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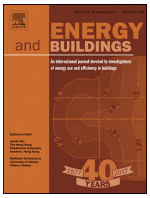

An experimental analysis of the impact of unequal flow on falling film drain water heat recovery system performance

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ABSTRACT

Drain water heat recovery systems are heat exchangers designed to recover energy from a building's greywater, and use it to preheat incoming mains water. The rated performance of such systems is determined at controlled mains-side and drain-side inlet temperatures, and under conditions of equal flow. This work aims to experimentally investigate the impact of having unequal mains-side and drain-side flow rates on the performance of these systems. As expected, experiments show that heat exchanger performance is strongly linked to fluid inlet flow rates. However, the findings also showed that variations in either of these flow rates lead to predictable changes in performance, regardless of diameter, length, or temperature. A semi-empirical equation is established that is capable of correcting system performance for different inlet flow rates based on the rated performance results.

1. Introduction

It is well understood that energy conservation will play a key role in allowing utilities to meet future energy demands, and the energy used to heat water for domestic purposes is no exception. In Canada, for example, surveys have shown that in 2014, 19.2% of the total energy consumed in residences was for water heating [14]. This represents 300 PJ (Petajoules), or 21.4 GJ (Gigajoules) per household. In the US, EIA's projections predicted that the estimated energy consumption for residential water heating was 2816.8 PJ, or 24.5 GJ per household for the year 2014 [15]. Also in the US, the estimated cost of water heating in 2010 was \$33.8 billion [21]. Clearly, many resources are used for domestic water heating, and as such, it is necessary to develop technologies to reduce this energy demand. One such technology is studied in this work.

Falling film drain water heat recovery (DWHR) systems could be an effective means to reduce water heating energy consumption. DWHR systems are single-pass, double-walled, counter-flow, and vented heat exchangers similar to what is shown in Fig. 1. They are comprised of a large diameter copper drain pipe, typically between 5.1 and 10.2 cm, which matches the size of the drain stack that they replace. Wrapped tightly around the drain pipe is a coil of smaller diameter copper tubes through which the mains water is circulated. Warm water flows into the top of the drain pipe, and exits at the base after transferring thermal energy to the cold mains-side water that enters the tubes at the bottom of the heat exchanger. Optimal system performance relies on a falling film of water shown in Fig. 2. That is, the drain water falls as an annular film that wets the inner surface of the drain pipe. This results in high heat transfer rates by maximizing the surface area and minimizing the thickness of water through which heat must be transferred to the walls.

There is significant potential to reduce water heating demand through the use of a DWHR system. Studies conducted at the Manitoba Advanced House [17], and by Oak Ridge National Labs [20] both estimated that about 50% of a typical family's annual domestic hot water load could be recovered. Later work conducted by the Canadian Centre for Housing Technology examined DWHR systems and concluded that gas consumption for water heating could be reduced by 9 to 27% depending on system configuration [22]. Other recent studies conducted in Canada and the Netherlands support these results [4,18]. Fittingly, DWHR systems are becoming more common in new and energy efficient construction. In Canada, the Governments of Manitoba and Ontario have mandated installation of DWHR systems in new residential buildings [6,8].

Each of the previously mentioned efforts focused on proving the feasibility of using DWHR systems to reduce energy consumption. Significant efforts have also been made to provide an understanding of DWHR system operation, and to produce perfor-

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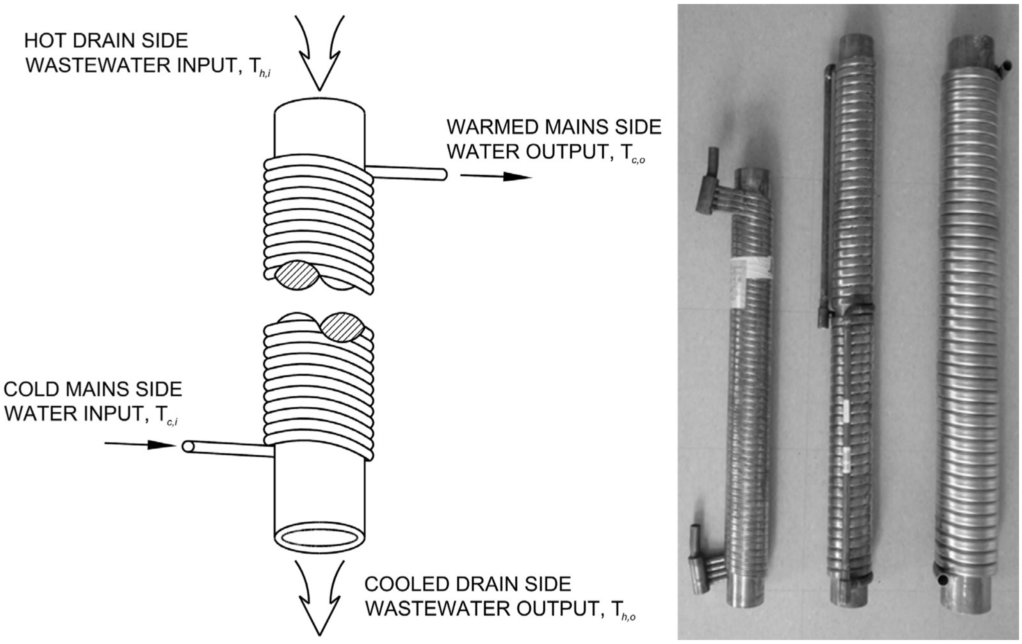

Fig. 1. Schematic of a typical DWHR system (left); photo of common DWHR systems (right).

Nomenclature

M	Fit coefficient, dimensionless
N	Fit coefficient, dimensionless
C	Heat capacity rate, kW/°C
C_p	Specific heat, kJ/kg°C
ε	Effectiveness, dimensionless
$\dot{m}$	Mass flow rate, kg/s
q	Heat transfer rate, kW
T	Temperature, °C
$\dot{V}$	Volumetric flow rate, LPM
ρ	Density, kg/m^3

subscripts

c	cold
h	hot
i	in
max	maximum
min	minimum
o	out
F1	Volumetric flow rate 1
F2	Volumetric flow rate 2

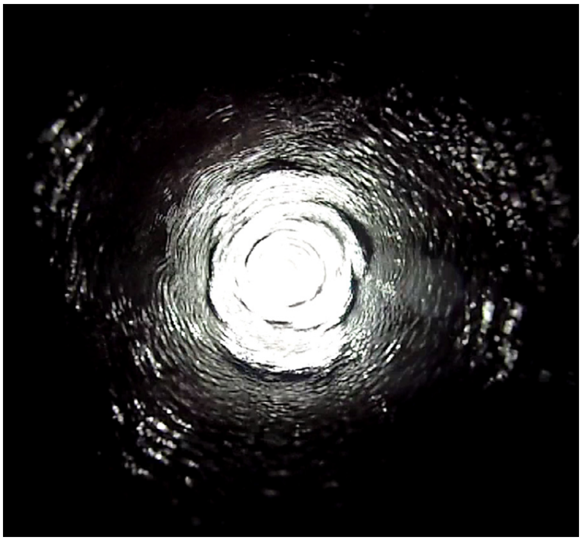

Fig. 2. The falling film in the drain-side pipe for a vertical installation.

mance models of DWHR systems. One study aimed to develop the characteristic effectiveness vs. flow rate curves for multiple DWHR systems [2], while others looked at the impacts of drain-side wetting [1] and off-vertical system installation [10]. The thesis of Manouchehri [9] examined the performance of DWHR systems with respect to fluid temperatures and unequal flow rates, with the ultimate goal of predicting steady-state DWHR system performance using data obtained from the rating process. The temperature correction model, later presented in Manouchehri and Collins [11], is capable of accurately predicting the impact of changing inlet fluid temperatures on DWHR system performance. The overall predictive model is presented in Manouchehri and Collins [12]. More recently, the work of Garcia [5] produced an analytical model of a DWHR system, and used it to predict energy recovery statistics. Garcia's conclusions indicate that payback periods of 5–6 years are achievable under average conditions and that DWHR units have higher saving potentials in dwellings with 3–4 occupants, compared to dwellings with 1–2 occupants.

In North America, the Canadian Standards Association (CSA) has produced Standard B55.1-15 *Test method for measuring efficiency and pressure loss of drain water heat recovery units* [3]. This standard specifies a nominal mains-side inlet temperature of 10 ± 0.4 °C and drain-side inlet temperature of 28 ± 0.6 °C above the mains-side temperature. This standard also includes the requirements for the design and configuration of a testing apparatus which can simulate the performance of a DWHR system in a typical installation. This standard also requires all DWHR systems be tested under conditions of equal flow. That is, the mains-side and drain-side mass flow rates are the same.

For end-use installations, DWHR systems operate under temperature and flow conditions that could be very different than those specified by the CSA standard. In a previous study [11], the impact of changing inlet temperatures was investigated, and a process by