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Termination control temperature study for an air source heat pump unit during its reverse cycle defrosting

SONG Mengjie[a,*], WANG Xuanjie[b], LIAO Liyuan[a], DENG Shiming[c]

[a] *Department of Energy Engineering, School of Materials and Energy, Guangdong University of Technolog, Guangzhou, China*
[b] *Department of Mechanical and Aerospace Engineering, The Hong Kong University of Science and Technology, Kowloon, Hong Kong SAR*
[c] *Department of Building Services Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong SAR*

Abstract

For an air source heat pump (ASHP) unit with a vertically installed multi-circuit outdoor coil, a reverse cycle defrosting (RCD) operation is always terminated when the tube surface temperature at the exit of the lowest circuit reaches a pre-set value. It is obviously that when the pre-set temperature is higher, the defrosting duration would be prolonged. Not only more energy would be consumed on heating cold ambient air, but also the occupants' thermal comfort adversely affected. However, if the pre-set temperature is lower, more residual water would be left on the downside surface of fin in an outdoor coil, which degrades the system performance during the next frosting/defrosting cycle. In order to find a suitable DTT or its range, in this paper, an experimental investigation on RCD operation for an ASHP unit with a multi-circuit outdoor coil was conducted and reported. As concluded, DTT is suitable at the range of 20-25 ^{o}C, around 22 ^{o}C.

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Keywords: Air source heat pump; Multi-circuit outdoor coil; Reverse cycle defrosting; Defrosting termination temperature; Experimental study

1 Introduction

Air source heat pump (ASHP) units have been widely used as cooling and heating sources for heating, ventilation and air conditioning installations over the recent decades in many parts of the world because of their advantages such as energy saving, environmental protection and flexibility. However, when an ASHP unit works in heating mode at high humidity and low temperature environment in winter, it is difficult to avoid frost formation and accumulation on its surface of outdoor coil. The frost layer degrades

* Corresponding author. Tel./fax: +86 20 39322581
E-mail address: Mengjie.Song@gmail.com.

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system heating/frosting performance and even results in an unexpected shutdown of the ASHP unit. Therefore, periodic defrosting becomes necessary [1].

Currently, there are many defrosting methods, such as 1) compressor shut-down defrosting [2], 2) electric heating defrosting [3,4], 3) hot water spray defrosting [5], 4) hot gas by-pass defrosting [6,7], 5) compressed air blowing defrosting [8,9], 6) ultrasonic vibration defrosting [10,11], etc. However, among these used methods, the most widely used standard defrosting method is reverse cycle defrosting (RCD). When a space heating ASHP unit is operated at a RCD mode, its outdoor coil acts as a condenser and its indoor coil acts as an evaporator [12]. It should be noted that for defrosting on ASHP unit, a complete defrosting process covers both melting frost and drying coil surface. For an outdoor coil used in an ASHP unit, on its refrigerant side, multi-circuit structures are commonly used for minimizing refrigerant pressure loss and enhancing heat transfer efficiency. To save more floor space, a multi-circuit outdoor is always vertically installed. Authors have carried out series experimental and numerical studies to improve the RCD performance of an ASHP unit with a multi-circuit outdoor coil, by eliminating the negative effects of melted frost [12-14], improving the frosting evenness values [15-17], optimizing the refrigerant distribution [18,19], and adjusting the installation style of outdoor coil [20,21], etc.

For an ASHP unit with a vertically installed multi-circuit outdoor coil, a RCD operation is always terminated when the tube surface temperature at exit of the lowest circuit reaches a pre-set value. It is obviously that when the pre-set temperature is higher, the defrosting duration would be prolonged. Not only more energy would be consumed on heating cold ambient air, but also the occupants' thermal comfort adversely affected [22]. Since the ambient air temperature is always at the lowest value at night, sleep thermal comfort problem due to the degraded performance of air conditioning system attract scholar's attentions [23-25]. On the contrary, if the pre-set temperature is lower, more residual water would be left on the surface of outdoor coil, which degrades the system performance during the next frosting/defrosting cycle [26]. In the open literatures, a suitable pre-set temperature, working as defrosting termination temperature (DTT) of a RCD operation, was not fixed. For example, used values consist of 10 ^{o}C [27], 12 ^{o}C [28], 15 ^{o}C [29], 18 ^{o}C [30], 20 ^{o}C [31], 24 ^{o}C [12-21], 26.7 ^{o}C [32], and 35 ^{o}C [33], etc. Consequently, in order to find a suitable DTT or its range, in this paper, an experimental investigation on RCD operation for an ASHP unit with a multi-circuit outdoor coil was conducted. This study makes contributions on the method to find a suitable DTT for RCD of ASHP units.

2 Experimentation

2.1. Experimental ASHP unit

An experimental ASHP unit was specifically established for carrying out the experimental work reported in this paper. The experimental ASHP unit was installed in an existing environmental chamber having a simulated indoor heated space and a simulated outdoor frosting space. Fig. 1 shows the schematics of the ASHP unit installed in the environmental chamber. The outdoor coil was specially designed and made for this study, as shown in Fig. 2.

2.2. Experimental procedures and conditions

Relative detailed information about the equipment is shown in References [12-14], including experimental procedures and conditions. Specially, in this study, only one experimental case was carried

out. The results were analysed to find the most suitable DTT or its range.

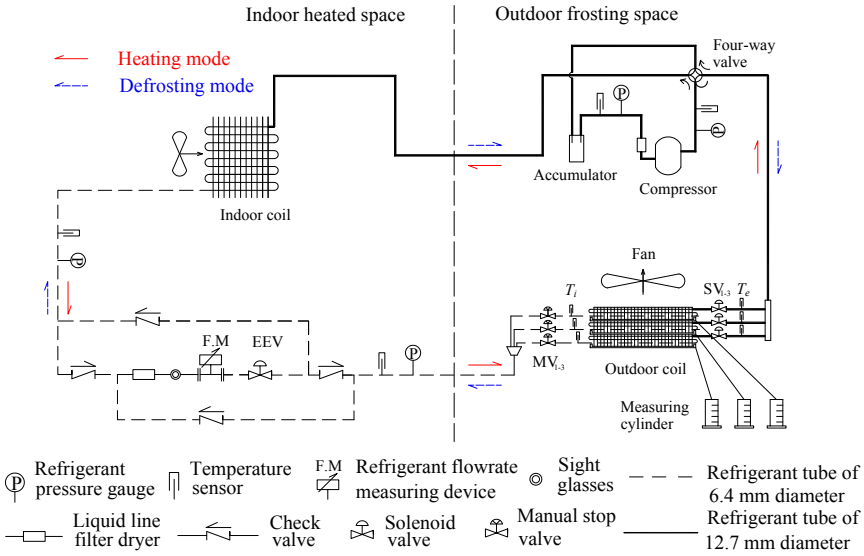

Fig. 1 Schematics of the experimental ASHP unit installed in an environmental chamber

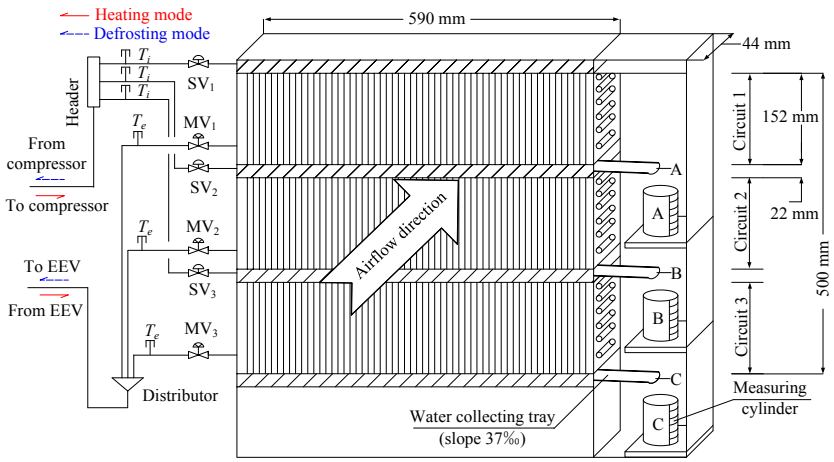

Fig. 2 Details of the three-parallel refrigerant circuit outdoor coil and locations of solenoid valves and manual stop valves

3 Results

As shown in Fig. 3, five phases were divided with six nodes, and Node 1 to 6 are at 10, 15, 20, 25, 30, and 35 °C, respectively. The six nodes are directly corresponding to the time of 151, 158, 172, 189, 211, 235 s, respectively. Fig. 4 shows the measured fin surface temperature at the centre of each circuit of outdoor coil. Clearly, the temperature range is changed from 10-35 °C to 6.2-31.2 °C. Temperature difference of P3 is the biggest, at 6.6 °C.

In addition, Figs. 5-10 show the other several operating parameters of system during RCD. Table 1 summarizes the DTT phase and nodes from the special points of different parameters. From these analysed special values in the following six figures, it is seems that the tube surface temperature at 175 s, about 22 °C in Fig. 3, could reflect the most suitable DTT. Therefore, it is demonstrated that, the most suitable DTT is about 22 °C, and the range is P3, 20-25 °C, in this study.

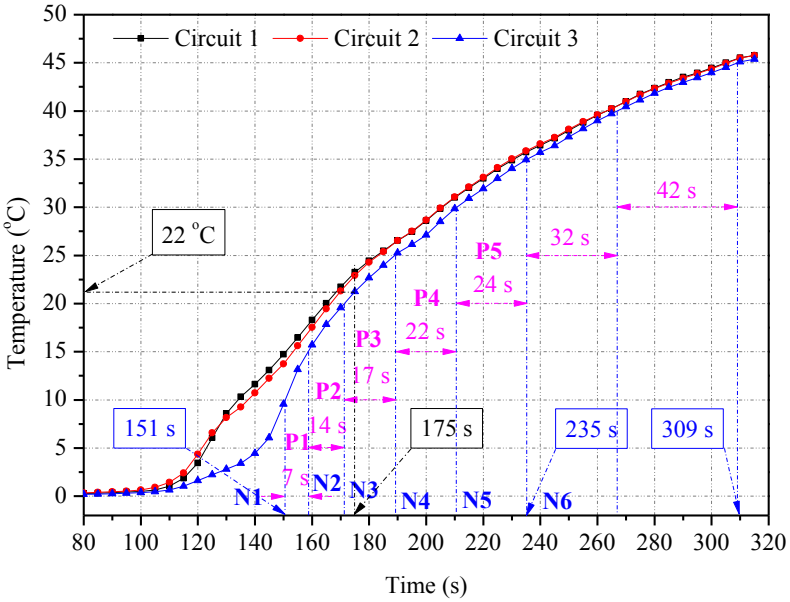

Fig. 3 Measured tube surface temperature at exit of the lowest outdoor coil circuit

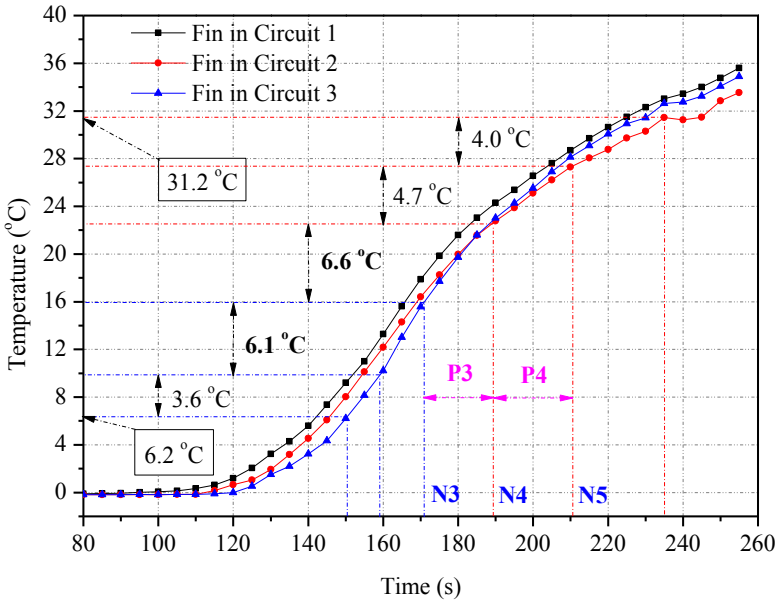

Fig. 4 Measured fin surface temperature at the centre of each circuit of outdoor coil

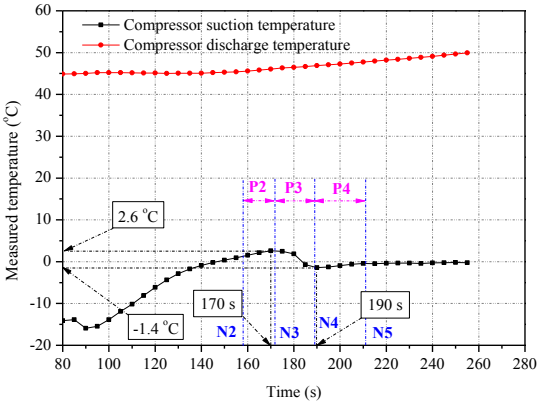

Fig. 5 Measured temperatures of compressor suction and discharge

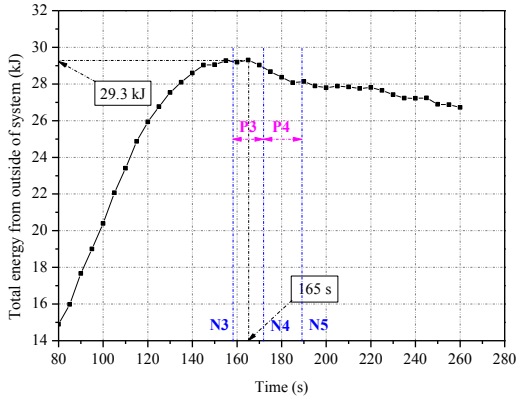

Fig. 6 Total energy coming from outside of system

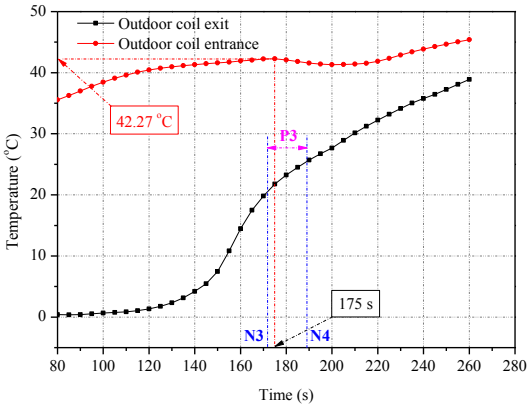

Fig. 7 Total inputs coming from outside of system

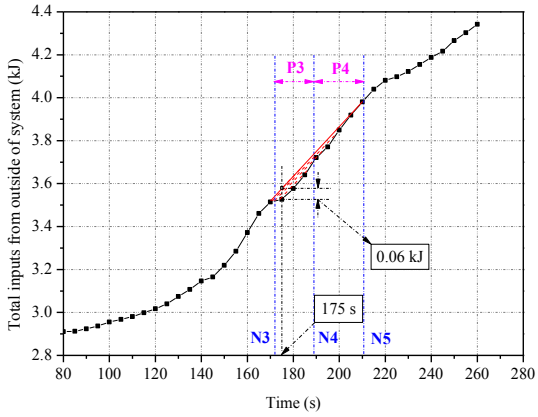

Fig. 8 Measured temperatures of tube surface at entrance and exit of outdoor coil

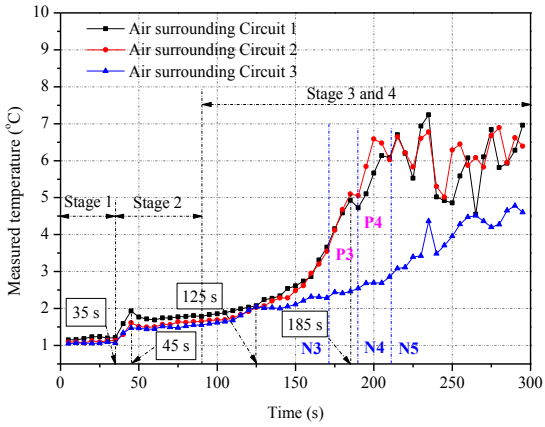

Fig. 9 Measured temperature of air surrounding each circuit

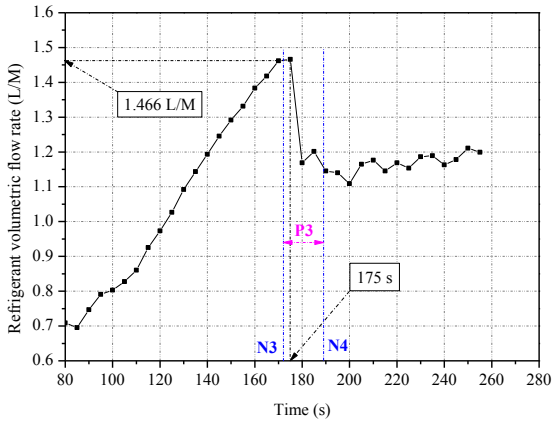

Fig. 10 Measured refrigerant volumetric flow rate

Table 1 DTT phase and node from different parameters

Item	Parameter	Duration
1	Total energy coming from outside of system	165 s -
2	Total inputs coming from outside of system	170 s -
3	Compressor suction temperature	170 s - 190 s
4	Average of fin surface temperature	172 s - 189 s
5	Temperature of air surrounding outdoor coil	172 s - 185 s
6	Tube surface temperature at the exit of outdoor coil	175 s
7	Measured refrigerant volumetric flow rate	175 s

4 Conclusions

For an ASHP unit with a vertically installed multi-circuit outdoor coil, a suitable DTT can effectively improve the frosting/defrosting operation performances. To find a suitable DTT or its range, an experimental investigation on RCD operation was conducted. Five phases were firstly divided with six tube surface temperature nodes. This was followed by analyzing experimental results, such as temperatures of fin surface and surrounding air, total energy, refrigerant flow rate, etc. Finally, the conclusion that DTT is suitable at 20-25 ^{o}C, around 22 ^{o}C, was given. In addition, using this method, suitable RCD DTTs could also be reached for other ASHP units. Consequently, saving more energy for ASHP units could be expected.

Acknowledgements

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Biography

Dr. SONG Mengjie is a young researcher, who graduated from the Hong Kong Polytechnic University, and working as an Associate Professor at the Department of Energy Engineering, Guangdong University of Technology, China. He has wide research interests, consisting of frosting/defrosting for ASHP units, heat and mass transfer around multi-circuit heat exchangers, Phase Change Materials, clean energy system, indoor thermal comfort, and Organic Rankine Cycle, etc.