The influence of domestic hot water maximum consumption on the district heating network dimensioning

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Abstract: Domestic hot water consumption trends in Estonian apartment buildings are presented. Changes in domestic hot water consumption profile are shown. The results of measuring show that the actual maximum consumption values are substantially less than the design values. A new formula for calculating the domestic hot water load for dimensioning instantaneous heat exchangers is recommended. The influence of the new calculation method for dimensioning the pipes of the district heating network is analyzed; the results of the calculation of initial and operating costs are presented.

Key-Words: Hot water consumption, consumption profile, dimensioning of heat exchangers, initial and operating costs of district heating network.

1 Introduction

Interesting aspects in the operation of building service systems are the domestic hot water consumption rate, changes in consumption in recent years and equipment dimensioning**.** Investigations in that line have been carried out in the USA, Great Britain, New Zealand, South Africa, Russia, Estonia, Denmark, Canada, Senegal, Hungary. [1,2,3,4,5,6,7,8,9,10,11,12,13, 14, 15].
In the 1970s the domestic hot water consumption in residential buildings was relatively high: for example, in the former Soviet Union 95 l/d per person or more [5, 6]. The latest investigations tell us about a decrease in domestic hot water consumption: in Russia 68-92 l/d per person (as design values) [7], in the USA residential homes 46-85 l/d per person [8]. The investigation carried out in Great Britain shows that domestic hot water consumption is influenced by the age of people, the number of children in the family, the income of the family, the number of persons in the family, etc [9].
Changes in the consumption profile vary from country to country. There have been only minimal changes in the domestic hot water consumption profile in Russia [10]. But the domestic hot water consumption profiles of apartment buildings in Estonia [11] have changed considerably and are close to the consumption profiles in the USA [12] and Denmark [13].

The dimensioning of a tree-form district heating network is usually based on the maximum values of heating and water heating loads, more exactly on flow rates of networks calculated by these loads. By optimal dimensioning of the pipes of the network it is possible to essentially reduce both the initial and the operation costs of the network.
The paper presents the influence of the new hot water load calculation method on dimensioning the diameters of the pipes of the district heating network and the operation costs.

2 Domestic hot water consumption and consumption load for apartment buildings in Estonia

A large-scale investigation of domestic hot water consumption in apartment buildings was carried out in Estonia in the years 1999 - 2005, Fig.1. The investigation shows great changes in water consumption and in the hot water consumption profile, Fig. 2, 3, 4. Domestic hot water consumption in Estonian apartment buildings during the last 30 years has decreased more than 3 times (l/d per m^2), Fig. 2. The main reasons for a decrease in domestic hot water consumption are: consumption metering in apartments and payment by real consumption, the high cost of water and heat and a continued tendency of increase, extensive renovation of domestic hot water systems.

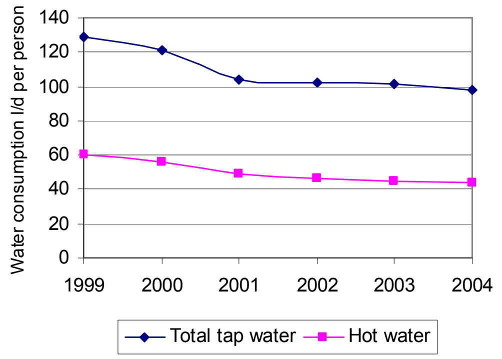

Fig.1 Domestic hot water and total tap water consumption in l/d per person in the years 1999-2004

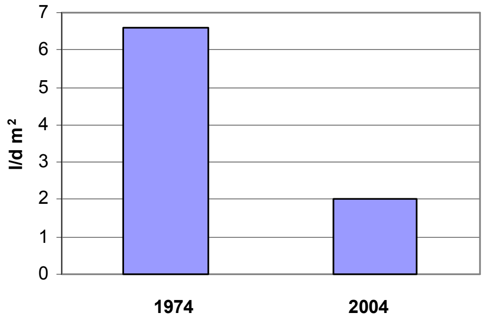

Fig.2 The domestic hot water consumption data in 1974 and 2004 per apartment area (the general area of apartments)

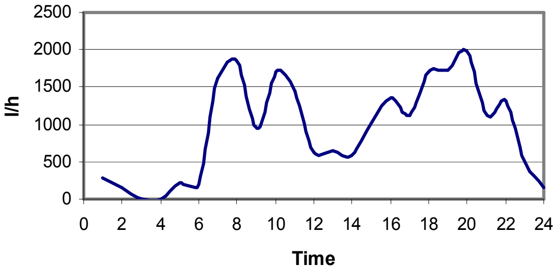

Fig.3 Consumption profile of a 90-apartment building in 1974 (on Monday)

At present the daily consumption is characterized by the morning maximum value, Fig.4, which is more close to the consumption profile in West European countries [13].
In Estonia and in other East European countries instantaneous heat exchangers are commonly used for domestic hot water heating in heat substations in the conditions of district heating.
Maximum domestic hot water consumption in apartment buildings was investigated by using impulse water meters (one impulse per one liter), which were connected with data loggers. The hot water temperature was adjusted to the level of 55°C. The data collection of hot water consumption in 23 apartment buildings (average number of tenants being 2.2 per apartment) lasted from one to two weeks. Besides the consumption profile this investigation enables us to get data about the maximum domestic hot water consumption.
The results of measuring the consumption show that the actual maximum consumption values are substantially less than the designed values by standard [16], Table 1.
As a result of great changes in domestic hot water consumption, a new method for dimensioning the domestic hot water load for instantaneous heat exchangers was necessary.
It is essential to remark that the maximum values presented in Table 1 are the largest for different groups of apartments. On the basis of maximum domestic hot water values (Table 1) and the difference in temperatures of 50°C, were calculated maximum heat load values for each group of buildings, (see points on Fig.5). On the basis of these heat load values the curve Φ=f(n) was constructed on the presumption, that all the calculated heat load values were below the curve, Fig.5.

Table 1 Measured and calculated (by EVS 835, 2003 [16]) values of maximum domestic hot water consumption in apartment buildings

Number of apartments	Measured maximum values, l/s	Calculated values by EVS 835, 2003 [16], l/s
18	0.64	0.93
30	0.71	1.17
40	0.59	1.35
48	0.66	1.48
60	0.73	1.67
80	0.73	1.97
90	0.8	2.11
120	0.96	2.51
165	1.61	3.07

Mathematically this curve is expressed by formula (1).
The worked-out formula is based on the measured maximum consumption values of hot water in buildings with a different number of apartments. The formula (1) being valid for the 50 degrees

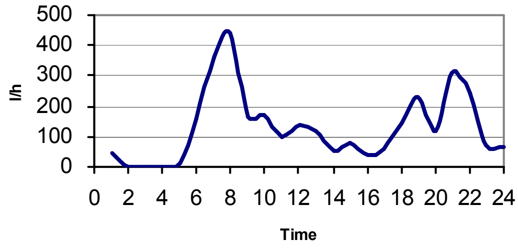

Fig.4 Consumption profile of a 30-apartment building in 2005 (on Tuesday)

difference in the temperatures of hot and cold water

$$\Phi = 30 + 15 \cdot \sqrt{2 \cdot n} + 0.2n \qquad [\text{kW}] \qquad (1)$$

where n is number of apartments.

As maximum load values used in working out the new method were about 20% higher than the average consumption values, formula (1) has a sufficiently large reserve.

In apartment buildings of Estonia domestic hot water heating by instantaneous heat exchangers is a basic method. Today the formula (1) is used for dimensioning heat exchangers in the heat substations of the district heating networks for apartment buildings [17].

Fig.5 presents the results of the dimensioned load calculated by the recommended formula (1), by the EVS method with results based on values measured and calculated on the basis of European Standard EN 806-3 [16]. We can see that the values calculated by the standards and by the real consumption differ more than 2 times.

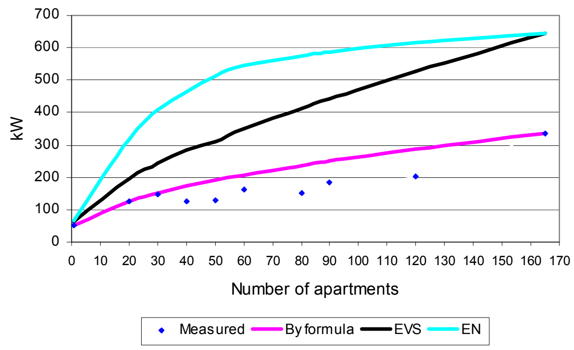

Fig.5 Values of the domestic hot water heating load for dimensioning instantaneous heat exchangers in different apartment buildings on the basis of formula (1), EVS, EN method and values calculated on the basis of domestic hot water consumption measured

Formula (2) is advised for determining the maximum water consumption in school buildings

$$q = 0.001 \cdot N + 0.06 \qquad [\text{l/s}] \qquad (2)$$

where N is number of pupils.

Domestic hot water heating load is calculated by formula (3)

$$\Phi = q \cdot c \cdot \Delta t \qquad [\text{kW}] \qquad (3)$$

where q is maximum water consumption; c is specific heat; Δt is difference in the temperature of hot and cold water.

3 Influence of the new load calculating method on dimensioning the pipes and on the operation costs for a smaller tree-form district heating network

The domestic hot water load calculated by standard differs 2 or more times from the one calculated by the new method. It is interesting to show the influence of the domestic hot water consumption on dimensioning the diameters of pipes and the operation costs of the district heating network if the calculation is based on the new load values and on the probability of the hot water consumption.

An example of the calculation was carried out for a tree-form network with 8 consumers, Fig. 6.

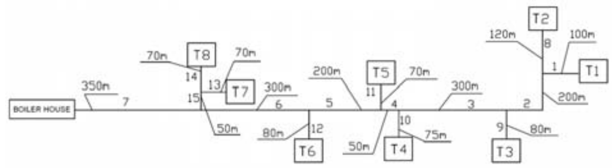

Fig.6 Scheme of the district heating network, T1…T8 consumers: apartment buildings and a school building

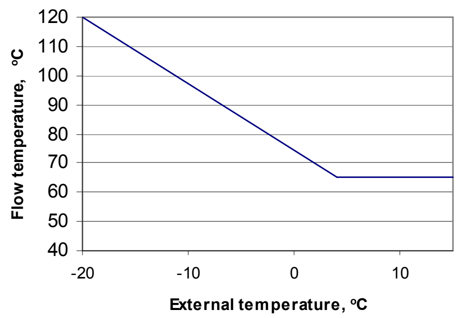

Fig.7 Temperature graph in flow pipes of district heating network

A combined temperature graph is often used in the flow pipes of the district heating network, Fig. 7. The water flow rates for different segments of the network were calculated in conditions of “brake point” by formula (4)

$$G_1 = \sum_1^m G_{1,h_i} + \sum_1^m G_{1,hw_i} \qquad (4)$$

where $G_{1,h\,i}$ is flow rate calculated by heating load and by the difference between the calculated temperatures for the consumer i; m is the number of consumers; $G_{1,hw\,i}$ is flow rate calculated by domestic hot water load and by the difference between the calculated temperatures for the consumer i.

The $G_{1,hw\,i}$ value is calculated differently for the standard and the new calculation methods. For the standard method the domestic hot water loads for each consumer were calculated by the EVS standard [10] and summed up, but for the new method the domestic hot water loads were calculated by formula (1) for each segment of the network with which a decrease in the relative consumption was taken into account as the number of consumers increased (coefficient of simultaneity decreases). Pipe diameters for different segments of the network were determined by a hydraulic calculation.
For standard calculation method, the diameters of the segments of the network varied from 40 to 125 mm. In using the new calculation method, the diameters of the segments of the network decreased, the new values varying from 32 to 80 mm.
The thermal energy for heat losses of the network is calculated by formula (4)

$$Q = \tau \sum_1^k \varphi_i \cdot l_i / 10^6 \qquad \text{MWh} \qquad (4)$$

where φ_i is special heat losses [W/m]; l_i is length of segments [m]; τ is operation time of network [h]; k is number of segments with different diameters.

Pumping costs for the district heating network are calculated by

$$C = P \cdot \tau \cdot C_e / 1000 \qquad \text{thousand kroons} \qquad (5)$$

$$P = H \cdot q \cdot 9.81 \cdot / (3.6 \cdot \eta_p \cdot \eta_m) \qquad \text{kWh} \qquad (6)$$

where C is pumping costs; P is the pumping consumption [kW]; τ is running time in hours; C_e is price of electricity for one kWh; H is pump head in meters WG; q is water flow rate [l/h]; η_p is pump efficiency; η_m is motor efficiency.

Table 2 Calculation results for district heating network

	Cost of pipes, million kroons	Heat losses and pumping costs, million kroons
Calculation by standard	5.23	30.3
Calculation by new method	3.79	27.8
Decrease in cost	1.44	2.5
Decrease %	28%	8%

Heat losses and pumping costs are calculated for a period of 40 years, increase in electricity and the cost of thermal energy was taken to be 3% per year. The price of electricity was taken to be 1.5 kroons per kWh and that of thermal energy 1 kroon per kWh.
The results of the calculation for the district heating network are presented in Table 2.
We can see that the new method of calculating the domestic hot water load and taking into account the probability of the hot water consumption in dimensioning the pipe diameters of different segments give an essential reduction in investments for the district heating network – 28%. At the same time the decrease in the operating costs is 8%.

4 Conclusions

Domestic hot water consumption in Estonian apartment buildings during the last 30 years has decreased more than 3 times (l/d per m^2). The main reasons for a decrease in the domestic hot water consumption are: consumption metering in apartments and payment by real consumption, the high cost of water and heat and a continued tendency of increase, extensive renovation of domestic hot water systems. Great changes in the domestic hot water consumption profile have taken place in recent years, the daily consumption is characterized by the morning maximum value unlike by the evening maximum value in the years 1970-1985. As the results of measuring show that the actual maximum consumption values are substantially less than the designed values, a new formula for calculating the domestic hot water load for dimensioning instantaneous heat exchangers is recommended for apartment and school buildings. An analysis was carried out to determine the influence of the new calculation method on dimensioning the pipes and the costs of operating the district heating network. The results showed that for a smaller tree-form network the decrease in investments was 28% and the decrease in operating costs 8%. For these networks with an essential part of domestic hot water in the heat load and taking into account the probability of domestic hot water consumption in the dimensioning of the pipe diameters of different segments, the new calculation method gives an essential reduction in investments for the district heating network and a decrease in the operating costs.

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