Applied Energy 164 (2016) 36–44

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

An experimental study on even frosting performance of an air source heat pump unit with a multi-circuit outdoor coil

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HIGHLIGHTS

- A special experimental rig was built and its details are reported.
- Even frosting could be reached by adjusting the refrigerant mass flow.
- Tube surface temperatures at circuit exits could reflect the FEV.
- Frosting COP increased from 4.10 to 4.26 as the FEV increased from 75.7% to 90.5%.

ARTICLE INFO

Article history:
Received 25 June 2015
Received in revised form 7 November 2015
Accepted 26 November 2015
Available online 15 December 2015

Keywords:
Air source heat pump
Multi-circuit outdoor coil
Even frosting
Frosting evenness value
Experiment

ABSTRACT

When the surface temperature of the outdoor coil in an air source heat pump (ASHP) unit is lower than both the air dew point and freezing point of water, frost can be formed and accumulated over outdoor coil's surface. On the other hand, an outdoor coil normally has multiple parallel circuits on its refrigerant side for minimized refrigerant pressure loss and enhanced heat transfer efficiency. Currently, most attentions were paid to the experimental and numerical studies on defrosting with different methods, without however paying attention to the distribution of frost accumulation on the multi-circuit outdoor coil. The phenomenon of uneven frosting exists, which also maybe the most important reason of uneven defrosting for an ASHP unit with a multi-circuit outdoor coil. Therefore, in this study, a comparative and experimental study on system frosting performance when frost accumulated on a three-circuit outdoor coil's surface in an ASHP unit at different frosting evenness values (FEVs) has been carried out. Experimental results indicated that, when the FEV was increased from 75.7% to 90.5% for an ASHP unit with a three-circuit outdoor coil, the COP could be increased from 4.10 to 4.26 at a 3600 s frosting process, and increased from 3.18 to 4.00 at its last 600 s.

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 have found their wide spread applications in recent decades, due to their advantage of high energy efficiency [2]. However, when an ASHP unit operates for space heating at an ambient environment of low temperature and high humidity in winter, frost will form and accumulate on its outdoor coil's surface [3]. The frost deposited and accumulated on the outdoor coil's surface acts as a thermal insulator between the surface and the humid ambient air, reducing heat transfer rate [4,5]. Furthermore, a frost layer reduces airflow passages and thus increases the air-side pressure drop [6], degrading the performances of the ASHP unit. Therefore, periodic defrosting is necessary.

Defrosting could be realized by a number of methods including: (1) warm-air defrosting [7], (2) electric heating defrosting [8–10], (3) hot water spray defrosting [11], (4) hot gas by-pass defrosting [6,12–14], and (5) reverse cycle defrosting [5,14–19]. However, although defrosting helps an ASHP unit returns to its rated performance, a defrosting process itself can cause a number of problems. Firstly, defrosting reduces the COP of ASHP units because energy is

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http://dx.doi.org/10.1016/j.apenergy.2015.11.036
0306-2619/

required to melt off the frost [18,19]. Secondly, the operation of an ASHP unit would be interrupted during defrosting, so that normal space heating in an indoor space served by the ASHP unit would be suspended, degrading the indoor thermal comfort of occupants [15,18,19]. Finally, defrosting increases equipment cost due to the addition of auxiliary heating elements and reduces equipment reliability. Therefore, to improve the COP of ASHP units, most attentions were abstracted to prevent or retard frosting in the past decades by changing surrounding environment [20–27] and optimizing the system or their components [6,28–32].

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. For an ASHP unit having a multi-circuit outdoor coil, uneven defrosting was reported in limited previous experimental studies [5,15,16,33]. This phenomenon means different circuits' defrosting process terminated (refrigerant temperature at exit of circuit reaching 24 °C) at different time [34]. O'Neal et al. [5] and Qu et al. [15] both investigated the transient defrosting performances of ASHP units, each with a vertically installed four-parallel refrigerant circuits outdoor coil. It was reported when a defrosting process was terminated, the tube surface temperature at the exit of the lowest circuit was much lower than that at the exit of the highest circuit. Similar results 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 et al. [33]. In the study by Wang et al. [16], 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 resulted from an uneven frosting start, which means the frost accumulations on each circuit surface of a multi-circuit outdoor coil in an ASHP were different. Wang et al. [35] reported an experimental study on the performance of an ASHP unit for a kind of mal-defrost phenomenon appearing in moderate climate conditions. As shown in Fig. 1, the frost accumulated on the downside is much more that on upside. Similar phenomenon could also be found in Figs. 2 and 3 [15,36].

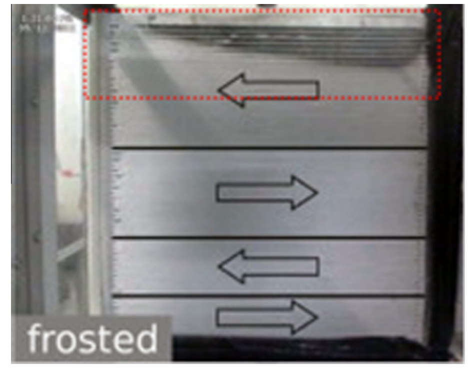

Fig. 2. Exterior heat exchanger during reverse cycle defrosting [36].

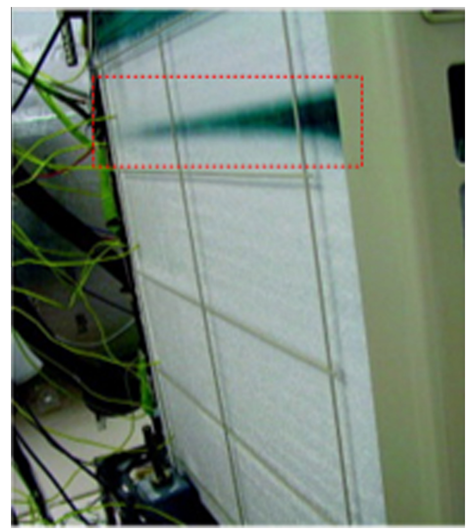

Fig. 3. Airside surface conditions of the outdoor coil during frosting [15].

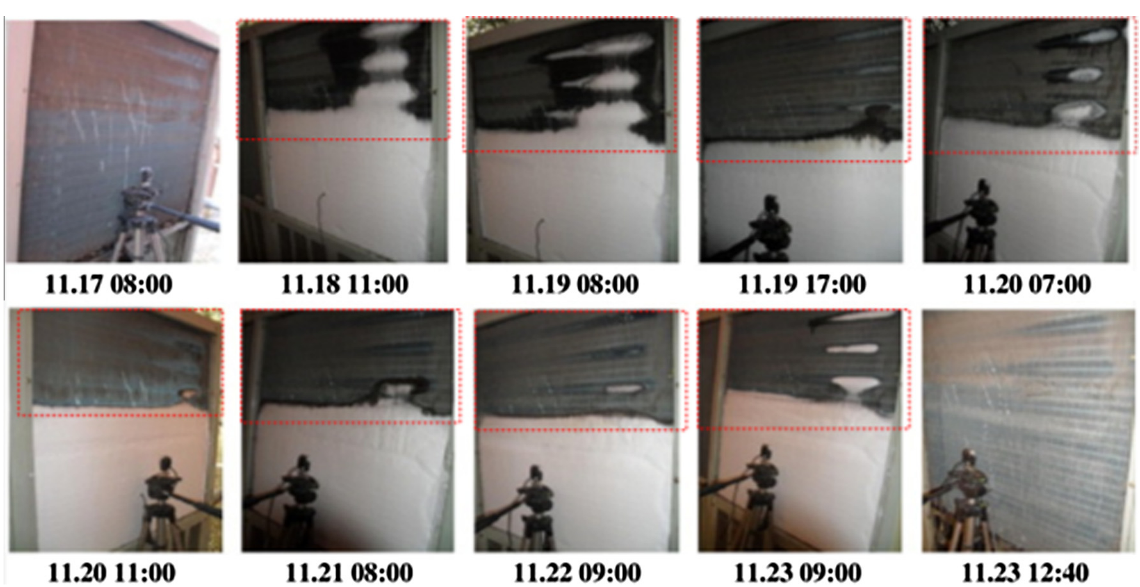

Fig. 1. Images of frosting process [35].