) and (4) are the same as referred to in the (2), which may cause sub-dimensioning pipes (simultaneous use of draw of points like in residential houses). This is the case that may occur at the separate pipes supplying WC-cisterns. Also, in the design flow rate calculated in accordance with the (5) for the pipes, which supplies only WC-cisterns, may be sub-dimensioning.

2.4 METHOD IN ACCORDANCE WITH THE EUROPEAN STANDARD

Since 2006 in Slovakia and in the Czech Republic the European Standard [1] has also been valid which enables the design flow-rate for so-called standard - installations, which are in accordance with national foreword installations in family houses, residential houses and office buildings. The design flow rate is determined according to loading units (LU) and the highest individual values of loading units.

3 MEASUREMENTS OF PEAK FLOW RATES IN SUPPLY PIPE INSTALLATIONS INSIDE BUILDINGS

In the project TAČR TA01020311 and another research peak flow rates were measured in the different buildings. The measurements were carried out for the period of 14 or more days and the flow rate was read every second. For the measurement Axial turbine flow meter for liquids AHLBORN Type FVA915VTH25 embedded in the pipeline was used and connected to the measuring switchboard AHLBORN ALMENO 5690 2M. The measurements and their comparison with design flow rates determined in accordance with the various standards are referred to in Table 4. Samples flow rates measured in the course of the day are set out in the figures 2, 3 and 4 (zero flow rates were deleted from the graphs). The figure 3 is clearly visible for implementation of the individual WC-cisterns.

Table 4 shows that:

- The design flow - rate of [1], [3] and [4] is not considered with separate water installations (it results from a low design flow-rate);
- The calculated relation in accordance with [2] provides good results for separate taps;
- Pipes in restaurants cannot be dimensioned in accordance with [1] (according to the Slovak and Czech National Foreword to this standard it is not permitted);

- design flow rates according to the cancelled standard [9], which were in force in the years 1933 and 1955, when the separate water installations were normally established in the former Czechoslovakia, seemed to be taken into account the specifications of separate water installations, but were too high. This is the old calculation method, which expected a high draw-off flow rates.

3.1 COMPARISON OF DESIGN FLOW-RATES IN SUPPLY PIPE SUPPLYING ONLY WC-CISTERNS

In the separate water installations it is necessary to determine design flow-rates in pipe supplying only WC - cisterns. As can be seen from Table 5, design flow-rates in residential houses which were determined in accordance with the various standards are different. The nearest fact is when design flow-rates, in our view, are determined in accordance with standard [2]. In the other buildings with equal water collection this comparison was carried out with Hunter method [6] (Table 6). Design flow-rates in accordance with standards [3] and [4] compared with Hunter´s assumptions are significantly lower. The question is whether Hunter method gives good results for the large number of WC - cisterns.

3.2 COMPARISON OF DESIGN FLOW RATES IN PIPE SUPPLYING ONLY WC FLUSH VALVES

WC flush valves are in operation only for a short period of time and "are a burden on "pipe installations inside buildings with a high flow-rate. Therefore, it is necessary, in particular in the pipes of separate installations, to determine as precisely as possible design flow-rate in pipe which supplies the toilet flush valves. In Table 7 design flow rate using Hunter method [6] is set out, and it is compared with design flow rate in accordance with the (4). The table shows that the formula for design flow rate referred to in (4) is comparable to Hunter method and for WC flush valves gives good results as well as for the greater number (if it is thought the flow through WC flush valves QA = 1,0 to 1,3 l/s). When the flow rate calculated in accordance with the (2) the number of WC flush valves is considering compared with actual number of half.

Building	Types and number of draw-off points	Max. measurement of peak flow rate (l/s)	Design flow-rates (l/s) in accordance with various standards				
			EN 806-3 [1]	ČSN 75 5455 [4]	STN 73 6655 [3]	Cancelled ČSN 1099 [7]	DIN 1988-300 [2]
Residential house "J"	5 x VA 5 x DJ 5 x WCNS 5 x AP	0,61 1)	0,90	0,98	0,95	1,98	0,82
Residential house "Š"	6 x DJ	0,24 2)	0,42	0,49	0,49	1,20	0,31
Residential house "K"	5 x WCNS	0,40	0,30	0,33	0,22	0,70	0,42
Office building with restaurant	15 x WCNS 8 x U 2 x UEO 9 DJEO 2 x PM	0,86	0,86	0,97	0,87	2,25 3)	1,15
Restaurant night-time operations	3 x WCNS 3 x U 2 x PM	0,62	0,50	0,73	0,73	0,87 3)	--

Notes:
1) Cold water flow rate (central preparation of hot water).
2) Hot water flow rate (central preparation of hot water).
3) The method is not intended for other than residential buildings.
The explanatory notes for abbreviations:

Table 4. Measurements of peak flow rates in different buildings and their comparison with design flow rates in accordance with various standards

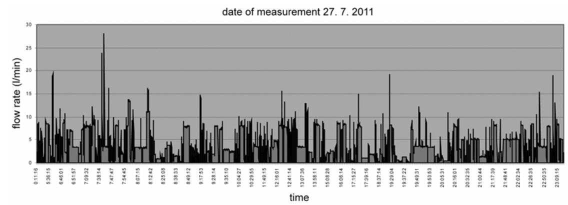

Fig.2 Flow rates in rising pipe in residential house "J" measured in the course of day

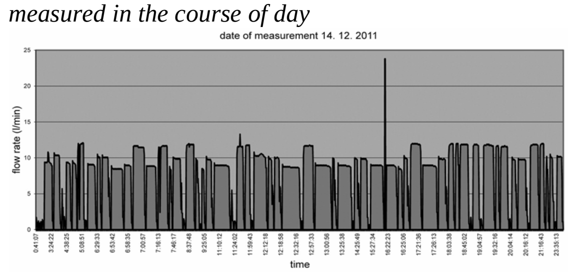

Fig.3 Flow rates in rising pipe to WC -cisterns in residential house "K" measured in the course of day

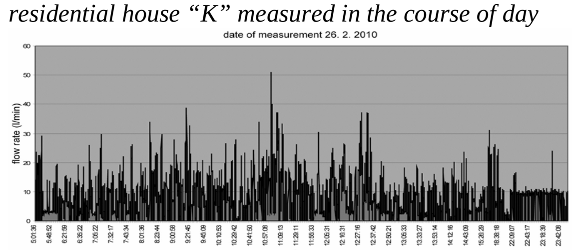

Fig.4 Flow rates in header pipe in administrative building with restaurant measured in the course of day

Number of WC-cisterns n	Design flow rate Q_D (l/s) in accordance with:			
	DIN 1988-300 [2] (relation (1))	EN 806-3 [1]	ČSN 75 5455 [4] (relation (2))	STN 73 6655 [3] (relation (2))
3	0,30	0,24	0,26	0,17
5	0,42	0,30	0,33	0,22
7	0,51	0,34	0,40	0,26
9	0,58	0,38	0,45	0,30
15	0,74	0,46	0,58	0,39
25	0,91	0,57	0,75	0,50
40	1,08	0,70	0,95	0,63
64	1,27	0,87	1,20	0,80
132	1,60	1,20	1,72	1,15
240	1,90	1,50	2,32	1,55
305	2,04	1,70	2,62	1,75

Table 5. Design flow rate in pipe supplying WC-cisterns in residential house.

Number of WC-cisterns n	*Number of WC-cisterns, which are operating simultaneously according to Hunter [6]*	*Design flow rate Q_D (l/s) in accordance with:*			
		Hunter [6], pro Q_A = 0,15 l/s (cistern of the volume 9l	*Hunter [6], pro Q_A = 0,1 l/s (cistern of the volume 6l)*	*ČSN 75 5455[4] (relation(4))*	*STN 73 6655[3] (relation(3))*
3	*2*	*0,30*	*0,20*	*0,26*	*0,17*
5	*3*	*0,45*	*0,30*	*0,33*	*0,22*
7	*4*	*0,60*	*0,40*	*0,40*	*0,26*
9	*5*	*0,75*	*0,50*	*0,45*	*0,30*
15	*7*	*1,05*	*0,70*	*0,58*	*0,39*
25	*10*	*1,50*	*1,00*	*0,75*	*0,50*

40	*14*	*2,10*	*1,40*	*0,95*	*0,63*
64	*20*	*3,00*	*2,00*	*1,20*	*0,80*
132	*36*	*5,40*	*3,60*	*1,72*	*1,15*
240	*60*	*9,00*	*6,00*	*2,32*	*1,55*
305	*74*	*11,10*	*7,40*	*2,62*	*1,75*

Table 6. Design flow rate in pipe supplying WC-cisterns in other buildings with equal water collection

Total number of WC flush valves *n*	**Number of WC flush valves, which are operating simultaneously according to Hunter [6]**	**Design flow rate considering simultaneous demand according to Hunter and with an assumption that the flow rate by one WC flush valve is 1,3 l/s (l/s)**	**Design flow rate in accordance with ČSN 75 5455 [4] (relation (4)) (l/s)**
6	2	2,6	2,5
16	3	3,9	4,1
30	4	5,2	5,6
47	5	6,5	7,0
66	6	7,8	8,3
85	7	9,1	9,4
107	8	10,4	10,5
151	10	13,0	12,5
199	12	15,6	14,4

Table 7. Determination of design flow rate in pipe, which supplies WC flush valve according to Hunter method and its comparison with relation (4)

4 CONCLUSIONS

The design flow rates set by the different methods are generally higher than the measured peak flow rates. Except for the pipes of separate installations supplying only WC - cisterns, where calculation method in accordance with the Slovak [3] and the Czech standards [4] and the method in accordance with the European Standard [1] does not provide good results. It will therefore be necessary to carry out another measurement and the calculation method in accordance with the Slovak [3] and the Czech standards [4] edit.

Acknowledgements

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[3] Slovak standard STN 73 6655 Výpočet vodovodov v budovách (Calculation of water installations inside buildings)

[4] Czech standard ČSN 75 5455 Výpočet vnitřních vodovodů (Calculation of water installations inside buildings)

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