DOMESTIC DRAIN WATER HEAT RECOVERY

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The aim of this thesis is to study and explain the purpose and the function of drain water heat exchangers. The thesis goes over theory behind heat transfer and heat exchangers and presents the general solutions of domestic drain water heat recovery systems. Systems gone over in detail are the different general shower drain water heat recovery systems.

Another part of the thesis is a case study of an actual shower drain water heat recovery system of a Finnish household. The purpose of the case study is to study the actual temperature increase of cold water in a drain water heat recovery unit and efficiency of such heat exchanger. An alternate goal is to study the difference in efficiency values and temperature gains between two heat exchangers of the same model, where the other has been used significantly more than the other. In other words, another target is to study the fouling effect. The calculations are done using real measurement data.

The most important findings are that utilizing a shower drain heat recovery unit provides real energy savings in the long run, and that there is a significant difference of efficiency between a dirty and a clean heat exchanger. Drain water heat recovery systems provided as high as 15 °C increase in the temperature of cold water. A clean heat exchanger boasts an impressive 50.4% efficiency, whereas the dirtier heat exchanger provides a 36.1% efficiency. The results can be further used to calculate the energy savings of the household on a yearly basis. Furthermore, the results show that domestic drain water heat recovery could potentially make a significant difference in national energy usage if implemented nationwide.
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SYMBOLS AND ABBREVIATIONS

\( \dot{\varepsilon}_n \)  Efficiency of heat exchanger  \([\%]\)

\( \dot{Q}_n \)  Heat flow of liquid \( n \)  \([\text{kJ/min}]\)

\( T_n \)  Temperature of flow \( n \)  \([\degree C]\)

\( \dot{W}_n \)  Volumetric flow of liquid \( n \)  \([\text{l/min}]\)

\( C_n \)  Heat capacity of liquid \( n \)  \([\text{kJ/KgK}]\)
1 INTRODUCTION

The subject of this thesis is domestic drain water heat recovery. The subject was chosen after considering a study on the drain water heat recovery on an industrial scale. At first, the idea was to study industrial water recovery systems and how they could be implemented in housing scale. The subject was further defined to study only domestic drain water heat recovery systems and a real life case study of said heat recovery systems.

The matters studied in this thesis are the different general solutions of domestic drain water heat recovery systems and their differences. Furthermore, a case study was carried out using data from a typical Finnish household where drain water heat exchangers are implemented in two different shower. In addition, a short theory revision on the subjects’ heat exchangers and heat transfer are presented.

Up to this point, the only research done on the subject has been carried out under laboratory conditions. The case study in this thesis uses data gathered from an actual household from two different heat exchangers that have been used to different degrees. Hence, this work additionally presents the effect of fouling of heat exchangers on their efficiency values.
2 DOMESTIC HEAT RECOVERY FROM DRAIN WATER

2.1 General

Energy efficiency is an important matter in today’s world not only in industry, but also more and more so in housing. Efficiency requirements in industry are driven mostly by financial factors, but also by political pressure due to climate change in order to reduce emissions. Energy efficiency in housing is a relatively new subject, and one that has yet to be implemented generally. However, it can be expected that the demand for applications in energy efficiency will rise in the future. The most obvious way to increase energy efficiency in small housing is heat recovery from drain water. (Kappel and Grechenig, 2009)

Recovering heat from shower drain water is a relatively simple procedure. Heat recovery can be done with a simple heat exchanger, which uses the heat energy of warm drain water that flows into the drain to preheat cold water going either to the hot water accumulator or straight to the shower’s water mixer or both. Installation costs and energy saving performance depend on how the preheated water is used.

Drain water recovery from utilities such as dish washers and laundry machines don’t have applications like shower drain heat exchangers and there are good reasons for that. One difficulty for recovering drain water from such utilities is that they don’t use hot water from the accumulator, but heat the needed cold water to washing temperature, as these machines don’t have a constant need for hot water. Furthermore, the machines may also use cold water in their operations and the drain water can be expected to be dirtier than shower drain water, making it difficult to implement an efficient heat exchanger. Furthermore, especially in the dish washer case there is a possible clotting risk.

2.2 Shower Drain Water Heat Recovery

The traditional shower setup without a heat recovery unit consists of an accumulator, a water mixer, which mixes hot and cold water for the shower, cold water pipelines to the accumulator and the mixer, and a hot water line from the accumulator to the mixer. An illustration of the traditional shower is presented in figure 1. In this case, the used shower
water goes down the drain along with wasted energy. It is possible to utilize this wasted energy by using a heat exchanger.

![Figure 1. Shower design without a drain water heat exchanger. Published by permission of Meander Heat Recovery.](image)

The purpose of the heat exchanger is to recover the otherwise wasted energy contained in warm drain water to preheat the cold water going either to the accumulator or shower water mixer. All the heat exchangers described in this work are based on transferring heat from one water stream to another. It should be noted that it is only the heat energy in drain water that is utilized, not the drain water itself. There are numerous commercially available heat exchangers available that are designed for domestic use. There are four types of heat exchanger setups in which heat exchangers can be categorized in: vertical heat recovery systems, shower platforms with an integrated heat exchanger, horizontal systems installed under the shower and tank based systems. It is important to note that none of these systems require a pump of any sort as they operate on the water flow caused by the pressure of the main water pipeline. (Kimmels 2011)

Vertical heat recovery systems consist of a large diameter copper pipe in which the drain water flows and a small diameter copper pipe wrapped around the larger pipe. The warm drain water runs along the surface of the copper pipe as a thin film, providing good heat transfer into the copper. The vertical systems are the most effective regarding heat transfer, but require a lot of space under the shower. Shower platforms with an integrated
heat exchanger can be used if there is not enough space to install other kinds of systems, but provide lower efficiency and are more expensive than other systems. Horizontal heat recovery systems are placed close to or under the shower, providing easier installation but lower performance than vertical systems. Tank based systems operate by feeding the drain water into an insulated water tank in which the drain water is stored temporarily. The cold water flows in a pipe inside the tank.

### 2.3 Shower Heat recovery system performance

The drain water heat recovery systems can also be categorized by how the preheated cold water is used. The best performance, but with the highest cost, is achieved with a balanced flow system, illustrated in figure 2, in which the preheated water is fed both into the shower water mixer as well as the hot water accumulator. In this case the flow of the cold water is equal to the flow of the drain water, thus giving the best performance energy savings wise.

![Figure 2. Shower with a drain water heat exchanger installed (balanced flow). Published by permission of Meander Heat Recovery.](image)

The second case is the accumulator only system, which is based on preheating the cold water going into the accumulator only. Energy savings come from the accumulator using
less energy to raise the cold water temperature to the desired level. In this case the flow of the cold water into the heat exchanger is smaller than the drain water flow. The final case is the shower only system, illustrated in figure 3, in which preheated water is only fed into the shower water mixer, which results in less hot water needed from the accumulator. Again, the flow of cold water into the heat exchanger is smaller than drain water flow. These two cases provide a lower energy performance than the balanced system, but are easier to install, thus lowering the initial costs.

Figure 3. Shower with a drain water heat exchanger (shower only). Published by permission of Meander Heat Recovery.
3 HEAT EXCHANGER THEORY

3.1 Introduction

When talking about heat recovery, be it from drain water or other substances, it is important to understand the mechanics behind heat transfer, mainly the driving force of the transfer phenomenon. In order to carry out meaningful calculations, some basic principles have to be established, which are the laws of thermodynamics. Equations relevant to the case study are also introduced.

3.2 General Laws of Thermodynamics

It is important to understand the definitions of a system and universe before discussing the laws of thermodynamics. A system is any set of substances and entities under inspection with stated imagined barriers that separate it from its surroundings. For example, if we study a hot cup of coffee, the cup itself and the coffee in it make up the system. The system under inspection along with its surroundings is the universe. (Atkins 2010)

The zeroth law of thermodynamics describes the concept of temperature. The zeroth law states that if system A is in thermal equilibrium with system B, and B is in thermal equilibrium with system C, the C will be in thermal equilibrium with A. The statement can be interpreted such that there exists a property that enables us to anticipate when two systems will be in thermal equilibrium regardless of their other physical properties. This property is called temperature. (Atkins 2010)

The first law of thermodynamics is an extension of the law of conservation of energy, which states that the internal energy of an isolated system is constant. In other words, energy cannot be created or destroyed. In the coffee cup system example, if the cup is assumed to be isolated, it would stay the same temperature regardless of how long it sits on the table. The first law of thermodynamics also dictates the concept of heat capacity, which is defined as the amount of energy required to bring about a rise of temperature in a substance. For example water, which has a high heat capacity, requires a larger amount of energy to heat than air, which has a smaller heat capacity. (Atkins 2010)
3.3 Equations used in the case study

Traditional heat exchanger modelling is based on energy balances derived from the first law of thermodynamics and the mass conservation principle. With this in mind, numerous assumptions have to be made in order to develop the calculations (Branson 2011):

- The heat exchanger is in a steady state
- The heat loss to the surroundings is negligible
- There is no heat source or sink in the heat exchanger
- The thermo-physical characteristics of the fluids are constant
- There are only two fluids in the heat exchanger

The heat flow to or from water can be calculated from:

\[ \dot{Q} = \dot{w} C_w (T_i - T_o), \]  

where \( \dot{Q} \) is the heat flow [kJ/min], \( \dot{w} \) is the volumetric water flow [l/min], \( C_w \) is the heat capacity of water [kJ/kgK], \( T_i \) is the temperature of water going in to the heat exchanger \(^\circ\text{C}\) and \( T_o \) is the temperature of water coming out of the heat exchanger \(^\circ\text{C}\). (Bird et al. 1960)

This applies to the cold side as well as the hot side. The value is positive for the hot side, since it releases energy into the system, and negative for the cold side, since it receives energy from the system. Furthermore, if no heat is generated in the system and there are no other heat flows out of the system, the total heat flow to and from the system is zero. The same conclusion is reached assuming the other heat flows to or from the system are minuscule. Therefore, the thermal energy received by the cold water flow is equal to the thermal energy released by the hot water flow:

\[ \dot{Q}_h = -\dot{Q}_c, \]  

where \( \dot{Q}_h \) is the heat flow released by hot water [kJ/min] and \( \dot{Q}_c \) is the heat flow received by hot water [kJ/min].
By inserting equation (1) into equation (2), the equation can be written in the form:

$$\dot{w}_h C_w (T_{h,i} - T_{h,o}) = \dot{w}_c C_w (T_{c,o} - T_{c,i}), \quad (3)$$

where subscript $h$ refers to hot water and subscript $c$ refers to cold water.

The temperature terms on the right side of equation (3) are swapped due to the negative multiplier in equation (2). Knowing that both liquids are water, so they share the same heat capacity, equation (3) can be written in a simplified form:

$$\dot{w}_h (T_{h,i} - T_{h,o}) = \dot{w}_c (T_{c,o} - T_{c,i}). \quad (4)$$

Equation (4) can be used to calculate the volumetric flow ratio of cold water and hot water into the shower water mixer. Using the water temperatures and the total flow of water from the shower and by rearranging terms and setting the final temperature of both flows to be the same:

$$\frac{\dot{w}_h}{\dot{w}_c} = \frac{(T_{final} - T_{c,i})}{(T_{h,i} - T_{final})}, \quad (5)$$

where $T_{final}$ is the final temperature of mixed water [$^\circ$C].

The total flow of water $\dot{w}_{tot}$ [l/min] is the sum of the cold water flow and the hot water flow:

$$\dot{w}_{tot} = \dot{w}_c + \dot{w}_h. \quad (6)$$

By rearranging and inserting equation (5) into equation (6), the volumetric flows of the cold and hot water flows can be calculated:

$$\dot{w}_c = \frac{\dot{w}_{tot}}{1 + \frac{(T_{final} - T_c)}{(T_{h,i} - T_{final})}}, \quad (7)$$

$$\dot{w}_h = \dot{w}_c \frac{(T_{final} - T_c)}{(T_{h,i} - T_{final})}. \quad (8)$$
The ε-NTU method for determining the effectiveness of heat exchangers is defined as the ratio between the actual temperature difference of the cold stream and the maximum rate of heat transfer for given inlet temperatures of the hot and cold streams (Cabezas-Gómez et al. 2015). The mathematical representation for the cold side is:

\[
\varepsilon_c = \frac{C_c(T_{c,o} - T_{c,i})}{C_{min}(T_{h,i} - T_{c,i})} \times 100\%,
\]

(9)

where \(\varepsilon_c\) is the cold side efficiency [%], \(C_c\) is the heat capacity of the cold liquid [kJ/kgK] and \(C_{min}\) is the smaller heat capacity of the two liquids [kJ/kgK].

Similarly, the hot side efficiency \(\varepsilon_h\) [%] is:

\[
\varepsilon_h = \frac{C_h(T_{h,i} - T_{h,o})}{C_{min}(T_{h,i} - T_{c,i})} \times 100\%.
\]

(10)

Furthermore, knowing that both liquids are water and they share the same heat capacity, the equations can be simplified to:

\[
\varepsilon_c = \frac{(T_{c,o} - T_{c,i})}{(T_{h,i} - T_{c,i})}.
\]

(11)

\[
\varepsilon_h = \frac{(T_{h,i} - T_{h,o})}{(T_{h,i} - T_{c,i})}.
\]

(12)

Power of the heat exchanger is calculated by changing the volumetric flow to be liters per second:

\[
P = \left(\frac{w_c}{60}\right)C_w(T_{c,o} - T_{c,i}),
\]

(13)

where \(P\) is the power of the heat exchanger [kW].
4 CASE STUDY

4.1 Experimental setup

The case under inspection is a Finnish household with two adults and three children. The first data set was collected on the 24th of January 2016 during sauna bathing, referred to from now on as case 1. Data was collected from a shower drain heat exchanger unit located under the bathroom shower, as well as some water flow and temperature measuring units. The shower thermostat is automated so that the water temperature stays constant without the need to manually control the temperature of shower water.

Another set of data was collected on the 27th of February 2016 during one normal shower use in the same household but in a different bathroom, referred to from now on as case 2. The heat exchanger in this second bathroom is of the same model as in the sauna bathroom, but hasn’t been used as often. Therefore, it can be concluded that the second heat exchanger is cleaner than the first. It is also notable that there is no automatic water mixing in the second shower, so water temperature has to be controlled manually.

The heat exchanger in this case is a commercially available shower drain counter-flow heat exchanger called “Recoh-Drain” by Hei-Tech Energiesystemen that has been in use for about a year’s time before the day of the data collection. The Recoh-Drain is a heat exchanger that is integrated into the floor in the shower area that can be used to preheat the cold water going into the shower mixer and the accumulator or, like in the cases under inspection, preheat only the cold water going to the shower mixer as shown previously in figure 3. (Hei-Tech Energiesystemen 2011)

Hei-Tech claims that when using a hot water storage system and the Recoh-Drain, less than half of the hot water used normally without a heat exchanger is needed. Hei-Tech also presents measured efficiency parameters of 44.1% with a fresh water flow of 9.2 liters/minute and 42.1% with a fresh water flow of 12.5 l/min. However, Hei-Tech did not state how the efficiency was calculated. (Hei-Tech Energiesystemen 2011)
4.2 Data presentation

Data for the analysis was collected on the following quantities:

- Total consumption of water
- Temperature of mixed shower water
- Temperature of cold fresh water flow into the heat exchanger
- Temperature of drain water into the heat exchanger
- Temperature of preheated cold water from the heat exchanger to the shower thermostat and the mixer
- Temperature of hot water into the shower water mixer and thermostat

Data was collected only at time steps, when the shower was on. The volume flow of shower water was calculated according to the total consumption of water and the time the shower was on. The temperature of mixed shower water was measured from the shower head. The temperature of cold water flow into the heat exchanger was measured from where the cold water pipeline to the heat exchanger parts from the main pipeline. The temperature of warm drain water into the heat exchanger was measured at ten different time steps above the floor drain grating. According to the ten measurements, a fitted curve was formulated and data points were evaluated according to match the other data points’ time steps. The temperature of preheated cold water into the shower mixer was measured from about ten centimeters away from the heat exchangers towards the shower mixer. The cold water pipeline from the heat exchanger to the mixer travels under the floor through insulation about one meters length before rising to about one meter’s height to the mixer or thermostat.

The temperature of hot water from the accumulator to the shower water mixer was measured about one meter away from the pre-mixer. The pre-mixer’s purpose is to control the temperature of hot water going into the shower water mixer. The motorized valve that determines the ratio of hot and cold water is controlled by this measurement. This pre-mixer receives cold water from the main pipe-line. The temperature of hot water for the shower was set to 56 degrees Celsius at the pre-mixer.
The measurements in the second case are similar to the ones described in the previous paragraphs. The main differences between the first and the second cases are that in the second case the heat exchanger is cleaner and that the shower is a closed shower stall. The drain water goes into the drain and to the heat exchanger length of a 0.8 m plastic pipe located below the shower stall.

The measured total water consumptions, calculated volume flows, temperatures of mixed shower water, and the number of data points for cases 1 and 2 are presented in Table 1.

Table 1. Consumption, volume flow and temperature of water during the showering.

<table>
<thead>
<tr>
<th></th>
<th>Case 1</th>
<th>Case 2</th>
<th>[Units]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling rate</td>
<td>10</td>
<td>10</td>
<td>[s]</td>
</tr>
<tr>
<td>Total consumption of water</td>
<td>218</td>
<td>109</td>
<td>[l]</td>
</tr>
<tr>
<td>Volume flow of mixed water from the shower</td>
<td>11.5</td>
<td>9</td>
<td>[l/min]</td>
</tr>
<tr>
<td>Temperature of mixed shower water</td>
<td>37</td>
<td>37.5</td>
<td>[°C]</td>
</tr>
<tr>
<td>Number of data points</td>
<td>110</td>
<td>74</td>
<td></td>
</tr>
</tbody>
</table>

It should be noted that the calculations and figures concerning the case 2 utilized a partial data set, because steady state conditions were selected for the analysis. Therefore, for the case 2, data points at range of 30 – 74 were included in the analysis.

The measured temperatures of hot water from the accumulator to the shower water mixer, warm drain water to the heat exchanger, preheated cold water to the mixer and cold water to the heat exchanger at specific time steps for cases 1 and 2 are presented in figures 4 and 5.
Looking at figures 4 and 5, it can be seen that data for the case 1 is not as smooth as the case 2. The reason for this is that the data for case 1 was collected during a longer period of time, where the shower was turned off occasionally. However, the data for the case 2 was collected during a single continuous showering, thus providing smooth results.
4.3 Data analysis and discussion

Data was analyzed and plotted with Matlab R2015b. The results are presented in five pairs of figures. The first figure of the pairs deal with the case 1 and the latter figures deal with the case 2. Furthermore, the data-axis in the figures have been scaled to provide easier visualization on similarities or differences between the two cases.

Figures 6 and 7 graphically present the temperature increase of cold water at specific time steps of cases 1 and 2. The values were calculated by subtracting the temperature of cold water going into the heat exchanger from the temperature of preheated cold water exiting the heat exchanger. It can right away be seen that case 2 yielded better increase in cold water temperature than case 1.

Figure 6. Temperature increase of cold water going through the heat exchanger of case 1.
Before going further into the results, some unknown terms had to be calculated. The calculated unknown terms were the flow rates of cold and hot water into the shower water mixer and the temperature of drain water exiting the heat exchanger. The time specific flow rates of cold and hot water going into the water mixer were calculated from equations (7) and (8). The results are graphically presented in figure 8 for case 1 and figure 9 for case 2.
Figure 9. Calculated flow rates of cold and hot water into the shower water mixer of case 2.

Studying figures 8 and 9, there doesn’t seem to be much of a difference between the two figures. The figures are not smooth because the hot water temperature from the hot water accumulator is not constant. However, flow rates of case 2 varies between 4 l/min and 5 l/min, whereas the flow rates in case 1 vary more. Both cases seem to provide good results concerning the use of hot water, however in the case 2 less hot water was proportionally consumed.

Using the before mentioned flow rates and the known water temperatures, the temperature of drain water exiting the heat exchanger was calculated from equation (4). The results are presented in figure 10 for case 1 and figure 11 for case 2. In addition, flow rates were calculated to the case without a heat exchanger, also with the equations (7) and (8).
Figures 10 and 11 both give a similar looking results starting from a lower temperature and then finding an almost stable value. The reason for the temperature being lower in the start is that the heat exchanger itself acts as a heat sink in the beginning. After a while though, after the heat exchanger has warmed, the water temperature exiting the heat exchanger rises. However, case 2 has a lower temperature of drain water after the heat exchanger than case 1. The logical conclusion, again, is that the heat exchanger used in case 2 is cleaner than the one used in case 1, thus providing better heat exchange. The
oscillation in the temperatures in both cases can be explained with the oscillating cold water flow. When the cold water flow decreases, heat exchange into the cold water decreases and thus the temperature of hot water exiting the heat exchanger decreases. Furthermore, for case 1, since the shower is turned off for some time between showers, there are some spikes in the temperature.

Figures 12 and 13 present the calculated efficiencies for cold and hot sides for both cases. The efficiency values were calculated from equations (11) and (12). It can be seen that case 2 provides higher efficiency than case 1. Furthermore, due to the same reasons as before, the figure concerning case 2 is smooth, whereas the figure for case 1 has large spikes. Again, the spikes for case 1 are due to the fact that the shower is turned off between showers. Turning the shower off causes cold water flow to stop, but warm drain water continues to flow to the drain for some time. This can be seen as a positive spike in efficiency.

Figure 12. Calculated efficiency of the heat exchanger at specific time steps of case 1.
Figure 13. Calculated efficiency of the heat exchanger at specific time steps of case 2.

Figures 14 and 15 present the calculated heating powers of the heat exchangers at specific time steps. The powers were calculated using equation (13). The figures are not constant due to the changes of the cold water flow. The power spikes in the figure for case 1 can be explained yet again with the inconsistent use of the shower and heat accumulating in the heat exchanger as a result.

Figure 14. Calculated power of the heat exchanger at specific time steps of case 1.
Figure 15. Calculated power of the heat exchanger at specific time steps of case 2.

Calculated average values for temperature increases, flow rates, drain water temperatures, efficiency values, heat exchanger powers and used electricity for cases 1 and 2 are presented in table 2. Presented are also calculations done for both cases assuming that no heat exchanger is utilized. Used energy without a heat exchanger was calculated by the amount of energy required to heat to total used amount of cold water to 37 ℃. It can be seen from table 2 that the case 2 provides better results.
Table 2. Average calculated values of the cases including calculations assuming no heat exchanger (HE) is utilized.

<table>
<thead>
<tr>
<th></th>
<th>Case 1 w/ HE</th>
<th>Case 1 w/o HE</th>
<th>Case 2 w/ HE</th>
<th>Case 2 w/o HE</th>
<th>[Units]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature increase of cold water</td>
<td>10.5</td>
<td>-</td>
<td>15.0</td>
<td>-</td>
<td>[°C]</td>
</tr>
<tr>
<td>Flow rate of hot water to the shower mixer</td>
<td>6.1</td>
<td>7.2</td>
<td>4.5</td>
<td>5.8</td>
<td>[l/min]</td>
</tr>
<tr>
<td>Flow rate of cold water to the shower mixer</td>
<td>5.4</td>
<td>4.3</td>
<td>4.5</td>
<td>3.2</td>
<td>[l/min]</td>
</tr>
<tr>
<td>Temperature of drain water</td>
<td>28.8</td>
<td>33.8</td>
<td>26.1</td>
<td>33.4</td>
<td>[°C]</td>
</tr>
<tr>
<td>Heat exchanger efficiency</td>
<td>36.1</td>
<td>-</td>
<td>50.4</td>
<td>-</td>
<td>[%]</td>
</tr>
<tr>
<td>Heat exchanger Power</td>
<td>4.0</td>
<td>-</td>
<td>4.7</td>
<td>-</td>
<td>[kW]</td>
</tr>
<tr>
<td>Heat recovered by HE</td>
<td>4340</td>
<td>-</td>
<td>2101</td>
<td>-</td>
<td>[kJ]</td>
</tr>
<tr>
<td></td>
<td>1.206</td>
<td></td>
<td>0.584</td>
<td></td>
<td>[kWh]</td>
</tr>
<tr>
<td>Total energy consumption</td>
<td>6.974</td>
<td>8.180</td>
<td>2.065</td>
<td>2.649</td>
<td>[kWh]</td>
</tr>
<tr>
<td>Energy savings percentage</td>
<td>14.7</td>
<td>22.0</td>
<td></td>
<td></td>
<td>[%]</td>
</tr>
</tbody>
</table>

Looking at the average results in table 2, it can be seen that the cleaner heat exchanger in case 2 provides better results on every subject than case 1, even though the heat exchanger is of the same model in both cases. The higher accumulated energy in case 1 is explained by the longer time period in which the shower was used. The main difference between the two cases is the cleanliness of the heat exchanger used. The shower in case 1 is used more than the shower in case 2, resulting in a dirtier heat exchanger. The other difference between the cases was the flow rate of water, which was higher in case 1. Higher flow rate results in a higher drain water temperature from the heat exchanger, as well as a smaller efficiency value. However, it seems that the cleanliness of the heat exchanger plays a greater role in the amount of heat transferred, than the flow rate of water.
The aim of the thesis was to study and explain the purpose and the function of drain water heat exchangers. The thesis explored theory behind heat transfer and heat exchangers and presented the general solutions of domestic drain water heat recovery systems. The systems gone over in detail were the different general shower drain water heat recovery systems.

Another part of the thesis was a case study of an actual shower drain water heat recovery system of a Finnish household. The purpose of the case study was to study the actual temperature increase of cold water in a drain water heat exchanger unit and the efficiency of such heat exchanger. An alternate goal was to study the difference in efficiency values and temperature gains between two heat exchangers of the same model, where the other has been used significantly more than the other. The calculations were performed with real measurement data.

The most important findings are that utilizing a shower drain heat recovery unit provides a temperature increase as high as 15 °C for cold water. Therefore, drain water heat exchanger provides real energy savings in the long run. Additionally, it can be concluded that there is a significant difference of efficiency between a dirty and a clean heat exchanger. The clean heat exchanger, referred to as case 2 in the case study, provided an efficiency of 50.4%. The dirtier heat exchanger utilized in case 1, provided an efficiency of 36.1%. The calculated energy savings percentage for the case 1 was 14.7% and 22.0% for the case 2.

The results can be further used to estimate the energy savings of households on a yearly basis. In general, heat recovery from drain water can become an important part when increasing energy efficiency of hot water usage.
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