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An experimental study on defrosting performance for an air source heat pump unit with a horizontally installed multi-circuit outdoor coil

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HIGHLIGHTS

- Negative effects due to gravity eliminated when outdoor coil horizontally installed.
- Defrosting efficiency increased 9.8% after outdoor coil horizontally installed.
- Defrosting efficiency decreased 6.6% when air fan reversed to blow the melted frost.
- Total mass of the retained water collected decreased 222 g less after wind blowing.
- Higher DEV respected better defrosting performance for multi-circuit outdoor coils.

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ABSTRACT

When frost forms and accumulates over the outdoor coil's surface in an air source heat pump (ASHP) unit, system operating performance will be dramatically deteriorated. Reverse cycle defrosting is the most widely used standard defrosting method. A previous related study reported that downwards flowing of melted frost due to gravity over a vertical multi-circuit outdoor coil would decrease the reverse cycle defrosting performance. If the outdoor coil can be changed to horizontally installed, the flow path of melted frost over coil surface can be shortened, and the flow directions of refrigerant and melted frost changed from opposite to orthogonal. Consequently, a better defrosting performance is expected. In this paper, therefore, an experimental study on defrosting performance for an ASHP unit with a horizontally installed multi-circuit outdoor coil was conducted. Experimental results show that, when a vertical outdoor coil was changed to horizontally installed, the defrosting efficiency increased 9.8%, however, with the same defrosting duration at 186 s. Furthermore, when the outdoor air fan was reversed to blowing the melted frost during defrosting, the total mass of the retained water collected decreased 222 g. However, the defrosting efficiency was not increased, but decreased 6.6% because of the heat transfer enhanced between hot coil and cold ambient air.

1. Introduction

As the worldwide electricity demand and price growing [1–3], environmental aspects represent a large concern and heavily influence the global energy policy, such as global warming, ozone layer depletion and high-levels of pollution, especially the PM 2.5 air pollution in Beijing in China. It is necessary to emphasize the use of emerging and well-known renewable energy, and different energy conservation approaches. Air source heat pump (ASHP) unit, utilizing low grade energy in the air as sources, has advantages of simple operation, high efficiency, no pollution, ability of both cooling and heating, etc. [4]. Accordingly, as a key type technology under clean development mechanism (CDM) to mitigate the climate change and avoid global warming [5], it becomes widely used as cooling and heating sources for heating, ventilation and air conditioning over the recent decades [6]. However, on its heating mode of an ASHP unit under extremely cold and high humidity environment, unexpected frost would appear and accumulate over the outdoor coil's airside surface, which severely deteriorates system operating performance. Therefore, it is necessary to implement periodical defrosting to maintain its normal operation.

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Currently, there are many defrosting methods investigated for ASHP units, such as (1) compressor shut-down defrosting [7], (2) electric heating defrosting [8], (3) hot water spray defrosting [9], (4) ultrasonic vibration defrosting [10], (5) air-particle jet defrosting [11], and (6) hot gas by-pass defrosting [12], among which the most widely used standard defrosting method is reverse cycle defrosting [13]. When an ASHP unit is operated at a reverse cycle defrosting mode, its outdoor coil which is usually installed vertically for floor space saving, acts as a condenser and its indoor coil as an evaporator. On the other hand, in order to minimize the refrigerant pressure loss along the tube inside and enhance the heat transfer between the inside refrigerant and outside ambient air via tube and fins, multi-circuit outdoor coil is usually used in ASHP units. The downwards flowing melted frost helps form or reinforces a water layer between the frost and the coil surface, which introduces a thermal resistance [14], and thus reduces the heat transfer between the two [15]. It is reported that when defrosting at the top circuits is terminated, the bottom ones are still covered with frost [16]. Also, when the tube surface temperature at exit of the top circuit reaches the pre-set defrosting termination temperature, the temperature of the bottom circuit is much lower [17–20]. Thereafter, the negative effects of downwards flowing melted frost due to gravity are demonstrated by authors [17–19], with water collecting trays installed between circuits to improve defrosting efficiency [17,18].

On identification of the negative effects of downwards flowing melted frost, traditional vertical multi-circuit outdoor coil is also suggested to be installed horizontally to reduce the flow path of melted frost during defrosting [21]. As shown in Fig. 1(a) and (b), when the vertically installed three-circuit outdoor coil [18] is horizontally installed, the maximum flow path of melted frost over coil surface can be shortened from 500 mm to 44 mm, being reduced 11.36 times. As illustrated in Fig. 1(c) and (d), the flow directions of hot refrigerant and cold melted frost during defrosting are also changed from opposite to orthogonal, which effectively shortened their heat transfer length. Consequently, a better defrosting performance is expected. However, it is found that there was some melted frost remained on the downside of each circuit due to surface tension during defrosting in the previous experimental studies [17–19]. From the definition of surface tension [22], it is concluded that the total mass of retained water is directly proportional to the total area of circuit downsides. During defrosting, the retained water would consume energy [23], and thus delay the defrosting process. As shown in Fig. 1(e) and (f), when the installation type of the three-circuit outdoor coil is changed, the total area of retained water is increased, from 590 mm × 44 mm to 590 mm × 500 mm, being increased 11.36 times. Therefore, it is contradictory for the maximum flow path of melted frost and the total area of remained water on improving system defrosting performance.

On the other hand, although horizontal heat exchangers are reported by many studies [9,24–29], few of them are related to a coiled heat exchanger. Most of them are horizontal ground heat exchangers [25,26], tube heat exchangers [27,28], or flat-panel heat exchangers [9,29]. Notably, Abdel-Wahed et al. experimentally studied a horizontal flat plated cooling surface. Their results indicate that the decrease in the thickness of frost layer is approximately linear with defrosting time [9]. However, it is not reverse cycle defrosting, but hot water defrosting. Later, Hambraeus et al. carried out an experimental setup with a horizontal evaporator to study the heat transfer of a special refrigerant, with the effects of melted frost neglected [30]. In 2012, an experimental study on comparison of heat transfer and pressure drop in a horizontal and vertical helically coiled heat exchanger with CuO/water based nano fluids was reported, in which, convective heat transfer coefficient and friction factors are comparatively studied. However, their heat transfer performance on the airside was also neglected [24].

Therefore, in this paper, to solve the previous contradictory problem and explore the heat transfer performance of a horizontally installed heat exchanger, an experimental study on reverse cycle defrosting performance for an ASHP unit with a horizontal multi-circuit outdoor coil has been carried out. Firstly, the ASHP unit under experiments is presented, followed by the experimental procedures and conditions. Thereafter, the experimental cases and their results are given. The defrosting durations and energy consumptions for each case study are measured and discussed, with a conclusion given at the end.

2. Experimentation

2.1. Experimental ASHP unit

An experimental ASHP unit was specifically established for carrying out the experimental work reported in this paper. It was modified from a commercially available 6.5 kW heating-capacity variable speed ASHP unit and was installed in an existing environmental chamber having a simulated indoor heated space and a simulated outdoor frosting space. The sizes of both indoor and outdoor spaces were each measured at 3.8 m (L) × 3.8 m (W) × 2.8 m (H). Fig. 2 shows the schematics of the ASHP unit installed in the environmental chamber. The experimental ASHP unit was a split-type one consisting of a swing type compressor, an accumulator, a four-way valve, an electronic expansion valve, an indoor coil and an outdoor coil.

The outdoor coil was specially designed and made for this study, as shown in Fig. 3. There were three individual and parallel refrigerant circuits and the airside surface areas corresponding to each of the three circuits were equal. There were four wind boards installed on the two air sides of the outdoor coil, which were used to prevent the air passing the outdoor coil through separations between circuits. The outdoor coil was horizontally installed, and in each circuit a solenoid valve (SV) and a manual stop valve (MV) were fixed on, with their locations shown in Fig. 3. In order to easily describe the process of frost melting, the topside and downside of the primary vertically installed three-circuit outdoor coil were named as Side A and Side B, as shown in Figs. 1 and 3. Side C was the inlet air side of the outdoor coil, where the frost will be formed and accumulated.

A 700 mm × 750 mm water collecting tray made of PVC placed under the outdoor coil was added to the experiment rig, and a 2000 mL water collecting cylinder made of PVC was connected to the tray. Both of them would be used for collecting and measuring the melted frost. At the same time, in the experiments, the retained water on the surface of fins, especially on the downside of each circuit, was absorbed by pre-weighed cotton tissues. In this way, the melted frost from the outdoor coil during defrosting was collected and weighed. The specifications of the three-parallel refrigerant circuit outdoor coil are shown in Table 1.

As shown in Fig. 4, there was a separate air conditioning system in the environmental chamber, and sensible and latent load generating units (LGUs) which were used to simulate thermal load, so that suitable experimental conditions in both indoor and outdoor spaces may be maintained. During normal heating (frosting) operation, a frosting environment in the outdoor space was maintained by running the experimental ASHP unit and LGUs together, while an indoor heated environment by the experimental ASHP unit and the existing air conditioning system.

Fig. 5 shows the airside details of outdoor coil in the experimental ASHP unit installed in the outdoor frosting space. On the windward side (Side C in Figs. 1, 3 and 5), air dry-bulb temperatures were measured at 6 points using thermocouples (Type K, of ±0.75% accuracy) and air wet-bulb temperatures at 3 points using temperature sensors (PT100, class A). In this way, there were 2 dry-bulb temper-