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Field performance measurements of a VRF system with sub-cooler in educational offices for the cooling season

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ABSTRACT

The effects of the subcooling heat exchanger (SCHX) on the performance of the multi-split variable refrigerant flow (VRF) system with long pipe were investigated in a field test during the cooling season. By varying the refrigerant mass flow rate via the electronic expansion valve, the degree of subcooling was controlled. It was found that VRF system with SCHX improved the cooling performance factor (CPF) about 8.5% under similar outdoor temperature profiles, as compared to the baseline without SCHX. However, when the fraction of total refrigerant that passes through the SCHX was higher than 5.27%, the CPF starts to decrease due to the decreased refrigerant mass flow rate through the evaporators. Employing a SCHX in a VRF system with long pipe was found to be an effective method for improving the system performance and reliability.

1. Introduction

Today's buildings consume about 41% of U.S. primary energy usage [1]. There are many strategies to reduce energy consumption, especially in heating and cooling devices. Since the variable refrigerant flow (VRF) systems, which were introduced about 20 years ago in Asia, have become popular in many countries, this technology has been widely studied, both experimentally and numerically. The VRF systems either transfer or remove heat from an outdoor condensing unit to a network of indoor units located within the conditioned space through refrigerant piping. It provides flexibility by allowing for many different indoor unit types, individual zone control, and the unique capability to offer simultaneous heating and cooling in separate zones on a common refrigerant circuit. Each indoor unit's capacity is controlled by adjusting the refrigerant flow via the electronic expansion valve (EEV) and sensing the room temperature. Through this individual capacity control, the VRF system not only has energy savings potential, but also provides better thermal comfort. Fujimoto et al. [2] examined the performance of a heat pump VRF system, which provides either cooling-only or heating-only at any time, in a psychrometric chamber and using different types of devices for measuring the refrigerant mass flow rate. They found that using a Coriolis flow meter is an effective method for measuring the performance of a VRF system under a wide range of conditions. Kang et al. [3] investigated the heat recovery type VRF system that allows simultaneous cooling and heating with multiple indoor units connected to one outdoor unit. The system performance, optimized by adjusting the EEV opening of the outdoor unit, was higher than those in the cooling-only and heating-only modes. Several different authors conducted field performance tests [4–7]. Zhang et al. [4] experimentally evaluated the seasonal energy efficiency ratio (SEER) of the VRF system under part load conditions. The result showed that both part load conditions and outdoor air temperature influenced the performance of the VRF system. The work by Aynur et al. [5] experimentally investigated the effect of individual and master control modes in both cooling and heating seasons in an office suite. They found that the VRF system in the individual control mode provides better thermal comfort than VRF system in the master control mode. The main disadvantage of VRF system is that, by itself, it does not have any ventilation capability. Extensive experimental data analysis and validation work were conducted to characterize the effect of the ventilation on the multi-split VRF system's performance which covers the indoor thermal comfort, energy consumption and the efficiency of the system [6,7].

The VRF system's refrigerant piping is sized in a range of vertical and horizontal lengths, based on distance and velocities required for efficient and stable system operation. Performance of VRF system can be decreased with the increase of pipe lengths and height differences. A subcooling heat exchanger (SCHX) is used to subcool the rest of the refrigerant in the liquid circuit, which then enters the evaporator [2]. The liquid refrigerant should be supplied to indoor units with sufficient subcooling to minimize the possibility of flash gas generation, which can result in the fluctuation of the refrigerant flow rate [8]. Despite the previous numerous studies on the VRF

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Nomenclature

CPF	cooling performance factor
SCHX	subcooling heat exchanger
EEV	electronic expansion valve
$\dot{m}$	mass flow rate
T	temperature (°C)
h	enthalpy (kJ kg^{-1})
η	efficiency
χ	ratio of the refrigerant mass flow rate of SCHX to total refrigerant mass flow rate

Subscripts

T	total
comp	compressor
e	evaporation
c	condensation
IUs	indoor units
SC	subcooling

system, the effect of the SCHX on the system performance has not been the subject of extensive studies. Therefore, the objective of this study is to investigate the effect of the SCHX on a VRF system through field performance tests.

2. Experimental set-up

2.1. Existing building

One VRF outdoor unit and six indoor units were installed in offices at the University of Maryland, College Park. The office suite with four rooms, shown in Fig. 1, was used for the field performance tests. Table 1 shows the zone description and internal loads of each room. Internal loads are assumed to be same during the working hours. The number of indoor unit and the capacity of indoor units were determined based on the building load estimation.

2.2. VRF system description

Fig. 2 shows the schematic diagram of multi-split heat pump VRF system. The outdoor unit consists of an inverter driven hermetically sealed scroll type compressor, a condenser, a 4-way valve, electronic expansion valves, and a SCHX. As shown in Fig. 3, the SCHX is a tube-in-tube heat exchanger with counter flow configuration. The SCHX is activated when the EEV B is opened. When the EEV B is opened, the refrigerant in the main stream after the SCHX is divided into two streams: one stream flows through the EEV B which causes the pressure drop. It then passes through the SCHX and exchanges heat with the main stream from the state point 5 to the state point 6. This results in the subcooling of the main stream. The refrigerant at state point 6 is merged with the refrigerant from the indoor units before entering the compressor. In the cooling mode, the EEV A in the refrigerant circuit between the condenser and the SCHX is fully opened. In the heating mode, the refrigerant flow is reversed by 4-way valve and the EEV A is used for the expansion process. Indoor units are all wall-mounted types and each one has an EEV consisting of a stepping motor and a needle valve that is used for the accurate control of the refrigerant flow rate. Table 2 shows the specifications of outdoor and indoor units.

2.3. Measurement instrumentation

T-type thermocouples and relative humidity sensors were used to measure the indoor and outdoor environmental conditions of the office. The sensors for outdoor conditions were installed on the roof and shielded against heat radiation and the rain. In

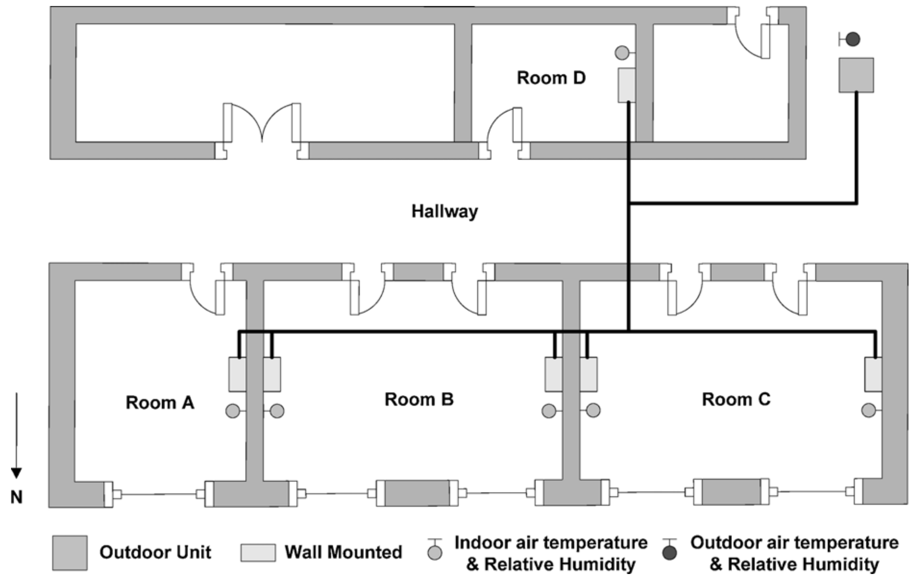

Fig. 1. Layout of the office suite.

Table 1
Zone description and internal loads.

	Total area (m^2)	Number of occupants	Number of computer	Number of light	Equipment (kW)
Room A	11.4	1	1	6	0.84
Room B	22.2	7	8	12	1.23
Room C	22.4	7	10	12	1.23
Room D	9.3	1	1	6	0.84