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Review on improvement for air source heat pump units during frosting and defrosting

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HIGHLIGHTS

- Frost retarding and defrosting studies published in 2000–2017 are reviewed.
- Two types of 12 frost retarding measures are classified and analyzed.
- 5 defrosting methods and 6 improvement methods are summarized.
- Initiation and termination control strategies of defrosting operation are presented.
- The existing gaps in the research works are identified and classified as 5 aspects.

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ABSTRACT

Air source heat pump (ASHP) units have found worldwide applications due to their advantages of high energy efficient and environmental friendly. Frost deposition and accumulation on the surface of the outdoor coil in an ASHP unit is inevitable and always play significant negative effects. To accurately predict and control a frosting-defrosting cycle, the interrelated heat, mass, and momentum transport phenomena within frost, melted frost and at the air-frost interface, a moving boundary condition, should be clearly understood. This review paper focuses on the developments in frost retarding and defrosting investigations for ASHP units from 2000 to 2017. 12 frost retarding measures and 5 defrosting methods are firstly introduced, followed by 6 typical system optimization methods during reverse cycle defrosting. Alternative control strategies to start and end a defrosting operation are thereby presented. Basing on previous analysis, the existing gaps in the research works on frost retarding and defrosting are identified, and recommendations are finally offered as per the viewpoint of the present authors. This comprehensive and systematic review around an entire frosting-defrosting cycle might provide an overview of the analytical tools for scholars, researchers, product developers, and policy makers, and shed new light on the designing and performance optimization of ASHP units.

1. Introduction

A heat pump unit is an environmentally friendly and reliable means to maintain thermal comfort level in an indoor space, and can be used for both space heating and cooling at a high operating efficiency. During a cooling season, it transfers heat from the indoor space to a heat sink, in the same way as an air conditioner does. During a heating season, it extracts heat from a heat source, and delivers the extracted thermal energy to a heated indoor space. From a global point of view, over 90% of the world population resides in the regions where heat pump units can be suitably used for indoor environmental control [1–3]. Compared with traditional space heating and/or heat generation method using coal or electric, studies have shown the potentials of using heat pump units to drastically reduce greenhouse gases, in particular CO_2 emissions. With the rising unit cost of energy being at the forefront of world attention, there has been a growing interest in using

Abbreviations: ASHP, Air source heat pump; COP, Coefficient of performance; CSDD, Compressor shutdown defrosting; DEV, Defrosting evenness value; EHD, Electric heating defrosting; FEV, Frosting evenness value; HGBD, Hot gas bypass defrosting; HWSD, Hot water spraying defrosting; PCM, Phase change material; RCD, Reverse cycle defrosting; RH, Relative humidity; TES, Thermal energy storage; TEV, Thermal expansion valve

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heat pump technology as an energy saving means.

A number of heat sources are available for space heating heat pump units, such as air, underground water, and soil [4]. Among these heat sources, air and water are the mostly common ones for space heating heat pump units [5]. Therefore, air to air heat pump units, air to water heat pump units, water to air heat pump units, water to water heat pump units are commonly applied in buildings or industry. Among them, air source heat pump (ASHP) units are relatively easy and inexpensive to install, and have therefore been the most widely used types of heat pump units for many years. Under the principles of vapor compression refrigeration, an ASHP unit uses a refrigerant system involving a compressor and a condenser to absorb heat at one place and release it at another.

Heat pump technology originated from the Carnot cycle, which was presented by Carnot in 1824. It is quite mature due to its long history, nearly 200 years. When an ASHP unit works at heating mode in winter, at the ambient air temperature of −7 to 5 °C and relative humidity (RH) higher than 65%, frost always forms on the surface of its outdoor coil [6]. The accumulated frost increases both heat transfer resistance and air flow passage resistance during heating operation, and thus adversely degrade the system performance, or even result in an undesired shutdown. Then, extensive experimental and theoretical investigations have been carried out on ASHP units to study their operating performances under frosting and/or defrosting conditions. Studies on this topic become very popular in recent years, which also results from the air pollution in winter and the corresponding governmental policy, such as the *Coal to Electricity* in China. Although some review articles published around topics of domestic heat pump [7,8], air-to-air heat exchangers [9–11], restraint frost methods [12], and defrosting methods [13,14], no one including frost retarding, defrosting, and control strategy for ASHP units is given. Additionally, aforementioned articles mainly focus on studies published before 2010. However, a large number of research articles have been published in the past several years. Therefore, to provide an overview of the analytical tools for scholars, researchers, product developers, and policy makers, a comprehensive and systematic analysis of the available literatures from 2000 to 2017 around frosting/defrosting studies for ASHP units are presented in this paper.

Roadmap of the present review work is shown in Fig. 1. A review of studies on frost retarding measures for ASHP units is firstly reported, covering changing ambient air parameters at outdoor coil inlet, optimizing the structure of an outdoor coil, as well as other frost retarding measures. This is followed by reviewing the previous related studies on various defrosting methods for ASHP units, especially the experimental and theoretical studies on system operation optimization during reverse cycle defrosting. Reviews on control strategies to start and end a defrosting operation for an ASHP unit during defrosting are included. Finally, issues where further extensive research work in achieve a better frosting/defrosting performance for ASHP units are identified.

2. Frost retarding measures for ASHP units

As discussed, frost formation and accumulation on the surface of outdoor coil in an ASHP unit is an undesirable phenomenon. Frosting duration accounts more than 80% of operation time in a frosting-defrosting cycle, and thus frost retarding measure exploration play important roles in optimization of ASHP units. To improve their operating performance, frost retarding measures attract more and more attention. Previous studies on developing frost retarding measures are classified and summarized into two types, outside of system type shown in Fig. 2(a), and inside of system type shown in Fig. 2(b).

2.1. Changing ambient air parameters at outdoor coil inlet

It is easy to understand that frost formation on the surface of outdoor coil of an ASHP unit is closely related to the ambient air conditions, at which the ASHP unit is operated, such as air temperature, RH, and airflow rate, etc. Consequently, many scholars devoted themselves to changing ambient air parameters at outdoor coli inlet of an ASHP unit, with the influence of these parameters on frost retarding quantitatively investigated. These outside of system type studies are meaningful for accurately controlling the operating performance of an ASHP unit at a fixed climate environment.

2.1.1. Reducing inlet air humidity

Since water is the source of frost, researchers firstly investigated the relationship of frosting performance and reducing inlet air humidity [6], demonstrating the leading role of inlet air humidity among these parameters. Meanwhile, the use of desiccant significantly reduced frost formation rate was experimentally investigated on an ASHP unit, with and without solid desiccant placed before inlet air [15]. Also using solid desiccant, a novel frost-free ASHP unit was presented, and its frost retarding characteristics were experimentally and numerically investigated [16–18]. Using this method, not only air humidity was reduced, but also air temperature increased by absorbing the heat from

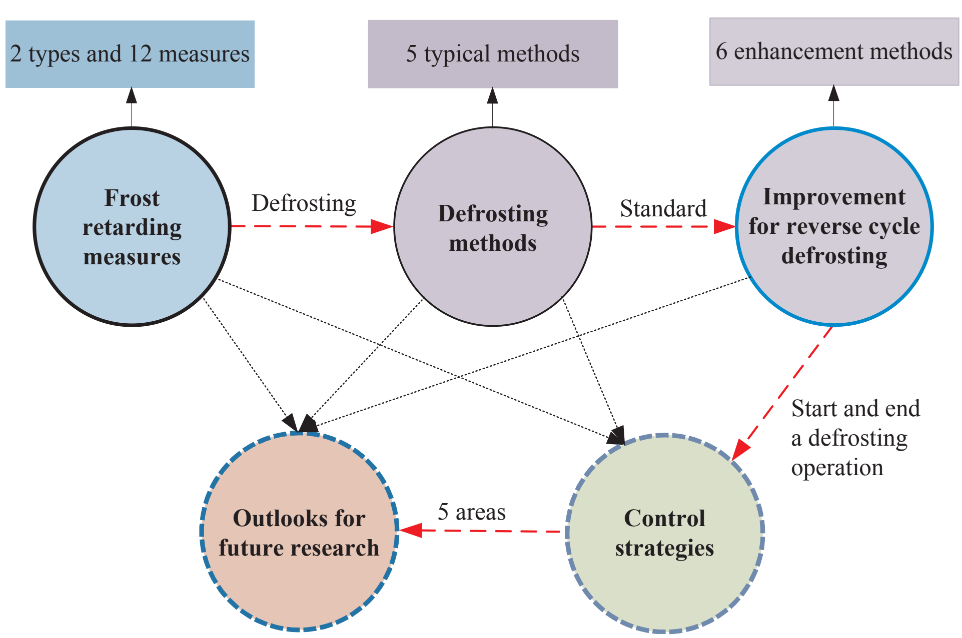

Fig. 1. Roadmap of the present review work.