Diagrams of seasonal and daily hot water consumption by apartment buildings (ab) in the moscow region

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Abstract. The article presents an analysis of hot water consumption in apartment buildings of the Moscow region. This study was conducted based on monitoring actual data on hot water consumption by apartment buildings (AB) in Moscow and the Moscow region. The results were used to develop a computational model for the daily use of hot water in apartment buildings.

1. Introduction
The object of this study is the consumption of hot water in residential apartment buildings located in Moscow and the Moscow region with an average population of 18-22 m²/person. The number of residents in buildings under study is about 400-500 people (depending on the area).
The amount of hot water consumption has a significant effect on energy consumption. The standard indicator used to describe water consumption is average water consumption per person. One of the most commonly used indicators in the world as a parameter of hot water consumption is the number of residents in apartments. Parker [1] noted that counting residents is a key factor determining the consumption of hot water. In this regard, he used the employment model in modeling the consumption of energy consumed for hot water. Evarts and Swan [2] found higher consumption of DHW in households, in particular, higher specific consumption of hot water in homes with a smaller number of inhabitants. As confirmed by the analysis of Ahmed, Pylsi and Kurnitsky [3], Merrigan [4], Georg, Pyrrha and Swan [5] and Hendron Birch [6], who found a linear relationship between water consumption and the number of inhabitants. In the work of Agnieszka Chmielewska and Małgorzata Szulgowska it is shown that consumption increases by 40-45 l/day for each additional resident. According to Canadian researchers [7], buildings where mostly older people live are consumed 44% less DHW than in standard apartment buildings [8]. Also, many authors note that the presence of children causes a higher level of hot water consumption [9]. Foekema and Engelsma [10] found that there is also a relationship between frequency of use and duration of showering, as well as age and size of households in a Dutch residential building. Despite many studies, the calculation method used in Poland [11] or Germany [12] is very simplified. Polish rules [11] regarding the calculation of the average daily consumption of hot water, use the total
area of the building as a parameter. In the case of German regulation, there is a reference to the number of tenants. It is also worth noting that it is important to use profiles based on data from the actual country and the current economic situation when creating energy consumption models.

In Russia, in 2007-2013, the specific energy consumption per 1 m² of living space, when reduced to comparable weather conditions, decreased by 13%. The specific energy consumption per 1 m² in 2012 was 43.4 kg sf/(m² per · year) in Russia, or 353 kWh/m². At the same time, in old buildings the specific consumption is higher - 44.5 kg sf/(m² per · year), and in new buildings (30.4 kg sf/(m² per · year) – below the average value. The share of apartments and apartment buildings increased significantly equipped with energy consumption metering devices[8]. However, despite the undoubted progress in recent years, in a number of cases the indicators of energy efficiency in the housing sector turned out to be worse than the targets of the State Program “Energy Saving and Energy Development” [13].

It should be noted that the average energy consumption in Russia per 1 m² of a residential building (363 kWh/m²) is not much different from the average value of Finland (320 kWh/m²), where climatic conditions are close to ours. At the same time, the average Russian values are much higher than the EU average (220 kWh/m²) or in Spain (150 kWh/m²), where the average number of degree-days of the heating period is significantly lower. In the USA, the specific energy consumption per 1 m² is 450 kWh/(m² per · year), in Japan - 300 kWh/(m² per · year), and for the urban population of China - about 175 kWh/(m² in · year) [14]. But this indicator does not reflect the influence of a number of factors, such as the structure of housing stock by height, the provision of household appliances and their average power and quality of the energy resources used do not separately reflect the DHW volume in the consumption structure.

The study of the consumption of hot water supply in residential premises is currently relevant in many countries of the world, including Russia. Experimental data can show the actual picture of the consumption of hot water by apartment dwellers, and measurements carried out over a long period of time show the dynamics and characteristics of changes in hot water consumption. All this may in the future serve as the basis for the calculation of the program for creating and optimizing more comfortable living conditions for the population.

Our study was conducted to determine the actual consumption of hot water during the year/week/day to create a metamathematical model of DHW consumption by a residential building, to predict and optimize consumed power for heating hot water, as well as to determine the potential of using battery tanks.

2. Methods
The data logging period was chosen analytically. Daily indicators were registered during the year, then, after confirming the most stressful period, data on hot water consumption were recorded at intervals of 1 hour. The following parameters were measured: water temperature and water flow in the cold water supply system, hot water supply line and hot water return circulation line.

The studies were carried out in three 16-storey buildings of the 111-MO series, 2 sectional and 4 sectional buildings. All houses are supplied with heat from the boiler house through the central heating point, where water heaters for heating and hot water are installed with circulation pumps. The population of building number 1 is 419 people, number 2 is 411 people, number 3 is 760 people. The heated area of the apartments of building No. 1 is 8021 m², buildings No. 2 are 7918 m², buildings No. 3-15980 m².

3. Results
It should be noted that in 2009, the regulatory requirements for hot water temperature changed in Russia, which was raised from 55 to 60 ºC at the point of water intake. This increase was due to the need to protect against legionella. However, in practice, consumers rarely use this temperature, actually mixing DHW and DCW up to 40 ºC. Accordingly, the temperature of hot and cold water has an effect on the flow of hot water.
The graph (Fig. 1) presents average daily temperature indicators in the DCW system for all months during the period under study.

**Figure 1.** Cold water temperature at the entrances to the building during the study period.

In fact, from October to December the temperature of cold water is +9.5 ºC, and from April to May +8 ºC and from December to April +3 ºC. It can be assumed that the calculation of heat consumption for DHW preparation in the winter period with an estimated temperature of +5 ºC somewhat does not correspond to the actual picture. The temperatures of the hot water in the supply and return lines were also measured.

Figures 2 and 3 present data on the temperature of cold and hot water at the entrances to the building over the study period.

**Figure 2.** The temperature of the hot water entering the building.

**Figure 3.** The temperature of the hot water at the entrances to the building.

The temperature of cold water is 5 ºC and lower than no more than 4 months for the period from December to April. However, when calculating the heat demand for DHW needs during the winter period, it is assumed that the temperature of the heated water is equal to 5 ºC during the whole heating period.

Periodically, the temperature of the water in the DHW system is not maintained either in the direction of decreasing temperature, or in the direction of significant excess. However, it is worth noting that
after the temperature drops, a prolonged increase in temperature follows. Perhaps this is due to the heating system for disinfection. [15]

The specific water consumption per day per inhabitant for several houses was also determined (Fig. 4). Measurements were carried out throughout the year. The graphs show significant fluctuations in water consumption for DHW during the period under review. DHW water consumption data correlates with DCW temperature.

![Graph showing water consumption fluctuations](image)

**Figure 4.** Daily water consumption per person during the study period in 2018 for several houses. The data obtained were grouped into two types: weekdays and weekends. Refinement was carried out on a group of buildings (as an example, the project indicators are one of the buildings in Table 1).

**Table 1.** Key indicators on the drawings of plumbing and sanitary (the whole building).

| Group      | Required head of pressure, mH2O | Daily | Hourly | All the time | Heat consumption for the hottest period of hot water supply, % |
|------------|----------------------------------|-------|--------|-------------|---------------------------------------------------------------|
| Residential, 1, Zone 1 (50 persons), offices (15 persons) | 7.9  | 2.26 | 0.08  | 0.00 | 2.00
| Hot        | 8.02                            | 2.27  | 0.08  | 0.00 | 2.00
| General    | 7.94                            | 2.30  | 0.08  | 0.00 | 2.00
| Residential, 2, Zone 2 (30 persons) | 5.9  | 1.95 | 0.06  | 0.00 | 2.00
| Hot        | 5.85                            | 1.98  | 0.06  | 0.00 | 2.00
| General    | 5.86                            | 1.99  | 0.06  | 0.00 | 2.00

Later on, DHW expenses per day were considered. All data were processed and brought to a specific indicator. Charts of water consumption per 1 inhabitant are shown in Figures 5-6.

![Graph showing DHW expenses](image)

**Figure 5.** Hourly expenses for DHW per person on weekends.
Figure 6. DHW hourly expenses for 1 person on weekdays.

In addition to the confidence interval and the average value, the gray lines in the graphs are medians. This allows you to roughly determine the probability density offset and the probability distribution format.

Average consumption per day from Monday to Friday was 68.23 liters per person. For weekends, it is 61.19 liters per person.

The mathematical model was adopted on the basis of polynomials and Fourier series, weekly data are fairly easily described by both methods.

The daily consumption of hot water is somewhat more complicated because of the proximity of extremes, but it is possible to describe the day off by Fourier series of the third order. A weekday has to be split into several equations: from 0 hours to 9 hours and the next from 9 to 24 hours. This allows you to get by with Fourier series up to degree 3 and polynomials up to degree 6, which greatly simplifies the further use of the model mat.

Similar experimental studies were conducted earlier by the authors in 2009 and 2016. They considered the dynamics of consumption and consumption of hot water in the same apartment buildings over a nearly ten-year period of time. As a result, it was found that the average daily consumption of hot water is gradually reduced for the same buildings, without significantly changing the number of inhabitants. Thus, in a building in 2009, the average daily DHW consumption during the year was 91.0 liters per person, and in the same building in 2016, the average daily consumption of DHW during the year was already 61.8 liters per person. The decrease was about 30%. The same picture is observed for the entire group of buildings studied, as well as a significant fluctuation of water consumption for DHW needs throughout the year. [16-17]

Studying the reasons for the annual fluctuation of DHW consumption in 2018 on a group of multi-apartment buildings in Moscow in houses with different populations in them, a method was developed to determine the occupancy of the building in the summer and winter periods. At the same time, the temperature of cold water in the winter and summer months and the smooth dynamics of changes in the temperature of cold water from 4-5 °C to 19-20 °C in the summer were taken into account. The calculation of the amount of hot water when mixing was carried out according to the following algorithm:

We determine the volume of hot water at the design temperature $t_w = 60^\circ C$ in the winter $V_{g, winter}$ and summer $V_{g, summer}$ periods, so that when it is mixed with cold water at the design temperatures $t_c = 5^\circ C$ and $t_c = 15^\circ C$, accordingly, to obtain 1 liter of water at an average temperature $t_{average} = 45^\circ C$.

When mixing masses $m_g, kg$ of hot and $m_c, kg$ cold water:

$$ m_g + m_c = \rho_{average} \cdot 1l $$

$$ t_{average} = \frac{(m_g t_g + m_c t_c)}{(m_g + m_c)} $$
where

\[ V_g = \frac{\rho_{\text{average}}(t_{\text{average}} - t_s)}{\rho_s(t_g - t_s)} \approx \frac{(t_{\text{average}} - t_s)}{(t_g - t_s)} \]

In winter at design temperatures: \( t_s = 60^\circ C \), \( t_{\text{average}} = 45^\circ C \), \( t_s = 5^\circ C \):

\( \rho_g = 983.3; \rho_{\text{average}} = 990.5 \text{ kg/m}^3 \)

\[ V_{g\text{, winter}} = \frac{990.5(45 - 5)}{983.3(60 - 5)} = 0.733l \]

In summer at design temperature: \( t_s = 15^\circ C \)

\[ V_{g\text{, summer}} = 0.672l \]

\[ \frac{V_{g\text{, winter}}}{V_{g\text{, summer}}} = \frac{12}{11} = 1.09 \approx 1.1 \]

According to actual temperatures in November and July:

\[ \frac{V_{g\text{, winter}}}{V_{g\text{, summer}}} = \frac{(45-6)(60-21)}{(60-6)(45-21)} = 1.17 \]

In the course of the experiment, it was determined that in the studied buildings in the summer time the population in the houses was about 59% of the population.

4. Conclusion

DHW consumption is completely dependent on the human factor. In winter, there is a peak in consumption with the least confidence intervals. In the summer, while reducing DHW consumption, the spread of data also increases. The amount of DHW expenditure associated with the temperature of cold water, with a pronounced dependence, as well as seasonal population migration. The winter period is the peak of DHW consumption, since there are large hot water costs for mixing with cold (the average temperature of cold water during the winter months is about 5 °C) and 100% population in houses. In the summer, in order to get an average temperature of 40-45 °C, warmer cold water of 15-20 °C temperature is mixed with a smaller consumption of hot water. [18]

A decrease in the specific consumption of DHW in the last decade by about 30% has also been revealed. Possible reasons for the installation of meters change sanitary devices and the use of household appliances do not use DHW.

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