Budownictwo o Zoptymalizowanym Potencjale Energetycznym 2(18) 2016, s. 21-28
DOI: 10.17512/bozpe.2016.2.03

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STORAGE WATER HEATERS DESIGN IN APARTMENT BUILDINGS

The paper is focused on the optimization and developing of design methodologies of storage water heaters for apartment buildings determined by experimental measurements in the different apartment buildings in Slovakia. The hourly maximum consumption of hot water in different apartment houses, the average hourly maximum of domestic hot water requirements determined for one person and energy balance of the domestic hot water system were found out by experimental measurements. Design methodology is composed of two steps. The first step is volume design of storage water heater and the second step is its power requirement design. This design methodology seems to be more accurate than the methodology of domestic hot water storage design in the Slovak Technical Standard currently in force. The proposed methodology better reflects the current demands of domestic hot water preparation in apartment buildings in Slovakia.

Keywords: **storage water heater, domestic hot water, apartment buildings, design methodology**

INTRODUCTION

To make a correct design of storage water heater in an apartment building, it is necessary to know the real hot water consumption in the building. In research of the authors, the hour consumption of hot water during one year was measured in four different apartment buildings in Bratislava. The conclusion of experimental measurement was that the highest hot water consumption was on Sunday from 21:00 to 22:00. This average hourly maximum hot water consumption is set on 1 occupant of apartment building and is changing by the number of occupants. In the apartment building with 150 occupants, it is 4.5 L/pers. In the apartment building with 300 occupants the average hourly maximum hot water consumption is 4.0 L/pers. The current constructions of storage water heaters enable to achieve sufficient power, to be able to heat up the required volume of hot water in 1 hour. Therefore, it is suitable to design the storage water heaters according to the real water consumption in apartment building used up in 1 hour.

1. THE MATHEMATICAL MODEL OF DESIGN THE VOLUME OF STORAGE WATER HEATERS IN APARTMENT BUILDINGS BY HOT WATER CONSUMPTION

The volume of storage water heater V_Z is calculated by formula [1]:

$$V_Z = n \cdot q_{max} \cdot \tau \quad [L] \tag{1}$$

where:

n - number of occupants in apartment building,

q_{max} - the average hourly maximum hot water requirement set on 1 occupant in apartment building [L/pers·h], q_{max} depends on the number of occupants in apartment building:

- to 150 occupants q_{max} = 4.50 L/pers·h,
- from 150 to 250 occupants q_{max} = 4.25 L/pers·h,
- from 250 to 300 occupants q_{max} = 4.00 L/pers·h,

τ - heating time [h], was chosen τ = 1 h.

Note:

The value of the average hourly maximum hot water requirement q_{max} set on 1 occupant of apartment building comes out from experimental measurements in four different apartment buildings during one year, where the number of occupants was from 150 to 300 persons. The value of q_{max} would be more precious, if the experimental measurements of average hourly hot water consumption were made on higher amount of different apartment buildings with different number of occupants.

2. THE METHODOLOGY FOR DETERMINING THE POWER REQUIREMENTS OF STORAGE WATER HEATERS IN APARTMENT BUILDINGS

For the correct design of storage water heaters, it is necessary to know the energy balance of preparation and distribution of hot water in the apartment building. The following types of energy need to be known:

- the energy delivered to the system for heating the water on the primary side;
- the energy delivered to the system for heating the water on the secondary side;
- the energy lost in circulation and in distribution system of hot water;
- the energy required to heat the hot water really consumed.

The energy delivered to the system for heating the water on the primary side is the total energy, which was delivered to the system for preparing hot water from heat supplier or directly from heating plant. The energy delivered to the system for heating the water on the secondary side is energy lost in circulation and in distribution system of hot water and energy required to heat the hot water really consumed. Fraction between energy delivered to the system for heating the water on the primary side and on the secondary side can be evaluated as the efficiency of the system. To determine the power requirements of storage water heaters, it is necessary to know the energy delivered to the system for heating the water on the primary side, as well as the time of heating.

The power requirements of storage water heaters P [W] on the secondary side is calculated by formula [1]:

$$P = \frac{V_Z \cdot \rho \cdot c \cdot (\theta_1 - \theta_2)}{x_{E2TV} \cdot \eta \cdot \tau} \quad [W] \qquad (2)$$

where:

V_Z - volume of storage water heater [m^3],

ρ - the density of water [kg/m^3], at 60°C ρ = 983.15 kg/m^3,

c - the specific heat capacity of water [Wh/kg·K], at 60°C c = 1.1622 Wh/kg·K,

θ_1 - temperature of heating water in feed piping [K], θ_2 - temperature of heating water in return piping [K],

x_{E2TV} - fraction of energy required to heat the real hot water consumption to energy delivered to the system for heating the water on the secondary side, x_{E2TV} depends on thickness of heat insulation in distribution system:

- if the thickness of insulation is ≤ 10, x_{E2TV} = 0.70,
- if the thickness of insulation is ≥ 10 mm and ≤ DN of pipes, x_{E2TV} = 0.85,
- if the thickness of insulation is ≥ DN of pipes, x_{E2TV} = 0.95,

τ - heating time [h], was chosen τ = 1 h,

η - efficiency of hot water heating, different efficiency depends on different types of heating the hot water, it is recommended to chose from annex no. 2 Decree no. 625/2006, implementing the Act. 300/2012 Energy performance of buildings (Table 1).

The power requirement of storage water heater P [W] on the primary side is calculated by formula:

$$P = \frac{E_1}{\tau} \quad [W] \qquad (3)$$

where:

E_1 - the energy delivered to the system for heating the water on the primary side [Wh],

τ - heating time [h], was chosen τ = 1 h.

The energy delivered to the system for heating the water on the primary side E_1 [Wh] is calculated by formula:

$$E_1 = \frac{E_2}{\eta} \quad [Wh] \qquad (4)$$

where:

E_2 - the energy delivered to the system for heating the water on the secondary side [Wh],

η - efficiency of hot water heating (Table 1).

Table 1. **Efficiency of hot water heating for different sources of power in accordance to Decree no. 625/2006**

Source of power	The process of transformation	Efficiency [%]
Natural gas	Standard boiler - old	83
	Standard boiler - new	88
	Low temperature boiler - old	90
	Low temperature boiler - new	93
	Condensing boiler - new	98.5
Coke coal	Solid fuel boiler	74
Coal assorted	Solid fuel boiler	72
Lignite, brown coal assorted	Solid fuel boiler	68
Light fuel oil	Standard boiler - old	80
	Standard boiler - new	85
	Low temperature boiler - old	86
	Low temperature boiler - new	91
Electricity	Electric heating	99
	Electric hot water heating	99
Wooden pellets	Biomass boiler	85
Wooden chips	Biomass boiler	76
Lump wood	Biomass boiler	68
Lump wood	Biomass boiler with gasification	83
Electricity	Heat pump - water, air, land	270

The energy delivered to the system for heating the water on the secondary side E_2 [Wh] is calculated by formula:

$$E_2 = E_{2Z} + E_{2D} \quad [\mathrm{Wh}] \tag{5}$$

where:
E_{2Z} - the energy required to heat the hot water is the storage water heater [Wh],
E_{2D} - the energy required to cover energy losses in distribution system of hot water [Wh].

The energy required to heat the hot water in storage water heater E_{2Z} [Wh] is calculated:

$$E_{2Z} = c \cdot m_Z \cdot (\theta_2 - \theta_1) \quad [\mathrm{Wh}] \tag{6}$$

where:
c - the specific heat capacity of water [Wh/kg·K], at 60°C c = 1.1622 Wh/kg·K,
m_Z - weight of water in storage water heater [kg],
θ_1 - temperature of heating water in feed piping [K],
θ_2 - temperature of heating water in return piping [K].

Weight of water in storage water heater m_Z [kg] is calculated:

$$m_Z = \rho \cdot V_Z \quad [\text{kg}] \tag{7}$$

where:
ρ - the density of water [kg/m^3], at 60°C ρ = 983.15 kg/m^3,
V_Z - volume of storage water heater [m^3] calculated by formula (1).
E_{2D} - the energy required to cover the energy losses in distribution system of hot water could be calculated exactly by the standard STN EN 15316-3-2 [2], but the calculation process by this standard is very difficult. It takes in consideration the lengths and dimensions of pipes in every part of the system and also the thickness of heat insulations and some more parameters.

The fraction between energy required to heat the hot water really consumed and the energy lost in distribution system of hot water and total energy delivered to system was determined for five apartment buildings with different distribution system by the experimental measurements. The measurements showed that in the considered apartment buildings the energy delivered to the system for heating the water on the secondary side is divided approximately 50% to energy lost in distribution system and 50% to heat the hot water really consumed. But in the time of maximum hot water withdrawal, the fraction between energies in system is divided 15% to energy lost in distribution system and 85% to energy required to heat the hot water really consumed.

The percentage of heat loses in distribution system depends on quality and thickness of heat insulation of hot water piping. Therefore, the proposal in the calculation process is to consider that to the energy delivered to system for heating the water on the secondary side with thickness of insulation max. 10 mm is divided 30% to energy for heat loses in distribution system and 70% to energy for heating the water really consumed and with thickness of insulation more than 10 mm is divided 15% to energy for heat loses in distribution system and 85% to energy for heating the water really consumed. When the heat insulation is thicker or the same as the dimension of the pipe, the energy is divided 5% to energy for heat loses in distribution system and 95% to energy for heating the water really consumed.

$$E_2 = E_{2Z} + E_{2D} \quad [\text{Wh}] \tag{8}$$

$$E_{2Z} = x_{E2TV} \cdot E_2 \quad [\text{Wh}] \tag{9}$$

$$E_{2D} = (1 - x_{E2TV}) \cdot E_2 \quad [\text{Wh}] \tag{10}$$

Energy delivered to the system to heat the hot water on the secondary side E_2 [Wh] is calculated:

$$E_2 = \frac{E_{2Z}}{x_{E2TV}} \quad [\text{Wh}] \tag{11}$$

where: x_{E2TV} - fraction of energy required to heat the real hot water consumption to energy delivered to the system for heating the water on the secondary side, x_{E2TV} depends on thickness of heat insulation in distribution system,

- if the thickness of insulation is ≤ 10 mm, x_{E2TV} = 0.70,
- if the thickness is ≥ 10 mm and ≤ DN of pipes, x_{E2TV} = 0.85,
- if the thickness of insulation is ≥ DN of pipes, x_{E2TV} = 0.95.

3. THE EXAMPLE OF DESIGN OF THE STORAGE WATER HEATER ACCORDING TO THE CONSUMPTION OF HOT WATER

Hot water is prepared in storage water heater by indirect heating of the condensing boiler in apartment buildings with 200 occupants. Distribution system exists, poorly insulated.

Solution:

The volume of storage water heater designed by (1):

$$V_Z = n \cdot q_{max} \cdot \tau \quad [L]$$

$$V_Z = 200 \cdot 4.25 \cdot 1 \quad [L]$$

$$V_Z = 850\ L = 0.85\ m^3$$

where:

V_Z - volume of storage water heater [m^3],

n - number of occupants in apartment building,

q_{max} - the average hourly maximum hot water requirement set on 1 occupant in apartment building [L/pers·h], in apartment building from 150 to 250 occupants was chosen q_{max} = 4.25 L/pers·h,

τ - heating time [h], was chosen τ = 1 h.

The power requirements of storage water heater designed by (2):

$$P = \frac{V_Z \cdot \rho \cdot c \cdot (\theta_1 - \theta_2)}{x_{E2TV} \cdot \eta \cdot \tau} \quad [W]$$

$$P = \frac{0.85 \cdot 983.15 \cdot 1.1622 \cdot (55 - 10)}{0.7 \cdot 0.985 \cdot 1} \quad [W]$$

$$P = 63{,}386.65\ W = 63.38\ kW$$

where:

V_Z - volume of storage water heater [m^3],

ρ - the density of water [kg/m^3], at 60°C ρ = 983.15 kg/m^3,

c - the specific heat capacity of water, at 60°C c = 1.1622 Wh/kg·K,

θ_1 - temperature of heating water in feed piping [K], θ_1 = 55°C,

θ_2 - temperature of heating water in return piping [K], θ_1 = 10°C,

x_{E2TV} - depends on thickness of heat insulation in distribution system, if the thickness of insulation is ≤ 10 mm, x_{E2TV} = 0.70,

η - efficiency of hot water heating, condensing boiler - η = 0.985,

τ - heating time [h], was chosen τ = 1 h.

The suitable volume of storage water heater in apartment building with 200 occupants is 850 liters and power requirement 63.38 kW.

4. THE DESIGN COMPARISON OF STORAGE WATER HEATER BY DIFFERENT REGULATIONS

The result of storage water heater design for apartment building with 200 occupants by STN 06 0320 [3], ČSN 06 0320 [4] and DIN 4708 [5] is shown in Table 2.

Table 2. **The design comparison of storage water heater by different regulations**

Methodology	Volume of storage water heater [L]	Power requirements [kW]	
STN 06 0320	5,956.0	134.10	
ČSN 06 0320	5,700.0	53.70	
DIN 4780, N = 53	1,623.4	62.50	
New design methodology by hot water consumption, q_{max} = 4.25 L/pers.·d	850.0	x_{E2TV} = 0.70	63.38
		x_{E2TV} = 0.85	52.20
		x_{E2TV} = 0.95	46.70

The volume of storage water heater calculated by the new methodology is the most approaching to calculation by DIN, but the power requirements are higher in comparison with DIN and ČSN, what is shown in Table 2.

5. DISCUSSION

Currently, designers have to decide, which design methodology to use to design the storage water heater in apartment buildings. They mostly design according to their own experience - empirically or by technical documents from heaters manufacturers. Technical standard STN 06 0320 [3] for storage water heater design is not used anymore, the volumes of storage water heaters are oversized. Calculation by this standard is based on number of occupants, heating time in storage, type of storage construction and operation of building. The calculation of storage power requirements is very inexact. It is based only on a number of occupants in the apartment building, but does not consider the volume of storage and the time of heating, which is the most important in the design process.

The calculation of storage water heater by ČSN 06 0320 [4] is based on the number of occupants and theoretical energy required to heat the hot water for 1 occupant, but does not take in consideration energy loses in the heating hot water system and the distribution of hot water. Daily energy requirement is divided in two periods and graphically elaborate the curve of heat loses. The volume of storage water heater is designed by the difference between heat delivery and heat consumption.

The rated thermal output is also determined as fraction between heat delivered to water by heater in period of time and the length of period. It was determined all day as the length of period.

According to the German technical standard DIN 4708 [5] the storage water heater is determined by a characteristic number of consumption N. The volume of storage is determined by this number empirically from technical document of the catalogue value of N_L. The calculation of characteristic number of consumption N is based on the heat requirement from one delivery point and from number of occupants.

CONCLUSION

New methodology of design of the storage water heaters for apartment buildings by the hot water consumption is based on the maximum hot water requirement set on 1 occupant of the apartment building and depends on the number of occupants in the apartment building. The power requirement of storage water heaters is based on calorimeter equation, the efficiency of the hot water heater and the heat insulation of distribution system. This new methodology seems to be optimal and describes the current requirements for heating of the hot water in apartment buildings in Slovakia in comparison to the currently valid Slovak standard STN 06 0320 [3].

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PROJEKTOWANIE POJEMNOŚCIOWYCH PODGRZEWACZY WODY W BUDYNKACH MIESZKALNYCH

Przedstawiono optymalizację i rozwój metodologii projektowania pojemnościowych podgrzewaczy wody dla budynków mieszkalnych na podstawie pomiarów przeprowadzonych w różnych budynkach mieszkalnych na Słowacji. Na podstawie pomiarów określono godzinowy maksymalny pobór ciepłej wody w różnych budynkach, średnie maksymalne godzinowe zapotrzebowanie na ciepłą wodę dla jednej osoby i bilans energetyczny dla systemu ciepłej wody użytkowej. Metodologia składa się z dwóch etapów. Pierwszy obejmuje projekt, a drugi obliczenie zapotrzebowania na moc cieplną. Proponowana metoda lepiej odzwierciedla aktualne wymagania związane z przygotowaniem ciepłej wody użytkowej w budynkach mieszkalnych na Słowacji.

Słowa kluczowe: **pojemnościowy podgrzewacz wody, ciepła woda użytkowa, budynki mieszkalne, metodologia projektowania**