Improving the efficiency of energy recovery from wastewater by using a double heat exchanger to protect the environment

M.S.A. Albaiyati¹ ² P. Danca¹ ³ A. Neagu¹ and M. Sandu¹

¹CAMBI Research Centre, Technical University of Civil Engineering Bucharest, 021414 Bucharest, Romania.
²kut Technical Institute, Middle Technical University, Iraq
³National Institute for R&D in Electric Engineering ICPE-CA, Department of Renewable Energy Sources and Energy Efficiency, 313 Splaiul Unirii, 030138 Bucharest, Romania

Abstract. A possible strategy for reducing energy consumption and carbon dioxide emissions in order to protect the environment is the recovery of heat from wastewater. This study aims to achieve an improvement in the effectiveness of heat transfer by changing the flow parameters by using a double heat exchanger to recover the heat from greywater. The results, the thermal energy from wastewater can be recovered, the effectiveness ranged between (25 % — 45 %) with the discharge of (0.15—0.51m³/h) lower to higher, respectively. The cold water flow has a clear effect on the heat transfer efficiency, the decrease in cold water velocity led to the increase in heat transfer performance. This technique is simple to implement and inexpensive. It can be designed and built on the basement of the multi-storey building. The dual heat exchanger splits the flow into two-pipe, decreasing the flow rate velocity and thus, increasing the heat transfer efficiency.

1. Introduction
Due to the pressures on the environment and the emission of carbon dioxide resulting from energy use, as well as the energy shortage the globe is going through, it has become imperative to reduce the use of this energy inside the building sector which is responsible for 40 percent of global CO₂ emissions and 30 percent of worldwide energy usage [1]. The heating in the building is the key component to energy consumption but also the hot domestic water could be at very high demand, also for particular applications (e.g. hotels or laundries). This is why the implementation of technologies using recovery sources for water heating and renewable energy are very important [2]. The energy used for heating water is therefore a large part of the overall energy consumed in a typical household. There's a lot of work here, i.e. Leidl and Lubitz [3], Boait et al.[4], To recover the energy of the residual from warm or hot greywater was designed the drain heat recovery (DWHR). This energy recovery is used to heat incoming cold water. This technology is an effective and low-cost way to re-use thermal energy in a conventional building process, such as space heating and sanitary hot water generation [5]. Many studies have focused on improving the effectiveness of recovering heat from domestic water in horizontal systems. McNabola et al.[6], Kamil et al. [7] Wong and et al. [8]. Looking for a commercial heat exchanger, the first option is a horizontal form, which could be placed at the basement[9]. In this
situation, it is possible to make use of all the waste water in the building, and could be easy to link it to the district heat[10].

This study aims to achieve an improvement in the effectiveness of heat transfer by changing the flow parameters by using a doubles heat exchanger to recover the heat from greywater. This experiment was established in the CAMBI Research Centre at the Technical University of Construction from Bucharest.

2. State of the art
There are many studies conducted to improve the effectiveness recover of heat transfer of domestic water in the horizontal since this method is economically inexpensive and does not require a large area and can be installed in the basement through which thermal energy can be recovered of all the wastewater.

For example, Pochwat et al. [6] proposed in his study a new design to improve the efficiency of heat transfer in the horizontal and in counterflow. The experiment consists of the greywater pipe (PVC) with a diameter of 40 mm and the copper water pipe with a diameter 12.7 mm passing through it. The copper water pipe was positioned at the bottom of the greywater pipe to improve heat exchange. This paper shows that it is theoretically possible to design the horizontal DWHR system to operate with a satisfactory level of efficiency. The results also show that, depending on a variety of external factors, such a system can be economically viable. It has been shown that it will considerably scale back energy usage and dioxide carbon emissions by implementing this technology at the national level. The efficacy of the prototype was found to be around 23 %. The effect of raising the drain water temperature to 65 °C and lowering the drain water flow rate to 6 L / min was found to slightly increase the efficiency above this value. The hot water flow rate was found to be an essential determinant of system performance, with flow rates above 10 l / min being significantly lower regarding efficiency than flow rates below 10 l / min in general terms.

Wong et al. [8] investigated the heat recovery from showers at high rise residential buildings in Hong Kong. The primary objective was to estimate the minimum heat transfer area needed for the duty in question. The heat exchanger consists of a cold-water pipe (PVC) with long 1 m, diameter 10 cm with a hot water pipe (copper) with 40 mm diameter passing through it. The copper pipe of hot water that simulates a slope drainage pipe is partly filled with hot water. It was noted that gravity water flows can be defined by simple fluid flow principles in partially filled slope drainage pipes. Using the effectiveness-number of transfer units (ε-NTU) method, the thermal energy exchange is measured. The results show that 4-15 %shower water heater for a drainage pipe of 50 mm diameter can be recovered through a 1.5 m long single-pass counter-flow heat exchanger. In hot and humid climates, waste heat recovery from shower drains in high-rise residential buildings is difficult. Good heat exchanger designs with a justified payback period are required, apart from space limitations for the installations.

Kamil et al.[7] made a comparison of two prototype efficiency-based recapture units of near-horizontal drain water heat. In this analysis, there are two parts of the experiment: a simple horizontal heat exchanger (HE-0) and a new heat exchanger (HE-1). A significantly horizontally focused body made of plastic to move greywater is part of the heat exchanger HE-0. There is a copper pipe positioned parallel to the lower inner portion of the body to move the water to be heated in the opposite direction to wastewater. The heat stored in the latter is transferred via the pipe walls. Such a system design eliminates all interaction between the two-flowing media. A downside of the solution is the efficacy of a relatively low heat exchanger that is verified by the study mentioned in this experiment. The operating concept of the current HE-1 brand heat exchanger is comparable. The heat exchange efficiency attainable in this case, however, is significantly higher. The effect was achieved by inserting baffles into the device's body, resulting in growing the time in the DWHR system for the water to remain. It was concluded through this study the heat exchanger created is especially intended for residential buildings with low consumption of shower water. In certain situations, by separating the streams of both media into two or more heat exchangers, there is a possibility to improve the efficacy of the heat greywater heat recovery system.
3. Experimental set up

The experimental setup is made of a Plexiglas pipe of 15 cm diameter and 230 cm length. The water flows gravitationally from an upstream tank through the Plexiglas pipe to the downstream tank from where it is pumped back to the upstream tank through a copper pipe. The two tanks are provided with water heaters in order to ensure a water temperature at about 40°C to 45°C. Inside the Plexiglas pipe there are placed two copper pipes of 1.5 cm diameter and 189 cm length crossed by cold-water at about 8°C to 11°C at the input. The flow of cold water inside the copper pipes is in counterflow with the hot water gravitationally flow outside the copper pipes and will increase its temperature using the heat given by the hot water.

Pictures from the experimental setup are shown in figure 1 and a schematic diagram of the experiment unit is shown in figure 2.

The gravitationally water flow inside the plexiglass pipe stands for the greywater issued from a wastewater system and the cold-water flow inside the copper pipes stands for the potable cold water which temperature should be increased using the heat recovery from the greywater.

We have tested three flowrate values for the greywater and five cold water flowrates values for every greywater value. The flowrates, velocities and temperatures values are shown in the table 1.

The flowrate for cold water and hot greywater is measured by ultrasonic flow Meter for Liquids (type transport PT 900). The temperatures values will be measured using thermocouples.

Evaluation of the experiment effectiveness of a double heat exchanger for energy recovery from wastewater has been estimated using the equation (1)

$$
\mathcal{E} = \frac{T_{c, outlet} - T_{c, inlet}}{T_{drain, in} - T_{c, inlet}}
$$

Figure 1. The experimental unit.
4. Results and discussions

It is very important to mention that this paper presents the preliminary results provided by this study. The goal here is to prove the feasibility of the system. Further studies will show how the efficiency of this system could be improved.

The results are shown in Table (1). There are five velocity values for cold water corresponding to one velocity value for greywater, considering three different velocities for the greywater.

The temperatures are measured for the cold-water at the inlet and at the outlet (respectively when the cold-water pipe is immersed in the greywater and where the cold water pipe goes out from the greywater flow). For the greywater the temperature is measured at the same sections but inside the greywater flow.

The results show that the decrease in cold water velocity led to the increase in heat transfer performance, and the reason for the decrease in the effectiveness when increasing the speed is not taking enough time to transfer the heat from the greywater to the cold water.

Through this double heat exchanger, we obtained the cold-water flow distributed on two tubes, which leads to a reduction in speed, which increases the effectiveness of heat transfer from greywater to cold water. No significant difference in effectiveness was observed when the greywater velocity changed.

Figure 2. Schematic diagram second experiment (1- first tank, 2- second tank, 3-greywater pump, 4- valve, 5- heater, 6- ultrasonic flowmeter, 7- thermocouples, 8- double copper pipe).
Table 1. experiment data: T₁, hot greywater inlet; T₂, hot greywater outlet temperature; T₃, cold water inlet temperature; T₄, cold water outlet temperature; V, velocity; Q, cold water flow rate.

| No. Exp. | V₁ m/s | Q m³/h | T₁ c | T₂ c | V₃ m/s | Q m³/h | T₃ c | T₄ c | Effect. % |
|----------|--------|--------|------|------|--------|--------|------|------|----------|
| 1.1      |       |        | 41.40| 40.43| 0.30   | 0.32   | 10.64| 23.84| 0.43     |
| 1.2      | 1.09  | 4.94   | 41.52| 40.09| 0.53   | 0.56   | 9.22 | 18.84| 0.30     |
| 1.3      |       |        | 43.07| 41.35| 0.73   | 0.77   | 9.16 | 18.55| 0.28     |
| 1.4      |       |        | 40.94| 38.90| 0.83   | 0.87   | 8.79 | 17.22| 0.26     |
| 1.5      |       |        | 39.05| 37.66| 0.97   | 1.01   | 8.58 | 16.36| 0.26     |

| 2.1      | 1.03  | 4.68   | 40.94| 39.81| 0.26   | 0.27   | 10.64| 23.31| 0.42     |
| 2.2      |       |        | 41.71| 40.19| 0.54   | 0.57   | 9.25 | 18.84| 0.30     |
| 2.3      |       |        | 43.55| 41.72| 0.72   | 0.76   | 9.13 | 18.55| 0.27     |
| 2.4      |       |        | 42.78| 40.62| 0.83   | 0.87   | 8.96 | 18.09| 0.27     |
| 2.5      |       |        | 39.47| 37.99| 0.96   | 1.00   | 8.62 | 16.42| 0.25     |

| 3.1      | 0.86  | 3.87   | 40.38| 39.13| 0.28   | 0.29   | 10.79| 23.01| 0.41     |
| 3.2      |       |        | 42.25| 40.45| 0.53   | 0.55   | 9.25 | 18.71| 0.30     |
| 3.3      |       |        | 44.25| 42.14| 0.65   | 0.68   | 9.86 | 18.77| 0.26     |
| 3.4      |       |        | 43.50| 40.98| 0.82   | 0.86   | 9.16 | 17.85| 0.25     |
| 3.5      |       |        | 39.94| 38.25| 0.97   | 1.01   | 8.73 | 16.30| 0.24     |

Figure 3. Correlation between flow rate and effectiveness.
5. Conclusions

1. All the conclusions issued from this paper are based on preliminary results. Final directions to follow in order to improve the heat exchanger efficiency will be available after further studies on this problematic.

2. It is very important that the thermal energy from wastewater can be recovered and the effectiveness of the heat exchanger could be between (25% - 43%) with the discharge of (0.15-0.51m³/h) lower to higher, respectively.

3. The cold-water flowrate has a clear effect on the heat transfer efficiency, the decrease in cold water velocity led to the increase in heat transfer performance.

4. The proposed technique is simple to implement and inexpensive. It can be designed and installed on the basement of multilevel buildings.

5. The heat transfer should be improved now in further studies acting on the flow structure in order to have a higher heat flow.

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