Hot Water Consumption Time in Multi-Apartment Buildings

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ABSTRACT

The effective consumption time of hot water in multi-apartment buildings depends on the daily activities of residents, their number, habits and overall size of the system. On the basis of the aggregated data from 8 multi-apartments building, with between 36 and 291 draw-off points each, the effective consumption time during the day was determined. The data was then calculated to show the daily consumption per draw-off point. The least squares method was applied to the assumed consumption model to determine the total number of consumption hours per day.

Keywords: hot water consumption, consumption time, stochastic modeling of water consumption

INTRODUCTION

The consumption of water in hot and cold water systems is an intermittent process. The size of the system and number of residents significantly influences the total consumption of water. Recent studies show a decrease in the total water consumption in previous years [American Water Works Association 2014]. The reduction in water consumption was possible owing to the installation of new draw-off points (water basin faucets and showers) and continuously increasing the number of washing machines and dishwashers [Buchberger, 2017] Due to the latter, it can be assumed that the increased automation influenced the consumption time of hot water. The study of the literature indicated the lack of focus on the aforementioned topic [PN-EN 806–2, 2005].

HOT WATER CONSUMPTION TIME

According to the currently used method for designing the hot water installations [PN-92/B-01706, 1992], appropriate choice of appliances should be based on: average daily, average hourly and peak hourly water demand. The average daily demand $q_{d\,av}$ is calculated based on the number of residents using the supply U and daily hot water demand per person q_c:

$$q_{d\,av}=Uq_c \tag{1}$$

Average hourly demand $q_{h\,av}$ is a ratio of average daily demand $q_{d\,av}$ and number of performance hours during the day τ:

$$q_{h\,av} = \frac{q_{dav}}{\tau} \tag{2}$$

Peak hourly water demand can me determined based on the changes in the average hourly distribution.

$$q_{h\,max}=q_{h\,av} N_h \tag{3}$$

According to [PN-92/B-01706, 1992] in residential dwellings, the average time of hot water consumption is τ_u = 18 [h/d], spreading between 6 AM and midnight.

The water consumption is strictly correlated to the human activities and daily cycle [Szaflik, 2011]. The are two distinguished phases of the circadian rhythm: the active, during the day and resting, during the night. The length of each phase depends on a person and is influenced by many different external factors that change daily. The phases can start and end at different times. As the

water is consumed only during the active phase, the larger the system and the more residents are connected to it, the shorter the intervals in the water consumption. The total pause in consumption is a sum of the rest times during the night and intervals between the consumption during the active period of the day.

A new probabilistic model of hot water consumption was proposed in [Nejranowski, 2018]. The model was determined based on the consumption measurement. It allows calculating the probability of a certain level of consumption in residential dwellings based on different factors. Those factors include the probability of valve opening, number of valves and hot water flow rate from a singular draw off point. The model can also determine the probability of intervals and their duration throughout the active phase of the day.

The study assumes that the total time of consumption intervals is a sum of the night phase t_n and duration of the intervals during the day. On the basis of the aggregated measurements, the consumption time during the days was determined. Using the iterative procedure with the least squares method, the consumption for each studied multi-apartment building was determined. In the buildings with high number of draw-off points (above 300) the consumption time was almost continuous. The assumption that in this case the total consumption time is equal to the duration of the active phase of the day was made. This allows determining the duration of the night phase. The study [Szaflik, Nejranowski, 2019] assumed that the total time of using the hot water system is equal to 24 hours.

MATERIALS AND METHODS

The measurements of hot water consumption (averages determined for each 5 second period) were performed for 8 heat centers connected to multi-apartment buildings. The number of residents, date of commission and location were different in each case. The hot and cold water meters have been installed in each apartment. The average number of residents exceeded 3 people (N) per dwelling (m). The aggregated data for studied building was acquired from the administration and presented in Table 1.

The hot water systems in the building were fully operational, with proper circulation. The temperature control systems in the heat centers

were functional. The heat intake into the heat centers as well as hot water flow were monitored. The measurements were performed for the existing, given hydraulic setup.

The measurements were performed under the continuous supervision of the administration workers and the local Thermal Energy Company. The water consumption was determined for the cold water intake flow using a portable ultrasound flowmeter – UNIFLOW 1010EP3 by Controlotron, which automatically compensates for the flow changes in the liquid was used. The measurement error caused by the unit type and measurement method was limited to 2.5%.

The measurements were carried out throughout the whole week, including weekends and holidays for at least 30 days in every building. The measurement interval was set to 5 seconds, with automatic recording into a spreadsheet and prepared software.

Five highest measurements for each building, including the specific date, were determined and compared. The results showed that there is no correlation between the type of the day and instantaneous peak consumption in the studied buildings. That conclusion was important for the determination of the initial parameters of the calculation model [Nejranowski, 2018].

The model assumes that the consumption of hot water in the system at a given time can be determined as a sum of individual outflows from draw-off points. The total stream of water at a given time depends on the number of opened valves and the degree they are opened at. Those numbers are random.

The process of opening valves in the installation was considered as a series of independent experiments with the number of experiments equal to the number of N draw-off points with a constant

Table 1. Buildings characteristics

Lp.	Adress	Residents, m	Number of draw-off points, N	N/m
1	Building 1	12	36	3.00
2	Building 2	15	47	3.13
3	Building 3	28	84	3.00
4	Building 4	32	96	3.00
5	Building 5	36	108	3.00
6	Building 6	50	160	3.20
7	Building 7	80	240	3.00
8	Building 8	97	291	3.00
Total		**350**	**1060**	**3.03**

probability P of opening a single valve. The probability of simultaneous opening of K valves was determined using the binomial distribution.

The distribution of the variability of the stream of the water drawn from the K draw-off points was determined by the K-fold integral of the convolution of probability distribution of the inverse value of the average consumption from the draw-off point.

The binomial distribution was calculated using the following model [Nejranowski, 2018]:

$$H(\dot{v}) = 1 - e^{-\lambda\dot{v}} \sum_{K=1}^{N} \left[\binom{N}{K} P^K (1-P)^{N-K} \sum_{j=0}^{K-1} \frac{(\lambda\dot{v})^j}{j!} \right] \quad (4)$$

and correlation for determination of the distribution parameters P and λ from the average value of measured consumption $\dot{v}_{av}$ and standard deviation s^2 [3]:

$$\begin{cases} \dot{v}_{av} = \dfrac{Np}{\lambda} \\ s^2 = \dfrac{Np(2-p)}{\lambda^2} \end{cases} \quad (5)$$

RESULTS

On the basis of equation (1) the probability of zero water consumption $H(0)$ was determined (water consumption $\dot{v}=0$). This corresponds to a zero number of opened valves ($K=0$):

$$H(0) = (1-P)^N \quad (6)$$

where: P – probability of opening an individual valve during the 24 hour cycle,
N – number of draw-off points.

The probability of opening a valve in the draw-off point was determined from:

$$P = \frac{\tau_{zd}}{\tau_d} \quad (7)$$

where: τ_{zd} –average time of hot water valve opening during the 24 hour cycle,
τ_d –average time of using the hot water installation during the 24 hour cycle.

The expected time of using the water installation during the 24 hour cycle in regard to the number of draw off points N is presented in Figure 1. The equation input data were determined based on the conducted measurements.

Figure 1 presents a clearly visible increase in the time of use for hot water installation with the increase of the number of the draw-off points.

The number of the installed hot water draw-off points in individual apartments in the studied multi-apartment buildings was 3. It can be assumed that the number of inhabitants is proportional to the number of apartments, and thus is also proportional to the number of the hot water draw-off points. Therefore, the increase in the time of the hot water consumption is also correlated to the increase in the number of people using the installation. It can be observed that for
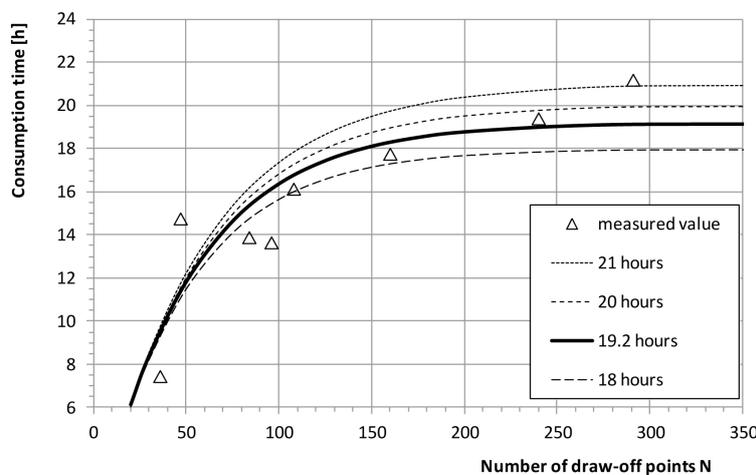

Fig. 1. Estimated hot water consumption times in the system, depending on the number of N draw-off points, determined on the basis of the presented hot water consumption model and the results of hot water consumption measurements for varying length of active phase
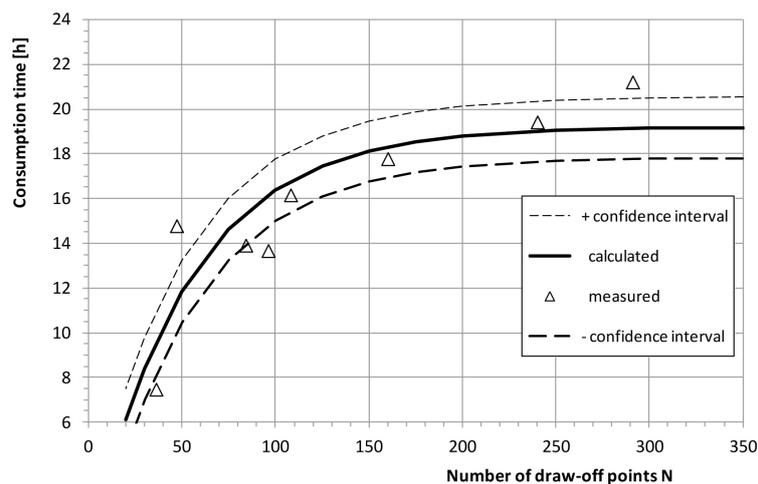
Fig. 2. Comparison of the optimal length of the daily phase calculated from the model for *N* draw-off points and conducted measurements for α=0.05

the number of the draw-off points greater than $N = 250$, this time is practically constant and corresponds to the duration of the active daily phase.

Figure 2 shows the comparison of the optimal length of the daily phase calculated from the model for *N* draw-off points and acquired from conducted measurements. The statistical significance level was assumed as 0.05.

In this study, the hot water consumption time determined using the least squares method for 350 draw-off points was 19.2 hours. It can therefore be assumed that this time corresponds to the period of the daily active phase. Figure 2 shows the confidence intervals for the assumed statistical significance of $\alpha = 0.05$. The duration of the night phase is therefore 19.2 ± 1.4 hours. It can be stated with a 95% probability that the average duration of the night, resting phase is in the range of 17.8 to 20.6 hours.

CONCLUSION

The paper presents the results of calculations of the average duration of hot water consumption in multi-apartment residential buildings with a different number of residents. The cumulative distribution function was used for the purpose of this study. The distribution parameters were determined on the basis of the results of long-term measurements of instantaneous hot water consumption in eight multi-apartment buildings with different population. The total number of the draw-off points in this study was 1060. On the basis of the analysis of the obtained results, the average consumption time of the hot water

system was determined. The mean value of this time for the assumed level of statistical significance $\alpha = 0.05$ is 19.2 ± 1.4 hours and fits in the range of 17.8 to 20.6 hours. The time given in the PN-92/B-01706 standard of 18 hours is also included in this range.

The European standards PN-EN 806, including the standard concerning the design of water supply systems, do not include the information on the average duration of the hot water consumption.

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