Possibility of heat recovery from gray water in residential building

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Abstract

Recovery of waste heat from gray water can be an interesting alternative to other energy saving systems in a building, including alternative energy sources. Mainly, due to a number of advantages including independence from weather conditions, small investment outlay, lack of user support, or a slight interference with the installation system. The purpose of this article is to present the financial effectiveness of installations which provide hot, usable water to a detached house, using a Drain Water Heat Recovery (DWHR) system depending on the number of system users and the various combinations of bathing time in the shower, which has an influence on the daily warm water demand in each of the considered options. The economic analysis of the adopted installation variants is based on the Life Cycle Cost (LCC) method, which is characterized by the fact that it also includes the operating costs in addition to the capital expenditure during the entire analysis period. For each case, the necessary devices were selected and the cost of their installation was estimated.

Key words: heat recovery, heat exchanger, hot water, DWHR, Life Cycle Cost, LCC

1 Introduction

In recent years there has been intensive development of energy efficient buildings, including passive and zero energy. This results in a change in the structure of energy consumption in buildings - an increasing share of primary energy is in the preparation of hot water and less participation lies in using the central heating. This fact makes current alternatives to the saving of water and the energy required to heat it. For this purpose, most installations use renewable energy sources, which is the subject of numerous publications [1,2,3]. On the other hand, the recovery of waste heat from gray water, especially in Poland, is very rarely used, although more and more frequently appearing publications point to the desirability of using this precipitation source to generate energy in both single-family (detached) [4,5] and multi-family buildings [6,7]. DWHR horizontal and vertical heat exchangers are the most commonly used energy recovery equipment deposited in the gray water in the construction

sector. A number of available solutions can be found on the market and their use is described in the literature [8,9].

The purpose of this article is to verify the profitability of vertical pipe heat exchangers, of the type “pipe in pipe” in the soil pipe discharging the gray water from the shower tray, compared to the traditional hot water supply system with only a condensing gas boiler. In order to determine the impact of various parameters on the financial performance of the system, variable data on the number of inhabitants and the duration of their bathing in the shower were taken, which has a direct influence on the daily demand for hot water.

2 Installation variants

For the analysis, 3 variants of systems which supply a single-family house with hot water have been adopted:

- Variant 0: traditional installation with condensing gas boiler with hot water storage tank;
 - Variant 1: installation of condensing gas boiler with hot water storage tank additionally equipped with vertical pipe heat exchanger DWHR1, of the type “pipe in pipe” height 1200 mm;
 - Variant 2: installation with condensing gas boiler with hot water storage tank additionally equipped with vertical pipe heat exchanger DWHR2 “pipe in pipe” with a height of 1600 mm.
- Heat exchangers of different heights were used for the analysis, due to the different efficiency of their operations. The scheme of the installations under consideration in variants 1 and 2 is shown in Figure 1, which assumes that the preheated hot water is directed to both - the hot water tank and the shower battery. In addition, this figure also shows how the “pipe in pipe” type heat exchanger works, which consists of a counter-current flow of hot, consumed water and cold water supplied from the water supply network.

Figure 1: Installation diagram with vertical heat exchanger [10]

3 Methodology

The legal basis for determining the annual requirement for the energy used to prepare the hot water $Q_{w,nd}$ [kWh/yr], and then annual operating costs for each variant analyzed is the Ordinance of the Minister of Infrastructure and Development of 27 February 2015 on methodology for designating the energy performance of a building or part of a building and energy characteristics certificates [11]. Operating costs include not only the amount of fuel necessary for the heating of hot water, in this case natural gas, but also the operating costs of auxiliary equipment such as circulating pumps or an auxiliary drive and boiler controls. Calculations in this regard were made using the ArCaDiA-TERMO 6.6 computer program for the data compiled in Table 1.

Table 1: Data used for calculations

Parameter	Parameter value
The number of occupants	3,4,5 persons
Daily hot water consumption in washbasins	6 L/person/day
Daily hot water consumption for cooking	2 L/person/day
Daily hot water consumption for cleaning	3 L/person/day
Daily hot water consumption for washing the dishes	5 L/person/day
Hot water temperature	55°C
Cold water temperature T_c	10°C
The temperature of the mixed water flowing out of the showerhead	40°C
Mixed water flow from the showerhead	9 L/min
Shower length	4,6,9 min/person/day
Performance of DWHR1 heat exchanger	52,7%
Performance of DWHR2 heat exchanger	60,1%
Water loss coefficient in the shower and tubes x	0,95
The efficiency of the hot water preparation system	68%

In order to determine the amount of energy that can be saved by equipping the hot water system with a vertical heat exchanger, the model presented in publication [12] is used, according to which the daily amount of energy saved is calculated using formula (1):

$$E_w = V_w \cdot \rho_w \cdot \gamma_w \cdot \Delta T \text{ [kWh/d]} \quad (1)$$

where:

V_w – the volume of shower water consumed per day [dm³/d],

ρ_w – specific gravity of water at 20 °C [kg/m³],

γ_w – specific heat of water [J/kg·K],

ΔT – increase in water temperature [°C].

The water temperature rise can be determined using the formula (2):

$$\Delta T = \eta_w \cdot (T_s \cdot x - T_c) \text{ [°C]} \quad (2)$$

where:

η_w – performance of heat exchanger [%],

T_s – the temperature of the mixed water flowing out of the showerhead [$^{\circ}\text{C}$],

x – water loss coefficient in the shower and tubes [-],

T_c – cold water temperature [$^{\circ}\text{C}$].

The LCC (Life Cycle Cost) method was used to determine the financial performance of selected variants providing hot usable water to a detached house using DWHR supply system. This concept takes into account the total life cycle cost of a product /premises/system and the cost of purchasing, owning, using, maintaining, disposing or utilization, etc. It is also characterized by a discounted nature, so it takes into account the change in the value of money over time [13]. This type of analysis is extremely helpful when choosing an investment option as it takes into account all the costs associated with using the installation system throughout its life cycle. The LCC life cycle cost can be calculated using the formula (3):

$$LCC = INV + \sum_{t=1}^T (1+r)^{-t} \cdot OC_t + RV \quad (3)$$

where:

INV – investments [€],

T - duration of the LCC analysis [years],

r - constant discount rate [-],

t - another year of the system use [year],

OC_t - operating costs in the year t [€],

RV - residual value [€].

In this case, the operating life of the installation system exceeds the length of the economic analysis period, it is assumed that the costs of shutdown will not be included in the calculations, which is in line with the guidelines in publication [14] according to which, in justified situations, the use a zero value of the shutting down costs is accepted. In addition, an annual increase of 3% in energy prices was assumed. A summary of the data for financial analysis is provided in Table 2.

Table 2: Data used in the calculation of LCC costs

Parameter	Parameter value
Analysis period T	20 years
The discount rate r	5%
The cost of purchasing electricity in the year 0	0,135 €/kWh
The annual increase in electricity prices	3%
The cost of purchasing gas in the year 0	0,485 €/m ³
The annual increase in electricity prices	3%
The cost of buying a gas condensing boiler	€1891
The cost of buying a hot water tank	€378, €414, €527
Installation cost of the boiler and storage tank with accessories	€355
The cost of buying DWHR1 exchanger together with the connection set	€430
The cost of buying DWHR2 exchanger together with the connection set	€480
The cost of installing a heat exchanger with accessories	€284

Prices of electricity and natural gas were based on local data. The costs of purchasing the necessary components and their parameters are read from the catalogs of the manufacturers. Condensing gas boiler MCR3 and SR100W, SR150W, SR200W hot water cylinders of the De Dietrich company [15] selected based on the number of inhabitants and daily domestic hot water demand. DWHR1 vertical heat exchangers were also used in calculations: Showersave QB1-12 and DWHR2: Showersave QB1-16 manufactured by Q-Blue [16].

4 Analysis of the results

The estimated seasonal demand for hot water, capital expenditures, operating costs in the first year of use and life cycle costs for each of the analyzed versions of hot water supply systems for a detached house are summarized in Table 3.

Table 3: Calculation results

	Shower length min/person/day	Variant	$Q_{w,nd}$	INV	OC _t	LCC
			kWh/rok	€	€	€
3 persons	4	0	2982	2624	229	6274
		1	2306	3338	180	6216
		2	2210	3388	173	6157
	6	0	4015	2660	287	7241
		1	2999	3373	214	6796
		2	2857	3423	204	6684
	9	0	5563	2660	398	9008
		1	4040	3373	289	7984
		2	3827	3423	274	7790
4 persons	4	0	3976	2660	284	7197
		1	3074	3373	220	6881
		2	2947	3423	211	6787
	6	0	5353	2660	383	8768
		1	3999	3373	286	7937
		2	3809	3423	272	7770
	9	0	7417	2773	530	11238
		1	5387	3487	385	9635
		2	5102	3537	365	9359
5 persons	4	0	4970	2660	355	8332
		1	3843	3373	275	7758
		2	3684	3423	263	7628
	6	0	6691	2773	478	10409
		1	4999	3487	357	9192
		2	4762	3537	340	8971
	9	0	9272	2773	663	13354
		1	6734	3487	481	11172
		2	6378	3537	456	10815

Based on the results of the calculations, the tendency is that the use of a DWHR heat exchanger in each case reduces the energy demand for hot water production, which directly triggers lower operating costs for facility users and the amount of recycled energy from gray water is directly proportional to the daily amount of water used for bathing. Considering the variants analyzed, the use of a heat recovery system in a single-family house reduces the annual utility demand for domestic hot water in the range of 23 to 31%, which translates into a difference in annual operating costs of €6 for variant 1, 3 inhabitants and shower duration 4 min/person/day up to €207 for variant 2, 5 inhabitants and shower duration of 9 min/person/day.

It is also evident that the lowest LCC values are in variant 2, which is best illustrated in Figure 2, which shows the results of the LCC analysis for all cases. This is due to the use of a higher-than-capacity variant 1 for the heat exchanger, so that more energy can be obtained from the gray water. There is therefore a relationship between the height of the device and its energy efficiency. It is therefore preferable to install higher-end devices even if the investment outlay is higher, as a result of the calculations made, although this choice should always be supported by detailed analysis.

In the context of twenty years of operation of a plant, the direct economic profitability of the facility's users resulting from the installation of the heat exchanger, including the cost of installation and annual operating costs, is €59 for variant 1, 3 inhabitants and shower duration of 4 min/person/day. €2539 for variant 2, 5 inhabitants and shower duration of 9 min/person/day.

Figure 2: Comparison of Life Cycle Cost analysis results

The use of a gray water heat recovery system has several advantages: it is cost-effective (in each of the cases analyzed, the life cycle cost of the system was lower than the exchanger variant), it does not require a high investment expenditure ("pipe in pipe" heat exchanger cost and installation costs are usually less than €1000), it does not involve the need for user service, and every day during each bath generates savings. Most importantly, this translates into environmental protection, since the recovered energy is "pure" energy, and its processing does not involve the need for fuel.

5 Conclusion

The use of financial analysis based on the Life Cycle Cost method makes it possible to choose the most economical and cost-effective option, assuming the calculation of all costs in the perspective of the twenty-year life of the system. The performed LCC analysis showed that Variant 0, despite the lowest capital expenditure, was characterized by the highest life cycle cost regardless of other accepted parameters. In each case analyzed, the fitting of DHW systems into the vertical pipe heat exchanger DWHR, of the type "pipe in pipe" (Variant 1 and 2) turned out to be a viable investment, and the life cycle costs of these systems were always lower than for traditional systems.

The use of heat recovery systems reduces the amount of energy required for domestic hot water production in the analyzed cases by up to 31%, which triggers the reduction in the amount of external energy required, mainly from fossil fuel fields. This is of great importance for sustainable economic development, as it helps to reduce the consumption of non-renewable raw materials, reduce greenhouse gas emissions and, consequently, improve the environment.

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