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Energy performance of a drainwater heat recovery system

Experimental results of drainwater heat recovery in ECN research dwellings

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Abstract

The unit ‘Renewable Energy in the Built Environment’ (DEGO) of the Energy research Centre of the Netherlands (ECN) has four research dwellings at its disposal to do integral energy research in buildings. Three of the research dwellings are equipped with a drainwater heat recovery (DHR) system in the drainwater pipe of the shower. The DHR system pre-heats the fresh (cold) supply water of the dwelling with the heat of the warm drainwater of the shower.

Measurements show a heat exchange efficiency of 51% to 63%, depending on the installation and use of the pre-heated supply water. Furthermore is estimated that up to 3GJ primary energy can be saved annually using the DHR system. It should be mentioned that the annual saved energy strongly dependents on the installation of the DHR in relation to the domestic hot water system. This makes it difficult to predict the energy performance of the DHR.

Introduction

A commercially available DHR system is installed in three ECN research dwellings. The research dwellings are low energy houses specially built to do integral research on energy systems. The buildings are equipped with a complete measurement system to monitor the dwellings, mainly their climate and comfort systems [1], [2]. Measurements of the functioning of the drainwater heat recovery are part of a larger research project called ‘Ecobuild fase II’.

The DHR itself consists of two concentric pipes placed vertically under the shower drain. The heat exchanger has a length of approximately 2.0m. Showers in new built houses are mainly located at the first floor in the Netherlands. The drainwater flows downward through the centre of the concentric pipes, the water to be pre-heated is streaming upward. See the schematic picture in figure 1.

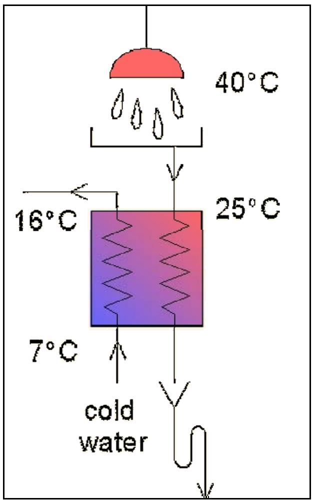

Figure 1: Heat exchange from drainwater to the cold supply water (temperatures are indicative)

The DHR system can be installed in two ways. Different ways of using the pre-heated water flow, results in different possible flows through the DHR. It is important to distinguish the ‘balanced’ and ‘unbalanced’ situation. In the balanced situation an equal amount of fresh water (to be pre-heated) and drainwater flows through the heat exchanger.

In the unbalanced situation the flows of fresh water and drainwater through the heat exchanger are unequal, see figure 2. The efficiency of the heat exchange is significantly influenced by the balance of flows. Furthermore can the use of pre-heated water impact the efficiency of the total domestic hot water system, this will be explained later on.

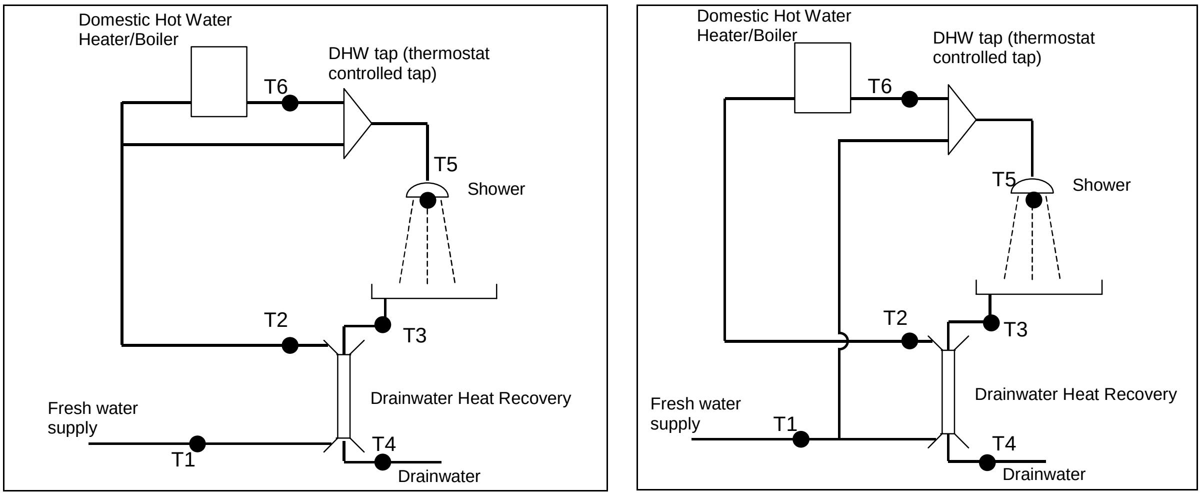

Figure 2: Balanced (left) and unbalanced (right) installation of the drainwater heat recovery.

Experimental Setup

The DHR systems in the research dwellings can be switched from the balanced to the unbalanced installation and can be by-passed. In the balanced situation, the pre-heated water is supplied to the domestic hot water heater (or boiler) and to the 'cold' side of the thermostat controlled shower tap. In the unbalanced situation, the pre-heated water is only supplied to the domestic hot water heating system. Unbalanced, a separate cold water flow is mixed at the shower tap this results in a larger drainwater flow through the DHR than fresh water flow.

During the day an automatic and fixed domestic hot water pattern is tapped. The pattern is directly derived from the norm NEN 5128. Part of the hot water is tapped at the kitchen sink and two taps a day are longer taps using the shower (and therefore the DHR). The taps at the shower are approximately 20 minutes, one in the morning and one in the evening. The shower water has a temperature of 40°C and a flow of 5 lt/min.

The domestic hot water in each dwelling is supplied by the domestic hot water system of the dwelling. One dwelling has a gas fired burner and two are equipped with heatpumps. All three domestic hot water systems include a solar water heater.

Using the measurement system of the dwellings the following subjects are determined:
1. The development of the temperatures and the efficiency of the heat exchanger during one single shower period of 20 minutes.
2. The static efficiency of the heat exchange in balanced and unbalanced installation.
3. By judging the energy performance of the total domestic hot water supply with and without DHR, an estimation of the annually saved primary energy is made. Different domestic hot water systems (gas-fired boiler, heat pump, additional solar water heater) are taken into consideration.

For the first measurement, temperatures T1 to T6 in figure 2 are recorded at a sample time of 10 seconds. Also the flow of the drainwater and the supply water is recorded. The development of the temperature and the warming up of the heat exchanger are analysed using the recorded data during a single shower period of 20 minutes. Combined with the recorded water flows, the efficiency of the heat exchanger during the tap can be determined.

For the second measurement the same temperatures and flows as for the first measurement are recorded. Now at a sample time of 10 minutes. For 14 shower taps at a row (7 days) the measurement points during the taps are used to determine the efficiency of the DHR. The single recording at the end of each tap is used to determine the static equilibrium of the efficiency. The measurements give a reliable average DHR efficiency. The measurement is performed for both the balanced and unbalanced installation.

During the measurement periods of one week for the second measurement, the domestic hot water system is also monitored. The heat needed to produce shower water of 40°C (5 lt/min) and the heat needed to produce the domestic hot water at the kitchen sink are measured. Depending on the use of the DHR, the needed heat to produce the same amount of domestic hot water is a direct measure of the energy saved due to the use of the DHR. (The domestic hot water patterns are also run without the use of the DHR).

Results

Temperature and efficiency during one shower tap of 20 minutes.

Measurements show it takes 2 to 3 minutes to heat up the heat exchanger. Taking the temperature of the pre-heated flow, it takes up to almost 6 minutes before the pre-heated water reaches it constant temperature. All can be seen in figure 3. Just after time equals 8 minutes the shower is turned on, it is shut down at t=26.5 min. The temperature sensors are thermo-couples attached to the outside of the water tubes, this gives them a starting temperature of about room temperature (~20°C). Figure 4 shows the efficiency development of the same shower tap.

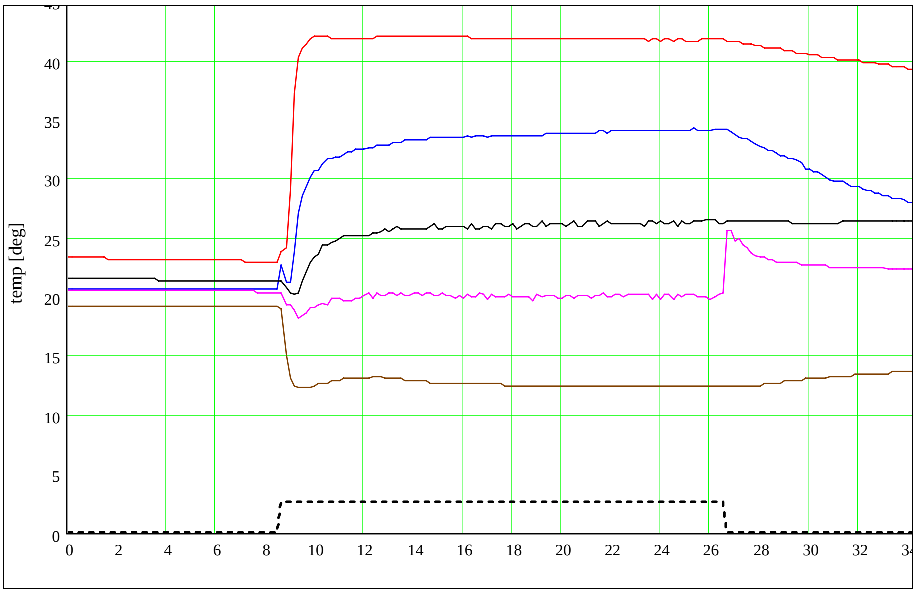

Figure 3: Temperature profile of the DHR during a 20 minutes water tap. The x-axis shows the time in minutes, the y-axis the temperature in degrees C. From up to down the lines show the temperatures of 1) the shower water at the shower head 2) the drainwater going into the DHR 3) the pre-heated water at the end of the DHR 4) the drainwater going down the plumbing 5) the fresh water supply.

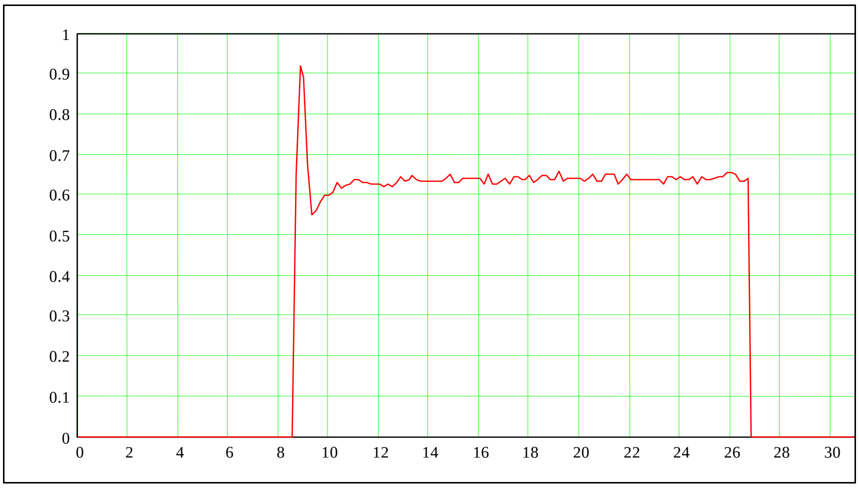

Figure 4: Efficiency of the DHR during a single shower tap. The x-axis shows time in minutes, the y-axis the efficiency in percentage. The stabilized efficiency is 63% with the DHR in balance.

Static efficiency of the DHR

Figure 4 shows a stabilized efficiency of 63% for a DHR system installed in balance. This is confirmed by measurements over 14 shower tap during one week. The stabilized efficiency of the DHR when installed unbalanced, equals 51%. So 63% or 51% of the total heat going into the DHR system is used to pre-heat the fresh water supply. It is however not straight forward to predict the annual energy saving based on the efficiency. This is explained in the following paragraph.

Primary saved energy

As mentioned, in the research dwellings a fixed tapping pattern for domestic hot water is applied. At fixed moments, a defined amount of domestic hot water (with a defined energy content) is tapped at the kitchen tap and at the shower. The total energy needed to produce the domestic hot water is measured for the complete tap pattern. The first row in table 1 gives the energy produced by the heating system (heatpump, or gas-fired boiler and/or the solar water heater) for a complete pattern of one week. The measurement is repeated using the DHR system (in two ways) and without using the DHR.

Because of the heat recovery, the domestic hot water system needs less energy to produce the same amount of tapped hot water. As can be seen in the efficiency measurements, the balanced installation has the highest efficiency, this is also shown by the lowest energy use for the domestic hot water pattern using the DHR in the balanced configuration.

The used energy in one week is extrapolated to the use in one year (2^{nd} row in table 1). From these figures the annual primary saved energy can be estimated by comparing the extrapolated energy use to the use without the DHR.

	DHR unbalance	DHR balance	Without DHR
Energy needed to produce domestic hot water for one week (measured)	147 MJ	140 MJ	199 MJ
Energy needed to produce domestic hot water for one year (extrapolation)	7.6 GJ	7.3 GJ	10.3 GJ
(Potential) annual primary saved energy	2.7 GJ	3.0 GJ	--

Table 1: Overview of energy use for the production of domestic hot water with and without the use of the DHR.

Row 3 of table 3 gives an estimation of the saved energy by the DHR. In the configuration like figure 2, using a gas-fired boiler to produce domestic hot water, the saved energy is 2.7GJ to 3.0GJ per year. This energy is primary energy which doesn't need to be converted to produce the demand of domestic hot water. Some remarks have to be made together with our approach, this will be done in the following discussion.

Discussion

The DHR has the most influence on the domestic hot water supply by means of the use of the pre-heated water flow. If the pre-heated water is fed back to the boiler of a heatpump (or solar water heater) the temperature of the ingoing flow to the heatpump (or solar water heater) is higher than normally. This influences the efficiency of the generation of hot water. For example the efficiency of a solar collector is reduced significantly if the incoming flow has a high temperature compared to the outgoing flow. The same yields for a gas-fired boiler. Furthermore it has shown that the gas-fired boiler has a less stable behaviour when it is fed with a higher temperature. The gas-fired boiler did not give a constant hot water flow and not a constant temperature.

Due to the DHR, it is very well possible that renewable gained (e.g. by the sun) energy is saved. If the saved energy is stored (or kept) in the heat storage, it can be used at a later stage. But it is also possible that the saved (renewable) energy is lost due to losses in the tubing systems (at transportation). And losses due to transportation are more likely to occur because the (pre-heated) water is transported at higher temperatures.

So on one hand the DHR saves energy, on the other hand, it causes less efficient behaviour of the domestic hot water heaters. To separate these processes and to determine the net outcome is difficult. To avoid potential less efficient behaviour of the domestic hot water system, the pre-heated water can be lead only to the cold water side of the mixing tap, but in that case, it efficiency is lower and there are no possibilities of storing the recovered heat. Therefore more and more detailed studies of the overall performances of DHR systems are useful.

Acknowledgements

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