Integrated heat exchanger for shower cabins

Legal issues, cost efficiency, designing a prototype

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Examiner: Nawzad Mardan
Abstract

The global energy usage have been growing and is expected to grow in the forthcoming years. The negative effects of increased energy use are greatly depending on the type of base raw materials required for converting the energy and the negative consequences those have on the environment. From the energy used, fossil fuels stands for the largest part. Excess use of fossil fuels have been shown to have considerable negative effects on the environment, including, but not limited to global warming.

Renewable energy is today the world’s fastest growing energy source limiting the negative consequences of growing energy use. The commercial and residential buildings stands together for about 40 % of the total energy usage. Residential buildings alone stands for 20 % of the total world delivered energy consumption by end-use sector. In EU the average residential energy use amounts to 25 % and for individual countries like Sweden and Finland it is 21 %.

The EU energy efficiency directive from year 2012 sets a target to save 20 % of the unions primary energy usage by year 2020 compared to the year 1990. The EU countries also agreed in October 2014 on a new energy efficiency target of at least 27 % by the year 2030. To reach this goal, improved energy efficiency are required in all sectors.

Finland’s energy efficiency law for buildings from 2013 greatly reduces the minimum energy usage allowed for new buildings. Finland is also preparing for a new law that would by 2020 require all new buildings to be zero or close to zero energy buildings. This is defined by the Ministry of the Environment as buildings that have very high energy efficiency, where the already greatly reduced energy demand is satisfied extensively by renewable energy.

As part of the goal to greatly increase buildings energy efficiency, this work focus on heat exchangers for showers. The purpose of this project is to investigate how two different heat exchangers works for shower cabins. This is done by testing a system where the heat exchangers are linked together. The system works by transferring heat from the drainage water and the moist air to the incoming colder drinking water before the cold water is heated in the mixer to desired shower temperature. The measurements are taken for different simulated shower situations. The Heat exchangers efficiency are calculated and the energy savings are examined with annual energy savings. The payback time shows that the system is not currently viable. The efficiency need to be improved, the main issue being the constituent materials heat transfer attributes between cold and hot water. The results are discussed and it is concluded that the system would be viable with improved heat exchanger efficiency and adequate shower use, which depends on the user and the amount of people using the shower. The main issue with increased heat transfer efficiency is the greater risk of contamination between the incoming cold drinking water and the outgoing dirty drainage water.

Keywords: Shower heat exchanger, hot water distribution, shower cabins, housing energy efficiency, Geberit Group
This master thesis have been done for Gävle University study program, *Energy Engineering*. The extent of the project is 15 study points, corresponding to 10 weeks of full time studying.

The layout and structure of this thesis have been developed together with the supervisor. I want to thank Martin Mattson and Geberit Group for accepting to join this project and providing me with a shower cabin to use and perform the tests on. I want also to give a special thanks to Taghi Karimipanah for supervising the work.

Finally, I want to thank the examiner Nawzad Mardan for making a great review of the work.

Vantaa, Finland 30th. June 2016
Ossian Pekkala
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1 INTRODUCTION

In Chapter 1 this report is described and the different chapters (1.1), the background to this project (1.2), aim and purpose (1.3), research questions (1.4) and limitations (1.5) are given.

1.1 Outline

In this report two different heat exchangers are built and the efficiency of them are tested for different flows, temperatures and shower times. The main goals are to present the efficiency and possibly other benefits of the heat exchangers and analyze them with consideration to the cost efficiency. Hot water distribution storage losses and the benefit of a flow heater are analyzed. The cold tap water regional and seasonal temperature variations are also investigated from the point of renewable energy.

In Chapter 1 background, research focus and research focus are described.

The theoretical framework in Chapter 2 gives a brief history about bathing and showers (2.1), earlier shower cabins and heat exchangers (2.2), the principle and physic behind heat transfer and heat exchangers (2.3-4), energy use for heating of domestic water in Finland, Europe and USA (2.5), theory used for the calculations (2.6). A short review of energy perspective related to heat exchangers are given in the end of chapter two (2.7) and the main products requirements for heat exchangers certification (2.8).

Chapter 3 describes how the testing and measurements have been executed and the equipment used (3.1). The calculation method that have been used for the results are shown (3.2) and the measurement site specified (3.3).

In Chapter 4 the main results and calculations of the test results are given. The temperature differences, cold tap water temperatures and increase of temperature from heat exchangers (4.1). Heat exchanger efficiency depending on shower flow (4.2), cost efficiency of the heat exchanger (4.3) and moisture content in the bathroom (4.4).
In Chapter 5 the reliability of the results are evaluated and discussed (5.1), the results from Chapter 4 is discussed and conclusions are given (5.2). The main conclusions and answers to the questions in 1.4 are given at Chapter 6.

1.2 Background

The author of this report have been working with shower room condition inspections and energy certificates for buildings. This have raised the question of the benefits with shower cabins. The direct benefits are that the water sprinkling are kept in one place, which is good for the shower room long term condition. The shower cabin does not need to be limited to just water sprinkling control, but also to include the energy efficiency aspect. An integrated heat exchanger can be invisible without making interference with the consumers shower experience. With a well-integrated heat exchanger the main remaining aspect from consumer point of view would be the cost efficiency.

1.3 Research Focus

The aim with this report is to investigate how two heat exchanger works for a shower cabin in practice, with aspect to energy efficiency, cost efficiency, clean water regulations and product certification. The main focus will be on the energy efficiency and cost efficiency.

1.4 Research questions

The aim is partitioned into following research questions (see Chapter 6 for answer):

1) What is the heat exchanger efficiency?
2) What is the heat exchangers pay-back time?

1.5 Limitations

Two heat exchanger designs are tested, limited to one shower cabin and to one location with a limited flow of cold and how water temperature.
2 THEORETICAL FRAMEWORK

The theoretical framework in Chapter 2 gives a brief history about bathing and showers (2.1). Earlier shower cabins and heat exchangers (2.2) and the principle and physic behind heat transfer and heat exchangers (2.3-4) are described. Energy use for heating of domestic water in Finland, Europe and USA (2.5) and theory used for the calculations (2.6) are given. A short review of energy perspective related to heat exchangers are given in the end of chapter two (2.7) and the main requirements for heat exchangers certification (2.8) are presented.

2.1 History

The first real showers with plumbed-water are known to be invented by ancient Greeks. The first bathing places were natural lakes, rivers, oceans or waterfalls. Bathing facilities were common among the Babylonians, Romans, Greeks, India and Turks. It is also believed that Egyptians devised showers as early as 3000 BC. Ceramic pipes and special rooms for bathing were found in the ruins of Minoan Crete from 2000 BC (Sherrow, 2001).

During modern times in Europe bathrooms were common for the wealthier people during 1800 AD. After 1930 a standardization process started to make bathrooms available for more people. Before that most people did only have access to public bathrooms. A shower in its modern form existed at 1940, but did not become common before 1970. Shower cabins started to be available during 1970th (Barr, 2013).

2.2 Shower cabins and heat exchangers

The earlier shower cabins started as heavy elements put together on site. The base of constructions was usually made from cement or concrete and side walls from sheet metal. These constructions did have difficulties in obtaining a water-tight connection between the base and the side walls. Also the concrete or cement easily cracked or broke during shipping.
Nathans patent from 1963 aimed to improve pre-fabricated shower constructions constructed from rust proof metal, see Figure 1 (Nathan Schooler, 1936).

![Image of Nathan Schoolers patent from 1936]

Figure 1. Pre-fabricated shower construction 1936 patent (Nathan Schooler, 1936)

An early heat exchanger between shower water and the shower floor comes from inventor Wesley P. Will with a patent application 1963. He describes a shower with a heat exchanger in the floor in the form of a coil (see Figure 2). The Figure shows how the hot shower water is cooled down in the floor, before it is dispensed at the shower head. The aim with this was to heat the shower floor, making it more comfortable to stand on.

![Image of Wesley P. Wills patent from 1963]

Figure 2. Shower bath with a shower water to floor heat exchanger (Will, 1963)
A more recent patent application comes from Christoph (Rusch, 2015), a patent application applied on March 2015, where the incoming cold water is pre-heated in a heat exchanger that transfers heat from the showers waste water to the cold water (Figure 3).

Similar heat exchanger patent exist by Patrick (Gilbert, 2009) where the cold water also circulates under a plate and waste water flows above.

![Figure 2](image1)

![Figure 3](image2)

Figure 3. Heat exchanger for shower (Rusch, 2015)

### 2.3 Heat transfer and heat exchangers

A heat exchanger transfers heat between substances. The aim is heating or cooling. If there is a demand of both heating and cooling within the right temperature range and distance, then both demands can be satisfied with one heat exchanger system. There exist different types of heat exchangers. The most basic are cross-flow, parallel-flow, counter-flow and adiabatic wheel heat exchangers.
2.3.1 Heat transfer

Heat transfers spontaneously from a hotter substance to a colder substance. The heat can transfer with conduction, convection and radiation.

Conduction means that heat transfers inside a solid substance, from hotter to colder. The thermal conductivity varies between different substances and are high for metals and low for isolation materials like expanded polystyrene.

The heat transferred per unit time [W] through conduction is 
\[ q = k \times A \times \frac{dT}{s} \]

Where \( k \) is the thermal conductivity [W/m² K] of the material, \( A \) the heat transfer area [m²], \( dT \) the temperature [K] difference and \( s \) the material thickness [m].

Convection means that heat transfers within a fluid or gas with flows. The hotter fluid or gas moves from a hotter place to a colder place within the substance with fluid flows or gas flows. The heat also transfers by conduction once it moves to a colder surrounding.

The heat transferred per unit time [W] through convection is 
\[ q = h \times A \times dT \]

Where \( h \) is the convective heat transfer coefficient [W/m² K] of the process, \( A \) the heat transfer surface area [m²] and \( dT \) the temperature [K] difference between the surface of the bulk fluid.

Heat transfer through radiation means that heat is transferred by radiation without the need of matter in-between the hotter and colder substance. Radiation occurs to both directions, but the colder substance receives more radiation from the hotter substance resulting it to heat up while the hotter substance cools down. Distance does not limit radiation, our sun heating the earth, is a good example of it.

The radiation energy per unit time [W] from a blackbody is 
\[ q = \sigma \times T^4 \times A \]

Where \( \sigma \) is the Stefan-Boltzmann Constant \( 5.6703 \times 10^{-8} \) [W/m²K⁴], \( T \) is the absolute temperature [K] of the emitting body and \( A \) the area [m²] of the emitting body (Incropera, et al., 2011).
2.3.2 Cross flow heat exchanger
The cross flow heat exchanger have perpendicular hot and cold flows (see Figure 4). This system have low efficiency. It is usable when the available cold flow is considerable more abundant than the hot flow, if cooling is desired. The hot flow can be cooled close to the cold flow temperature. The heat exchanger rate from hot flow to cold flow is increased by increasing the cold flow. An example of a common cross flow heat exchanger is the automobile radiator (Incropera, et al., 2011).

![Figure 4. Principle for cross flow heat exchanger](image)

2.3.3 Parallel flow heat exchanger
A parallel flow heat exchanger (see Figure 5) have a better efficiency than a cross flow heat exchanger. The theoretical maximum limit occurs when both temperatures of the ingoing substances have been perfectly mixed, with both substances ending with equal temperature limiting to the theoretical maximum of an unlimited parallel flow heat exchanger to 50% heat exchanger efficiency (Incropera, et al., 2011).

![Figure 5. Principle for a parallel flow heat exchanger](image)
2.3.4 Counter flow heat exchanger

In a counter flow heat exchanger (see Figure 6) the hotter and colder substances flows to opposite directions. This gives a high efficiency since almost all heat energy can be switched between the substances. The Theoretical maximum of an unlimited counter flow heat exchanger is 100 %, but this can never be achieved. In practice this is limited to 90-95 % for good heat exchangers (Incropera, et al., 2011).

![Counter flow heat exchanger](image)

Figure 6. Principle for counter flow heat exchanger

2.3.5 Adiabatic wheel heat exchanger

In an adiabatic wheel exchanger (see Figure 7) the cooled down fluid/gas changes place with the hotter fluid/gas. The heat is stored in the heat exchangers mass. This reminds of a counter flow heat exchanger and have also high efficiency. These are commonly used for ventilation, where also part of the moisture can be recycled. The flows are not entirely separated from each other and can only be used for applications where this is acceptable (Taplin, 1991).

![Adiabatic wheel heat exchanger](image)

Figure 7. Principle for an adiabatic wheel heat exchanger
2.3.6 Heat conductivity of materials

Heat is transferred inside a material by heat conductivity. The speed of this heat transfer is called thermal conductivity and varies greatly between different materials. Thermal conductivity unit is [W/m K] and higher value means higher heat transfer. For pure copper this is 386, aluminum 220 and tin 64. For different solder and steel mixes the heat transfer between 30 and 100. For heat conductive pastes or epoxies the thermal conductivity varies typically between 1 and 5 (Engineers Edge, 2000).

2.4 Typical shower cabin heat exchanger

The heat exchanger in the shower consist of a thin metal plate on top. This is the floor of the shower cabin. Next below it is the second and third layer that encloses around the cold water that circulates under the shower cabin. The waste heat is first transferred to the first layer by convection and conduction, and from there to the second layer by conduction. The second layer transfers heat to the colder water by convection and conduction.

Figure 8 shows how the shower cabins heat exchanger works. The cold water (1) flows first to the heat exchanger (2, see Figure 10) where it is preheated. The preheated water is then mixed with hot water from district heating (3) and is then used for the shower (4). The shower water is used and flows down to the heat exchanger where it cools down and flows down the drain (Wibberding, 2006).

Figure 8. Shower heat exchanger above and below the shower cabin
A shower heat exchanger typically save between 40-60% (Olander, 2014). There is also some claims for up to 85% energy saving (Wibberding, 2006). The energy saved comes from the energy that would otherwise been required to heat the used shower water.

Figure 9 and 10 shows how the heat exchangers used for this projects works. The used shower water flows on top of the heat exchanger and down to the drain. The cold tap water that is linked to the heat exchanger circulates under first shower plate. The cold tap water and the used shower water have no direct link with each other. The heat is transferred through the heat exchangers material by conduction (2.3.1).

Figure 9. Heat exchanger above shower cabin (towel rail)

Figure 10. Heat exchanger below shower cabin (copper coil)
Previous studies about heat recovery from drainage water have been done by Nassiri (2014), Grönholm (2011) and Olander (2014). Nassiri did investigate heat recovery from the sewage of apartment buildings with the help of a sewage heat exchanger. Grönholm researched different ways of heat recovery from drainage and did also look at shower heat recovery. Olander did analyze a heat exchanger meant for a single shower system. Nassiri’s and Grönholm’s work was focused on larger systems that included several drainages. Olander did mainly focus on a single heat exchanger meant to be used in a shower. This work is focusing on the individual shower cabin and the use and benefit of a shower heat exchanger.

2.5 Heating of domestic water

2.5.1 Heating of domestic water

From the total energy usage in all 28 EU countries year 2014, the residential energy use did account for 25 %. For Sweden and Finland the residential energy use part was 21 % (Eurostat, 2016). This can be compared with the U.S residential energy use of 22 % from the total usage during the year 2013 (EIA, 2015).

The energy use for Finland’s households amounted to 64 TWh in 2014, which is on level with the previous year. Figure 11 shows the residential energy usage between years 2008 and 2014.

Figure 11. Energy usage in households for 2008 to 2014 (Finland, 2014, p. 1)
2.5.2 Heating of shower water

The Figure 12 with a table about energy use in households shows that the energy usage variations between different years are mostly depending on the building’s heating needs. From the table we can also see that the heating of domestic water have been increasing with 0.6-0.7 % amounting to a total of 9.8 TWh.

The typical water consumption for a Finn varies between 60-270 liters per day and person, but the individual consumption can be considerably smaller or higher from this (Ministry of Environment, 2009).

For the year 2010 an average household in Finland consumed 128 liter/day per person, comparing to 475 for U.S in 2008 (IWA, 2010) and an average European with 130 liters/day (EEA, 2014). From the average water consumption about 40% are considered to be used for personal hygiene (Motiva, 2009). The average price of district hot water for years 2013-2015 varies between 5-8 cents/kWh in Finland (Energiateollisuus, 2016).

Figure 12. Energy usage in households in 2010 – 2014 and energy source (Finland, 2014)

The default values according to the Finnish building regulation (D5, 2012) for heating of 1000 liter of hot water requires 58 kWh/m³. Also the standard hot water heating requirement is calculated by 35 kWh/m² for heated area per year for residential houses (D3, 2012).
2.5.3 Shower use and water flows
An average shower in America can pump out 11 liters/minute and the average American spends 12 minutes in the shower each day (Wibberding, 2006, p. 32). The European Ecolab have a scheme for sustainable shower flow rates with labelling classes for maximum flows between 4.5 and up to 16 liters per minute (Wolf & Kaps, 2011). The water flow is also greatly depending on the age of the building and shower pin equipment (Olsson, 2003).

2.5.4 Heat losses from hot water distribution and storage
Standby energy accounts for heat lost through the storage tank’s walls. Standby losses amount from 20 to 60 per cent of the total water-heating energy. Households that use less hot water have a higher percent of standby losses. Distribution losses consist of heat escaping through the pipes and fixtures (Krigger & Dorsi, 2004).

Domestic water heat loss occur from distribution and storage (D5, 2012). These losses is defined in the Tables down. Residential small houses, no circulation

Table 1. The efficiency of how water distribution

<table>
<thead>
<tr>
<th></th>
<th>Residential small houses, no hot water circulation</th>
<th>Residential small houses, no hot water circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With hot water circulation 0.96 for all</td>
<td>With hot water circulation 0.96 for all</td>
</tr>
<tr>
<td>No isolation</td>
<td>0.75</td>
<td>0.76</td>
</tr>
<tr>
<td>Protective pipe</td>
<td>0.85</td>
<td>0.86</td>
</tr>
<tr>
<td>Standard isolation</td>
<td>0.89</td>
<td>0.90</td>
</tr>
<tr>
<td>Improved isolation</td>
<td>0.92</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Multi store building, no circulation
With circulation 0.97 for all

<table>
<thead>
<tr>
<th></th>
<th>Residential small houses, no hot water circulation</th>
<th>Residential small houses, no hot water circulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>With hot water circulation 0.96 for all</td>
<td>With hot water circulation 0.96 for all</td>
</tr>
<tr>
<td>No isolation</td>
<td>0.76</td>
<td>0.76</td>
</tr>
<tr>
<td>Protective pipe</td>
<td>0.86</td>
<td>0.86</td>
</tr>
<tr>
<td>Standard isolation</td>
<td>0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Improved isolation</td>
<td>0.94</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Source: Ministry of the Environment, D5 table 6.3: (D5, 2012)
Table 2. Hot water storage losses

<table>
<thead>
<tr>
<th>Hot water storage unit volume, liters</th>
<th>Heat losses through the hot water storage unit, kWh/ year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 mm isolation</td>
</tr>
<tr>
<td>50</td>
<td>440</td>
</tr>
<tr>
<td>100</td>
<td>640</td>
</tr>
<tr>
<td>150</td>
<td>830</td>
</tr>
<tr>
<td>200</td>
<td>1000</td>
</tr>
<tr>
<td>300</td>
<td>1300</td>
</tr>
<tr>
<td>500</td>
<td>1700</td>
</tr>
<tr>
<td>1000</td>
<td>2100</td>
</tr>
<tr>
<td>2000</td>
<td>3000</td>
</tr>
<tr>
<td>3000</td>
<td>4000</td>
</tr>
</tbody>
</table>

Source: Ministry of the Environment, D5 table 6.3b: (D5, 2012)

2.5.5 Cold tap water temperature variations

The average annual cold tap water temperature varies normally between 4-15 °C depending on the regional climate. The seasonal temperature variations is usually 5 °C from coldest to warmest period. (Sinclar, 2008), (Euromekanik, 2015) and (Kling, 2003). Olsson shows (Figure 13) that the seasonal domestic hot water heating requirement can be twice as high during winter compared to the summer due to the higher cold tap water temperature during winter and reduced use in summer. The cold tap water temperature can also vary greatly depending on the usage. Olander (2014) shows with his cold water temperature measurements that for a larger building with extensive piping network the cold water temperature can stay high for several minutes, starting with 11°C and slowly decreasing to 5 °C during the period of 30-60 minutes.

![Figure 13. Seasonal variation of hot water heating energy need (Olsson, 2004)](image)
2.6 Theory

The calculations done for the measured values in Chapter 4 to get the results are shown in Table 3.

For Table 3 applies:

<table>
<thead>
<tr>
<th>T difference S-D</th>
<th>Temperature difference between shower water and the water entering the drain.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HX saving above</td>
<td>Heat exchanger energy saving of district hot water [kWh] for the showering period, t.</td>
</tr>
<tr>
<td>HX saving below</td>
<td>Combined heat exchanger energy savings from both heat exchangers [kWh], from the incoming cold tap water to the heated shower water.</td>
</tr>
<tr>
<td>T1, T2, T3, T4, T5 and T6</td>
<td>Temperature loggers that logs the temperature every minute, see Figure 14.</td>
</tr>
<tr>
<td>t</td>
<td>Showering time in hours</td>
</tr>
</tbody>
</table>

Table 3. Calculations

<table>
<thead>
<tr>
<th>HX saving above,</th>
<th>(T2 - T1)</th>
<th>*</th>
<th>Flow</th>
<th>*</th>
<th>0,998</th>
<th>*</th>
<th>4,18</th>
</tr>
</thead>
<tbody>
<tr>
<td>HX saving below,</td>
<td>(T3 - T2)</td>
<td>*</td>
<td>Flow</td>
<td>*</td>
<td>0,998</td>
<td>*</td>
<td>4,18</td>
</tr>
<tr>
<td>HX total saving,</td>
<td>(T3 - T1)</td>
<td>*</td>
<td>Flow</td>
<td>*</td>
<td>0,998</td>
<td>*</td>
<td>4,18</td>
</tr>
</tbody>
</table>

Source: Calculations, table 4 (Olander, 2014)
2.7 Energy perspective

The global energy usage have been growing and is expected to grow by 1.4 % yearly in the forthcoming years (EIA, 2016). The negative effects of increased energy use are greatly depending on the type of base raw materials required for producing the energy and the negative consequences those have on the environment. From the energy used, fossil fuels stands for the largest part. Excess use of fossil fuels have been shown to have considerable negative effects on the environment, including, but not limited to global warming.

Renewable energy is today the world’s fastest growing energy source, with a yearly increase of 2.6 %, limiting the negative consequences of growing energy use. The residential and commercial buildings together amount to about 40 % of the total energy usage. From total world delivered, the residential buildings amounts to 20 % of the delivered energy usage by end-use sector. In EU the average residential energy use amounts to 25 % and for individual countries like Sweden and Finland it is 21 % (EIA, 2016).

The EU energy efficiency directive from year 2012 sets a target to save 20 % of the unions primary energy usage by year 2020 compared to the year 1990. The EU countries also agreed in October 2014 on a new energy efficiency target of at least 27 % by the year 2030. To reach the goals, improved energy efficiency use are required in all sectors (European Parliament, 2012).

Finland’s energy efficiency law for buildings from 2013 greatly reduces the minimum energy usage allowed for new buildings. Finland is also preparing for a law that would by 2020 require all new buildings to be zero or close to zero energy buildings. This is defined by the Ministry of the Environment as buildings that have very high energy efficiency, where the already greatly reduced energy demand is satisfied extensively by renewable energy (Ministry of the Environment, 2016).
### 2.8 Kiwa product certificate

The Kiwa institution tests, inspects and certifies products. It is well known in Europa and internationally. A Kiwa product certificate ensures that the product have been properly tested for both quality and safety. The certificate for heat exchangers intended for the indirect heating of drinking water have several requirements that has to be met before it can be granted. The goal with the requirements are to minimize health risks for those in the heat exchangers range of influence during its lifetime. These basic requirements include poisonous substances, pressure limits, corrosive materials and heat resistivity (Kiwa, 2012).

The product certification can be done for heat exchangers where the drainage water and drinking water are separated by one wall or by two walls. When using two walls then also a third medium, between the two separating walls, can be included to ensure safety (Kiwa, 2012).

The product certificate requirements are easier for double sided walls. The main difference for double sided walls is a test requirement where leakage in one of the walls shall lead to a visual leakage signaling outside the heat exchanger within 300s. This is tested by a leakage test, where a 2 mm diameter continuous hole is drilled through both walls at the most critical location. After drilling the heat exchanger is subjected on both sides directly to a water-pressure of 50 kPa and time measured until the leakage liquid is signaled (Kiwa, 2012).
3 METHODOLOGY

Chapter 3 describes how the testing and measurements have been executed and the equipment used (3.1). The calculation methods that have been used for the results are shown (3.2) and the measurement site (3.3).

3.1 Method and system setup

In this report two heat exchangers are investigated while being used in a shower cabin. Both of the heat exchangers are of cross flow type (see 2.3.2). The heat exchanger below the shower cabin have the water flowing to the middle giving it also some parallel and counter flow heat exchanger characteristics (see 2.3). All of the tests are done with actual showering, with the shower in use. The showerings are done by person 1 and person 2. The measurements have been done during April 2016.

The equipment and the gauges are shown in table 4.

Table 4. Equipment and gauges

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pc. Shower cabin, NKH 97 VS överdel 90x70</td>
<td>-</td>
</tr>
<tr>
<td>1 pc. Towel rail (to use as cooler above the shower cabin)</td>
<td>50 €</td>
</tr>
<tr>
<td>10 meter copper coil pipe (under the shower cabin)</td>
<td>55 €</td>
</tr>
<tr>
<td>Other equipment (joints, heat conductive paste, etc.)</td>
<td>100 €</td>
</tr>
<tr>
<td>Measuring instruments</td>
<td></td>
</tr>
<tr>
<td>3 pc. Air moisture and temperature logger, ebro EBI 20-TH1</td>
<td></td>
</tr>
<tr>
<td>5 pc. Water temperature logger, ebro EBI 20-TF</td>
<td></td>
</tr>
<tr>
<td>1 pc. Oras Flowmeter</td>
<td></td>
</tr>
</tbody>
</table>
3.2 The system setup

Two heat exchangers are connected to the cold tap water provided for the shower cabin, see Figure 14. The first heat exchanger is above the shower cabin (2) to condensate and cool down moist air in order to heat up the incoming cold tap water (1) and reduce the air humidity in the bathroom. The second heat exchanger is stationed below the shower cabins bottom plate to transfers heat from the used shower water (6) to the cold tap water (3). This is the floor of the shower cabin with a copper coil under it where the cold tap water flows.

1) Incoming cold tap water
2) Heat exchanger above the shower cabin (see table 3) that is used to cool down air and condensate water. Circulating cold tap water inside are heated up.
3) Heat exchanger at the bottom of the shower cabin. This consist of a metal plate with a copper coil piping under it. The cold tap water flows through the copper pipe.
4) Mixer to reach desired shower temperature for the water by mixing cold and hot district water. Here the cold water is preheated in the heat exchangers before it reach the mixer.
5) Shower water with desired shower temperature and flow.
6) Used shower water passing through the heat exchanger and leaving for the drain.

The process for the incoming cold tap water (1) before it reaches the shower (5) is following, see Figure 14: The cold tap water (1) goes first to the heat exchanger that is above the shower cabin (2). Moist hotter air goes up through the heat exchanger (2) and some of the moisture condensates on the colder surface. During condensation heat is released to the surface causing the cold water inside the heat exchanger (2) to heat up. After the incoming tap water have passed the first heat exchanger it is lead to the second heat exchanger (3) that is below the shower cabin. When the tap water passes through the second heat exchanger, it is heated up by the used shower water (6). After the tap water have been preheated in both of the heat exchangers it is led to the mixer (4) where it is mixed with hot water from district heating to reach desired temperature. The shower water (5) flows down to the cabin bottom plate (6) to the heat exchanger (3) and down to the drainage.
Figure 14. *Shower heat exchanger above and below the shower cabin*

The measuring equipment are placed following: Temperature logger T1 at the incoming cold water (1) before it enters the first heat exchanger (2), temperature logger T2 before the second heat exchanger (3), temperature logger T3 before the mixer for cold water (4), temperature logger T4 before the mixer for hot water and temperature logger T5 after the mixer (5). Also a temperature logger T6 at the drain. The flow measurement is taken from the shower water (5). The air temperature and moisture contents are measured with logger HT at a distance of 2 meters from the shower cabin. See 2.4 for more information about these heat exchangers, Figure 9 for the heat exchanger above and Figure 10 for the heat exchanger below.
3.3 Location of the measurement execution

The place of the measurements was at a private home in a bathroom at Vantaa, Finland. The location is pointed out in the map, Figure 15. The measurements was taken during four different time periods in April 2016. Between 1-7th, 11-16th, 17-21th and 22-28th April. The measurements was taken using ebro loggers EBI 20-TF (water temperature) and EBI 20-TH1 (Air moisture and temperature), see 3.1 and table 4 for more information. The data from the loggers were collected and transferred to Excel between the different measurement periods.

![Figure 15. Location of the measurement execution](image)
4  PROCESS AND RESULTS

In Chapter 4 the test measurements and the results of these are given. These are shown in the Figures 16 to 21. The efficiencies are given depending on the heat exchanger, times, flows and temperatures. The heat exchangers efficiency and distribution losses are used to calculate costs and pay-back times.

4.1 Measurements

4.1.1 Temperature difference of shower and drain water without heat exchanger

In Figure 16, the shower temperature and drain temperature difference are shown depending on the measured shower water temperature. The shower temperature is measured from the shower output, and the drain temperature taken from the water passing to the drainage. The red dots stands for measurements that have been taken before the shower cabin was installed. The blue dots stands for measurements that has been taken after the shower cabin was installed. The temperature difference varies between 3 and 8 degrees depending on flow and temperature. For the measurement taken at 24.4 we can see a temperature difference of almost 8 °C at a shower temperature of 42 °C.

![Figure 16](image.png)

Figure 16. *Shower and drain water temperature difference without heat exchangers*
4.1.2 Cold tap water temperature variations

Figure 17 shows how the cold water temperature changes with time. The water flows vary between 6 and 16 liters per minute. The temperatures are the average from the past 5 minutes. The 5 minute temperature is the average from measures taken every minute taken from start of shower and until 5 minutes of shower time. The 10 minute temperature is the average starting from minute 6 until minute 10. The 15 minute temperature is the average starting from minute 11 until minute 15. The 20 minute temperature is the average starting from minute 16 until minute 20. The higher average temperature for each time range are for low flows and the lower average temperature stands for high flows.

![Figure 17. Cold tap water temperature variations depending on flow and time](image)

4.1.3 Increase of cold water temperature from heat exchangers

Figure 18 shows the increased temperature for the cold tap water after it passes the heat exchanger above the shower cabin and when it passes the heat exchanger below. It also shows the combined temperature difference. The measurements are taken from flows directly before and after the heat exchangers and the result presented as a temperature difference. By using the temperature difference the effect from cold tap water temperature variations are limited (see Figure 17). From Figure 18 we can see that with a flow of 6 liters per minute the combined temperature increase is 8°C.
Figure 18. *Cold tap water temperature increase from heat exchangers*

### 4.2 Efficiency depending on shower flow

Figure 19 shows the efficiency of the heat exchangers at shower temperatures 36-38 °C. The efficiency have been calculated based the hot district water use with and without the heat exchangers. The efficiency shows how many percent hot district water can be saved depending on the flow. At 8 liters per minute the heat exchangers efficiency is 8%.

Figure 19. *Heat exchanger efficiency depending on water flow*

24
4.3 Cost efficiency of the heat exchanger

Figure 20 shows the cost efficiency of the second heat exchanger that is below the shower cabin. The estimated cost of the heat exchanger is 200€ (see table 1) and the interest rate of the investment estimated to be 2%. The shower water use is calculated for 100 liters per day with a temperature of 39 °C (10 liters flow and 10 minutes). The initial cost for district hot water is 6 cents/kWh in Helsinki (see 2.5.2). The payback time have also been calculated for energy prices up to 24 cents/kWh. This corresponding to possible higher energy prices in the future, different energy source or for more users using the shower cabin. From the Figure 20 we can see that the savings after 20 years with a price of 24 cent/kWh is just below 200€.

Figure 20. The heat exchangers cost efficiency
4.4 Moisture content in the bathroom

Figure 21 shows the moisture content in air depending on time for various shower times. The moisture content of air is measured 2 meters from the shower place. The measurements are taken from normal shower use during a period of 20 days starting from 4.4.2016. The red line shows the moisture without the heat exchangers and the blue dotted line shows the moisture when the heat exchanger is in use.

![Air moisture depending on time (10 minutes shower times)](image)

Figure 21. The bathroom air moisture content, g/m³, 10 minutes shower times
5 DISCUSSION

In Chapter 5 the reliability of the results are evaluated and discussed (5.1), the results from Chapter 4 are discussed and conclusions are given (5.2).

5.1 Reliability of the result

Heat exchanger above the shower cabin: Figure 16 shows that there are heat losses from the shower water before it enters the drain. The heat have been transferred to the person using the shower, to the surrounding air and the surrounding surfaces. This means there might be energy available for a heat exchanger that transfers it directly from the bathroom air. Figure 18 shows that the temperature increases in the heat exchanger, indicating the heat exchanger works, which we can also see from Figure 21 that shows a reduction in both temperature and air humidity when the heat exchanger have been used. The figures 16, 18 and 21 together shows reliably that the heat exchanger above the shower cabin works.

The measurement results are not entirely exact. Some leakages in the joints have to be expected and the measuring equipment have a margin of error. However, considering the clear results at figure 20, the error can be up to 40 % before changing the outcome to the answer for the research question. Several measurement loggers have been used and their results compared to each other which shows a logical change of measuring values supporting each other.

The conclusion is that the answers to the research questions are reliable.
5.2 Discussion

Figure 16 shows that before the shower water reaches the drain, some of the heat transfers to the surroundings. The person showering, nearby surfaces and the surrounding air are receivers. From this the heat exchanger above the shower cabin may recover heat that have been lost to the surrounding air by lowering the air temperature and condensation of water humidity in the air. Figure 21 gives indications that the heat exchanger above the shower cabin slightly reduces the water content in the air and decreases the temperature. The Figure also shows that there is room to significantly increase the heat exchangers effect above the shower cabin to account for the showering heating of the bathroom air.

Figure 17 shows how the cold tap water varies depending on shower time and shower flow. The cold tap water temperature varies between 6°C and 10°C. This is a significant temperature difference that means the first 5 minutes of showering uses less energy than the next 5 minutes when the flow and temperatures are kept constant.

Figure 19 shows how the heat exchangers efficiency are depending on the water flow. With increased flow the heat exchangers efficiency are reduced. Increased flow also means more energy can be saved for less efficiency. Figure 19 gives indications that the energy saved per minute remains relatively constant.

Figure 20 shows the payback time of the heat exchanger that is below the shower cabin, with the copper coil (see table 4 and Figure 14). Here the payback time with interest rate are calculated for the increased cost to the shower cabin if the heat exchanger would be added. For the energy price the current market price and also a possible higher energy price in the future is considered. The Figure shows that the heat exchanger will not be cost effective in any reasonable scenario with the heat exchanger efficiency (see Figure 19). The payback time for the heat exchanger above the shower cabin have not been calculated due to its low efficiency.

Figure 20 shows the payback time of the heat exchanger that is below the shower cabin, with the copper coil (see table 4 and Figure 14). Here the payback time with interest rate are calculated for the increased cost to the shower cabin if the heat exchanger would be added. For the energy price the current market price and also a possible higher energy price in the future is considered. The Figure shows that the heat exchanger will not be cost effective in any reasonable scenario with the heat exchanger efficiency (see Figure 19). The payback time for the heat exchanger above the shower cabin have not been calculated due to its low efficiency.

Both of the heat exchangers are of cross flow type (see 2.3.2). The heat exchanger below the shower cabin have the water flowing to the middle giving it also some parallel and counter flow heat exchanger characteristics (see 2.3). It is a prototype far from perfected, with the main issue being the glue and filling paste between the two walls separating the
drainage water and drinking water (see 3.1 and 3.2). To ensure high heat conductivity the filling material between the copper coil and shower plate would need to be made from highly thermal conductive metals.

The potential for shower heat exchangers are very promising. If the planned energy efficiency law in Finland for year 2020 becomes reality; it would greatly increase the demand for energy efficient solutions (see 2.7). The close to zero energy building demand would mean that the building permits are denied until the buildings energy efficiency requirements are met. A likely outcome of the law would then be that a shower heat exchanger would be competing with more expensive energy producers, like energy from expensive battery systems charged by solar panels. However, a heat exchanger that only saves 8 % would not get much attention in the market. To have any practical use, the efficiency would need to be above 40 %, preferably 60 % or more. This can at least be achieved by heat exchangers that have one wall separating the drainage water from drinking water (see 2.4). The main problem with one wall separating heat exchangers are the safety and higher risk for contamination which makes the design, permit and certification process difficult (see 2.8).
6 CONCLUSION

The heat exchanger above the shower cabin can be used to decrease the air humidity and temperature in the bathroom air, this to counter the effect of showering in the bathroom (see Figure 21). The heat exchanger is of a typical cross flow type (see 2.3.2). The energy savings in this test system are insignificant compared to the costs. However, considering the benefit of reduction of air humidity, further tests and improvements of the system might be beneficial.

The heat exchanger below the shower cabin have crossflow characteristics. It increases the incoming cold water temperature by transferring heat from the passing water leaving for the drain. The heat exchanger efficiency is too low compared to the cost to give a reasonable payback time. The effect needs to be at least doubled while the cost remains the same for the system to be considered. However to meet the new energy efficiency demands for residential buildings the heat exchanger efficiency would need to be higher, preferably above 60 % (see 5.2). Cost effective shower heat exchanger efficiencies of at least 60 % are currently only available for single wall separation of the drainage and drinking water. The recommendation for further study are to focus on finding a solutions for the higher risk of contamination with single wall separation heat exchangers, so that the greater efficiency can be utilized.

Answers to the questions in 1.4 is given:

1) The heat exchangers efficiency is 8 % for a flow of 8 liters per minute and shower temperature of 37 °C (see 4.2).

2) The heat exchangers payback time is above 20 years, making it unreasonable high (see 4.3). With increased energy efficiency demands (see 2.7) the payback time will reduce, however the efficiency still needs to be drastically increased.
REFERENCES


Engineers Edge, 2000. *Thermal Properties of Metals, Conductivity, Thermal Expansion, Specific Heat*, u.o.: Engineers Edge,


Sparavarmvatten, u.d. [Online].


Figure 22. *Energy sources for heating of residential buildings in 2008 to 2014* (Finland, 2014, p. 2)
Annex 2

Figure 23 shows the measurements taken between 4/22/2016 7 PM and 4.28/2016 7 AM. The measurements are taken every minute from the shower temperature, drain temperature, RH content inside the bathroom and RH content outside bathroom. Heat recovery is turned off.

![Moisture content and shower use](image)

Figure 23. Moisture content and shower use

Table 5. Measured flows, temperature and calculated heat exchanger efficiency

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<th></th>
<th></th>
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