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Simulation of variable refrigerant flow air conditioning system in heating mode combined with outdoor air processing unit

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ABSTRACT

Variable refrigerant flow (VRF) air conditioning system has become attractive due to better energy performances than traditional air conditioning systems. However, the shortcoming of no outdoor air (OA) intake has not been solved thoroughly. A new VRF and outdoor air processing unit combined air conditioning system is proposed and simulated. The first obstacle is that there is no well-known simulation tool for VRF unit in heating mode. A VRF model of condenser-number independence is developed and validated first. The combined system is modeled by integrating the individual sub-system or component models into a complete system. The average error of the developed model to predict heating capacity, input power and COP are 7.87%, 12.45% and 6.19% respectively. Finally the combined system is simulated under conditions of the same and different set-points of the air conditioning zones. The combined system could maintain all the zones at their specific set-points within small errors no matter the set-points are the same or different. Moreover, indoor air quality can be ensured. The demand of one air conditioning system possessing independent units serving separate zones in the same building could be met by the combined system.

1. Introduction

Conventional heating, ventilating and air-conditioning (HVAC) systems, such as the all-air variable air volume (VAV) systems, are widely used in many types of buildings in spite of the fact that these common systems have several significant deficiencies [1], which yet have triggered the HVAC engineers to develop new types of air conditioning systems to reduce energy use and to improve comfort performance. During the last two or three decades, HVAC engineers witnessed a wide application of the multi-split variable refrigerant flow (VRF) system in various commercial constructions such as office buildings, hotels and schools [2,3], for the purpose of energy saving and the demand of an air conditioning system possessing independent units serving separate zones. It is claimed that the multi-split VRF system has greater energy saving potentials than other HVAC systems such as VAV systems and fan-coil unit plus fresh air systems [4–7]. The multi-split VRF system has high energy efficiency under part load condition, due to the modulation of the compressor speed to adapt the load changing. In addition, duct losses in the multi-split VRF systems can be almost eliminated due to the in-space location of the indoor units [2]. However, the multi-split VRF system can hardly ensure the indoor air quality (IAQ) because it does not induce outdoor air (OA) into the air conditioning zone(s). In most circumstances, an energy recovery ventilator (ERV) will be installed accompanying with the multi-split VRF system for inducing efficient amount of ventilation air as required by ASHRAE Standard 62. However, ERV is usually not controllable for the OA flow [8], i.e. fixed rather than suitable OA flow is introduced into the air conditioning zones, which often results in energy wasting especially in places where the number of occupants changes frequently. In other words, inadequate combination of VRF with the ventilation system (such as the ERV) either results in poor indoor thermal comfort, or more energy consumption due to the additional OA load [9]. It is a pity that most of the research endeavors have been pursued in the past few years aiming at the field testing, energy and control simulation of the whole and/or the components of the multi-split VRF system [4–7,10–15]. Very few attentions, except the work reported by Karunakaran and Parameshwaran [16,17] are paid to joint control of the multi-split VRF system and ventilation devices. Nevertheless, the Parameshwaran and Karunakaran's system actually is a variant of VAV system that the air is processed by two evaporators (in cooling mode) of the VRF laid in series. This system cannot make full use of the advantages of the VRF unit.

With the above considerations, a new air conditioning system combining multi-split VRF unit and OA processing unit is proposed aiming to take advantages of both parts. A direct expansion (DX) VRF unit processes OA and then supplies the processed OA to air conditioning zones through VAV boxes. The VAV boxes regulates the OA flow to the indoor zones according to their requirements

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Nomenclature

HVAC	Heating, ventilating and air-conditioning
VRF	Variable refrigerant flow
VAV	Variable air volume
ERV	Energy recovery ventilator
IAQ	Indoor air quality
IDU	Indoor unit
DCV	Demand-controlled ventilation
OA	Outdoor air
DX	Direct expansion
EEV	electronic expansion valve
$\dot{M}$	Mass flow rate (kg/s)
h	Enthalpy (kJ/kg)
T	Temperature (°C)
ΔT	Temperature difference (°C)
ΔP	Pressure difference (Pa)
V	Displacement volume
n	Compressor speed
A	Flow area of EEV

Greeks

λ	Volumetric efficiency
v	Specific volume of suction vapor
ξ	Flow coefficient of EEV

Subscript

com	compressor
ref	refrigerant
sh	superheated degree
cal	calculated
dsgn	designed
c	condensing
e	evaporating

based upon contaminant concentration, and the parallel multi-split VRF system accommodates the remaining loads, including the indoor loads and the possible OA load.

In this paper, the combined system in heating mode is planned to be investigated with computer simulation in terms of energy performances, thermal comfort and IAQ with the VRF part and the OA processing part being controlled together. System model of the multi-split VRF unit is developed first, which constitutes the most important part of the work of this paper since there is no well-known simulation model for the VRF system in heating mode. The VRF model in heating mode is rarely seen in literatures due to two reasons: the model developed for conventional single condenser heat pump is not able to extend to multi-condenser ones, and the model developed for cooling mode is not suitable for heating mode due to the more complex characteristics of the VRF unit in heating mode. Detailed models for other components, including VAV damper, supply fan, sensor, controller, actuator and major components of the VRF unit and the DX rooftop unit, which can be found in authors' previous works [18–20], are not repeated. The model is validated by the experimental data reported by Zhou [21]. Extensive information which are used to simulate the combined system including climate information, building element thermal properties, as well as system operating schedules are described. Then the control strategy is proposed. Finally, simulation results are discussed and conclusions are made.

Besides the introduction, remainder of this study is organized as follows: Section 2 gives descriptions of the conceptual building and the combined system and its control designing. Section 3 discusses the system simulation model. And the validation of the simulation model using the existed experimental data is carried out in Section 4, while tests and case studies for the combined system are illustrated in Section 5. And Section 6 concludes this study.

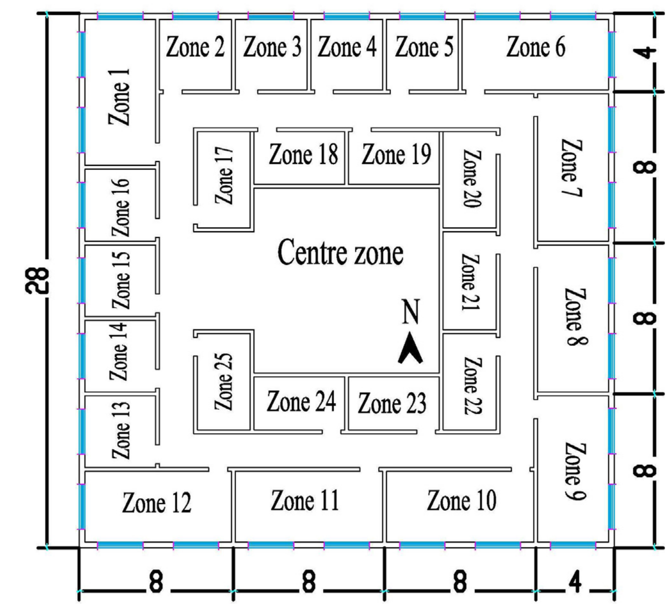

Fig. 1. Typical floor plan of the building (unit in drawing: meter).

2. Building and combined system description

2.1. Building description

An office building of frame structure is designed to accommodate the combined air conditioning system. The building has six floors in total above ground. Each floor of the building is divided into six conditioned thermal zones, corresponding to four outdoor exposures (east, west, south and north), an interior zone (including a ring-shaped corridor), and a center zone. The typical floor section is shown in Fig. 1, and a summary of the key parameters of the building is given in Table 1, while the construction material properties are listed in Table 2. The air conditioning zones in one typical floor are numbered from zone 1 to zone 25 for conveniently identifying their positions. As is determined by the usage of the building, internal heat gains are mainly from the sources of occupants, lighting and equipment. Table 3 describes the methodology of heat gain calculation (per unit). The real time occupants of each zone is detected and estimated by a dynamic occupant detecting module originally developed by Wang and Jin [22] based on the variation of the CO_2 concentration.

Table 1
Critical information of the building.

Item	Description
Building location	Shanghai, China
Building type and storeys	Office building, 6-story above ground
Gross floor area (air conditioned area)	4700 m^2
Typical floor area and height	28 m × 28 m, floor-to-floor height = 3.5 m
Zone height (m)	2.7 m
Solid wood door size	width × height = 1.0 m × 2.0 m
Windows and shading	Low-e double pane glazing. Window width × height = 1.8 m × 1.5 m; sill height = 0.80 m; no shading device