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Evaluation of defrosting methods for air-to-air heat/energy exchangers on energy consumption of ventilation

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HIGHLIGHTS

- Frosting degrades the energy recovery of heat/energy exchangers in cold climates.
- Average effectiveness of exchangers under frosting is experimentally tested.
- Cold weather has less impact on energy exchangers' performance than heat exchangers.
- Outdoor air preheating method performs better than bypassing method for defrosting.
- Colder city has higher reduction in energy recovery due to frosting.

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ABSTRACT

Energy consumption for ventilation is extensive in cold climates. Air-to-air heat/energy recovery is a well-known and effective method to reduce the energy consumption. However, frosting commonly occurs inside heat/energy exchangers in cold climates, which would significantly degrade the performance of the exchangers. Preheating the outdoor air and bypassing the outdoor airflow are two effective methods for frosting prevention or defrosting. In this study, the performance of two cross-flow heat/energy exchangers at frosting and defrosting periods are experimentally tested under different operating conditions and the values of frosting limit and defrosting time ratio are presented. As well, the effects of these two defrosting methods on energy consumption of ventilation in three cold cities (i.e. Saskatoon, Anchorage and Chicago) are evaluated. The results show the outdoor air preheating method performs better than the outdoor air bypassing method. In addition, the heat/energy recovery potential in Saskatoon undergoes the largest reduction under frosting, and the cold weather conditions have less impact on energy exchangers than heat exchangers for heat/energy recovery.

1. Introduction

Outdoor air ventilation is necessary for modern commercial and residential buildings in order to maintain acceptable indoor air quality and provide a healthy indoor environment for occupants. The required energy consumption for conditioning outdoor air is extensive, which accounts for 20–40% of the overall energy consumed by air-conditioning systems in buildings [1]. The ratio can be even higher in hot and humid climates or cold climates, due to larger difference between outdoor and indoor air conditions. Air-to-air heat/energy recovery is a well-known and effective method to improve energy efficiency of air-conditioning systems because the heat/energy exchangers can precondition outdoor air through transferring heat (or moisture) between outdoor supply air and indoor exhaust air [2–6]. Besant and Simonson [2] reported that the annual energy consumption can be reduced between 31% and 64% by using an energy wheel and a heat wheel in a Chicago building air-conditioning system. Rasouli et al. [4] found that a run-around membrane energy exchanger (*RAMEE*) provided up to 40% annual heating energy saving and up to 20% annual cooling energy saving in an office building, depending on the climate and exchanger effectiveness. Moreover, the air-to-air heat/energy exchangers can significantly downsize the heating/cooling equipment, such as boilers and chillers, in new buildings [2,3].

Frosting is a significant challenge for the heat/energy exchangers when they are used in cold climates. Frost may form in the

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Nomenclature

c_P	specific heat capacity (kJ/kg K)
DTR	defrosting time ratio
h	enthalpy (kJ/kg)
m	mass flow rate (kg/s)
Q	heat or energy (kJ)
RH	relative humidity (%)
T	temperature (°C)
t	time (h)
W	humidity ratio (kg/kg)

Greek letters

ε	effectiveness

Subscripts

air	air flow
aux	auxiliary
avg	average
DF	defrosting
F	frosting
frost	frosting limit
EI	exhaust inlet/indoor
SI	supply inlet/outdoor
rh	re-heater
rec	recovered
Sup	supply to indoor
s	sensible
t	total

Superscripts

$'$	properties under preheating method
$''$	properties under bypassing method

exhaust air side of heat/energy exchangers if the exchanger surface temperature is lower than both the air dew-point and the freezing temperature [7]. The frosting would partially or fully block the air flow channels [8], increase the pressure drop [9,10], decrease the air flow rate [9], degrade the heat/energy recovery effectiveness [11], and decrease the total heat (or moisture) transfer rate [7,9]. If frosting occurs in exchangers for a long period, using the exchangers for energy recovery would be not economical and the frost may damage the exchangers. The frosting formations in heat/energy exchangers strongly depend on some factors, i.e. the outdoor air temperature, exhaust air humidity ratio and the type of exchanger (sensible heat only or energy recovery). Generally, the frosting limit (the lowest outdoor air temperature which does not lead to frosting in the exchanger) of energy exchangers is 5–15 K lower than of typical heat exchangers [7,12,13].

In order to maintain high energy recovery effectiveness and minimize the reduction of total recovered energy by heat/energy exchangers, numerous frost protection techniques and defrosting methods for the air-to-air heat/energy exchangers have been proposed and investigated over the past 30 years [7,9,11,14–16]. Preheating the outdoor air, bypassing the outdoor airflow, reducing the supply airflow rate, recirculating warm exhaust air, reducing the effectiveness of the exchanger, etc. are effective methods to protect exchangers against frost or remove frost (defrost) [7,11]. Phillips et al. [14] compared different frost protection strategies for counter-flow heat recovery ventilators under different climatic conditions, and found that outdoor air preheating strategy achieved lower heat recovery rate, since preheating reduced the heat available for recovery.

In general, using energy recovery ventilators (*ERV*), such as energy wheels or membrane based energy exchangers, instead of heat recovery ventilators (*HRV*) will reduce risk of frosting in the exchanger core. However, if the temperature of outdoor air goes very low the energy exchangers will experience frosting as well. Most of the open literature focused on the study of frosting limit and changes in effectiveness due to frosting in heat/energy exchangers. However, little has been conducted to investigate the energy performance of exchangers under frosting and defrosting conditions, especially for the energy (both sensible heat and moisture) exchangers. The recovered energy by exchangers and required energy consumption for ventilation strongly depend on the defrosting methods and operating conditions. In this study, the performance of two air-to-air cross-flow heat/energy exchangers at frosting and defrosting periods are experimentally tested under different operating conditions (i.e. different outdoor air temperatures) and the values of frosting limit and defrosting time ratio (*DTR*) are presented. Moreover, the influences of two simple and widely used defrosting methods, preheating the outdoor supply air and bypassing the supply airflow, for the heat/energy exchangers on energy consumption of ventilation in three cold cities (i.e. Saskatoon, Anchorage and Chicago) are evaluated.

2. Defrosting methods

2.1. Preheating the outdoor supply air

A common frost-protection technique for heat/energy exchangers is to preheat the outdoor supply air above the frosting limit before the air enters to the exchangers' cores (Fig. 1). When the outdoor air temperature goes below the frosting limit, the heating elements are activated. Preheating the cold outdoor air consumes auxiliary energy (i.e. electricity or gas), but the exchangers' operation is not interrupted by the frost-prevention system. The actual effectiveness of heat/energy exchangers is essentially equal to the nominal effectiveness without frosting.

2.2. Bypassing the outdoor airflow

Another common method to defrost the exchangers is bypassing the outdoor supply air periodically, as shown in Fig. 2. In general, this is accomplished by fully closing the supply airstream in

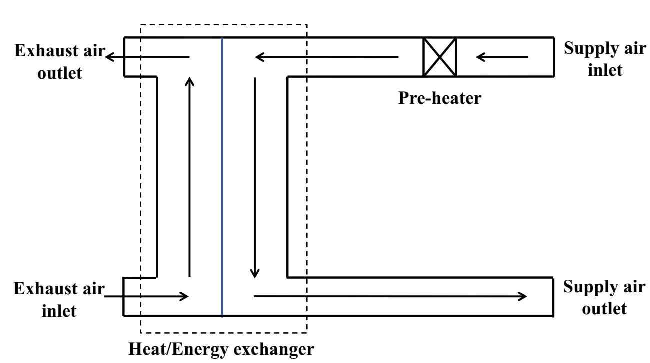

Fig. 1. The schematic of a heat/energy recovery system with preheating.