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Experimental investigation of counter flow heat exchangers for energy recovery ventilation in cooling mode

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ABSTRACT

Ventilation heat recovery is a system that requires low power to operate and has a high capacity to reduce the energy consumption and increase the overall efficiency for air conditioning. This paper reports the experimental investigation of air-to-air heat exchangers employed for heat recovery ventilation in cooling mode. The two main objective of this research are to design, fabricate and testing two polymers heat exchangers of different plate geometries and to evaluate and compare the thermal performance two quasi-counter flow plate heat exchangers. The key aims were to evaluate the effect of the surface geometry of the plates heat exchanger on the performance parameters specified in ANSI/ASHRAE Standard 84 and ANSI/AHRI Standard 1060 and narrow the gap of the limited experimental comparison of polymers sensible heat exchanger in cooling mode. The experiments were conducted on two polymer heat exchangers, one with a flat plate and the other with a dimpled surface plate.

The experimental results showed that the cooling capacity of the dimpled surface heat exchanger as ventilation heat recovery system in cooling mode was 50–60% better than that of the flat surface plate heat exchanger. In addition, the sensible efficiency of the dimpled surface heat exchanger was higher than that of the flat surface plates heat exchanger at lower air velocities and higher air initial temperatures. The highest COP was 6.6 achieved with dimpled surface heat exchanger under primary air operating temperature of 32.6 °C.

Étude expérimentale sur les échangeurs de chaleur à contre-courant pour la ventilation avec récupération d’énergie en mode refroidissement

Mots-clés: Échangeur de chaleur; Ventilation avec récupération de chaleur; Efficacité énergétique; Expérimental

1. Introduction

Air conditioning systems are responsible for significant energy consumption in buildings. HVAC systems take up to 40% of the total energy consumption in office buildings in Australia, with an annual average consumption of about 412 MJ/m^2 (Lecamwasam et al., 2012). The building ventilation required to maintain the building indoor air quality usually accompanied by additional cooling or heating load (Nguyen et al., 2005). The cooling loads are expected to increase due to the climate change, which will lead to increasing the load on the grid. Therefore, serious actions on increasing the system efficiency or developing economic cycles are required to address the sustainability while meeting the increasing need of HVAC systems.

Air-to-air heat exchangers have played an important role in energy regeneration to reduce the energy consumption by using the energy wasted by the exhaust air in air conditioning systems. The fixed plate’s heat exchangers can efficiently replace the enthalpy wheel heat regeneration with shape flexibility and less operation cost (Chang et al., 2017). Air-to-air heat exchangers are classified into heat recovery ventilators (HRVs) and energy recovery ventilators (ERVs). HRVs are used for recovering the sensible heat only and ERVs for recovering both sensible heat and latent heat. The fixed-plate heat exchanger is one common unit used in HRVs and

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Nomenclature

b	gap between two plates [mm]
c_{pa}	specific heat of air [J/kg °C]
COP	coefficient of performance [Dimensionless]
db	dry-bulb
$eff._S$	sensible efficiency [%]
h	enthalpy of air [J/kg]
H	height of plate [mm]
HX	heat exchanger
l_{fg}	latent heat of vaporization of water [J/kg]
$\dot{m}$	air mass flow rate [kg/s]
N	number to plates
P	power [W]
Q	heat transfer rate [W]
RH	relative humidity [%]
t	temperature [°C]
v	air velocity [m/s]
w	moisture content of air [g/kg]
W	total width [mm]
Z	length of plate [mm]
Δx	plate thickness [mm]
Subscript	
1	inlet
2	outlet
p	primary air
s	secondary air
wb	wet-bulb

ERVs (O'Connor et al., 2016). In HRVs plates made of non-porous materials such as aluminium, steel or polymers are commonly used.

Cross, concurrent and counter-current flows are the most common flow arrangements of ERV's fixed plate heat exchangers. Among these three arrangements, the manufacturing process for the cross flow heat exchanger is the least complicated, and the counter flow heat exchanger has the best performance (Nasif et al., 2010). Munters presented the Thermo-Z® heat exchanger with a quasi-flow which was a combination of cross and counter flows (Munters 2017). The quasi flow heat exchanger integrated the high performance of the counter flow arrangement and the ease of manufacturing property of the cross-flow heat exchanger. The shape modified later to a hexagonal shape with apex angle at the entrance resulted in the reduction of air turbulence at the inlets and exits of the heat exchanger (Zhang, 2010).

Manz and Huber (2000) reported experimental and simulation results of a combined duct/heat exchanger with comprising multiple parallel ducts for recovering the exhaust air energy. The heat exchanger unit they investigated was made of aluminium and used for air transport and heat recovery. Its recovery efficiency was up to 70%. Chen et al. (2016) performed experiments on heat recovery ventilation systems in four modes, including dry air-to-air, and using an aluminium fixed plate heat exchanger in a cross-flow arrangement. They investigated the effect of condensation in the heat exchanger channels with high relative humidity (RH) in the secondary air stream. Their results showed that due to the significant latent heat, the HRV system acted as an indirect evaporative cooling system. Fernández-Seara et al. (2011) tested a polymer plate heat exchanger with a counter-flow arrangement for heat recovery ventilation. They investigated the fresh air pre-heating mode. Their results showed that heat exchanger efficiency varied with the temperature, relative humidity and airflow rate of the fresh air.

HRV systems can also be used in a hybrid mode with indirect evaporative cooling, direct evaporative cooling and heat pumps. Different HRVs have been developed, such as the Smartbox© by Smart faćade (CEPEZED 2017). A hybrid heat recovery system was experimentally investigated by Fucci et al. (2016). Their results showed a significant increase in the heat pump's COP when the heat pump was working in parallel with a counter-flow heat exchanger. They verified that applying the static heat recovery to preheat the fresh air reduced the power consumption of the heat pump.

The surface geometry of the heat exchanger plate can intensify the sensible efficiency in the heat exchanger plate, mainly due to the turbulence generated in airflows (Vera and Quintero, 2015). Increasing the surface area and improving the air distribution over the plate area can be achieved by changing the plate surface geometry to increase the heat transfer rate and the system efficiency (Vera and Quintero, 2015). However, strong turbulence may increase the pressure drop across the heat exchanger and reduce the overall system efficiency. Therefore, to optimize the performance of a heat exchanger, pressure drop must be considered. Nevertheless, the dimple arrangements and dimple pitch had a positive influence on the heat transfer rate (Vorayos et al., 2016). The CFD results showed that the dimpled surface of the heat exchanger resulted in 20% higher sensible efficiency than the flat surface did (Al-Zubaydi et al., 2016).

Reducing greenhouse gas emissions is a critical contemporary world issue. It may be the key point in a decision making analysis of different HVAC systems, not only from the environmental point of view, but from an economic viewpoint as well, especially after the carbon tax charges in many countries, including Australia, have been applied. An extra cost is thus added to the operating costs of HVAC systems depending on their reliance on conventional energy. By increasing the air conditioning system efficiency, the HRV systems can save a significant amount of energy consumption required in building thermal comfort, and this energy saving can be represented as a reduction in greenhouse gases emission (Mardiana-Idayu and Riffat, 2012).

The extensive literature review shows that there is a substantial need of research on understanding the quasi-counter flow HRV system in cooling mode. In sum and experimental studies are required to investigate the influence of the plate surface geometry on the HRV heat exchanger performance. An environmental study of the greenhouse gases reduction with the HRV system applications is an advance scope in the HVAC studies.

The aim of this study is to build the experimental research gap with extend analyses of laminar quasi-counter-flow fixed-plate heat exchangers and to measure the effect of small scale wall dimples. In particular, a new design of a longitudinal low amplitude dimples with specified arrangements. In this study, the effect of the surface geometry on the HRV system overall performance is experimentally investigated. Two polymer plates with different surface geometries, flat and dimpled, were tested under different operational conditions to compare the thermal performance.

2. Experimental apparatus

2.1. Heat exchangers tested

Two sensible polymer heat exchangers were tested in the present study. Fig. 1 shows the dimensions and surface geometries of the two heat exchangers. As shown in Fig. 1, the first heat exchanger (HX_1) is a one with parallel plates that have flat surface and seven cylindrical spacers (4 mm diameter) in each channel to maintain the space between the plates with minimum air turbulence. The second heat exchanger (HX_2) has a thermally formed PVC sheet in a hexagonal shape, with the surface geometry comprising multiple parallel rows of longitudinal dimples, upward and downward in sequence. The dimpled surface is aimed to generate