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Research Paper

Improving quick cooling performance of a R410A split air conditioner during startup by actively controlling refrigerant mass migration

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HIGHLIGHTS

- The refrigerant distribution inside the air conditioner is measured.
- The dynamic characteristics of the air conditioner after startup are investigated.
- Active control strategies are proposed to improve quick cooling performance.
- Increasing the refrigerant mass in the condenser can improve cooling performance.

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ABSTRACT

This paper presents experimental investigations on the transient refrigerant migration during the start-up and shut-down of a R410A split air conditioner. The refrigerant distribution inside the main components of the air conditioner is measured by using "quick-closing valves" technique in which the components are isolated and the refrigerant is removed to be weighed. Results indicate that the refrigerant distribution rapidly changes within 300 s during start-up and becomes gently after 300 s. On the other hand, the refrigerant distribution rapidly changes within 60 s during shut-down and becomes gently after 60 s. In addition, the dynamic characteristics of the air conditioner after startup are also investigated at the standard cooling capacity rating condition. Several active control strategies for refrigerant mass migration during on–off cycling are proposed to improve quick cooling performance during startup. And it is verified that increasing the refrigerant mass in the condenser can improve cooling performance during startup.

1. Introduction

Room air conditioners (RACs) have been widely used to provide both cooling and heating for residential building indoor environment. The major purpose of RAC applications is to maintain thermal comfort in indoor environments along with essential energy consumption. Therefore, manufacturers and researchers have shown more and more concern on the thermal comfort [1,2] and energy consumption [3,4] of using the RACs. With the improvement of standard of living, especially, there is a growing request about thermal comfort for occupants in an indoor environment with various air conditioning systems [5,6]. Ahmed et al. [7] presented a novel ventilation system for office room and experiment investigation reveals that the new system has better performance in terms of energy saving, thermal comfort and inhaled air quality. Chu et al. [8] proposed a novel control method on multi-room fan coil unit of HVAC to improve thermal comfort and achieve energy saving effect simultaneously. Cui et al. [9] investigate the effect of indoor air temperature on thermal comfort and found that the optimum temperature is 22–26 °C. In this case, thermal comfort improvement of the use of RACs can be considered to be one of the most important aspects in the development of the modern RAC technology.

As well known, when a RAC is operated to create lower indoor environment temperature at hot climatic conditions, it is usually expected that the RAC can have fast cooling effect to provide occupants with thermal comfort. In particular, quickly cooling down the supply air temperature of the RAC during startup could benefit the thermal comfort and the occupants' satisfaction from the point of actual applications. Thus, the dynamic characteristics of a RAC during startup are equally as important as the steady-state performance [10]. Bruno et al. [11] outlines a simulation model for the

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Nomenclature

P	pressure (MPa)
t	temperature (°C)
t_a	room temperature (°C)
$t_{a,o}$	outlet air temperature of the evaporator (°C)
$t_{c,mid}$	temperature in the middle of condenser (°C)
$t_{e,m}$	average temperature of the evaporator (°C)
$t_{e,mid}$	temperature in the middle of evaporator (°C)
t_f	the time of the outlet air temperature decrease (s)
W_1	the total mass of the component (g)
W_2	the mass of the component after discharging refrigerant (g)
W_r	the mass of the refrigerant in the component (g)
$W_{r,l}$	the mass of the refrigerant leakage (g)
ε	total error
ε_m	refrigerant measurement error
$\varepsilon_{r,l}$	refrigerant mass leaking error
δW_1	balance measurements error
δW_2	balance measurements error

Subscripts

a	air/accumulator
c	condenser
d	discharge
e	evaporator
m	mean
mid	middle
l	leakage
o	outlet
r	refrigerant

cycling behavior of household refrigerators to predict the performance. Christian et al. [12] presented A methodology for simulating the dynamic behavior of household refrigerators during startup. But for a RAC, its startup performance is strongly related to the refrigerant mass migration and the resulting redistribution of the refrigerant mass across the components in the RAC system [13]. Overall, the refrigerant mass migration and distribution in air conditioning or refrigeration systems as well as their impact on system performance have been studied continuously [14,15]. The existing method to determine the refrigerant mass inside the refrigeration system components are quick-closing valves technique [16], liquid nitrogen method (LNM) [17,18], on-line measurement method (OMM) [19] and quasi on-line measurement method (QOMM) [20]. Björk and Palm [21,22] adopted quick-closing valves method to measure the refrigerant quantity in different components of a domestic refrigerator in both transient condition and steady state condition. Li et al. [23] investigated the refrigerant mass distribution within a R290 split air conditioner under different operation modes the by liquid nitrogen method. Tang et al. [24] proposed the quasi-liquid nitrogen method to measure the R290 distribution and evaluate the refrigerant leaking rate near the solenoid valve. Li et al. [25] presented a dynamic model to investigated the refrigerant mass migration in the automotive air conditioning system. In addition, the oil distribution characteristics along with the refrigerant migration together are investigated in both RAC and automotive air conditioning system [26,27]. However, these researches mainly focused on the energy loss due to refrigerant mass migration in dynamic process. Actually, the refrigerant mass migration also causes the cooling capacity loss following a compressor start and stop that affects the startup and overall performance. Hence, it is important to study the transient refrigerant migration and the cooling performance of such systems in order to identify and overcome capacity losses.

This paper presents experimental investigations on the transient refrigerant migration and startup performances of an inverter-driven R-410A split room air conditioner with an electronic expansion valve. During startup and shutdown process, the refrigerant mass migration and distribution are measured by using "quick-closing valves" technique in which the components are isolated and the refrigerant is removed to be weighed. The experimental study on transient refrigerant migration of RAC is carried out to evaluate the dynamic operation characteristics during the start-up and shut-down period. The dynamic refrigerant distribution inside the main components of RAC is investigated at the nominal cooling capacity rating condition. The novel active control strategies, which are used to control the refrigerant mass migration during on-off cycle operation, are proposed to improve the quick cooling performance during RAC startup period. The experimental validations of the proposed control strategy are reported. The presented investigation is an attempt to provide a guide in the further development of the inverter-driven RACs.

2. Experimental method

An inverter-driven RAC unit was placed in the air enthalpy type psychrometric rooms, i.e., indoor and outdoor chambers, which can provide specified air temperature and humidity with individual air handling unit and humidifier. Dry-bulb and wet-bulb temperatures were maintained within ±0.1 °C during steady-state operation The RAC unit used for the test is a R410A split air conditioner with a nominal cooling capacity of 2600 W (Midea KFR-26GW/BP3DN1Y-KB). The detailed specifications of the key components including compressor, condenser, evaporator and electronic expansion valves are listed in Table 1. The quick-closing valves method is chosen to measure the refrigerant mass distribution inside the refrigerant system of the test RAC unit. For this purpose, the

Table 1
Specification of RAC system components.

Components	Specifications
Compressors	Type: Rotary DC inverter compressor Displacement volume: 9.8 cm^3 Accumulator volume: 650 cm^3 Oil quantity: 370 cm^3
Condenser	Type: fin/tube heat exchanger (aluminum/copper) Tube length: 17,800 mm Tube outer diameter: 10.0 mm Tube outer diameter:9.0 mm Number of tube rows: 2 Number of tubes: 24
Evaporator	Type: fin/tube heat exchanger (aluminum/copper) Tube length: 20,400 mm Tube outer diameter: 7.0 mm Tube outer diameter: 6.0 mm Number of tube rows: 2 Number of tubes: 30
Electrical expansion valve	Type: electronic expansion valve Control resolution: 0–500 steps