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EXPERIMENTAL MEASUREMENT OF HEAT RECOVERY FROM SHOWER WASTEWATER

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Abstract. The wastewater generated during showering represents a potential source of low-grade thermal energy that can be utilised to reduce the energy required for domestic water heating. This paper presents an experimental investigation of a shower wastewater heat recovery system in laboratory conditions. Measurements were carried out during summer and autumn periods under operating modes with and without heat recovery for 6- and 10-minute showering cycles. Temperatures and flow rates of the hot water, cold water, preheated cold water, mixed water, and wastewater were monitored.

The results showed that the temperature of the cold water flowing through the heat exchanger increased by approximately 6–6.5 K. The experimentally determined heat exchanger efficiency reached 38–39 %, while the relative heat savings were approximately 23 %. The measurements also confirmed the effect of real operating conditions, particularly ambient temperature and non-insulated pipelines, on the measured parameters.

Keywords: Experimental measurement, wastewater, shower.

1. Introduction

In the context of energy management, current global efforts are increasingly focused not only on renewable energy sources but also towards reducing the overall energy consumption, which remains a primary concern [1]. Renewable energy sources, such as wind, solar, and geothermal energy, originate from naturally replenished resources [2], however, effective energy management, particularly through the control and optimisation of energy systems, plays a crucial role in reducing energy consumption [3]. Within the framework of energy management, it is therefore essential to utilise energy that has already been consumed, for instance in domestic water heating.

Energy recovery represents a significant technological advancement that enables energy consumption to be reduced by transferring thermal energy from otherwise unused waste streams to other systems [4]. In typical households, a substantial volume of wastewater with relatively high temperatures is discharged into sewer systems on a daily basis. According to a study reported in [5], a residential building occupied by a household of four people may consume approximately 1 300 litres of potable water per day and generate around 800 litres of wastewater. A suitable source of waste heat in residential sewer systems is greywater, originating from showers, washbasins, and washing machines. The implementation of separate sewer systems for greywater and blackwater may be technically and economically demanding in certain cases. However, the utilisation of wastewater heat at a basic level, namely directly downstream of a shower, does not represent a significant technical challenge. Approximately two-thirds of domestic hot water consumption is associated with showering, and the recovery of heat from shower wastewater represents one of the simplest forms of energy recovery, as it involves relatively low-contaminated greywater [6].

After being discharged into the sewer system, the temperature of shower wastewater decreases by approximately 2 to 4 K; nevertheless, the wastewater downstream of the shower still retains a considerable energy potential. This energy can be recovered effectively using the appropriate technical solutions, for example, for domestic hot water preheating, thereby contributing to a reduction in the overall energy consumption [7].

2. Utilisation of waste heat from wastewater for domestic hot water production

In the case of small-scale heat recovery systems, the principle of utilising waste heat from sewer systems is based on the transfer of thermal energy from the wastewater to a heat transfer medium, typically cold water, by means of a local heat exchanger [8]. In this configuration, the heat exchanger consists of a copper coil through which the cold water flows, wrapped around a drainage pipe carrying the wastewater. The thermal energy from the wastewater is transferred to the cold water through the walls of both pipes; thus, the fluids are separated by a double wall in accordance with the requirements of STN EN 1717 [9]. After absorbing thermal energy from the wastewater, the temperature of the cold water flowing through the heat exchanger increases by several kelvins, depending on the efficiency of the heat exchanger. Following

the heat transfer process, the preheated cold water flows into a thermostatic mixing valve in the shower, where it is mixed with the hot water supplied from a storage water heater. In addition to supplying the thermostatic shower valve, the preheated cold water may also be directed to the storage water heater, or to both simultaneously (depending on the system configuration) [10]. However, this arrangement is not the subject of the present study. It is assumed that by increasing the temperature of the incoming cold water and subsequently mixing it with hot water, a lower amount of energy from an external source is required to achieve the desired outlet water temperature in the shower. To obtain more accurate data on hot water consumption, experimental measurements were carried out in laboratory conditions.

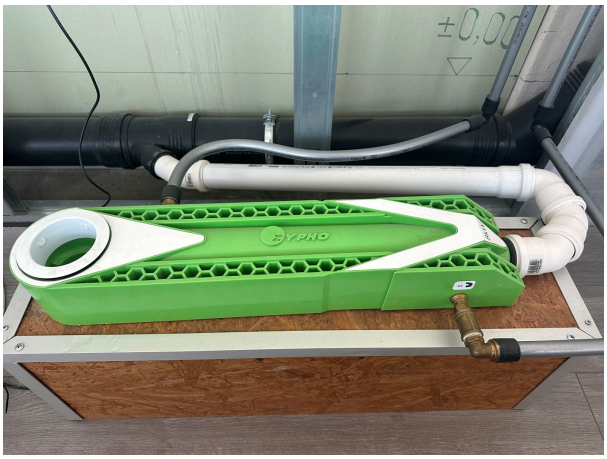

Figure 1. Heat exchanger.

3. Experimental investigation of a wastewater heat recovery system under laboratory conditions

The experimental measurements were conducted in an experimental laboratory at the Faculty of Civil Engineering of the Slovak University of Technology in Bratislava. The measurement setup consisted of a shower equipped with a heat exchanger (Figure 1) and a storage water heater. The hot water for showering was heated in a 100-litre electric storage water heater. Due to insufficient pressure conditions in the existing cold water supply piping, a pressure boosting station was used, set to an operating pressure of 3.7 bar. The water supply pipelines were made of multilayer plastic-aluminium pipes (Geberit Mepla), while the sewer pipes were made of polyethylene (Geberit Silent). The shower was equipped with a thermostatic mixing valve. A schematic diagram of the measurement setup is shown in Figure 2.

Due to the laboratory conditions, it was not possible to simulate real showering directly above the heat exchanger. Therefore, the wastewater from the shower outlet was conveyed directly into the heat exchanger by means of a 1.5 m long flexible hose. The wastewater flowed without any intermediate accumulation or contact with surrounding surfaces in order to minimise uncontrolled heat losses prior to entering the heat exchanger. The experimental measurements on the measurement setup (Figure 3) were carried out in July and October 2025. The heat exchanger consists of a plastic box through which the sewer pipe from the shower is routed. The cold water supply pipe is wrapped around the sewer pipe inside the heat exchanger. The preheated cold water from the heat exchanger then flows into the thermostatic shower mixing valve.

The measurements were performed both with and without the heat exchanger. For the measurements not utilising wastewater heat, the water supply was provided through a safety bypass equipped with stop valves (Figure 3).

Since the efficiency of the heat recovery system is affected by several factors, one of which is the duration of showering, showering intervals of 6 and 10 minutes were considered in the experiment.

For both showering durations, two measurement cycles without the heat exchanger and two cycles with the heat exchanger were performed during both the summer and autumn periods. During the measurement cycles, six parameters were monitored: the flow rate of hot water, the temperature of hot water, the temperature of mixed water, the temperature of wastewater, the temperature of cold water, and the temperature of preheated cold water.

For experimental purposes, the hot water flow rate and the temperatures of hot water, mixed water, wastewater, cold water, and preheated cold water were measured in both periods using the ALMEMO 2590 measuring device (Figure 4). The water flow rate and temperature at the thermostatic shower mixing valve were measured using the Kemper Control Plus device (Figure 5).

3.1. Experimental study during the summer period

During the summer measurement period, the air temperature in the laboratory ranged from 30 °C to 32 °C. The measurements were carried out in July 2025 using a heat exchanger (HE) with a manufacturer-declared efficiency of 39 % [11]. The temperature of the water supplied to the shower was set to 39 °C. The mixed water flow rate was set to 15 l min^{-1} (M2), representing a flow rate corresponding to a comfortable shower using a conventional showerhead. The temperature profiles of the measured variables during the 10-minute showering cycles without heat recovery are shown in Figure 6, while the results with heat recovery are presented in Figure 7.

The measured variables were recorded using an ALMEMO data acquisition device for all experiments at 10-second intervals. The temperature (T1) PWH

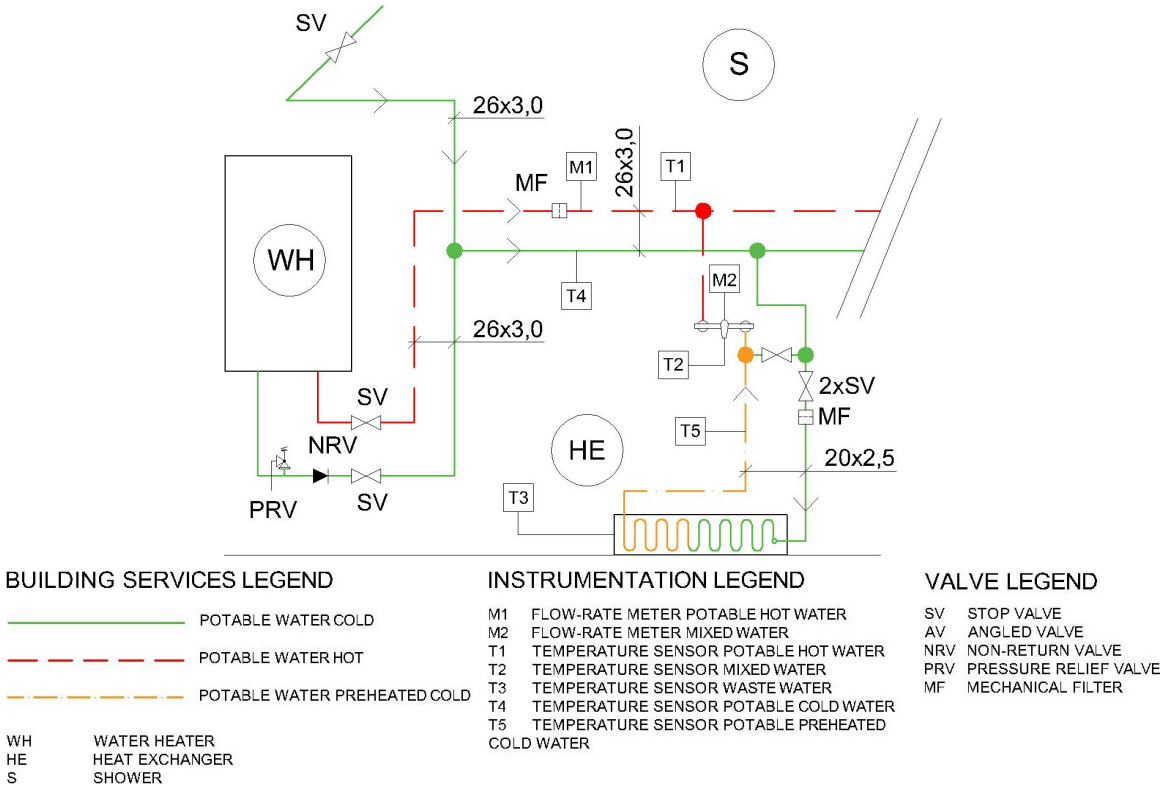

FIGURE 2. Schematic diagram of the laboratory measurement setup.

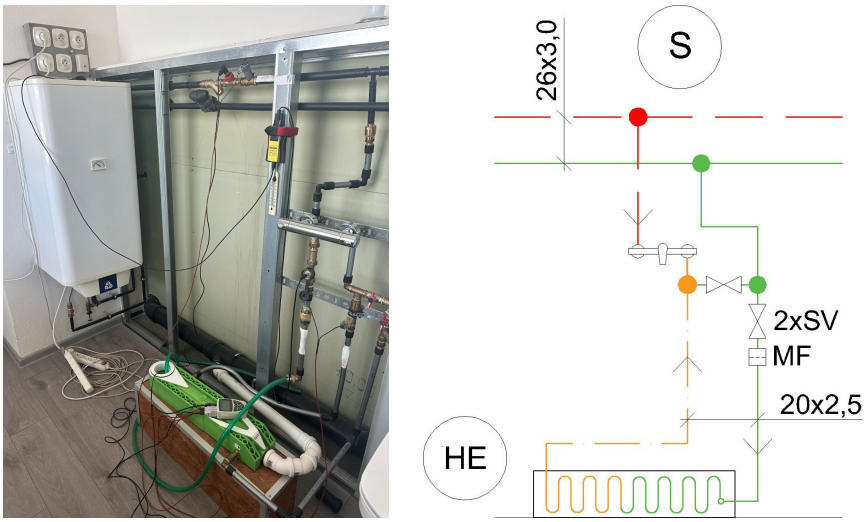

FIGURE 3. Part of the measurement setup including a heat exchanger and a safety bypass.

denotes the hot water supplied from the storage water heater, the temperature (T2) MW represents the mixed water in the thermostatic shower valve directly at the outlet, WW (T3) is the temperature of the wastewater in the heat exchanger, PWC (T4) is the temperature of the cold water, and PPWC (T5) represents the temperature of the preheated cold water which, after receiving thermal energy, flows to the thermostatic valve.

Since the cold water pipelines were not insulated, the high air temperatures in the laboratory significantly affected the temperature of the cold water in the pipes. At the start of the experimental setup, the cold water temperature sometimes reached temperatures of up to 28 °C. For this reason, a large amount of water had to be discharged from the pipelines before the actual measurements were initiated. The measurements started only after the temperature of the cold water dropped below 23 °C.

Both graphs show that during the measurements, the temperature of the cold water decreased by approximately 2 K on average over the 10-minute cycle as a result of flushing the pipelines. The temperature of the cold water flowing through the heat exchanger increased by approximately 6 K after receiving thermal energy from the wastewater. This means that

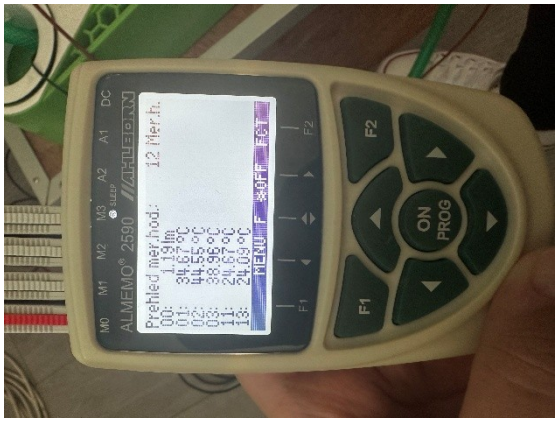

Figure 4. ALMEMO 2590.

Figure 5. Kemper Control Plus.

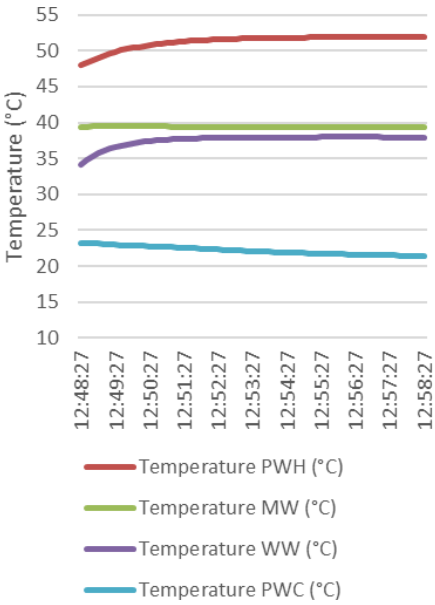

Figure 6. Temperature profile graph for the 10-minute measurement taken during the summer period without heat recovery.

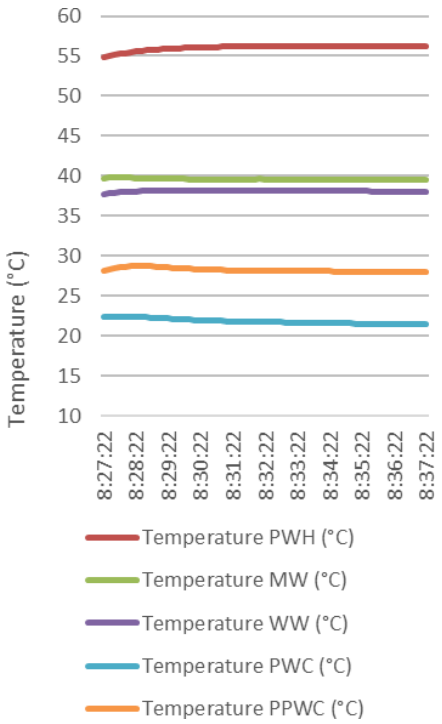

Figure 7. Temperature profile graph for the 10-minute measurement taken during the summer period with heat recovery.

during waste heat recovery, hot water from the storage water heater with an average temperature of 56.03 °C was mixed in the thermostatic shower valve with preheated cold water having an average temperature of 28.22 °C.

The average values obtained from all experimental measurements during the summer period are summarised in Table 1.

3.2. Experimental study during the autumn period

During the autumn period, the temperature of the cold water in the pipelines ranged between 20 °C and 21 °C, and therefore it was not necessary to discharge such a large amount of water from the pipelines as was required during the summer measurements. The thermostatic shower valve was set to a water temperature of 39 °C.

The temperature profiles of all measured variables during the 10-minute showering cycle are shown in Figures 8 and 9.

Similarly to the summer period, during the 10-minute showering cycles in October 2025, the temperature of the cold water decreased by approximately 2 K. Using the heat exchanger to utilise waste heat, the temperature of the cold water flowing through the heat exchanger increased by approximately 6.5 K. This means that hot water with an average temperature of 48.23 °C was mixed in the thermostatic shower valve with preheated cold water having an average temperature of 26.11 °C.

Shower duration without/with HE	Hot water flow rate M1 [l min^{-1}]	Temperature T1 PWH [°C]	Temperature T2 MW [°C]	Temperature T3 WW [°C]	Temperature T4 PWC [°C]	Temperature T5 PPWC [°C]
6 min without HE	2.25	56.09	38.12	36.86	21.41	26.58
6 min without HE	2.59	51.98	37.15	36.32	21.10	25.92
6 min with HE	1.67	56.40	38.10	36.97	22.23	27.17
6 min with HE	1.69	56.37	38.04	37.00	21.66	26.89
10 min without HE	2.26	55.29	38.44	37.15	22.33	27.64
10 min without HE	2.68	51.26	39.39	37.56	22.17	27.49
10 min with HE	1.78	54.90	38.18	37.65	21.98	27.66
10 min with HE	1.83	56.03	39.60	38.09	21.82	28.22

TABLE 1. Average values measured during the summer period for a mixed water flow rate of 15 l min^{-1}.

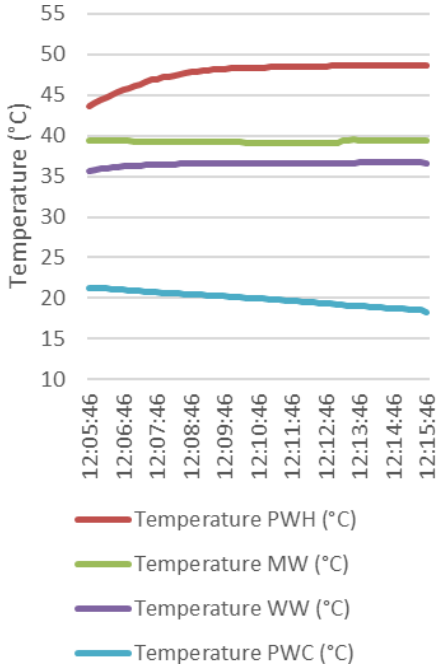

FIGURE 8. Temperature profile graph for the 10-minute measurement taken during the autumn period without heat recovery.

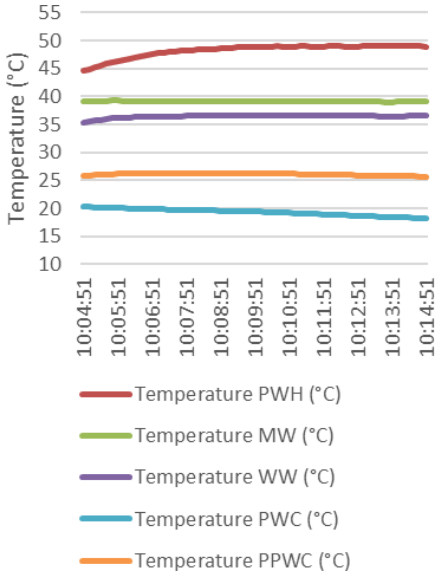

FIGURE 9. Temperature profile graph for the 10-minute measurement taken during the autumn period with heat recovery.

The average values obtained from the experimental measurements conducted during the autumn measurement period are presented in Table 2.

4. Results and discussion

The manufacturer of the heat exchanger declares an efficiency of 39 % [11], however, this value is often determined under ideal laboratory conditions. In our laboratory, the conditions for experimental measurements are not ideal, since the pipelines are not thermally insulated and the temperature of almost all measured variables is significantly affected by the ambient air temperature. This effect was particularly noticeable in the measured temperatures of the cold water during the summer measurements.

The efficiency of the heat transfer depends not only on the temperature difference ratio, but also on the flow rates of the wastewater and cold water streams, since the flow conditions affect the residence time and intensity of heat transfer within the heat exchanger. Therefore, the thermal efficiency of the heat exchanger declared by the manufacturer will be verified according to [12]:

$$\begin{aligned}\eta &= \frac{Q}{Q_{\max}} \\ &= \frac{V_{\mathrm{PPWC}}\,\rho_{\mathrm{PPWC}}\,c_{\mathrm{PPWC}}\,(\theta_{\mathrm{PPWC}}-\theta_{\mathrm{PWC}})}{V_{\mathrm{PPWC}}\,\rho_{\mathrm{PPWC}}\,c_{\mathrm{PPWC}}\,(\theta_{\mathrm{WW}}-\theta_{\mathrm{PWC}})} \\ &= \frac{\theta_{\mathrm{PPWC}}-\theta_{\mathrm{PWC}}}{\theta_{\mathrm{WW}}-\theta_{\mathrm{PWC}}},\end{aligned} \tag{1}$$

where:

η efficiency of the heat exchanger [–],

Q heat flow [W],

$Q_{\max}$ maximum heat transfer rate [W],

V_{PPWC} volumetric flow rate of preheated potable cold water [m^3 s^{-1}],

Shower duration without/with HE	Hot water flow rate M1 [l min^{-1}]	Temperature T1 PWH [°C]	Temperature T2 MW [°C]	Temperature T3 WW [°C]	Temperature T4 PWC [°C]	Temperature T5 PPWC [°C]
6 min without HE	2.46	48.24	39.17	36.56	19.15	20.95
6 min without HE	2.59	49.13	39.13	36.58	18.21	20.58
6 min with HE	2.01	48.91	39.14	36.61	17.87	25.51
6 min with HE	2.07	48.89	39.08	36.53	17.56	25.49
10 min without HE	2.76	47.70	39.26	36.50	19.92	20.08
10 min without HE	2.71	48.47	39.38	36.80	18.00	19.92
10 min with HE	1.93	48.23	39.16	36.44	19.33	26.11
10 min with HE	1.99	48.05	39.33	36.74	20.16	26.84

Table 2. Average values measured during the autumn period for a mixed water flow rate of 15 l min^{-1}.

Shower duration without/with HE	Hot water flow rate M1 [l min^{-1}]	Temperature T1 PWH [°C]	Temperature T2 MW [°C]	Temperature T3 WW [°C]	Temperature T4 PWC [°C]	Temperature T5 PPWC [°C]
6 min with HE	1.86	52.64	38.59	36.78	19.83	26.27
10 min with HE	1.89	51.80	39.07	37.23	20.82	27.21

Table 3. Average measured values for both periods.

ρ_{PPWC} density of preheated potable cold water [kg m^{-3}],

c_{PPWC} specific heat capacity of preheated potable cold water at constant pressure [J kg^{-1} K^{-1}],

θ_{PPWC} temperature of preheated potable cold water [°C],

θ_{PWC} temperature of potable cold water [°C],

θ_{WW} temperature of wastewater [°C].

In order to determine the heat transfer efficiency, it is necessary to evaluate the average measured values for the 6-minute and 10-minute measurements performed only with the heat exchanger, combining the results from both the summer and autumn measurement periods.

The average measured values for both measurement periods are presented in Table 3.

By substituting the average values obtained from the 6-minute and 10-minute measurements with heat recovery (Table 3) into Equation (2) according to [12], the heat transfer efficiency can be calculated as follows:

$$\begin{aligned} \eta_6 &= \frac{\theta_{\mathrm{PPWC}} - \theta_{\mathrm{PWC}}}{\theta_{\mathrm{WW}} - \theta_{\mathrm{PWC}}} = \frac{26.27 - 19.83}{36.78 - 19.83} = 38\,\%, \\ \eta_{10} &= \frac{\theta_{\mathrm{PPWC}} - \theta_{\mathrm{PWC}}}{\theta_{\mathrm{WW}} - \theta_{\mathrm{PWC}}} = \frac{27.21 - 20.82}{37.23 - 20.82} = 39\,\%. \end{aligned} \tag{2}$$

The heat transfer efficiency for the 6-minute showering cycles, with an average temperature of preheated cold water of 26.27 °C, wastewater temperature of 36.78 °C, and cold water temperature of 19.83 °C, is 38 %.

For the 10-minute showering cycles, with an average temperature of preheated cold water of 27.21 °C, wastewater temperature of 37.23 °C, and cold water temperature of 20.82 °C, the efficiency reaches 39 %.

However, the efficiency of the heat exchanger and the heat savings are not identical, since the temperature of the wastewater in the heat exchanger decreases along the exchanger length [13, 14]. According to the performed measurements, the temperature difference between the water at the shower outlet and the wastewater temperature in the heat exchanger is approximately 2–3 K.

The relative heat savings can be calculated as a direct function of the heat transfer efficiency and the temperature conditions as follows [12, 14]:

$$\begin{aligned} \Theta_{\mathrm{WWHR}} &= 1 - \frac{1-\eta}{1-\eta\frac{\theta_{\mathrm{WW}}-\theta_{\mathrm{PWC}}}{\theta_{\mathrm{PWH}}-\theta_{\mathrm{PWC}}}}, \\ \Theta_{\mathrm{WWHR\text{-}6}} &= 1 - \frac{1-0.38}{1-0.38\frac{36.78-19.83}{52.64-19.83}} = 23\,\%, \\ \Theta_{\mathrm{WWHR\text{-}10}} &= 1 - \frac{1-0.39}{1-0.39\frac{37.23-20.82}{51.80-20.82}} = 23\,\%, \end{aligned} \tag{3}$$

where:

θ_{WWHR} relative heat savings of wastewater heat recovery [–],

η efficiency of the heat exchanger [–],

θ_{PWC} temperature of potable cold water [°C],

θ_{WW} temperature of wastewater [°C],

θ_{PWH} temperature of potable water hot [°C].

After substituting the average measured values into Equation (3) for the 6-minute and 10-minute showering cycles, the relative heat savings were calculated

to be 23 % in both cases, which is approximately one third lower than the calculated heat exchanger efficiency.

5. Conclusion

Experimental measurements of the wastewater heat recovery system have shown that usinga shower heat exchanger in real (not ideal) laboratory conditions can contribute to reducing the energy demand for domestic water heating. Based on the average values obtained during the summer and autumn measurement periods, the temperature of the cold water flowing through the increased by approximately 6 to 6.5 K on average after receiving thermal energy from wastewater.

The heat exchanger efficiency of 39 %, as declared by the manufacturer, was confirmed by the experiment, despite the unfavourable laboratory conditions, which were mainly related to the ambient air temperature and the absence of thermal insulation of the pipelines.

After considering the average measured values, the relative heat savings were determined to be 23 %, since heat savings and the thermal efficiency of the heat exchanger are not identical parameters. This finding indicates that the achieved energy savings depend strongly on the temperature conditions of the cold and wastewater streams. The measurement results confirm that integrating a shower heat exchanger into the system can significantly reduce the amount of energy required to heat shower water supplied from an external energy source.

For a more accurate determination of the energy benefits under real operating conditions, it is necessary to conduct long-term measurements, including the monitoring of domestic hot water consumption during showering and the analysis of the effects of different inlet cold-water temperatures on heat savings. Future research could also focus on experimental measurements performed at lower flow rates of mixed water, since modern water-saving showerheads typically operate with lower flow rates. It can be assumed that the mixed water flow rate may affect the achieved heat savings and the overall thermal performance of the system. Further research may additionally address the optimisation of heat exchanger configurations and the effect of thermal insulation of pipelines on the overall thermal performance of the system.

List of symbols

η efficiency of the heat exchanger [–]

Q heat flow [W]

$Q_{\max}$ maximum heat transfer rate [W]

V_{PPWC} volumetric flow rate of preheated potable cold water [$\mathrm{m^3\,s^{-1}}$]

ρ_{PPWC} density of preheated potable cold water [$\mathrm{kg\,m^{-3}}$]

c_{PPWC} specific heat capacity of preheated potable cold water at constant pressure [$\mathrm{J\,kg^{-1}\,K^{-1}}$]

θ_{PPWC} temperature of preheated potable cold water [°C]

θ_{PWC} temperature of potable cold water [°C]

θ_{WW} temperature of wastewater [°C]

θ_{PWH} temperature of potable water hot [°C]

Θ_{WWHR} relative heat savings of wastewater heat recovery [–]

PPWC preheated potable water cold

PWC potable water cold

PWH potable water hot

WW wastewater

MW mixed water

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