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Investigating the efficiency of a vertical inline drain water heat recovery heat exchanger in a system boosted with a heat pump

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ABSTRACT

In the present study, the performance of a vertical inline drain water heat recovery heat exchanger is investigated. The system recovers the heat with the aid of a heat pump. To produce quality measurement data for the analysis special attention have been given to the calibration of sensors and the analysis of the propagation of uncertainty. The results from the analysis of the heat exchanger reveal that the contact resistance between the two copper pipes and the heat resistances on the inside of the drain water pipe are the dominating resistances to the heat transfer. Investigation of the heat recovery ratio shows that the heat exchanger has the capability to recover more than 25% of the available heat in the drain water at the flow rates investigated.

1. Introduction

The European Union has introduced a Roadmap for moving to a low-carbon economy by the year 2050 [1]. The goal of the Roadmap is that, by 2050, the greenhouse emissions shall be reduced by 80% compared to the 1990 levels. The Roadmap also identifies that one of the main sectors responsible for the greenhouse emissions is energy use in buildings. One of the key drivers to reach the goal is to increase the energy efficiency, especially in the buildings since they account for about 40% of the total energy demand.

To address this issue the European Union has initiated a number of directives aimed to reduce the energy use in buildings [2–4] and the different member states have adapted the directives to the local conditions. As an example Sweden has set a goal, supported by the European Union Directive 2010/31 [5], that all new buildings shall be “nearly zero energy buildings” from the year 2020. Since a large part of the energy loss in many types of buildings can be attributed to losses in the drain water, heat recovery from the drain water will be instrumental to reach the energy efficiency goal. The quantity of the losses in the drain water can be considered to be roughly the same as the domestic hot water demand [6]. Domestic hot water demand will vary but the average demand for a multifamily building is around 30 kWh/m^2 [7]. Heat from the drain pipe in buildings can be extracted with different methods, for example; falling film heat exchanger, tilted shell and tube heat exchanger and storage tank heat exchanger. The heat can for example be used to pre-heat incoming hot water for showers or it can be boosted with a heat pump to have a more flexible usage.

In the literature some studies can be found; Cooperman et al. [8] described how heat can be recovered from the drain pipe by pre-heating the incoming tap water. They presented three different ways to connect the system. Eslami-Nejad and Bernier [9] investigated the impact of gray water heat recovery by simulating demand in TrnSys, in their model they also heat exchanged incoming tap water. They concluded that the heat recovery ratio varied between 10.4 and 21.5% depending on the situation. Zaloum et al. [10] investigated 5 different standing film heat recovery heat exchangers also with the outside coil pre-heating the incoming tap water. Their conclusion was that 9–27% of the gas to the water heater can be saved. The amount is dependent on the heat exchanger design and the water draw profile of the building, for situations when no showers was taken the savings of gas to the water heater is between 3.3 and 5.4%. To increase the heat recovery rate a heat pump can be fitted to the heat exchanger, Baek et al. [11] concluded that for a hotel with a sauna 90% of the heating load can be covered by the heat pump, TrnSys was used to do the analysis. Other drain water heat recovery solutions include heat recovery in shower drains, McNabola et al. [12] looked into how these types of system should be developed to achieve maximum efficiency. Slyś et al. [13] investigated financial aspects of heat recovery from showers in single family buildings.

The literature survey returns information on a number of investigations that present studies on heat recovery from drain water, most of these studies are on systems that uses incoming water mains coupled directly to the heat exchanger. No studies of heat

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Nomenclature

Variables

A	heat transfer area (m^2)
C	constant
C_{min}	minimum heat capacity rate ($W K^{-1}$)
C_{max}	maximum heat capacity rate ($W K^{-1}$)
C_p	specific heat capacity ($J kg^{-1} K^{-1}$)
C_r	heat capacity ratio (−)
D	diameter (m)
De	Dean number
ESS	error sum of squares
h	convective heat transfer coefficient ($W m^{-2} K^{-1}$)
m	degrees of freedom (−)
$\dot{m}$	mass flow rate ($kg s^{-1}$)
N	sample size
n	number of observations
NTU	number transfer units
Pr	Prandtl number
$\dot{q}$	heat transferred per unit time (W)
Re	Reynolds number
R_{tot}	total heat transfer thermal resistance by contact resistance and conduction (K/W)
s	Standard deviation
s_y	propagation of uncorrelated uncertainty
S_{yt}	standard error of fitted equation
t	temperature (°C)
$\bar{t}$	average temperature (°C)
$t'_{95\%}$	measurement uncertainty at 95% confidence level
$t_{v,95\%}$	Student's *t* value at 95% confidence level
Δt	temperature difference (K)
U	overall heat transfer coefficient ($W m^{-2} K^{-1}$)
$\dot{V}$	volumetric flow rate ($m^3 s^{-1}$)
$\eta_{8^\circ C}$	heat recovery ratio compared to 8 °C maximum outgoing temperature (−)

Subscripts

all hex Cr = 0	stating all types of heat exchange with heat capacity ratio = 0
c	calibrated
calib	calibrated value
coil	value contributed to the coil side
coil in	value contributed to incoming on the coil side
cold	value contributed to the coil side
cross flow	stating cross flow type of heat exchange
counter flow	stating counter flow type of heat exchange
drain	value contributed to the drain side
drain in	value contributed to incoming to drain side
hot	value contributed to the drain side
inner	value contributed to the drain pipe inside
measured	measured value
s	drain side
t	coil side

Superscripts

a	constant
d	constant

recovery from drain water in multi-family houses using a heat pump have been found in the literature survey.

The present study investigates how an inline drain water heat recovery heat exchanger performs under changing conditions in a system boosted by a heat pump. The introduction of a heat pump to the system introduces a few changes to the characteristics of the system compared to a system where the water main is coupled directly to the heat exchanger. As an example the flow rate on the coil side is constant and can be optimized, and the recovered heat can be utilized more freely since the system can increase the temperature of the recovered heat. Using a heat pump also means that heat recovery is possible anytime there is heat available in the drain, thereby eliminating the mismatching problem experienced by a system that uses incoming water mains to recover heat. In the project an experimental facility has been built in order to facilitate the investigations.

The heat exchanger type that has been used in the present study is a falling film gravity heat exchanger with an inner pipe made from copper with another thinner copper pipe wound on the outside of the inner pipe. The outer pipe has the shape of a coil which introduces a demand for other formulas compared to a strait pipe since the curvature of the coil changes the flow profile. Naphon and Wongwises [14] present formulas to analyze parameters for a coil for example critical Reynolds number and Dean number. Dean number is a critical parameter because it takes the geometry of the pipe into account. Another source of information for flow in coils is Heat exchanger design handbook [15].

2. Experimental facility

A test facility has been built in a lab setting; the layout of the test facility can be seen in Fig. 1. The test facility will make it possible to test the performance of a vertical heat exchanger installed in an environment that mimics the situation of a drain water system.

The facility consists of a 1100 mm vertical copper pipe with a inside diameter of 70 mm, this gives the heat exchanger an inside heat transfer area of 0.20 m^2. Around the inner copper pipe a second copper pipe is wound to create the heat exchanger, Fig. 2 displays the heat exchanger. The outside coil consists of 25 m copper pipe giving the heat exchanger a 0.57 m^2 heat transfer area of the coil. In order to reduce the contact resistance between the inner and outer pipes a water proof jacket is fitted on the outside of the heat exchanger and the inside of the jacket is filled with water. In this design the space between the outside and inside pipes is water filled instead of air filled which is the usual case for this type of heat exchanger. This leads to lower contact heat resistance and a more efficient heat exchanger.

A 200 l barrel is used to collect the drain water after it has passed through the drain pipe. The barrel is also used as reservoir for the heat pump condenser cooling. Since the whole purpose of the system is to recover heat from the drain water and transport it back to the building heating system, this barrel can be seen as a part of the building heating system. The temperature in the barrel is controlled to be somewhat constant. The temperature in the barrel is controlled because the barrel is also used as a reservoir for the water that is used as drain water.

The drain water flow rate is controlled by a motor valve, the valve is computer operated through an Excel based schedule.

A storage tank is used to store cold water from the system heat pump; the storage tank supplies the outside coil of the drain water heat exchanger. The heat pump made up of a small R134a compressor, thermostatic expansion valve, two brazed plate heat exchanger acting as evaporator and condenser and a high/low pressure switch to protect the heat pump is also fitted to the heat pump.

Besides the previously mentioned components there is a heater and a cooler installed in the heat pump condenser circuit. The heater is installed to enable test the system at different temperatures in the building heating system and the cooler acts as the building heating load, lowering the temperature of the circuit to the desired drain water temperature.