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Defrosting performances of a multi-split air source heat pump with phase change thermal storage

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ABSTRACT

Recently, multi-split air source heat pumps (ASHPs) have been used increasingly for space heating in cold winter. When it operates in frosting environment, periodic defrosting is necessary to maintain a high system performance. However, researches on its defrosting were few due to its high capital and complicated controls. To solve its fundamental problem of insufficient heat available during defrosting, a novel reverse-cycle defrosting (NRCD) method based on the phase change thermal storage has been developed. In this paper, comparative experiments using both standard reverse-cycle defrosting (SRCD) method and NRCD method were carried out on a multi-split ASHP unit with a phase change material heat exchanger (PCM-HE) acting as energy accumulator during heating operation and heat source during defrosting operation. Experimental results suggested that when using the NRCD method, the system performances, such as suction pressure and temperature, defrosting and heat-resumption durations, COP during defrosting operation can be effectively improved.

Capacités de dégivrage d'une pompe à chaleur aérothermique en multi-split avec accumulation thermique à changement de change

Mots clés : PAC aérothermique en multi-split ; Dégivrage ; Matériau à changement de phase ; Accumulation thermique

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Nomenclature

COP	coefficient of performance (–)
C_l	liquid specific heat of the PCM (W m^{-1} K^{-1})
C_S	solid specific heat of the PCM (W m^{-1} K^{-1})
DSC	differential scanning calorimetry (–)
EEV	electric expansion valve (–)
HPD	heat pump desiccant (–)
L_{PCM}	latent heat of the PCM (kJ kg^{-1})
L_{sf}	latent heat of fusion (kJ kg^{-1})
m_{PCM}	mass of the PCM (kg)
m_w	mass of the water from frost (kg)
Q	total energy consumption during defrosting (kJ)
Q_c	input power to the compressor (kJ)
Q_{HE}	energy supplied from the PCM-HE (kJ)
Q_L	latent heat supplied from the PCM (kJ)
Q_S	sensible heat supplied from the PCM (kJ)
T	melting point of the PCM (°C)
T_{max}	temperature of the PCM at the start of defrosting (°C)
T_{min}	temperature of the PCM at the end of defrosting (°C)
VRF	variable refrigerant flow (–)
w	energy consumption of the compressor (kW)
Greek letters	
η_{el}	electrical efficiency of the compressor (–)
Subscripts	
c	compressor
el	electrical
HE	heat exchanger
L	latent heat
l	liquid
max	maximum
min	minimum
S	sensible heat
s	solid
w	water

1. Introduction

As a kind of air source heat pump (ASHP), multi-split ASHP has been popular because it requires less outdoor plant space than conventional ASHP. The multi-split ASHP usually uses one external unit that is connected to several indoor units, and it is able to cool and heat through common pipework.

However, like small split-type ASHP unit, when a multi-split ASHP unit operates for space heating in winter, the frost will also form on its outdoor coil if the outdoor coil operates below freezing temperature. Furthermore, the accumulated frost reduces the quantity of airflow and acts as a thermal insulator, leading to deteriorated heating performance, lower energy efficiency and heating capacity, and even shutdown of the compressor (Jiang et al., 2000). Therefore, the frost needs to be removed periodically to keep its performance at a high level.

Currently, researches on defrosting performance of ASHPs were mainly targeted at small split-type ASHPs because of its low-cost experiment and wide applicability. Several defrosting methods for ASHPs have been reported, such as reverse-cycle defrosting (O'Neal et al., 1989), hot-gas bypass defrosting (Huang et al., 2009) and refrigerant charge compensation defrosting (Wang et al., 2008). Reverse cycle defrosting (RCD) is the most widely used method for ASHP units and almost all multi-split ASHP units adopt this method. However, it has many disadvantages including halfway defrosting, long defrosting duration and negative influence on indoor environment (Ding et al., 2004). To improve the effect of RCD, performances of different components, such as compressor (Payne and O'neal, 1995), throttle (O'Neal and Peterson, 1990) and fan (Huang et al., 2004), were studied by experiment and simulation. However, all these methods and improvement could not solve the fundamental problem of insufficient heat available during defrosting.

On the other hand, only a few studies on defrosting energy consumption were found in open literature. Niederer (Niderer, 1976) in 1976 defined defrosting efficiency and found out that only 15–25% of defrosting energy consumption was used for melting frost and vaporizing the melted frost, with the rest used for heating fin-tube and ambient air. Baxter (Baxter and Moyers, 1985) in 1985 measured the defrosting energy consumption for a high-efficiency ASHP installed in a single-family residence. The measured results indicated that defrosting power consumption accounted for 10.2% of the total power consumption of the ASHP during a heating season. Dong et al. (2012a,b) evaluated the defrosting heat supplies and energy consumptions during a RCD operation for a space heating ASHP unit. It was found that the heat supply from indoor air contributed to 71.8% of the total heat supply for defrosting and energy consumption for melting frost accounted for 59.4% of the total supplied energy.

Most previous studies on the multi-split ASHP were focused on its cooling mode, such as refrigeration performance (Xu et al., 2013; Park et al., 2001; Choi and Kim, 2003), compressor (Tu et al., 2011), refrigerant flow distribution (Lin and Yeh, 2009), and control method (Elliott and Rasmussen, 2013). However, few researches were concerned about the heating and frosting/defrosting performances due to the complexity and high experiment cost of the multi-split ASHP units. Aynur et al. (2010) integrated variable refrigerant flow (VRF) with heat pump desiccant (HPD) system and tested it in heating season. This novel system could provide moist air without additional ventilation loads. Tu et al. (2012), who theoretically analyzed and experimentally verified the disadvantage of the time-coil temperature determination criterion, built the defrosting criterion model of time-coil temperature-condensation temperature. New criterion could avoid delayed and premature defrosting, even false and inaccessible defrosting.

Currently, studies on heating and defrosting performances of the multi-split ASHPs are few. Obviously the severe problems of frosting/defrosting still exist in heating process of the multi-split ASHPs, which has a significant impact on overall heating performance of the units. Since the structure of the multi-split ASHPs differs from that of small split-type ASHPs, such as the structure of the outdoor unit, defrosting control methods and the distribution of indoor units, the defrosting process in the multi-split ASHPs is different from that in