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THE UNIT COST OF HOT WATER PREPARATION

Summary

On the basis of technical and economic analysis the unit costs of hot water preparation were calculated for single family homes and multiplex houses, assuming the number of people from 2 to 40 at three different options of hot water consumption: 35, 45, 55 dm^3/per capita. The comparative analysis used two accumulation systems for hot water preparation, i.e. a set of solar panels and a system using a gas-fired boiler. Conducted calculations have indicated the system using gas-fired boiler as the one, which in view of the assumed 15-year operating period reveals the best economic indicators, i.e. the costs of hot water preparation will be the lowest.
Key words: *the costs of hot water preparation, solar panels, gas-fired boiler*

KOSZTY JEDNOSTKOWE PRZYGOTOWANIA CIEPŁEJ WODY UŻYTKOWEJ

Streszczenie

Na podstawie analizy techniczno-ekonomicznej obliczono koszty jednostkowe przygotowania ciepłej wody użytkowej dla domów jednorodzinnych oraz wielorodzinnych, zakładając liczbę osób od 2 do 40 przy trzech wariantach zużycia ciepłej wody: 35, 45, 55 dm^3/os. Do analizy porównawczej przyjęto dwa zasobnikowe systemy przygotowania ciepłej wody użytkowej, tj. system solarny oraz wykorzystujący podgrzewacz gazowy. W wyniku przeprowadzonych obliczeń wskazano na system, który w perspektywie założonego 15-letniego okresu eksploatacji cechuje się najlepszymi wskaźnikami ekonomicznymi a więc koszty przygotowania ciepłej wody użytkowej będą najniższe - jest nim system wykorzystujący gazowy podgrzewacz pojemnościowy.
Słowa kluczowe*: koszt przygotowania ciepłej wody użytkowej, kolektory słoneczne, gazowy podgrzewacz pojemnościowy*

1. Introduction

In the climatic conditions in Poland, a household consumer most frequently uses energy to meet four energy needs: heating and ventilation, preparation of usable hot water (u.h.w), cooking meals and feeding all electrical devices. At the design (or modernization) stage the way in which energy will be supplied to the building must be determined, i.e. one must decide which energy source materials and devices generating energy from these sources should be used to satisfy each energy demand of the consumer [1, 9].

Although usable hot water supply to a house is a lesser economic problem than central heating, still when properly solved will greatly affect the inhabitants' quality of life. The choice of a fuel or energy source material which will power the usable water heating system is one of the most important decisions made by the investor, because he can choose among several options which use both renewable and non-renewable energy sources. The basic criterion conditioning the installation of an individual heating system in a building is economic calculation. In practice, energy analysis cannot be an agent determining the selection of heat source. A potential user should evaluate both technical and economic aspects of each considered system and choose the one which in the perspective of the total operating period will prove the most advantageous [2].

The aim of the paper was a technical and economic analysis of two accumulation systems for usable hot water (u.h.w) preparation in single family homes and multiplex houses, assuming the number of between 2 and 40 users at three options of hot water consumption: 35,45 and 55 dm^3 per capita.

The comparative analysis comprised a flat plate solar collector set and a gas-fired boiler.

The scope of the work covers calculations of power demand for preparing u.h.w, selection of the container, selection of the area and number of solar collectors, computing annual consumption of final energy and estimation of investment and operational costs. These provided a basis for economic analysis using life cycle costs analysis, which served to determine the unit costs of usable hot water preparation. For solar panel systems also the degree to which the annual demand for heat will be satisfied (u.h.w) by the installation was determined.

2. Results of calculations and analysis

The power of the device for u.h.w preparation in the accumulation system was calculated according to the Polish standard PN-92/B-01706 [5], whereas the container volume acc. to [6], and the results were compiled in Table 1. Meeting annual demand for heat for hot water preparation by solar panel installation (for Krakow), calculated using KOLEKTOREK 2.0 computer programme, is between 53 and 62% depending on the assumed option. The other part of energy will be supplied by electric heaters installed in the containers (which is the solution usually applied in this type of heating systems).

The number of solar collectors depends on the number of users, i.e. a family of four living in a single family house, at an average hot water consumption of between 35-45 dm^3 would need two collectors and a container cooperating with

the installation of the minimum volume of 226 dm^3. In multiplex houses the number of collectors increases, so when water is supplied to 40 users the installation should be composed of 20 collectors and the hot water container should have the volume of at least 1035 dm^3. Application of the system using gas-fired heating device installed in a single family home should base on a boiler with a power of c.a.3kW cooperating with a c.a.160 dm^3 hot water container. In a multiplex house, the power of heating device preparing water for 40 users should be about 28kW and the minimum volume of accumulation container 740 dm^3.

Annual consumption of final energy *FE* for the analyzed usable water heating systems was calculated according to the Decree of the Minister of Infrastructure dated 6.11.2008 on the methodology of computing energy performance of a building, Journal of Laws, No.201, item 1240 [8]. The efficiency of generating, transfer and accumulation was computed on the basis of dependencies [7, 8], the computations considered also energy consumption by accessory devices, such as circulator pumps cooperating with the solar panel system and also devices for usable hot water distribution in the building and the buffer tank loading pumps. Results of the computations for the system based on solar collector system were presented in Figure 1, whereas for gas-fired water boiler in Figure 2.

Final energy consumption when solar panel set is used fluctuates, depending on the assumed variant of water consumption, from c.a.10GJ/year (for two consumers) to c.a.110GJ/year at 35 dm^3/person and 170 at 55 dm^3/person (at forty consumers).

If a system based on a gas-fired boiler is applied, final energy consumption changes depending on the water consumption from c.a. 12GJ/year (for two consumers) to c.a. 120 at 35 dm^3/person to even 170GJ/year at 55 m^3/person (for forty users).

Table 1. Calculation of results for various options

Number of users	Area of collectors [m^2]	Number of collectors [pcs.]		Calculated volume of u.h.w. container for solar panel system [dm^3]	Calculated power of gas-fired heating device [kW]	Calculated volume of u.h.w. container [dm^3]
		u.h.w. consum-ption 35; 45 [dm^3/pers.]	u.h.w. consum-ption 55 [dm^3/pers.]			
2	2.09	1	2	140	1.7	100
4	4.19	2	3	226	3.3	162
6	6.28	3	4	298	4.8	213
8	8.37	4	5	362	6.3	258
10	10.47	5	6	420	7.7	300
12	12.56	6	7	475	9.2	339
14	14.66	7	8	525	10.6	375
16	16.75	8	9	575	12.0	410
18	18.84	9	10	620	13.4	443
20	20.94	10	11	664	14.8	475
22	23.03	11	12	700	16.2	500
24	25.12	12	13	747	17.6	534
26	27.22	13	14	786	18.9	560
28	29.31	14	15	825	20.3	590
30	31.41	15	16	862	21.6	615
32	33.50	16	17	897	22.9	641
34	35.59	17	18	933	24.3	666
36	37.69	18	19	968	25.6	690
38	39.78	19	20	1000	27.0	715
40	41.87	20	21	1035	28.3	740

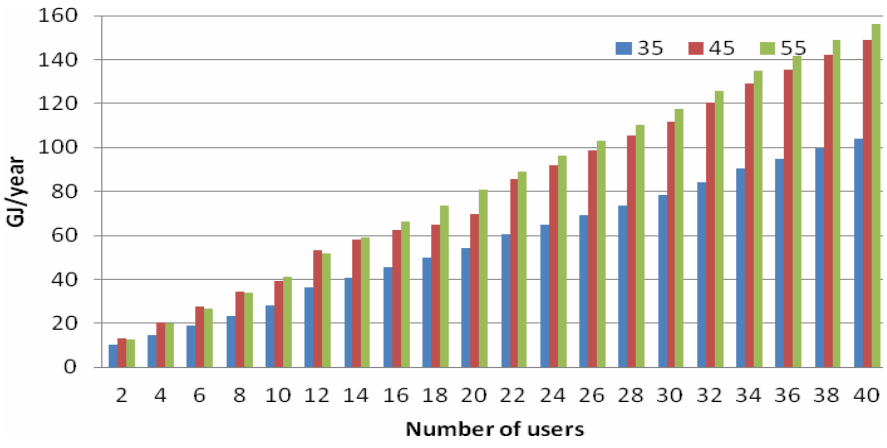

Fig. 1. The annual final energy demand for the system with solar collectors

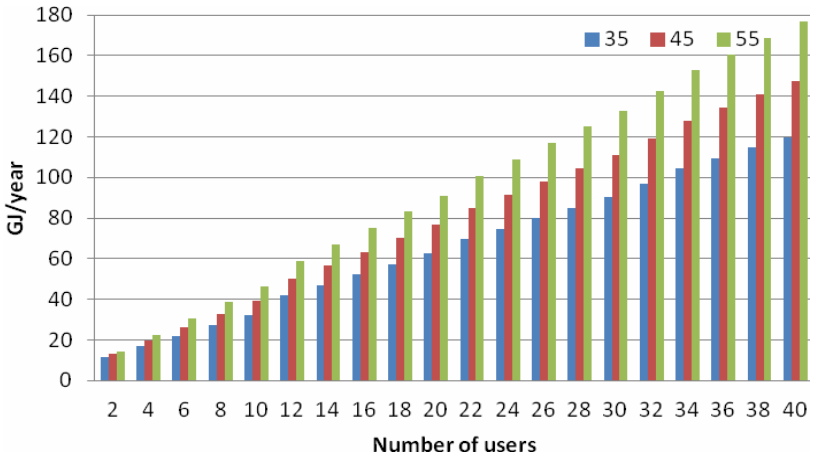

Fig. 2. The annual final energy demand for the system with gas-fired boilers

3. Economic estimation of usable hot water preparation systems

A choice of an individual system of usable hot water supply should be based on objective criteria. It is a common belief that an surplus of outcomes over the outlays is such a criterion [2, 4]. The technical and economic analysis of the compared systems was conducted basing on a life cycle cost method (LCC) used to estimate the value of real investment. The method allows to determine total investment and operational costs of the system throughout its life cycle:

$$LCC = Kp + \sum_{n=1}^{n=t} \frac{Ke,o \cdot (1+re)^n}{(1+i)^n} \text{ [thous.PLN]} \qquad (1)$$

For an objective comparison of the analysed systems a unit cost method was used and the following dependencies were set:

$$UC = \frac{LCC}{EK \cdot n} \text{ [PLN/GJ]} \qquad (2)$$

where:

Kp – initial cost (the cost of purchasing and starting the installation),

Ke, o – annual costs of installation using (costs of energy, overhaul and repairs),

t – subsequent year of installation operation,

re – energy price increase rate,

i – discount rate,

n – 1…15 subsequent year of costs (n=assumed years of installation life cycle),

EK – annual final energy demand for u.h.w preparation.

For the needs of estimating life cycle costs of the compared system only the costs of purchasing and starting the installation *Kp* and operating costs were determined. The operating costs comprise the costs of gas (2.2 PLN m^3) used by gas-fired boiler and electricity (0.65 PLN/kWh) absorbed by electric heaters and heating system accessory devices. Considered were also the outlays on services during the operating period *Ke,o* which are on average 180 PLN/year for gas-fired boiler or 150 PLN/year for solar panel set - for overhaul and exchange of "solar fluid" every five years, plus the cost of fluid from 250 PLN (for 4 collectors) to 670 PLN (for 20 collectors). Table 2 shows the initial costs *Kp* for the respective water heating systems (u.h.w).

Table 2. Initial costs for individual systems of usable hot water preparation

Number of consumers	Solar set *Kp* [thou. PLN]		Gas-fired boiler *Kp* [thou. PLN]
	u.h.w. consumption 35; 45 [dm^3/pers.]	u.h.w. consumption 55 [dm^3/pers.]	
2	4.8	5.9	5.6
4	5.9	7.1	5.6
6	7.7	8.8	6.5
8	9.2	10.2	6.9
10	10.2	11.3	7.7
12	12.5	13.6	10.1
14	13.6	14.7	10.1
16	15.5	16.6	11.7
18	16.6	17.7	11.7
20	18.9	20.0	13.1
22	20.0	21.1	13.4
24	21.4	22.5	13.7
26	23.7	24.8	13.4
28	24.8	25.9	13.4
30	25.8	26.9	16.1
32	26.9	28.0	16.1
34	29.4	30.4	21.7
36	31.7	32.8	21.7
38	32.8	33.9	21.8
40	33.9	35.0	21.8

Due to the fact that the purchase of solar collectors is supported by the State, the initial costs of solar panel sets take into consideration the funds from the National Fund for Environment Protection and Water Management constituting 14% of investment costs of these systems [3].

The cost of purchase and installation of solar set in a single family house (for 4 persons) ranges from 6 to 7 thousand PLN and in the building where water would be supplied to 20 consumers, the initial investment cost should be within 19-20 thou. PLN. The installation supplying hot water to 40 consumers would cost between 24 and 35 thousand PLN. Initial costs for gas-fired boiler for a single family house are from 5 to 20% lower than in case of solar panel installation. The higher the number of users, the greater the difference in the initial costs between the gas and solar panel system. So, for 20 consumers the difference in the investment costs ranges from 30to 34%, whereas for 40 it is between 35 and 37%.

On the basis of LLC method total investment and operating costs of the analysed systems were determined for their fifteen-year operating period. Results of the computations for three options of u.h.w. consumption were compiled in Table 3. LLC value for a single family house, depending on the applied option, ranged from 22-30 thou. PLN for the solar panel set and 21-26 thou.PLN for gas system. For a multiplex house (40 users) the costs of solar panel set are within the range from 142 to 207 thou. PLN, whereas for gas-fired boiler they are between 125 and 175 thou. PLN. In case of small installations the difference in costs between the gas boiler and solar panel set is 5-13% for four consumers, whereas between 12-16% for 40 consumers. It is due mainly to higher investment outlays and servicing costs for the solar panel installation.

The subsequent stage of comparative analysis involved calculation of unit costs of usable hot water preparation *UC* for the system with the solar panel set and for gas-fired boiler. The results were illustrated in Figures 3 and 4.

Table 3. Comparison of life cycle costs for the analysed heating systems

Number of consumers	Solar panel set			Gas-fired boiler		
	LCC [thou. PLN]			LCC [thou. PLN]		
	u.h.w. consumption 35 [dm^3/pers.]	u.h.w. consumption 45 [dm^3/pers.]	u.h.w. consumption 55 [dm^3/pers.]	u.h.w. consumption 35 [dm^3/pers.]	u.h.w. consumption 45 [dm^3/pers.]	u.h.w. consumption 55 [dm^3/pers.]
2	17.6	21.6	18.9	17.2	18.4	19.7
4	22.5	29.2	30.3	21.5	24.0	26.5
6	28.6	36.9	41.2	26.9	30.7	34.4
8	34.3	45.9	51.8	31.6	36.6	41.6
10	40.3	58.0	63.1	36.8	43.0	49.2
12	49.8	67.4	79.5	47.3	54.8	62.3
14	56.1	79.6	91.8	51.7	60.5	69.2
16	64.2	92.6	107.7	57.7	67.7	77.7
18	74.2	105.4	120.0	62.1	73.3	84.5
20	82.9	117.3	125.0	67.9	80.4	92.9
22	83.7	117.9	120.5	74.0	87.7	101.4
24	89.6	126.7	129.6	78.7	93.7	108.6
26	96.5	136.4	139.6	82.8	99.0	115.2
28	102.2	144.9	148.4	87.1	104.6	122.1
30	107.7	153.3	157.1	94.2	112.9	131.7
32	114.9	163.7	167.6	100.1	120.0	140.0
34	123.7	175.8	179.7	111.8	133.0	154.2
36	130.6	185.5	189.7	116.1	138.6	161.1
38	136.2	194.0	198.6	120.5	144.2	168.0
40	141.9	202.6	207.4	124.9	149.9	174.8

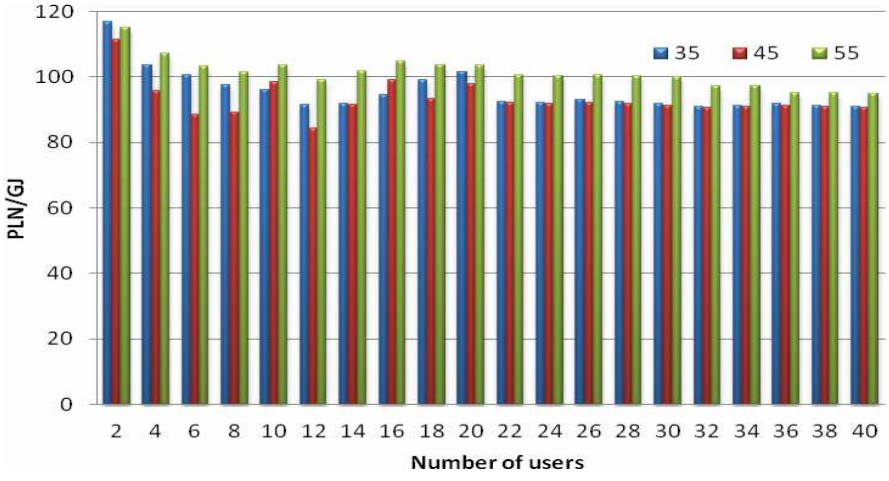

Fig. 3. Unit costs of usable hot water preparation for the system with solar panel set

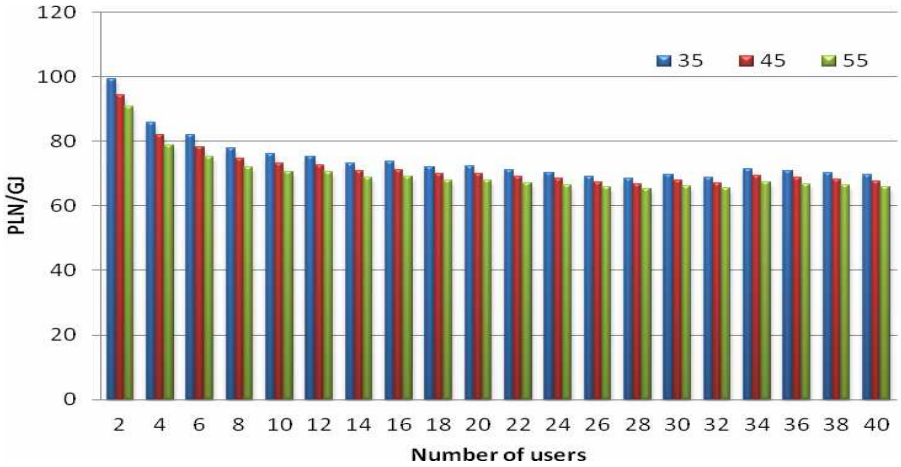

Fig. 4. Unit costs of usable hot water preparation for the system using gas-fired boiler

The unit cost of u.h.w. preparation by solar panel set depends on the number of users and therefore on the dimension of the applied system. In single family homes it is c.a. 110 PLN/GJ for two users and c.a. 100-105 PLN/GJ for the households of four or six. The lowest unit costs are registered for houses inhabited by between 12 and 14 users where u.h.w. preparation reaches c.a. 82-90 PLN/GJ. For large installations, supplying water to 30-40 consumers, the unit costs are c.a. 90 PLN/GJ.

Preparation of usable hot water by a system based on gas-fired boiler costs between 90-98PKN/GJ for two consumers and 75-85 PLN/GJ in a building inhabited by four to six persons. The unit costs of u.h.w. preparation in multiplex houses for 30-40 consumers is between 70-75 PLN/GJ depending on the amount of used water.

4. Conclusion

Parameters for the system of usable hot water preparation were selected for the assumed number of consumers and amount of hot water consumption, which allowed to estimate investment costs involved in its purchase and installation in single family and multiplex houses. Calculated consumption of final energy for usable hot water preparation for the individual variants provided a basis for estimating the operation costs. The data served to conduct economic analysis of life cycle costs analysis (LLC), which during the assumed operating period allowed to determine total investment and operational costs of the compared systems.

Analysis of the obtained results allows to indicate the option using gas-fired boiler as a better solution than the solar panel set. Unit costs of u.h.w. preparation for this system determined on the basis of LCC method are between 15 and 25% lower than the water consumption for the installations supplying water to users in single family houses, whereas for the multiplex houses (30-40 users) the difference is 16-22%.

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