Domestic hot water consumption in educational premises, apartment and office buildings

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Abstract: Investigations of domestic hot water (DHW) consumption and the consumption profiles have been carried out in many countries. Over-dimensioning of systems and equipment has been observed in the US. The last 15–20 years have seen drastic changes in people's DHW consumption in Estonia. Great changes have also taken place in top consumption. In Estonia it is customary to determine DHW design flow rates for schools and children's institutions, residential and office buildings proceeding from the sum of the standard flow rates. The design flow rate calculated by standard EVS 835:2003 for residential and office buildings, ordinary schools and children's institutions are considerably bigger than the actually measured ones. For determining the design flow rates for the determination of the water heating devices for schools, children's institutions, office and residential buildings calculation formulas are recommended. By the recommended formulas the design flow rates for ordinary schools are approximately 1…1.2 times smaller than those calculated by the EVS standard, 1.1…2.1 times smaller for children's institutions and 2 times smaller for office and residential buildings. Recommended calculation formulas reduce over-dimensioning both the DHW instantaneous heat exchangers and the flow rates of the district heating network.

Key-Words: DHW consumption, determining the design flow rates, schools, kindergartens, office and residential buildings.

1 Introduction – literature review

In the 70s of the past century research into domestic hot water (DHW) consumption and the consumption profiles was done by [1, 2]. It should be pointed out that both the DHW consumption level and the consumption profile have radically changed in Estonia during the last 20 years.

The DHW consumption and the consumption profiles have been treated of in many countries. In Asia mention can be made of a year-round study of DHW consumption in Hong-Kong's quality hotels [3].

A large number of investigations in the field of DHW consumption have been made in the US. In 1995 ASHRAE issued new instructions for designing DHW systems in apartment buildings [4], its aim being the prevention of over-dimensioning the systems. In reality the current DHW heating devices proved to be 30-200% over-dimensioned practically all over the States, because very big reserve coefficients were used. Of interest is the study carried out in the United States [5], which analyzes investigations in the field of DHW consumption profiles in small dwelling houses. An investigation by Lutz, Liu, McMahon, Dunham, Shown, McGrue [6] presents a detailed model of residential hot water consumption patterns in individual households.

In Africa investigations of DHW consumption have been carried out in the Republic of South Africa. In Johannesburg a year-round study of DHW consumption was carried out in which the researchers have also displayed the hourly consumptions of DHW [7], [8]. Calmeyer and Delport have dealt with the subject of DHW consumption, including variations in consumption in a students' hostel of Pretoria University [9].

The year 1998 saw a thorough investigation of DHW consumption in English residential buildings [10]. In Hungary Nemetti and Szentho have studied DHW consumption and the consumption profiles in more than 60 residential buildings [11]. In Estonia, in Tallinn University of Technology (TUT) investigations concerning DHW consumption and the consumption profiles have been made by Kõiv, Toode [12, 13, 14, 15, 16, 17, 18].

2 EVS standard calculation method

Investigation of domestic hot water consumption and the consumption profiles in educational buildings have seldom been carried out [9].

In Estonia it is customary to determine the DHW design flow rates for schools and children's institutions proceeding from the sum of the standard flow rates [19] (1)

$$q_{SV,arv} = q_N + \Theta \cdot (\Sigma q_1 - q_N) + A \cdot \sqrt{q_m \cdot \Theta} \cdot \sqrt{\Sigma q_1 - q_N}, \qquad (1)$$

where q_N is the maximum standard flow rate, l/sec for water outlets weighted by the piping studied; Σq_1 is the sum of standard flow rates for water outlets, l/sec; Θ is the probability that the design flow rate $q_{SV,arv}$ occurs at the peak hour; q_m is the mean flow rate for the water outlet studied, l/sec; A is the factor that takes into consideration how often the design flow rate $q_{SV,arv}$ is exceeded; A = f(Θ'), where Θ' is the probability that the necessary standard flow rate $q_{SV,arv}$ is not achieved.

It must be pointed out, however, that in a number of types of buildings (e.g. schools, educational institutions) the use of a large number of DHW devices (first of all mixers in classrooms) is very, very small. Such a situation leads to over-dimensioning of the DHW heating devices and also to that of the flow rates of the district heating network water necessary for heating DHW.

3 DHW consumption in residential buildings

3.1 Changes in DHW consumption

Comparing the average DHW consumption per 1m² of heated area today and in the 1970s, we can see that it has decreased 3.3 times, Fig.1.

In such a situation essential changes have also taken place in the maximum consumption in apartment buildings.

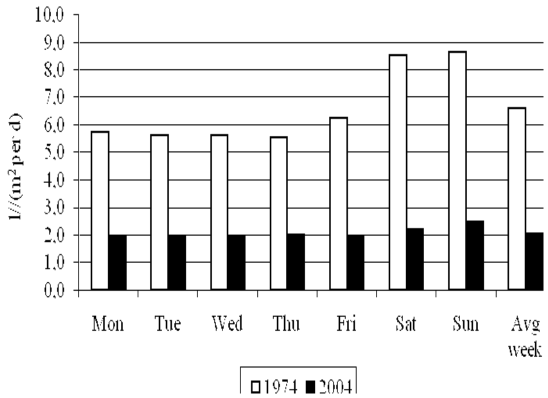

Fig. 1 Average DHW consumption per weekdays and per week in the years 1974 and 2004

3.2 Recommendations for dimensioning DHW heating load

The DHW maximum consumption and consumption profiles was investigated in 23 apartment buildings. Proceeding from the flow rates obtained by recording DHW consumption in characteristic apartment buildings (Table 1) and their analysis a new formula (2) for determining the heating load has been worked out. The latter is presented graphically in Fig. 2 (dependence of the heating load on the number of apartments).

The measured points correspond to the loads determined by the maximum DHW consumption in apartment buildings with a given number of apartments in them.

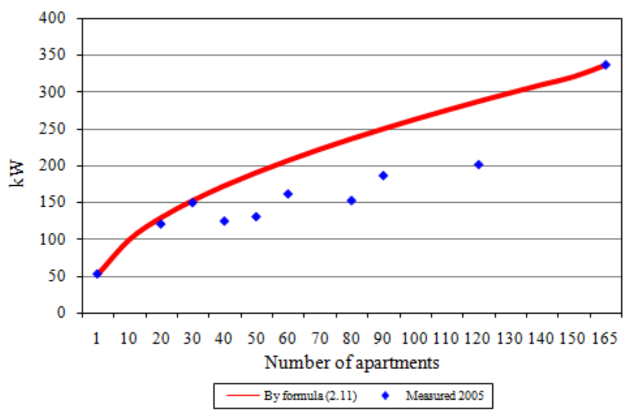

Fig. 2 Dependence of the DHW heating load on the number of apartments in a residential building

Table 1 Apartment buildings where the investigation of the DHW consumption profile was carried out

Address	Number of apartments
Ravi 19	18
Sütiste tee 10	30
Tammsaare tee 104	30
Siili 13	35
Ehitajate tee 54	40
Vilde 135	48
Vilde 137	48
Akadeemia tee 52	48
Sütiste tee 15	60
Tammsaare tee 106	59
Mustamäe tee 171	60
Mustamäe tee 171a	60
Sõpruse pst. 244	60
Ehitajate tee 84	60
Keskuse 14	80
Mustamäe tee 124	80
Sütiste tee 13	89
Mustamäe tee 173	89
Vilde 78	89
Sõpruse pst. 219	119
Tammsaare tee 107	119
Sõpruse pst. 202	165

Below we present a formula for determining the heating load of DHW instantaneous heat exchangers if the temperature difference of hot and cold water is 50°C.

$$\Phi_{sv} = 30 + 15 \cdot \sqrt{2 \cdot n} + 0.2 \cdot n \qquad (2)$$

where n is the number of apartments.

The average number of inhabitants in an apartment is 2.2, in every apartment there is mixer in the kitchen and another in the bathroom. If the DHW temperature is other than 55°C, a correction factor should be used in determining the load, e.g. at the temperature

60°C – correction factor 1.1 and
65°C – correction factor 1.2.

Fig. 3 presents the loads of DHW instantaneous heat exchangers determined for apartment buildings by the proposed formula and by the EVS/D1 (Estonia-Finland) method against the background of the maximum values of the results of measuring. Fig. 3 shows that in larger apartment buildings the heating loads of the heat exchangers differ up to two times.

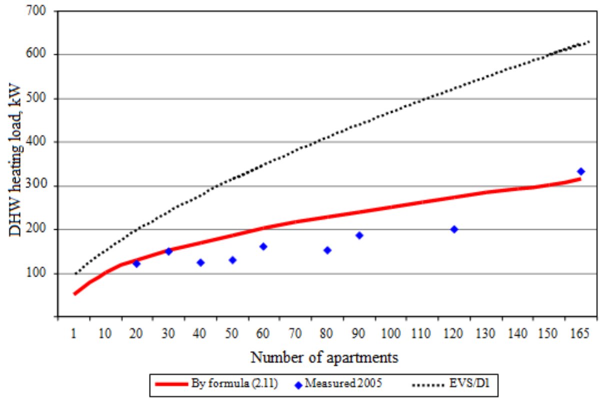

Fig. 3 DHW design heating load depending on the number of apartments by the EVS/D1 method and by the proposed formula together with the points calculated on the basis of the results of measuring

3.2 DHW consumption profile in residential buildings

The investigation of the consumption profile covers 22 apartment buildings at Mustamäe 30-, 35-,40-, 60-, 80-, 90-, 120-, 165- apartment residential buildings and one 18-apartment brick building in the center of the city.

For studying the DHW consumption profile impulse water meters were used. For recording the data they were connected with loggers. The measuring diagram is in Fig.4. Data processing was made by software PDL-Win. The consumption profile of the building was recorded during a week.

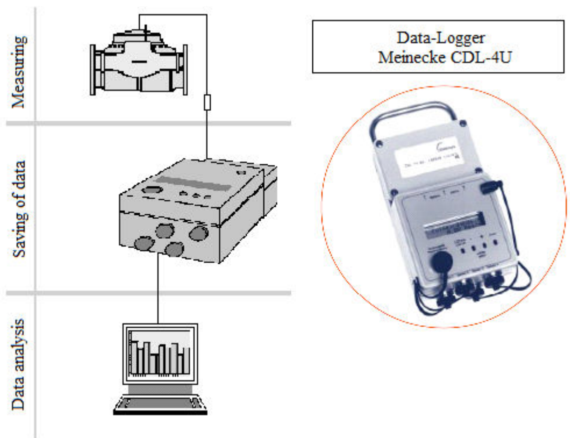

Fig.4 Diagram of the data recording for the investigation

The weekly variability which characterizes DHW consumption profiles is determined on the basis of formula (3)

$$K_h = G/G_{av} \quad (3)$$

where G is the given hourly DHW consumption; G_{av} is the average hourly DHW consumption of the week.

The characteristic variability graphs of DHW consumption in apartment buildings are presented in Figs. 5, 6, 7, 8, 9 and 10.

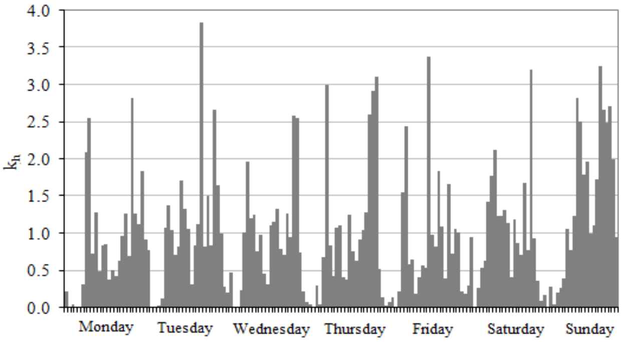

Fig.5 Variability graph of DHW consumption within a week in the 30-apartment residential building at 104 Tammsaare Road

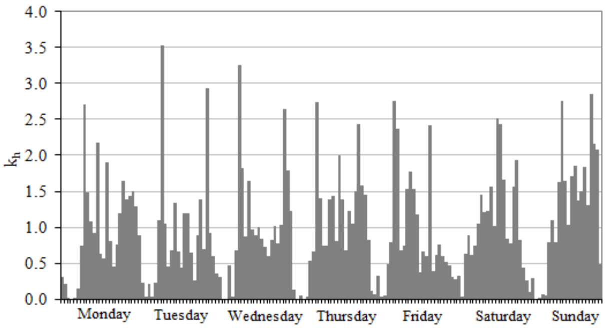

Fig.6 Variability graph of DHW consumption within a week in the 48-apartment residential building at 137 Vilde Road

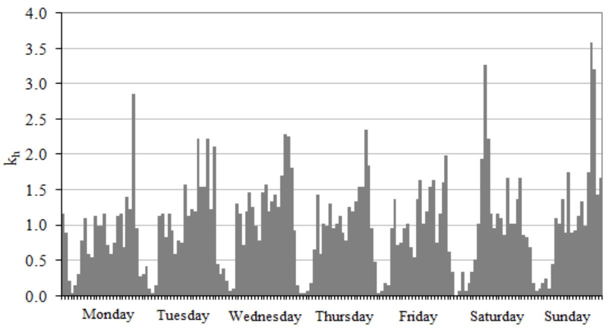

Fig.7 Variability graph of DHW consumption within a week in the 60-apartment residential building at 171 Mustamae Road

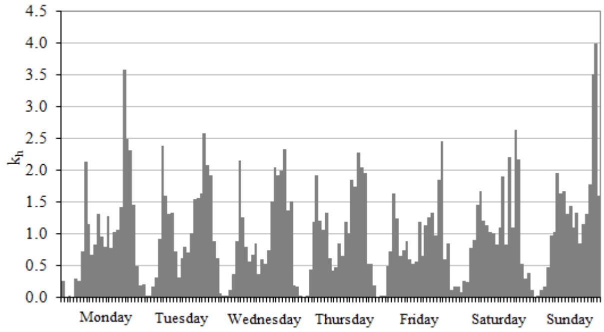

Fig.8 Variability graph of DHW consumption within a week in the 90-apartment residential building at 13 Sutiste Street

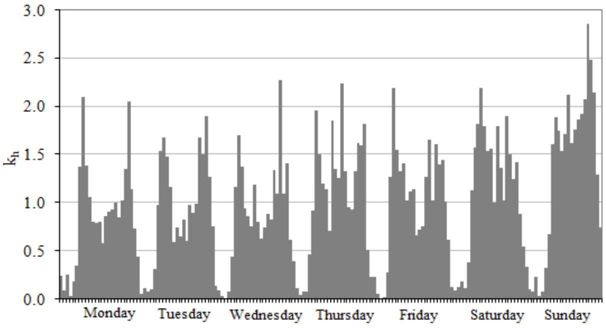

Fig.9 Variability graph of DHW consumption within a week in the 165-apartment residential building at 202 Sopruse Road

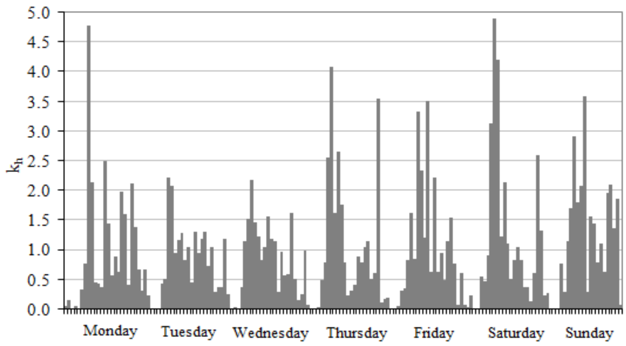

Fig.10 Variability graph of DHW consumption within a week in an 18-apartment residential building

Hourly maximum variability factors within a week in characteristic apartment buildings are given in Table 2 and in Fig.11.

In Fig. 11 it can be seen that the hourly maximum variation within a week in characteristic residential buildings vary from 2.9 to 4.9 (in 165-and 18-apartment residential buildings).

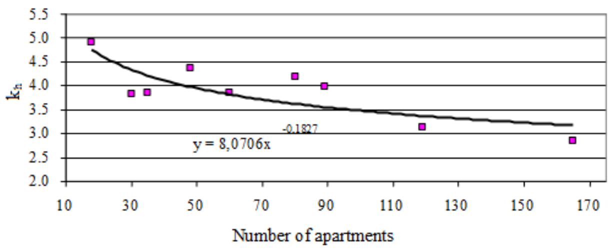

Fig. 11 Hourly maximum variability factors within a week in characteristic residential buildings and a trend line with an equation

Table **Error! No text of specified style in document.** Hourly maximum variability factors

Address	Number of apartments	The hourly variability in DHW consumption (maximum value)
Ravi 19	18	4.9
Tammsaare tee 104	30	3.8
Siili 13	35	3.9
Vilde 135	48	4.4
Sopruse pst. 244	60	3.9
Keskuse 14	80	4.2
Sutiste tee	89	4.0
Sopruse pst. 219	119	3.1
Sopruse pst. 202	165	2.9

within
a week in characteristic apartment buildings

In addition weekly variability graph of DHW consumption in the apartment building at 16 Siili Street in 1973 in Fig 12.

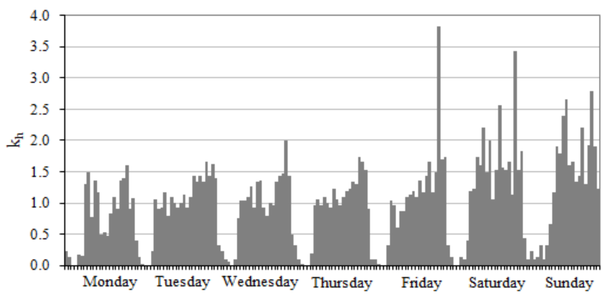

Fig. 12 Weekly variability graph of DHW consumption in the apartment building at 16 Siili Street in 1973

Comparing DHW consumption today and in the 1970s we can see apparent changes, especially concerning weekdays. In today's DHW consumption we can quite clearly see both the morning and the evening maximum consumption, with the morning maximum consumption often surpassing the evening one. In the 1970s DHW consumption on workdays was characterized by a definite increase in the evening consumption, a certain increase in consumption could be observed only on the morning of some particular day. Characteristic of DHW consumption on rest days in the 1970s was a considerable increase (approximately 1.5 times) in consumption when compared with that on workdays. Maximum consumption also took place on rest days, occasionally also on Friday evenings. Recent years have seen considerable changes in DHW consumption at weekends. Increase in consumption is no longer so distinctly prominent. When compared with that on workdays, the average increase in consumption is 1.2 times. It should be pointed out, however, that in a few apartment buildings the consumption profile is very much the same as it was in the 1970s.

4 Domestic hot water consumption in educational and office buildings

4.1 Educational institutions

In the last 3 years TUT investigated the DHW maximum consumption and consumption profiles in 25 schools. Most of them use one-stage instantaneous water heaters.

For studying the DHW consumption profile impulse water meters were used. For recording the data they were connected with loggers, Fig. 4. Data processing was made by software PDL-Win.

The characteristic data of schools are presented in Table 3.

The flow rates recorded in schools and those determined by the standard method EVS 835:2003[19], European standard EN 806 – 3 [20] and by the formula (4) are presented in Table 4.

In determing the design flow rates by EVS 835:2003 we proceeded from the standard flow rates which are 0.2 l/sec both for showers and sinks.

In Table 4 it can be seen that the design flow rates calculated by the EVS 835:2003 schools without swimming-pools are considerably bigger than the actually measured ones, which fact results in over-dimensioning both the DHW instantaneous heat exchangers and the control devices.

From the data in Table 4 we can see that the design flow rates determined for schools without swimming-pools by the Euro standard do not suit Estonia's conditions. The results received for schools without swimming-pools by the EN standard are approximately 4 times bigger than the flow rates determined by the EVS standard.

Table 3 The characteristic data of schools

School	Number of pupils/ students	Number of showers	Number of DHW outlets
Westholm Gymnasium	500	9	66
Humanitary Gymnasium	710	12	109
Liivalaia Gymnasium	400	9	44
Sõle Basic School	190	9	24
Mustamäe Gymnasium	620	6	59
Kadrioru Gymnasium	750	4	47
Mustjõe Gymnasium	650	6	29
Rahumäe Basic School	565	9	102

Table 4 Comparison of the actual flow rates determined by the results of recording with those determined by the EVS 835:2003, the EN 806-3 and by formula (4)

School	Design flow rate by EVS l/sec	Design flow rate by EN 806-3 l/sec	Flow rate mea-sured l/sec	Design flow rate by formula (4) l/sec
Westholm Gymnasium	1.01	4.54	0.62	0.86
Humanitary Gymnasium	1.31	5.20	0.71	1.25
Liivalaia Gymnasium	0.83	3.99	0.25	0.73
Sõle Basic School	0.63	2.83	0.49	0.55
Kadrioru Gymnasium	0.85	3.66	0.30	0.73
Mustamäe Gymnasium	1.29	5.19	0.77	0.98
37th Secon-dary School	0.69	2.72	0.26	0.69
Rahumäe School	1.29	5.14	0.46	1.03

By the EN 806-3 the standard flow rate of every kitchen sink and shower in 0.2 l/sec, that of other sinks is 0.1 l/sec.

Because the flow rates determined by the EVS for schools are 1.6…3.3 times bigger than the actual consumption, a new empirical formula is recommended for determining the design flow rates on the basis of which the water heating devices can be selected for schools without a swimming-pools (4)

$$q= 0.04\ N_1 + 0.00053\ N_2 + 0.0036\ N_3 \quad (4)$$

where q is design flow rate l/sec; N_1 is number of showers; N_2 is the number of students, N_3 is the number of DHW outlets.

In Table 4 it can be seen that the design flow rates determined by the calculation formula (4) are 1.1…1.2 times smaller than those calculated by the EVS standard.

In Fig.13 we can see the comparison of the design flow rates determined by calculation formula (4) and by the EN standard.

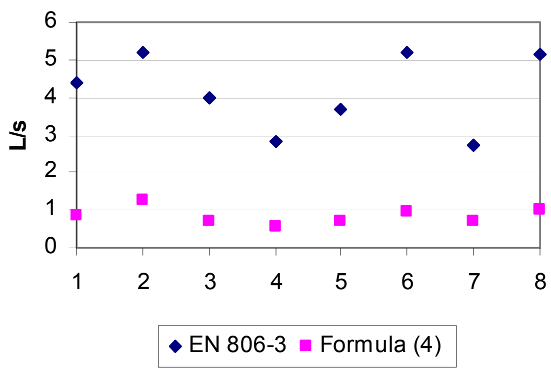

Fig.13 Comparison of the design flow rates determined by the EN standard and by formula (4) for different schools.

The weekly variability which characterizes schools' DHW consumption profiles is determined on the basis of formula (3).

The weekly variability graph of DHW consumption is presented in Fig.14.

As can be seen in Fig. 14 in schools without swimming-pools there is no DHW consumption at weekends in practice. Maximum consumption on weekdays takes place at lunchtime.

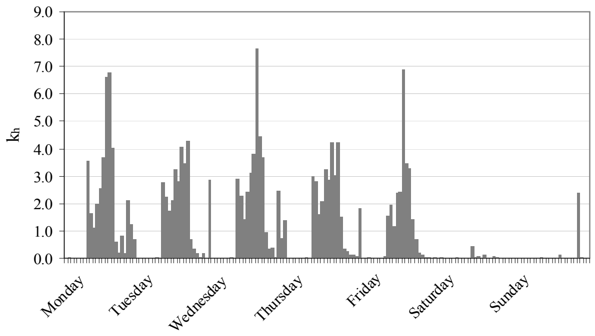

Fig. 14 Weekly variability graph of DHW consumption in the Õismäe Gymnasium (2006)

4.2 Children's institutions

DHW maximum consumption and consumption profiles were investigated in 18 children's institutions.

The characteristic data of kindergartens are presented in Table 5. The flow rates of DHW recorded in kindergartens and those determined by the standard EVS 835:2003[19] and by the formula (5) are presented in Table 6.

Table 5 Data characterizing the kindergartens

Children's institution address	Number of children	Number of showers	Number of DHW outlets
Kannikese 13	82	7	47
Uus-Kalamaja 6	179	10	58
Ädala 3	215	14	78
Komeedi 3	94	5	21
Mardi 5	224	14	69
Sütiste 7	240	13	83
Endla 21	100	6	30
Järveotsa 15*	186	8	65

*With swimming-pool

In Table 6 we can see that the design flow rates determined by the EVS 835:2003 are bigger than the actual ones, which fact results in over-dimensioning the DHW instantaneous heat exchangers and the control devices.

As the design flow rates determined by the EVS for kindergartens are 1.4…4 times bigger than the measured ones, a new empirical formula is recommended for determining them in selecting water heating devices (5)

$$q= 0.0009\, N_1 + 0.0035\, N_2 + 0.0025\, N_3 \quad (5)$$

where q is design flow rate l/sec; N_1 is number of showers; N_2 is the number of children; N_3 is the number of DHW outlets.

It can be seen that the design flow rates determined by calculation formula (5) are 1.1…2.1 times smaller than those calculated by the EVS standard.

Table 6 The flow rates recorded in kindergartens and those determined by the standard EVS 835:2003 and by the formula (5)

Children's institution address	Design flow rate by EVS l/sec	Flow rate measu-red l/sec	Design flow rate by calculation formulas (5) l/sec
Kannikese 13	0.85	0.21	0.41
Uus-Kalamaja 6	0.94	0.43	0.78
Ädala 3	1.09	0.57	0.96
Mardi 5	0.70	0.42	0.64
Komeedi 3	0.60	0.39	0.39
Sütiste 7	1.13	0.82	1.06
Endla 21	0.70	0.39	0.43
Järveotsa 15*	1.00	0.62	0.82

*With swimming-pool

The weekly variability which characterizes kindergartens' DHW consumption profiles is determined on the basis of formula (3).

Variability graphs of DHW consumption in the kindergarten in 16 Planeedi Street is presented in Fig.15. In kindergartens there is no DHW consumption at weekends.

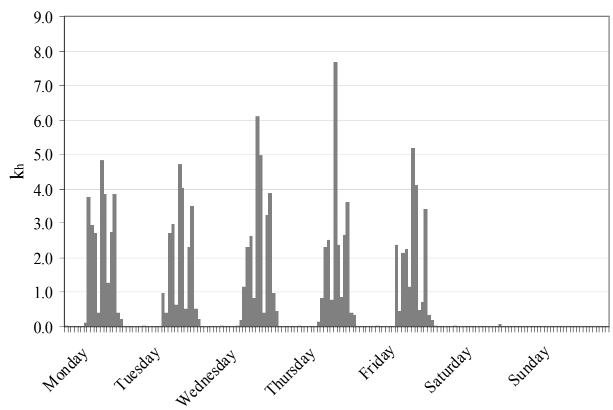

Fig.15 Weekly variability graph of DHW consumption in the 16 Planeedi Street

4.3 Office buildings

In the last years in TUT investigated the DHW maximum consumption and consumption profiles in 18 office buildings. The characteristic data of office buildings are presented in Table 7.

Table 7 Data characterizing the office buildings

Office building address	Number of people	Number of showers	Number of DHW outlets
Tartu mnt 85	152	6	41
Pärnu mnt 7	110	3	15
Endla 10a	150	1	19
Tatari 39	104	2	17
Endla 13	125	7	35
Kotzebue 14	95	1	19
Kentmanni 13	140	2	25
Liivalaia 24	175	4	44
Ehitajate Vb	117	2	20

Table 8 Comparison of the actual flow rates determined by the results of recording with those determined by the EVS 835:2003, the EN 806-3 and by formula (6)

Office buildings	Design flow rate by EVS l/sec	Design flow rate by EN 806-3 l/sec	Flow rate mea-sured* l/sec	Design flow rate by formula (6) l/sec
Tartu mnt 85	0.8	3.3	0.26	0.47
Pärnu mnt 7	0.53	1.8	0.19	0.28
Endla 10a	0.58	2.0	0.20	0.35
Tatari 39	0.55	1.9	0.24	0.27
Endla 13	0.74	3.1	0.20	0.41
Kotzebue 14	0.56	2.0	0.14	0.25
Kentmanni 13	0.64	2.4	0.23	0.36
Ehitajate Vb	0.56	2.1	0.13	0.30

*Maximum flow rates

The flow rates recorded in office buildings and those determined by the standard method EVS 835:2003[19], European standard EN 806 – 3 [20] and by the formula (6) are presented in Table 8. In Table 8 it can be seen that the design flow rates calculated by the EVS 835:2003 office buildings are considerably bigger than the actually measured ones. We can see that the design flow rates determined for office buildings by the Euro standard do not suit Estonia's conditions.

A new empirical formula is recommended for determining the design flow rates in office buildings (6)

$$q= 0.008*N1 + 0.0019*N2 + 0.0032*N3 \quad (6)$$

where q is design flow rate l/sec; N_1 is number of showers; N_2 is the number of people, N_3 is the number of DHW outlets.

In Table 8 it can be seen that the design flow rates determined by the calculation formula (6) are 1.2…2.2 times smaller than those calculated by the EVS standard**.** In Fig.16 we can see the comparison of the design flow rates determined by calculation formula (6) and by the EN standard, the difference between the design flow rates determined by formula (6) and by the EN standard being up to 8 times.

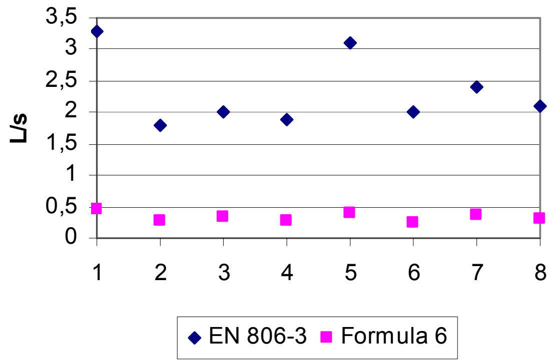

Fig.16 Comparison of the design flow rates determined by the EN standard and by formula (6) for different office buildings**.**

The hourly variation in DHW consumption is indicated with the ratio of the given hourly consumption to average hourly consumption of a week, formula (3) and the consumption profile graphs are presented in Figs. 17, 18 and 19.

The graph given in Fig. 17 is typical of smaller office buildings that have no sauna and no rest room. Characteristic of such office buildings is the DHW consumption only on workdays with the top consumption only at lunchtime. In office buildings with a sauna and a rest room DHW is consumed also on rest days, i.e. on Saturdays and Sundays, Fig. 18. In big office buildings where there are saunas and rest rooms (Fig. 19) DHW consumption at weekends is quite considerable. A characteristic feature of smaller office buildings is a great variation in DHW consumption.

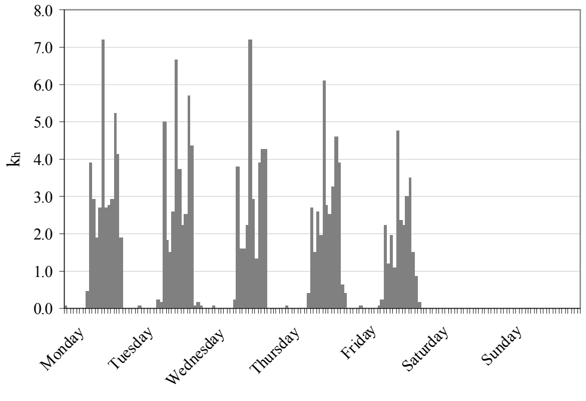

Fig. 17 Weekly variability graph of DHW consumption in the office building at 14 Kotzebuse Street (2006)

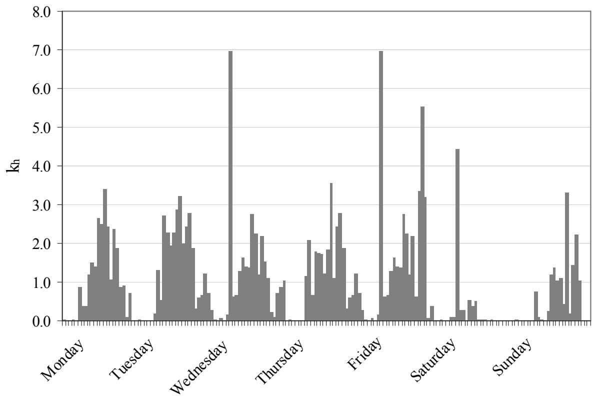

Fig. 18 Weekly variability graph of DHW consumption in the office building at 13 Kentmani Street (2006)

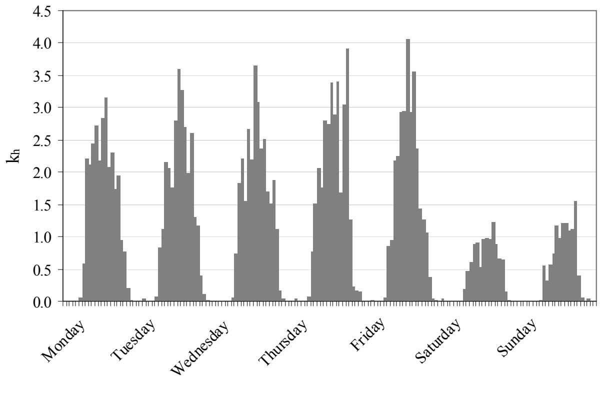

Fig. 19 Weekly variability graph of DHW consumption in the office building at 1 S-Ameerika Street (2006)

5 Conclusions

The last 15–20 years have seen drastic changes in people's DHW consumption in Estonia. The great changes have been caused primarily by

- Transition to payment for actual consumption in connection with water meters installed in apartments
- A sharp increase in the price of water and heat
- Renovation of DHW system in residential buildings, including that of circulation systems
- Use of water-saving water outlet devices.

Great changes have also taken place in top consumption. It goes without saying that in such a situation it is necessary to take into use a new method for maximum consumption.

Investigations show that the design flow rates in schools determined by the recommended formula are 1.1…1.2 times smaller than those calculated by the EVS standard and 3.9…5.5 times smaller than those determined by the EN standard.
It must be pointed out that the recommended calculation formulas are fairly conservative, when compared with the actual consumption, as there is a double reserve in most buildings.

In kindergartens the design flow rates determined by the recommended formula are approximately 1.1…2.1 times smaller than those calculated by the EVS standard.

In office buildings the design flow rates determined by the recommended formula are approximately 2 times smaller than those calculated by the EVS standard and up to 7.5 times smaller than those determined by the EN standard.

In residential buildings the design load determined by the recommended formula are up to 2 times smaller than those calculated by the EVS standard.

Investigations show that the recommended calculation formulas reduce over-dimensioning of both the DHW instantaneous heat exchangers and the flow rates of the district heating network. A comparison of calculations for small tree-form district heating networks shows that in using the new method of determining the flow rates for heating the DHW it is possible to decrease the cost of the district heating network by about 30% and with the heat losses decreasing by 25% [15].

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