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An experimental study on the effects of downwards flowing of melted frost over a vertical multi-circuit outdoor coil in an air source heat pump on defrosting performance during reverse cycle defrosting

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HIGHLIGHTS

- A special experimental rig was built and its details reported.
- The negative effects of downwards flowing of melted frost were shown.
- Defrosting duration was shortened after installing water collecting trays.
- Energy waste during defrosting can be avoided after installing trays.

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ABSTRACT

A previous related study has indicated that for an air source heat pump (ASHP) unit having a vertically installed multi-circuit outdoor coil, during reverse cycle defrosting, downwards flowing of melted frost over the outdoor coil surface could affect the defrosting performance, without however giving a detailed quantitative analysis. Therefore an experimental study has been carried out and the study results are reported in this paper. Firstly, a detailed description of a specially built experimental ASHP unit having a vertical multi-circuit outdoor coil is presented. This is followed by reporting the experimental results. Finally, a detailed quantitative analysis is presented. The experimental results and the corresponding analysis demonstrated that allowing downwards flowing of the melted frost over a vertical multi-circuit outdoor coil would result in a longer defrosting duration and more energy consumption. The study results also suggested that the use of water collecting trays can help mitigate these negative impacts on defrosting performance.

1. Introduction

Since the oil crisis in the early 1970s, there has been much research effort in developing smaller, quieter and higher efficiency heat pump systems. One obvious advantage for using a heat pump unit is that it can provide heating or cooling from one single machine without any major modification [1]. Air source heat pump (ASHP) units used as cooling or heating sources for building heating, ventilation and air conditioning installations have found increasingly wide applications over the recent decades in many parts of the world [2,3]. It is noted that an outdoor coil is usually of multi-circuit structure in order to minimize its refrigerant pressure loss and enhance its heat transfer [4–6]. Also an outdoor coil is usually installed vertically for floor space saving.

When the surface temperature of the outdoor coil in an ASHP unit is below both the air dew point and freezing point of water, frost can be formed and accumulated over the surface of the outdoor coil. The frost deposited and accumulated on the outdoor coil surface acts as a thermal insulator between the surface and the humid ambient air, reducing heat transfer rate [7,8]. Furthermore, a frost layer reduces airflow passages and thus increases the air-side pressure drop [9], degrading the performances of the ASHP unit. Therefore, periodic defrosting is necessary.

Although there are several defrosting methods for ASHP units, such as electric resistance heating, hot refrigerant reverse cycle and hot water spray, reverse cycle defrosting is the most widely used standard defrosting method [10–14]. When a space heating ASHP unit is operated at a reverse cycle defrosting mode, its outdoor coil

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acts as a condenser and its indoor coil as an evaporator. While most melted frost drains off from outdoor coil surface due to gravity, some may retain on the surface of finned coil, and the retained water should be removed to prevent it from becoming ice when the ASHP unit returns to heating mode. Therefore, a complete defrosting process covers both frost melting and coil surface drying. During a defrosting process, not only a great deal of energy for melting frost and vaporizing the retained melted frost off the outdoor coil surface is consumed, but also the occupants' thermal comfort may be adversely affected because no heating is provided during defrosting [15]. Therefore, shortening a 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.

Allowing the melted frost to flow downwards on the surface of a vertical outdoor coil due to gravity would adversely affect the defrosting performances of an ASHP unit. It was reported [16] that when defrosting at the top circuits was ended, the bottom ones were still covered with frost. One important reason for this was believed to be the existence of melted frost flowing from top to bottom due to gravity. While, few studies about the effects of downwards flowing of melted frost due to gravity over a vertical multi-circuit outdoor coil on defrosting performance may be identified in open literature, a previous related study [16] has suggested that downwards flowing of melted frost over a vertical multi-circuit outdoor coil during reverse cycle defrosting could adversely affect the defrosting performance of an ASHP unit, by using more energy for defrosting and prolonging a defrosting process. This was because the downwards flowing of melted frost helped form or reinforced a water layer between the frost and coil surface, introducing a thermal resistance [17], and thus reducing the heat transfer between the two. Furthermore, more residual water could be left on the surface of bottom circuits and thus more energy needed to dry the residual water on the bottom circuits. However, no detailed quantitative analysis of these negative effects was carried out and reported.

This paper reports on an experimental study on the effects of downwards flowing of melted frost due to gravity over a vertical three-circuit outdoor coil surface on the defrosting performance of an experimental ASHP unit during reverse cycle defrosting. A detailed description of the experimental ASHP unit is firstly presented. This is followed by reporting various experimental conditions and experimental results. Finally, based on the experimental results, a quantitative analysis on the impacts of the downwards flowing of the melted frost due to gravity on defrosting performance is reported.

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. The experimental ASHP unit was installed in an existing environmental chamber having a simulated heated indoor space and a simulated outdoor frosting space. The sizes of both spaces were each measured at 3.8 m (L) × 3.8 m (W) × 2.8 m (H). Fig. 1 shows the schematics of the ASHP unit installed in the environmental chamber. The experimental ASHP unit was a split-type one and it consisted 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. 2. There were three individual and parallel refrigerant circuits and the airside surface areas corresponding to each of the three circuits were equal. The outdoor coil was vertically installed, and in each circuit a solenoid valve and a manual stop valve were used. The specifications of the three-parallel refrigerant circuit outdoor coil are shown in Table 1.

Three water collecting trays made of PVC were added to the outdoor unit. They can be placed under each circuit of the outdoor coil when necessary. In this way, the flowing of melted frost would be restricted within a circuit. Furthermore, three water collecting cylinders were connected to these trays, so that melted frost from each circuit during defrosting may be collected and weighed. For easy referencing this paper, the tray installed under Circuit 1 was named Tray A, under Circuit 2 Tray B, and under Circuit 3 Tray C. Their connecting water collecting cylinders named Cylinder A, B, C, respectively.

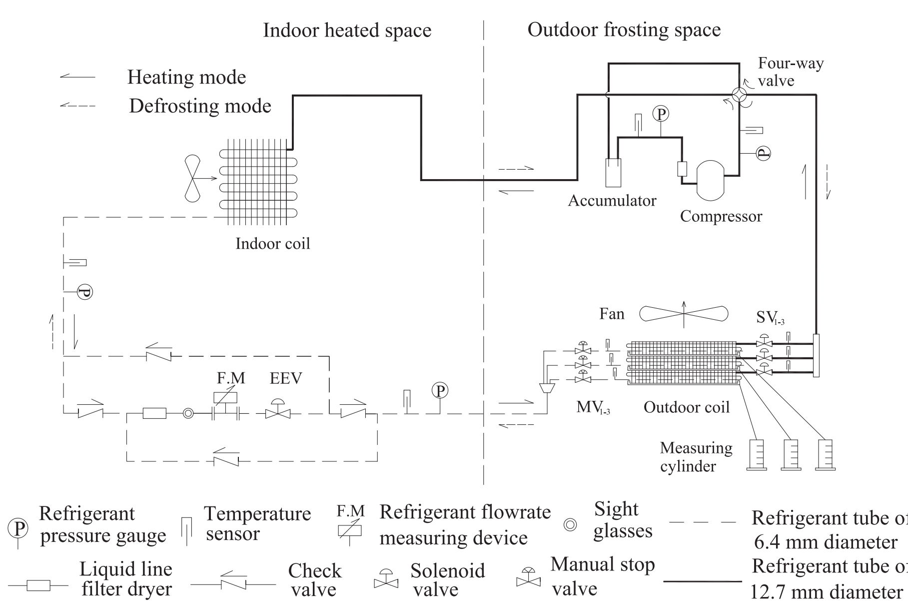

Fig. 1. Schematics of the experimental ASHP unit installed in an environmental chamber.