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Research Paper

An experimental study on defrosting performance of an air source heat pump unit with a multi-circuit outdoor coil at different frosting evenness values

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HIGHLIGHTS

- A special experimental rig was built and its details are reported.
- Defrosting at different FEVs (82.6%, 90.6% and 96.6%) was comparatively studied.
- Uneven frosting accumulation has negative effects on defrosting performance.
- Defrosting performance improved 6.8% when FEV increased from 82.6% to 96.6%.

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ABSTRACT

For an air source heat pump (ASHP) unit with a vertically installed multi-circuit outdoor coil, it is rarely possible to make the frost accumulations on each circuit's surface equal, leading to different frosting evenness values (FEVs) as a reverse cycle defrosting operation starts. On the other hand, uneven defrosting phenomenon was found and reported as many methods were developed to improve defrosting performance of ASHP systems, which may be attributable to the reverse cycle defrosting starting at an uneven frosting. Understanding of defrosting performance of an ASHP unit with a multi-circuit outdoor coil at different FEVs is of importance for ASHP units' application, but studies are scarce in the open literatures. In this paper, we report an experimental study on defrosting performance when frost accumulated on the surface of outdoor coil at different FEVs. This paper presents details of an experimental ASHP unit and the experimental conditions, followed by results, and conclusions. Finally, an increase of 6.8% in defrosting efficiency was confirmed when the FEV changed from 82.6% to 96.6%.

1. Introduction

Air source heat pump (ASHP) units have being widely used as cooling and heating sources for heating, ventilation and air conditioning installations in many parts of the world because of their advantages such as energy saving, environmental protection and flexibility [1]. However, it is difficult to avoid frost formation and accumulation on its surface of outdoor coil when the ASHP unit works at heating mode in winter with high humidity and low air temperature [2,3]. The frost layer would raise heat transfer resistance and consequently reduce the heat transfer rate between the outdoor coil and humidity surrounding air [4,5]. The frost layer can also reduce airflow passages and thus increase the air-side pressure drop [2,6], degrade system heating/frosting performance and even result in a shutdown of the ASHP unit [7,8]. Therefore, periodic defrosting is necessary.

Defrosting could be realized by a number of methods including: (1) compressor shut-down defrosting [9], (2) electric heating defrosting [10–12], (3) hot water spray defrosting [13], and (4) hot gas by-pass defrosting [6,14–17]. Currently, reverse cycle defrosting is the most widely used standard defrosting method [1,3,5,17–26]. When a space heating ASHP unit is operated at a reverse cycle defrosting mode, its outdoor coil acts as a condenser and its indoor coil acts as an evaporator. During a defrosting process, not only a great deal of energy is consumed for melting frost and vaporizing the retained melted frost off the outdoor coil surface, but also the occupants' thermal comfort may be adversely affected because no heating is provided during defrosting [26]. Therefore, shortening a

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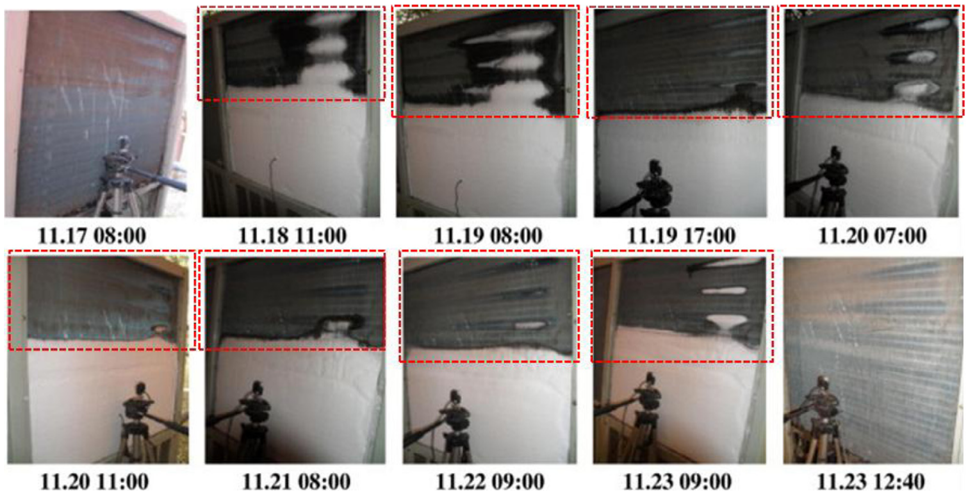

Fig. 1. Airside surface conditions of the outdoor coil at frosting process (fig. 4 in Wang et al.'s paper) [22]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

defrosting period should be one of the control purposes for ASHP units. For example, Chinese Standard GB/T 7725-2004 specifies that the defrosting duration for an ASHP unit should not exceed 20% of its total working hours [24].

On the other hand, for an outdoor coil used in an ASHP unit, on its refrigerant side, multiple parallel circuits are commonly used for minimized refrigerant pressure loss and enhanced heat transfer efficiency [1–6,12,14–18,21–31]. Furthermore, for an ASHP unit having a multi-circuit outdoor coil, uneven defrosting was found and reported in several previous experimental studies [1,5,16,18,19,24,25]. This phenomenon means different circuits' defrosting processes terminated (refrigerant temperature at exit of circuit reached 24 °C) at different times. O'Neal et al. [5] and Qu et al. [18] both investigated the transient defrosting performances of ASHP units, each with a vertically installed four-parallel refrigerant circuits outdoor coil. It was reported that when a defrosting process was terminated, the surface temperature at the exit of the lowest circuit was much lower than that at the exit of the highest circuit. Similar uneven defrosting phenomena can also be seen in the experimental study on an outdoor coil having six rows and fourteen circuits during hot gas by-pass defrosting conducted by Stoecker and Lux [16]. In the study by Wang et al. [19], it was shown that for a seven-circuit outdoor coil, at 6 min into defrosting, the surfaces of down refrigerant circuit(s), which accounted for almost 1/4 of the entire surface area, were still covered by frost while that of up circuits were already free of frost.

However, for a multi-circuit outdoor coil in an ASHP unit, uneven defrosting might be the result of an uneven frosting start, which means the frost accumulations on each circuit's surface of a multi-circuit outdoor coil in an ASHP unit were different. In this paper, the same as previous studies [20,21,24,25], frosting evenness value (FEV) was defined as the ratio of the minimum frost accumulation among three circuits to the maximum one, and could be calculated by the melted frost collected from each water collecting cylinders, with the water vaporized into the ambient air neglected. The outcomes from previous studies [2,29–31] demonstrated that the FEV on an outdoor coil surface is decided by the distribution of inlet air passing through each circuit, distribution of refrigerant flowing into each circuit, structure of the outdoor coil, fin space, type, and its surface characteristics, and so on. Therefore, it is hardly possible to make the frost accumulations on each circuit's surface equal, leading to different FEVs as a reverse cycle defrosting operation starts for an ASHP unit. For example, as shown in Fig. 1 [22], the frost accumulated on the downside was obvious much more than that on the upside, as marked in the red dotted block, during frosting process. Similar uneven frosting phenomena could also be found in Figs. 2 and 3 [18,23]. At the start of reverse cycle defrosting operations, in the region marked with red dotted block, only a few frost accumulated on the surface of outdoor coil.

Furthermore, for an uneven defrosting operation, the most important possibility is the reverse cycle defrosting starts at an uneven frosting. At the same time, as the start of a defrosting process, FEV would affect the heat transfer between frost, melted frost, ambient air and the refrigerant. And thus the FEV affect the defrosting performance of the whole system. This is a fundamental and meaningful problem for ASHP units with multi-circuit outdoor coils. Understanding of the defrosting performance of an ASHP unit with a multi-

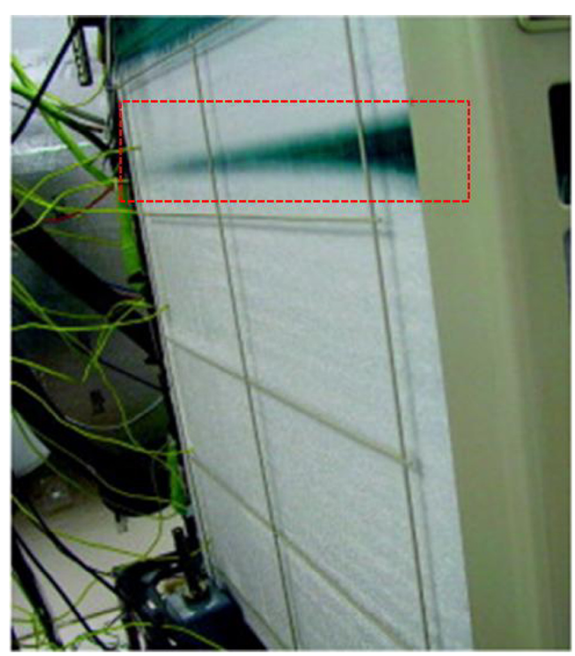

Fig. 2. Airside surface conditions of the outdoor coil at the start of reverse cycle defrosting (fig. 4 in Qu et al.'s paper) [18]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)