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ASSESSING THE FINANCIAL BENEFITS OF USING A SHOWER DRAIN HEAT RECOVERY SYSTEM – A CASE STUDY

OCENA KORZYŚCI FINANSOWYCH Z WYKORZYSTANIA INSTALACJI ODZYSKIWANIA CIEPŁA Z ODPŁYWU SPOD PRYSZNICA – STUDIUM PRZYPADKU

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Abstract

The production of hot water for bathing in Poland accounts for around 15% of the total energy consumption of a typical household. According to EU data, final energy consumption for lighting and appliances is similar to final energy consumption for hot water preparation. This makes it a significant contributor to housing and utility costs, exceeded only by heating expenses. Research has indicated that only about 10% of the water utilized during a shower is necessary for hygiene purposes. Consequently, around 90% of the hot water supplied to the shower is ultimately discharged into the sewage system. By harnessing the primary energy from wastewater, we can effectively conserve heat energy and reduce the overall expenditure associated with hot water. The objective of this article is to explore the utilization of heat recovery from domestic wastewater as a means to enhance the energy efficiency of residential buildings.

Keywords: wastewater heat recovery, grey wastewater, heat exchangers

Streszczenie

Wytwarzanie ciepłej wody w Polsce do kąpieli stanowi około 15% całkowitego zużycia energii w typowym gospodarstwie domowym. Według danych UE, końcowe zużycie energii na oświetlenie i urządzenia jest zbliżone do końcowego zużycia energii na przygotowanie ciepłej wody użytkowej. To sprawia, że jest to znaczący czynnik wpływający na koszty mieszkaniowe i użytkowe, przewyższany jedynie przez wydatki na ogrzewanie. Badania wykazały, że tylko około 10% wody zużywanej podczas kąpieli pod prysznicem jest niezbędna do celów higienicznych. W rezultacie około 90% ciepłej wody dostarczanej do prysznica jest ostatecznie odprowadzane do kanalizacji. Wykorzystując energię pierwotną ze ścieków, możemy skutecznie oszczędzać energię cieplną i zmniejszyć ogólne wydatki na ciepłą wodę. Celem tego artykułu jest zbadanie wykorzystania odzysku ciepła ze ścieków domowych jako sposobu na zwiększenie efektywności energetycznej budynków mieszkalnych.

Słowa kluczowe: odzysk ciepła ze ścieków, ścieki szare, wymienniki cieplne

1. INTRODUCTION

An analysis of total primary energy consumption in buildings has shown that the percentage of energy consumption for heating hot water is approximately 15% [1]. With continued efforts to reduce energy consumption for heating buildings, the percentage of energy consumed for heating water by hot water supply systems will increase every year. The huge

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amount of heat energy contained in wastewater is usually not used but simply discharged into the sewer system. To meet European climate protection targets, the use of heat from wastewater provides a huge and largely untapped potential for the development of a cost-effective heat supply for buildings [2].

The idea of extracting heat from wastewater by means of heat pumps is not new. Since the 1980s, centralized systems in Germany, Switzerland, Sweden or Norway have been using the heat from wastewater collected in sewers and in treatment plants [1]. The temperature of the wastewater at the collection points is from 10-15°C all year round, and reaches up to 20°C in summer, which is sufficient for guaranteed and uninterrupted operation of the heat pumps. In the winter months, when there is a high heat demand, the wastewater temperature at the centralized heat pump sites is only around 10°C, which reduces the efficiency of the heat pump [3].

There are four main possible locations for heat recovery from wastewater in a sewerage system [4]: at the sanitary level (A), at the building level (B), in the sewer pipe network (C) and from the sewage treatment plant (D). The main and most economical and most common option is variant (A).

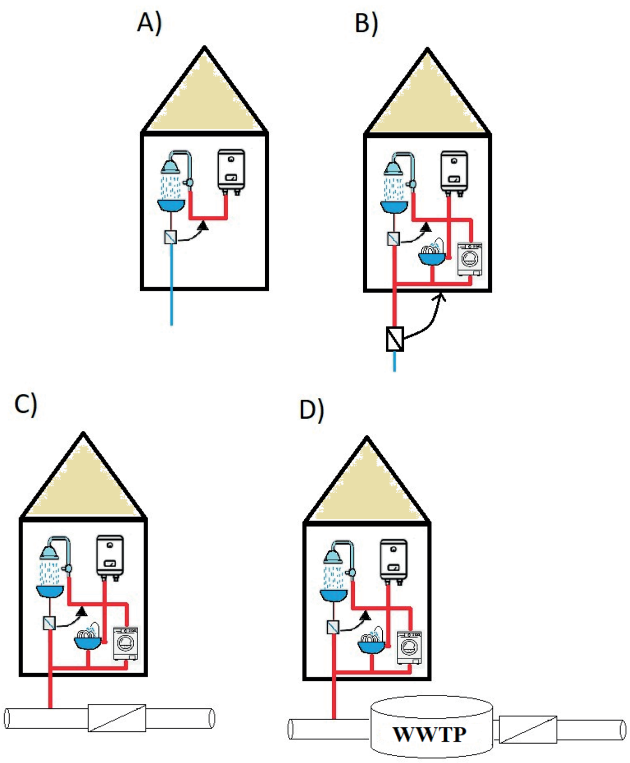

Fig. 1. Possible options for heat recovery from wastewater [4]

At the sanitary appliance level, heat is recovered from waste water immediately after it is generated during specific single-factor activities (e.g. showering, cooking, eating). The heat is recovered using a heat exchanger directly downstream of the sanitary appliance in question. The recovered heat can be used to pre-heat the feed water, in domestic or commercial shower installations.

Heat recovery from shower water is the most common application found in practice. The advantage of this application is the continuous, simultaneous counter-current flow of wastewater and cold water supply to the shower. Heat recovery in this case, can be realized with high efficiency, and in addition, there is no time delay between the availability of waste heat and the heat demand for showering, eliminating the need for heat storage and the resulting losses [5, 6].

A general scheme for heat recovery from shower water is shown in Figure 2.

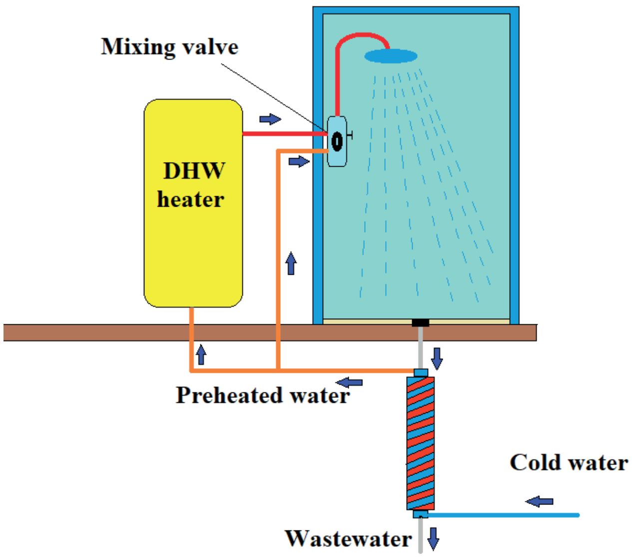

Fig. 2. Schematic of heat recovery from under the shower (own research)

2. MATERIALS AND METHODS

The studies analyzed in this document, focusing on the WWHR for option A at different shower durations and different numbers of residents using the shower. In order to carry out these calculations, it was necessary to use the average water consumption data for the sanitary facilities and the water temperature at the inlet and outlet. The cost analysis was carried out in terms of investment and operating costs.

The flow rate of the grey waste water draining from the shower and the cold water drain are equal. When mixing hot water from the effluent (which is warm due to the shower) with cold water, the thermal energy transferred between the two depends on the temperature difference between them and the flow rate [7]. If the temperature difference between cold water and wastewater (ΔT) is different, the increase in the temperature of the cold water supply will be different from the decrease in the wastewater temperature. Conversely, if ΔT is equal, there will be no change in the temperature of the cold water supply.

The Building America Research benchmark definition [8] provides a general model for end-user hot water consumption, as described in Table 1. N_{br} [-] is the number of bedrooms in a dwelling. Figure 3 shows the hourly hot water consumption for each end-user as a fraction of the total end-user consumption [9].

Table 1. Hot water consumption by end use [5]

End use	End water temperature °C	Water consumption/ dm^3/d
Clothes washer	49.0	$28.4 + 9.46N_{br}$
Dishwasher	49.0	$9.46 + 3.15N_{br}$
Shower	40.6	$53 + 17.67N_{br}$
Bath	40.6	$13.25 + 4.43N_{br}$
Sinks	40.6	$47.32 + 15.75N_{br}$

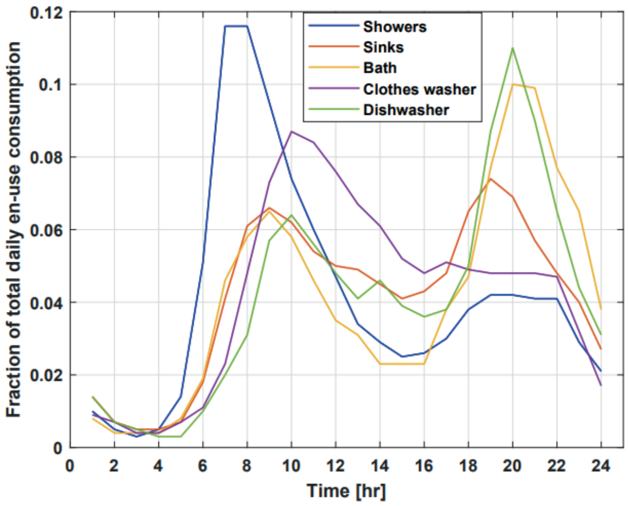

Fig. 3. Typical hot water consumption profile [5, 9]

For the selected prototype, i.e. the number of bedrooms N_{br} = 2, the total hot water consumption is approximately 250.35 m^3/d based on the equations given in Table 1.

The amount of energy consumed by the DHW heater can be determined by the equation [10]:

$$W = c \cdot \Delta T \cdot q \cdot \sigma \cdot t \cdot 10^{-3} \text{ [kWh]} \quad (1)$$

where:

- W – amount of energy consumed by the DHW heater during the shower [kWh];
- t – duration of showering [s];
- q – volumetric water flow rate heated in the heater – 0.15 dm^3/s;
- σ – density of water heated in the heater [kg/dm^3];
- c – specific heat of water heated up in heater [$Wh/kg \cdot K$];
- ΔT – temperature difference between cold and hot water [K];
- Thw – temperature of hot water [K];
- Tcw – temperature of cold water [K].

3. CASE STUDY

This paragraph presents an example of the calculation of potential financial gains using a heat recovery system for grey waste water discharged from a shower. The cost of a shower lasting 3, 5, and 10 minutes, without heat recovery, and with recovery, was analyzed. Three-phase instantaneous water heaters of 27 kW were used.

A hot water temperature of 40.6°C and a cold water temperature of 10°C was assumed. The grey waste water temperature oscillates between 35-40°C, and a value of 35°C was assumed for the calculations. Temperature-dependent water properties such as specific heat and density were assumed on the basis of tables of water physical properties [11]. The cost of electricity was determined for the average total cost of 1 kWh in Poland in 2023 for the G11 tariff group of 0.627 PLN/kWh [12]. Calculations were made for variants with two, three, and four people assuming that each person uses the shower once a day. Table 2 shows the amounts of electricity required for the operation of the heater in the two variants, for different showering times.

Table 2. Summary of the results of cost recovery calculations in the case of the use of wastewater heat recovery systems, for different variants of the duration of the shower, and the number of people using the shower

Duration of shower		3 min			5 min			10 min		
Number of people using the shower		2	3	4	2	3	4	2	3	4
Without heat recovery	kWh	1.92	2.88	3.84	3.20	4.80	6.40	6.39	9.59	12.79
	Cost [PLN]	1.20	1.81	2.41	2.01	3.01	4.01	4.01	6.01	8.02
Annual cost [PLN]		433	650	867	722	1083	1445	1442	2165	2887
With heat recovery system	kWh	0.37	0.56	0.74	0.62	0.93	1.24	1.24	1.86	2.48
	Cost [PLN]	0.23	0.35	0.46	0.39	0.58	0.78	0.78	1.17	1.55
Annual cost [PLN]		84	128	168	143	212	285	285	427	565
Annual profit with heat recovery [PLN]		349	522	699	579	871	1160	1157	1738	2322
Period in years needed to recover the investment [years]		14.3	9.5	7.2	8.6	5.7	4.3	4.3	2.9	2.15

4. RESULTS AND DISCUSSION

The amount of investment outlay was assumed to be the purchase price of the heat exchanger and the cost of its installation. The cost of such an exchanger ranges from 2000 to 4500 PLN [13], depending on the model and manufacturer. The installation price depends mainly on whether the installation will be carried out in a new or old building. For the calculations, the total investment cost for 2023 was assumed to be PLN 5,000. Figure 4 presents a graph of the annual costs of domestic hot water preparation for showers with and without heat recovery for different calculation variants.

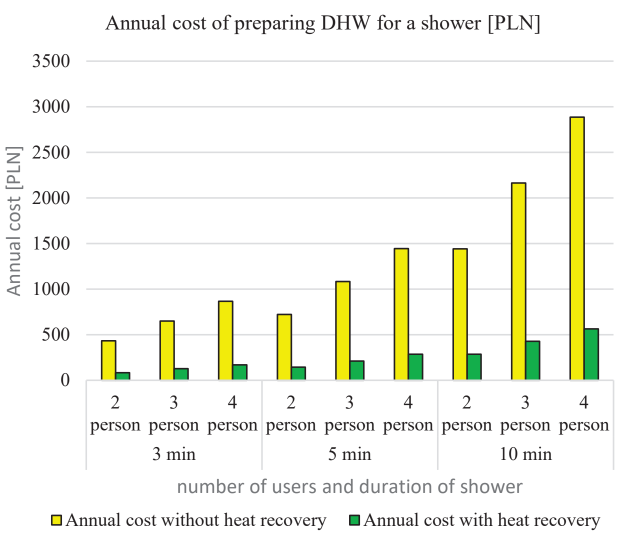

Fig. 4. Cost for shower with and without recovery [values given in PLN]

The expected annual profits from installing a wastewater heat recovery system range from approximately 349 PLN for the shortest bathing time, with two users, to 2,322 PLN per year for 10-minute baths with four users.

The calculation results presented show that the duration of the bath and the number of users have a significant impact on the financial efficiency of the project. Assuming an average shower duration of 5 minutes, the payback period for such a shower varies from about 8.5 years (2 persons) to about 4.5 years (4 persons). For long showers, on the other hand, the payback period should not exceed 4.5 years.

5. CONCLUSIONS

An analysis of the financial efficiency of using a heat recovery system from shower drain water from the shower allowed the following conclusions to be drawn:

- There is a relationship between the daily duration of the shower use and the number of users and the possible financial savings. The financial efficiency increases with increasing shower duration and water consumption. Consequently, the benefit of a heat recovery system is most cost-effective for large families, sports, service facilities and industrial facilities where showers are frequently used.
- For families of at least 4 people, with each person using the use the shower at least once a day for 5 minutes, the payback time should not exceed 5

years. The annual return for families of 4 people ranged from 699 to 2322 PLN, depending on the duration of the shower.
- Reducing DHW consumption means that less energy will be needed to heat the water, resulting in measurable savings. Furthermore, by reducing energy consumption, heat recovery systems can help reduce greenhouse gas emissions and contribute to a more sustainable future.

Overall, a shower waste heat recovery system can be an effective way to improve the efficiency and sustainability of a domestic hot water system.

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