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Simulation on effects of subcooler on cooling performance of multi-split variable refrigerant flow systems with different lengths of refrigerant pipeline

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ABSTRACT

Multi-split variable refrigerant flow (VRF) systems have wide applications in offices and commercial buildings. In the multi-split VRF system, a subcooler is usually adopted to avoid flash vapor generation in the liquid pipeline. At present, the effects of the refrigerant pipeline length of the multi-split VRF system with a subcooler have not yet been investigated, nor the optimization of the subcooler. In this paper, the model of a multi-split VRF system with a subcooler has been developed and validated. In nine cases with different lengths of the main pipelines and the subcooling heat exchanger (SCHX), the cooling performance of a multi-split VRF system has been studied by simulation. The results indicate that the subcooler has little benefit in a system with a short pipeline, while it can help improve the coefficient of performance (*COP*) of a system with a long pipeline by controlling the bypass mass flow rate ratio in a proper range, and a higher maximum *COP* can be obtained by increasing the length of the SCHX in the subcooler. Furthermore, it is recommended to control the outlet superheated degree of the bypass stream in the SCHX in order to maximize the *COP* of a multi-split VRF system.

1. Introduction

Heating, ventilation and air conditioning (HVAC) systems have been increasingly popular in buildings worldwide to meet the demand for indoor thermal comfort. As an air-conditioning system featuring high part-load energy efficiency, individual control in separate zones, installation space saving and simple maintenance, the multi-split variable refrigerant flow (VRF) system has already been widely applied in Asia and Europe after more than thirty years of development [1]. In Japan, where the first multi-split VRF system was produced, it was reported that multi-split VRF systems are used in about half of the medium-sized commercial buildings (up to 6500 m^2) and one third of the large commercial buildings (more than 6500 m^2) [2]. The multi-split VRF system was introduced in China in the late 1990s, where it has already gained great popularity in offices, shopping centers, hotels and unit residential buildings. According to a market summary report [3], the share of multi-split VRF systems in sales of central air-conditioning products in China was more than 40% in the first half of 2014.

Typically, a multi-split VRF system consists of one or several outdoor units and multiple indoor units, which are interconnected by refrigerant pipelines. Usually, a multi-split VRF system can be alternatively operated in space cooling mode or heating mode by reversing a four-way valve located in the outdoor unit. The refrigerant flow rate in each indoor unit is modulated to match the cooling or heating load by adjusting the compressor speed and the opening of electronic expansion valves (EEVs). Inevitably, there are interactions among the operations of indoor units, which results in more difficulty in control compared with that of a single-unit air conditioner. Great efforts have been made on the simulation of the operational characteristics and control strategy of multi-split VRF systems. Shao et al. [4] presented a universal simulation model of a fin-and-tube condenser using a distributed-parameter method, which showed high accuracy and provided a numerical basis for the simulation of air-cooled multi-split VRF systems. Various steady-state simulation models have been developed and used to investigate the part-load performance of the multi-split VRF system [5–7]. Additionally, there are also several studies [8–11] concerning the interaction of EEV regulation on each evaporator and the optimization of the control algorithm through dynamic

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Nomenclature

A	Channel area of electronic expansion valve, m^2
COP	Coefficient of performance, W/W
C_d	Coefficient of discharge for orifice equation
D_i	Internal diameter, m
e	Relative error or absolute error
e'	Acceptable relative error or absolute error
f	Friction factor
f_{L0}	Friction factor of liquid
f	Friction factor of liquid
f_{loss}	Heat loss coefficient
h	Enthalpy, J/kg
j	Serial number of each indoor unit
J	Mass flux, kg/(m^2 s)
l	Length, m
L	Length, m
m	Mass flow rate, kg/s
n	Rotating frequency, hz
N	Number of indoor units
P	Pressure, Pa
q	Blasius resistance index in eq. (14)
Qe	Total cooling capacity, W
r	Mass flow rate ratio
Re	Reynolds number
T	Temperature, °C
V_{th}	Displacement of compressor, m^3/rev
W	Power input, W
x	Refrigerant vapor quality
Y	Chisholm factor in eq. (14)

Greek symbols

ΔTsc	Subcooling degree, °C
ΔTsh	Superheated degree, °C
ε	Absolute roughness of pipe wall, m
η_s	Isentropic efficiency
η_v	Volumetric efficiency
ρ	Density, kg/m^3
ϕ_{L0}^2	Two-phase flow resistance correction coefficient

Subscripts

ai	Indoor air
ao	Outdoor air
bp	Bypass stream in SCHX
c	Condenser
cp	Compressor
db	Dry-bulb
e	Evaporator
eev	Electronic expansion valve
f	Friction
fan	Fan
hplp	High-pressure liquid pipeline
h	Enthalpy
i	Inlet
lpgp	Low-pressure gas pipeline
L	Liquid
m	Mass flow rate
mn	Main stream in SCHX
mp	Main pipeline
o	Outlet
od	Outdoor
p	Pressure
s	Isentropic process
schx	Subcooling heat exchanger
set	Preset value
total	Total mass flow rate
tsc	Subcooling
tsh	Superheat
wb	Wet-bulb

thermodynamic models of the multi-split VRF system. With the advanced controls, the sizes of outdoor units and the number of indoor units in a multi-split VRF system have been greatly extended [12].

In the design of a multi-split VRF system, the layout is closely related to the building geometry. It is hard to avoid a long pipeline between the outdoor and indoor units when installing a multi-split VRF system in a large-scale building. However, increase of the refrigerant pipeline length will cause performance degradation especially in the cooling mode. As the horizontal pipelines between outdoor and indoor units are lengthened, the indoor EEVs are likely to have the risk of control instability and noise, due to the liquid refrigerant flashing before it passes the EEVs [13,14]. Moreover, the specific volume of refrigerant sucked into the compressors will be significantly increased, resulting in a decline in the cooling capacity and energy efficiency. Shi et al. [15] quantitatively analyzed the effects of refrigerant pipeline lengths between the outdoor units and indoor units on the performance of a multi-split VRF system utilizing R22, and pointed out that the total coefficient of performance (*COP)* of the multi-split VRF system can be lower than that of the air-cooled water chiller & heater unit plus fan-coil air conditioning system when the pipeline is too long. A numerical research on the nominal cooling operating performance of a dual-evaporator VRF system utilizing R22, which was carried out by Yan et al. [16], also indicated that the cooling capacity and *COP* of the system will decrease with the increment of refrigerant pipeline lengths.

Usually, a subcooler, including a subcooling heat exchanger (SCHX) and an EEV, is introduced in a multi-split VRF system to prevent flash vapor generation in the liquid line before entering the indoor EEVs [14]. There are some studies involving the cooling performance of the multi-split VRF system having a subcooler. Guo [17] experimentally investigated the effects of refrigerant pipeline length on the part-load cooling performance of a multi-split VRF system, where the subcooler was operated only under a high cooling load and long pipeline condition, while the control strategy of the subcooler was unknown. Laeun et al. [18] carried out a field test on the effects of the subcooler on the cooling performance of a multi-split VRF system in offices. It was found that for the tested system, the *COP* is improved when the refrigerant mass flow fraction that passes through the subcooler is lower than 5.27%, as compared to the baseline without a subcooler.

Despite the previous field test on the effects of the subcooler in a certain multi-split VRF system, the influence of the pipeline length and the SCHX capacity has not yet been investigated. In China, most of the multi-split VRF systems in buildings mainly operate in the cooling season and the transition season. Therefore, this study aims at the effects of three factors, i.e., the length of the main pipelines, the capacity of the SCHX and the bypass refrigerant mass flow rate ratio in the subcooler, on the cooling performance of a multi-split VRF system. In Section 2, a steady-state mathematical model of a multi-split VRF system with a subcooler has been developed and it was validated using the experimental data in the literature [17]. In Section 3, the developed model was applied to predict the cooling performance of a multi-split VRF system under the influence of the pipeline length, the SCHX capacity and the bypass refrigerant mass flow rate ratio in the subcooler. Finally, the results were discussed for the use of the subcooler in a multi-split VRF system and the