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Field test study of a novel defrosting control method for air-source heat pumps by applying tube encircled photoelectric sensors

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ABSTRACT

To improve the defrosting accuracy of air source heat pumps (ASHPs), this paper proposes a novel defrosting control method by applying tube encircled photoelectric sensors (TEPSs). A field test was conducted for two heating seasons in Beijing, China, to verify the feasibility and practicality of the novel TEPS method. The test results revealed that irrespective of the environmental conditions, the TEPS method can initiate defrosting in similar situations: most of the heat exchanger surface had been covered by frost; the compressor suction temperature decreased by ~9 °C; the compressor discharge temperature increased by ~16 °C; and the heating capacity decreased by ~30%. Furthermore, the TEPS method was verified to make more accurate and more reasonable defrosting decisions than the traditional T-T method under both frosting and non-frosting conditions. The results indicate that the TEPS method is a competitive defrosting control method that can be used for ASHPs.

Étude par essai sur le terrain d'une nouvelle méthode de régulation du dégivrage pour des pompes à chaleur aérothermiques en appliquant des capteurs photoélectriques encerclés de tubes

Mots clés : Pompe à chaleur aérothermique ; Régulation du dégivrage ; TEPS ; Essai sur le terrain

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Nomenclature

F	flow [$m^3 s^{-1}$]
M	mass [kg]
Q	heating capacity [W]
T	temperature [°C]
t	time [min]
U	normalized output of TEPS
V	output voltage [V]
W	wasted work [J]
ΔT	temperature difference [°C]
$\Delta\eta$	loss of heating capacity [%]
φ	relative humidity [%]

Subscript

a	air
c	outdoor coil
df	defrosting
dfw	defrosting water
di	defrosting interval
dis	discharge
suc	suction

1. Introduction

Air-source heat pumps (ASHPs) have been used widely around the world as the heating and cooling equipment of buildings, owing to their merits of energy-saving and environmental protection (Mohanraj et al., 2012; Wang et al., 2005). However, there are still some problems to be solved. One of the main problems is the evaporator frosting problem in winter. Once the surface temperature of outdoor heat exchanger is below both the air dew point temperature and the water freezing temperature (Dong et al., 2012), frost will inevitably occur on the ASHP outdoor heat exchanger. The growth of frost can seriously affect the performance of the unit and even result in physical damage (Kondepudi and O'Neal, 1990; Yang et al., 2006). When the outdoor heat exchanger surface is covered with frost, the coefficient of performance (COP) of an ASHP unit can decrease by 35–60%, and the heating capacity can decrease by 30–57% (Brian et al., 1970; Guo et al., 2008; Sanders, 1972; Wang et al., 2013a). Therefore, frost must be removed from the outdoor heat exchanger surface of ASHPs.

The most common way of defrosting is to reverse the refrigerant cycle (Dong et al., 2012), which will also cause energy consumption, and affect the comfort of the indoor environment. Accurate defrosting is very important for ASHPs, to ensure their good performance and minimize the adverse impacts of defrosting. The ideal control method is to conduct defrosting operations based on demand. However, it is hard to monitor the degree of frosting on the outdoor heat exchanger surface directly, which means inaccurate defrosting is still a difficult problem. Many defrosting control methods have been investigated, based on some indirect factors – such as the surface temperature of outdoor coil and heating operation time (T-T), air pressure difference, refrigerant superheat degree, fan power (Lawrence and Evans, 2008; Liang et al., 2010; Llewelyn, 1984; Tassou et al., 2001; Thybo et al., 2002; Woodley, 1989), etc. Although these factors can reflect the degree of frosting to some extent, the actual degree of frosting is hard to forecast accurately under different environmental conditions, because frosting is a complex process with dynamic heat and mass transfer (Wang et al., 2012). In practical applications, while in practice defrosting is often initiated improperly, sometimes when a "critical" level of frosting has been reached for a long time, and sometimes when no frost has occurred on the outdoor heat exchanger surface. This phenomenon is defined as mal-defrosting (Wang et al., 2011). Baxter and Mogers (1985) found that in a T-T controlled ASHP unit, approximately 27% of defrosting was carried out when no frost was observed, and Feng (2013) found that nearly 68% of defrosting was unnecessary in a heating season in Beijing, China.

To improve the defrosting accuracy, some researchers have tried to develop a direct method of measuring the degree of frosting. Several methods have been used in the laboratory, such as microscope (Liu et al., 2006a, 2006b; Wang et al., 2012), low energy laser beam (Besant et al., 1990), micrometer (Fossa and Tanda, 2002; Lee and Ro, 2001) and infrared camera (Fuller and Wisniewski, 1998), but none of these has gained widespread acceptance in practical application owing to their unsuitable size or high cost. There is a serious need for a more accurate and practicable defrosting control method. More recently, photoelectric technology has been found to be suitable for detecting the frosting process and a series of related studies has been carried out. In the study by Byun et al. (2006), a laboratory test was conducted to investigate reliability and effectiveness by using photocoupler to detect frost formation. In the work by Xiao et al. (2009), two agreeable properties of the photoelectric technology, "on–off" and "linear", have been demonstrated by experiments. Xiao et al. (2010) further revealed that the output voltage of the photoelectric sensor has a strong correspondence with the frost height, owing to the "linear" properties. Subsequently, Wang et al. (2013b) proposed an innovative Tube Encircled Photoelectric Sensor (TEPS), and confirmed that it has the expected potential to control the defrosting process. Although TEPS has the advantages of small size, low cost and sensitivity to the degree of frosting, it was only tested on an ASHP unit in a climate chamber. To promote the application of TEPS and improve the defrosting accuracy, TEPS should be applied in the defrosting control of ASHP, and should be examined in real ASHP units under various environmental conditions to validate its feasibility and applicability.

In this paper, a novel defrosting control method based on TEPS is proposed and TEPS is used for ASHP defrosting control for the first time. A field test was conducted during the 2012–2014 heating seasons in Beijing, China. Test results revealed that the TEPS method can make accurate and stable defrosting decisions, and exhibits great superiority over the T-T method. Therefore, the novel TEPS defrosting control method is a promising alternative defrosting control method for the ASHP.