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Simulation of Variable Refrigerant Flow Air Conditioning System in Heating Mode Combined with Outdoor Air Processing Unit

MD TARIQUE ANWAR[1], RAZA AHMED KHAN[2], MOHAMMAD ABRAR HUSSAIN[3]
[1]PG Scholar, Dept of Mechanical Engineering, Nawab Shah Alam Khan College of Engineering and Technology, Hyderabad, India.
[2]Assoc Prof, Dept of Mechanical Engineering, Nawab Shah Alam Khan College of Engineering and Technology, Hyderabad, India.
[3]Asst Prof, Dept of Mechanical Engineering, Nawab Shah Alam Khan College of Engineering and Technology, Hyderabad, India.

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. In this study, 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 autonomyis 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, good 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.

Keywords: Variable Refrigerant Flow (VRF), Outdoor Air (OA), COP, ECM Motors.

I. INTRODUCTION

Variable Refrigerant Flow (VRF) systems, which were introduced in Japan more than 20 years ago, have become popular in many countries, including India. The technology has gradually expanded its market presence, reaching European markets in 1987, and steadily gaining market share throughout the world. In Japan, VRF systems are used in approximately 50% of medium-sized commercial buildings (up to 70,000 ft^2 [6500 m^2]) and one-third of large commercial buildings (more than 70,000 ft^2 [6500 m^2]). Although vigorous marketing of VRF systems in the U.S. began recently, several thousand systems are likely to be sold in the U.S. this year, amounting to tens of thousands of tons of capacity. Of course, the market is still very small compared to the chiller market, but VRF systems are marketed in the U.S. by at least five manufacturers. The success of the VRF in other countries, and its historically limited market presence in the U.S.

A. Definition of Air Conditioning:

Air conditioning is the removal of heat from indoor air for thermal comfort. In another sense, the term can refer to any form of cooling, heating, ventilation, or disinfection that modifies the condition of air. An air-conditioner is an appliance, system, or machine designed to change the air temperature and humidity within an area (used for cooling as well as heating depending on the air properties at a given time), typically using a refrigeration cycle, but sometimes using evaporation, commonly for comfort cooling in buildings.

B. Types of Air Conditioning Systems:

1 Unitary Heat Pumps and Air Conditioners
2 Evaporative Cooling Systems
3 Air Conditioning System
4 Evaporative coolers
5 Evaporative cooling
6 Split systems
7 Add-on cooling
8 Ducted cooling

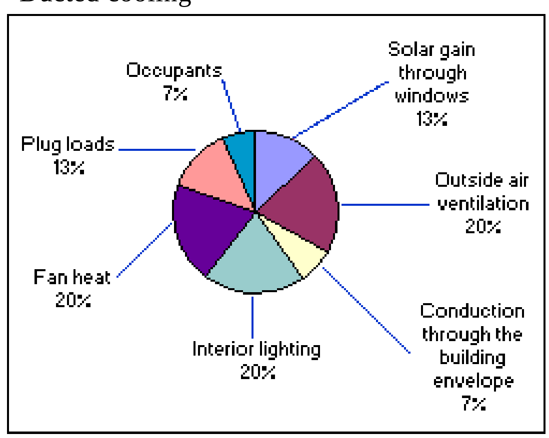

Fig1. Breakdown of Cooling Loads in a Commercial Office Building in the Phoenix Area.

II. AIR CONDITIONING SYSTEMS

A. Reversed Carnot Cycle T/S & PV diagram, COP

Reversed Carnot cycle is shown in Fig below. It consists of the following processes. **Process a-b:** Absorption of heat by the working fluid from refrigerator at constant low temperature T2 during isothermal expansion.

Process b-c: Isentropic compression of the working fluid with the aid of external work. The temperature of the fluid rises from T2 to T1.

Process c-d: Isothermal compression of the working fluid during which heat is rejected at constant high temperature T1.

Process d-a: Isentropic expansion of the working fluid. The temperature of the working fluid falls from T1 to T2.

Practically, the reversed Carnot cycle cannot be used for refrigeration purpose as the isentropic process requires very high speed operation, whereas the isothermal process requires very low speed operation

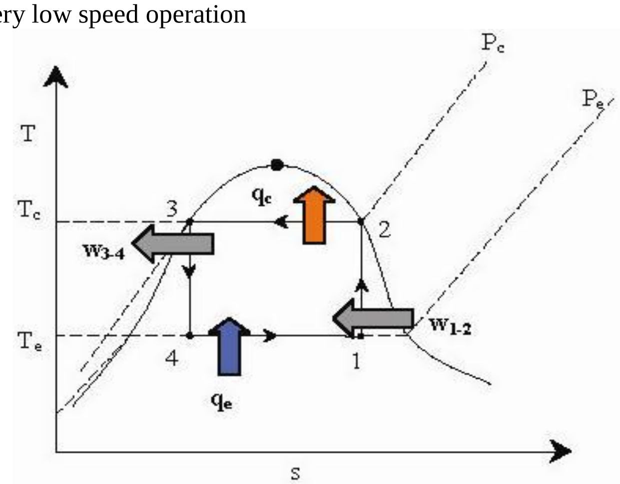

Fig2. Reversed Carnot cycle.

There are various types of air conditioners like window air conditioner, split air conditioner, packaged air conditioner and central air conditioning system. This series of articles describes all types of air conditioners.

B. Types of Air Conditioning Systems

1. Window Air Conditioning System
2. Split Air Conditioner System
3. Central Air Conditioning Plants
4. Packaged Air Conditioners.

C. The Working Principle of Central Air Conditioner

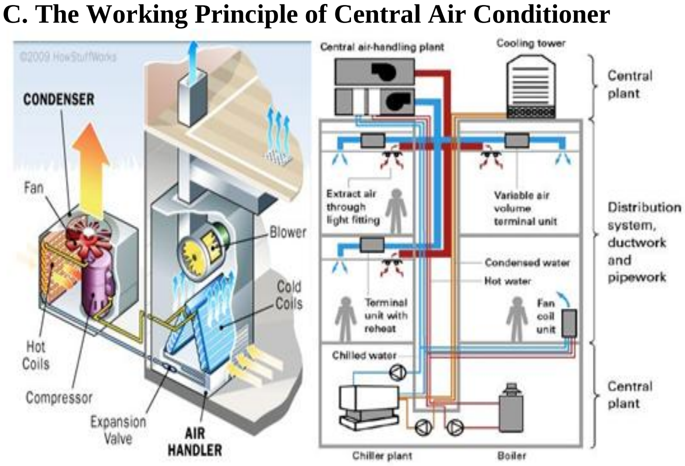

Fig2. Central Air Conditioning & Heating System.

D. Working of Air-Conditioners

Air conditioners and refrigerators work the same way. Instead of cooling just the small, insulated space inside of a refrigerator, an air conditioner cools a room, awhile house, or an entire business. Air conditioners use chemicals that easily convert from a gas to a liquid and back again. This chemical is used to transfer heat from the air inside of a home to the outside air. The machine has three main parts. They are

- Compressor,
- Condenser and
- An evaporator

The compressor and condenser are usually located on the outside air portion of the air conditioner. The evaporator is located on the inside the house, sometimes as part of a furnace. The working fluid arrives at the compressor as a cool, low-pressure gas called Freon. The compressor squeezes the fluid. This packs the molecule of the fluid closer together. The closer the molecules are together, the higher its energy and its temperature. The working fluid leaves the compressor as a hot, high pressure gas and flows into the condenser. If you looked at the air conditioner part outside arouse, look for the part that has metal fins all around. The fins act just like radiator in a car and help the heat go away, or dissipate, more quickly. When the working fluid leaves the condenser, its temperature is much cooler and it has changed from a gas to a liquid under high pressure. The liquid goes into the evaporator through a very tiny, narrow hole. On the other side, the liquid's pressure drops. When it does it begins to evaporate into a gas. As the liquid changes to gas and evaporates, it extracts heat from the air around it. The heat in the air is needed to separate the molecules of the fluid from a liquid to a gas. The evaporator also has metal fins to help in exchange the thermal energy with the surrounding air. By the time the working fluid leaves the evaporator, it is a cool, low pressure gas. It then returns to the compressor to begin its trip all over again. Connected to the evaporator is a fan that circulates the air inside the housetop blow across the evaporator fins. Hot air is lighter than cold air, so the hot air in the room rises to the top of a room. There is a vent there where air is sucked into the air conditioner and goes down ducts. The hot air is used to cool the gas in the evaporator. As the heat is removed from the air, the air is cooled. It is then blown into the house through other ducts usually at the floor level. This continues over and over and over until the room reaches the temperature you want the room cooled to. The thermostat senses that the temperature has reached the right setting and turns off the air conditioner. As the room warms up, the thermostat turns the air conditioner back on until the room reaches the temperature.

E. Components of A/C Systems

A typical refrigeration system consists of several basic components such as compressors, condensers, expansion devices, evaporators, in addition to several accessories such as controls, filters, driers, oil separators etc. For efficient operation of the refrigeration system, it is essential that there be a proper matching between various components. Before analyzing the balanced performance of the complete system, it is essential to study the design and performance characteristics of individual components. Except in special applications, the refrigeration system components are standard components manufactured by industries specializing in individual components. Generally for large systems, depending upon the design specifications, components are selected from the manufacturers' catalos and are assembled at site. Even though most of the components are standard off-the-shelf items, sometimes components such as evaporator may be made to order. Small capacity refrigeration systems such as refrigerators, room and package air conditioners, and water coolers are available as complete systems. In this case the manufacturer himself designs or selects the system components, assembles them at the factory, tests them for performance and then sells the complete system as a unit.

III. VARIABLE REFRIGERANT FLOW

Variable Refrigerant Flow (VRF) systems, which were introduced in Japan more than 20 years ago, have become popular in many countries, yet they are relatively unknown in the United States. The technology has gradually expanded its market presence, reaching European markets in 1987, and steadily gaining market share throughout the world. In Japan, VRF systems are used in approximately 50% of medium-sized commercial buildings (up to 70,000 ft^2 [6500 m^2]) and one-third of large commercial buildings (more than 70,000 ft^2 [6500 m^2]). Although vigorous marketing of VRF systems in the U.S. began only two to three years ago, several thousand systems likely will be sold in the U.S. this year, amounting to tens of thousands of tons of capacity. Of course, the market is still very small compared to the chiller market, but VRF systems are marketed in theU.S. by at least five manufacturers. The success of the VRF in other countries, and its historically limited market presence in the U.S., has several sources, including: Differences in construction practices.

A. VRF Benefits

VRF systems have several key benefits, including:

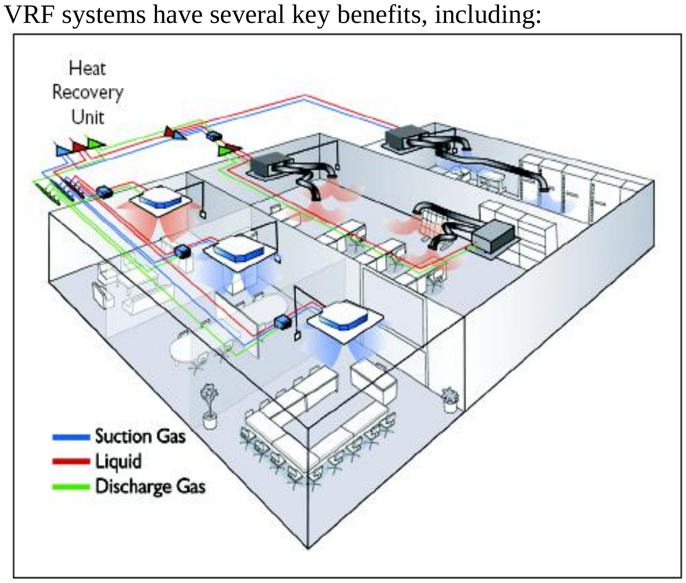

Fig3. Heat recovery VRF system.

Installation Advantages: Chillers often require cranes for installation, but VRF systems are lightweight and modular. Each module can be transported easily and fits into a standard elevator. Multiples of these modules can be used to achieve cooling capacities of hundreds of tons. Each module (or set of two) is an independent refrigerant loop, but they are controlled by a common control system. The modularity also enables staged, floor-by-floor installations, for example, if a building is only partly occupied, which is similar to currently available self-contained VAV systems. The improved efficiency of the newest VRF systems compared to older generations is due to component changes such as variable speed fan motors and compressors that use ECM motors. The chiller efficiency is higher than that of the VRF only at >90% load, but 80% of the chiller operating hours occurred at 45% to 80% load. Variable speed compressors in chillers are now common, but other components such as pumps are often single speed.

B. Applications

VRF systems are generally best suited to buildings with diverse, multiple zones requiring individual control, such as office buildings, hospitals, or hotels. A VRF system does not compete well with rooftop systems in a large low-rise building such as a big box retail store. Although VRF heat pumps operate at ambient temperatures as low as 0°F (–18°C), as in all heat pumps, their efficiency drops off considerably at low temperatures, so they are less cost effective compared to gas heating in very cold climates.

C. TRNSYS

TRNSYS (pronounced 'Tran-sis') is an extremely flexible graphically based software environment used to simulate the behavior of transient systems.

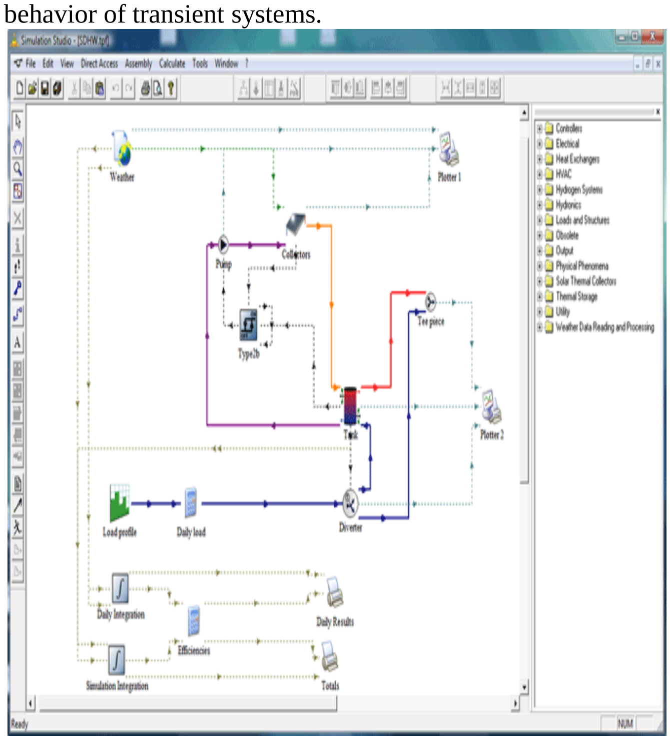

Fig4. Simulation model.

While the vast majority of simulations are focused on assessing the performance of thermal and electrical energy systems, TRNSYS can equally well be used to model other dynamic systems such as traffic flow, or biological processes. TRNSYS is made up of two parts. The first is an engine (called the kernel) that reads and processes the input file, iteratively solves the system, determines convergence, and plots system variables. The kernel alsoprovides utilities that (among otherthings) determine thermo physicalproperties, invert matrices, perform linear regressions, and interpolate external data files. Finally, simulation results are discussed and conclusions are made.

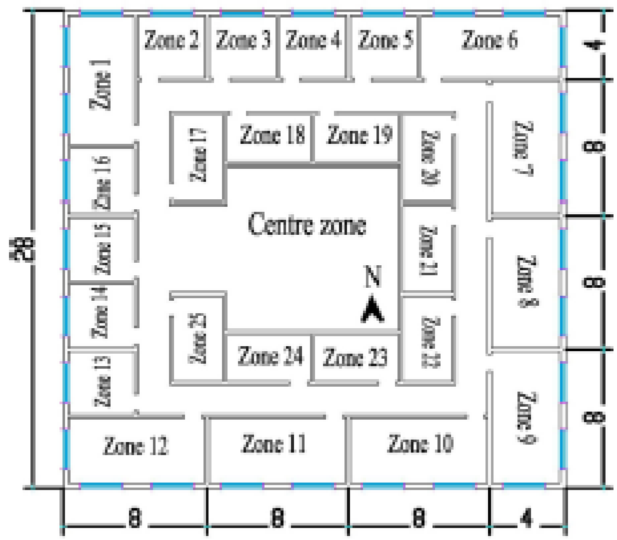

Fig5. Typical floor plan of the building.

D. Building And Combined System 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 normal floor area is appeared in Fig1, and an outline of the key boundaries of the structure is given in Table1, while the development material properties are recorded.

Table:1

Item	Description
Building location	India, China
Building type and storeys	Office building, 6-story above ground
Gross floor area (air conditioned area)	4700 m2
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

E. Combined system description and control designing

A schematic diagram of the proposed combined system is shown in Fig6.

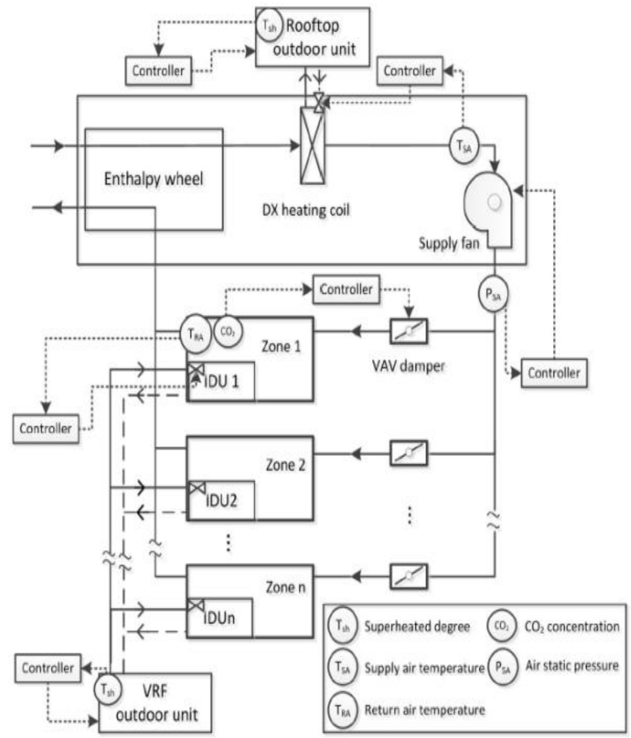

Fig6. Schematic and control designing of the combined system.

IV. SIMULATION OF THE COMBINED SYSTEM

A. Parameter and setting

For the prototype building (Fig7), it is a common practice to bring the supply outdoor air in zones 1–16, which are mostly offices, and then let the air go through the door grills (overflowing) to zones 17–25, which are mostly auxiliary rooms (equipment rooms, toilets,etc.), where the exhausted air is removed from the building. In this way, the flow-back from the toilets (unpleasant smells) and the heat load from equipment can be prevented. It needs a reasonable design of the indoor pressure and duct system for practical applications. In this paper, however, as it mainly focuses on two issues, i.e. to propose and test the simulation models for heating mode considering that there is no available simulation tool, and to have a preliminary knowledge about the system performance under combined control of the VRF part and the outdoor air processing part, only part of the floor plan, i.e. not all of the zones, are served by the simulated combined system. Zones 7–12 are selected due to good representing of internal and external factors such as orientations, radiations, etc. The heat generated by the light and the equipment are designed the same for each zone. Fig7 depicts schedules of the light and the equipment. The light schedule (0–1) describes the possibility of maximum lighting load to mimic those offices with intensive light that one can turn some of them on and off conveniently.

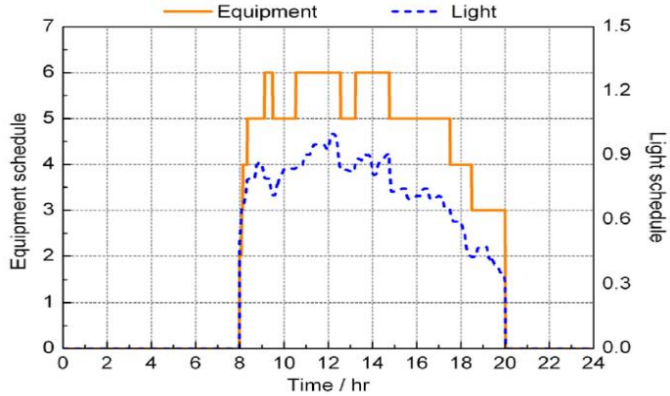

Fig7. Schedules of light and equipment.

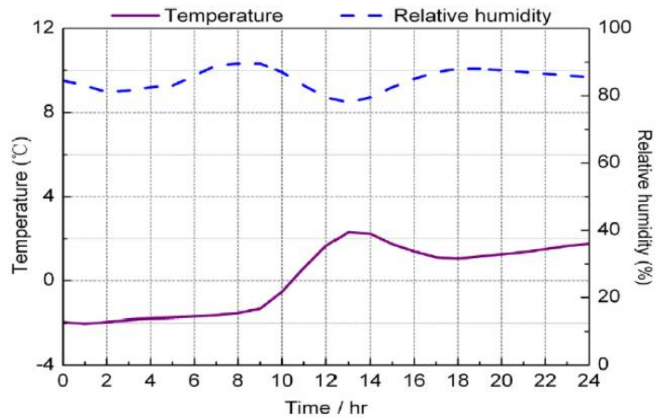

Fig8. Weather profile of 16th Jan for India.

However, the occupant varies in each zone, which results in the difference of the heating load of the zones. 16th January of India TMY (Typical Meteorological Year) weather profile, shown in Fig8, is chosen for the simulation. The average ambient temperature and relative humidity are 0.11 .C and 84.8% respectively.

V. RESULTS AND DISCUSSION

Two cases, the same and different set-points of the zones temperature, are carried out for studying the performances of the combined system.

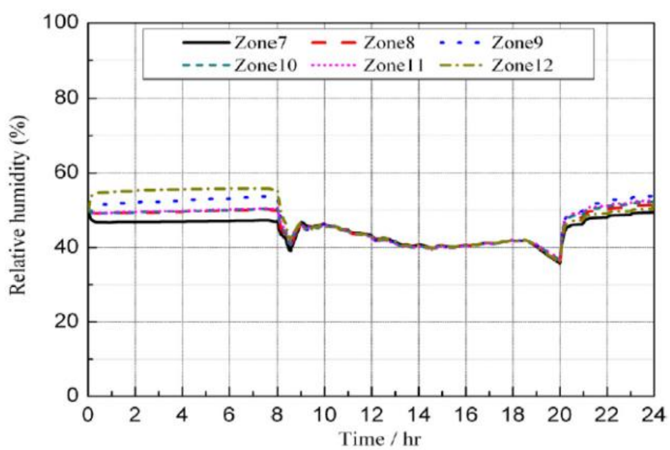

Fig9. Zone temperature result in the case of the same set-point.

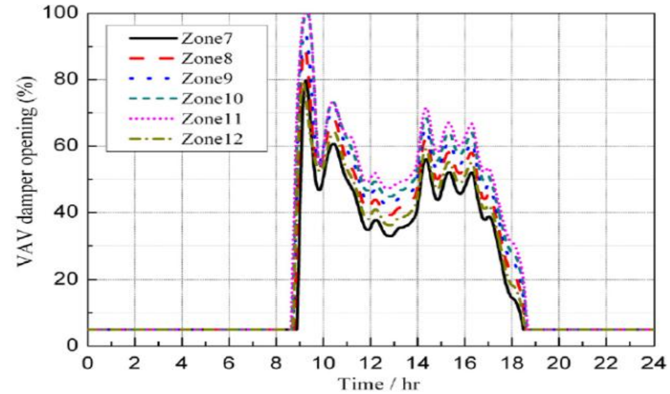

Fig10. Opening of the VAV dampers.

A. Zone temperature and humidity

- For the case of the same set-points of the zones temperature, the set-points of the 6 zones are all 22 ^{o}C.
- The OA supply temperature set-point is 22 ^{o}C as well. Figs9 and 10 show the simulation results of the temperature and relative humidity of the zones respectively.
- All the zone temperatures are well controlled that the deviations are all smaller than 0.5^{o}C except the start-up periods. In one hand, it indicates that the heating capacity meets the heating load in this condition. In the other hand, it also shows that very good control performances of the system are obtained.

B. Outdoor airflow and IAQ

The OA flow is regulated according to CO_2 concentration, which is used as the indicator of the IAQ of the zones. The CO_2 concentration upper limit, called IAQ-limit here, is 1000 ppm. The OA mass flow rate, as well as the CO_2 concentration, mainly depending on the variation of occupants in this paper, is independent of the zone temperature and the relative humidity. Therefore, the OA mass flow rate of the combined system under the case of either the same or different set-points is the same neglecting the calculation error. The OA mass flow rate and supply air temperature are shown in Fig11.

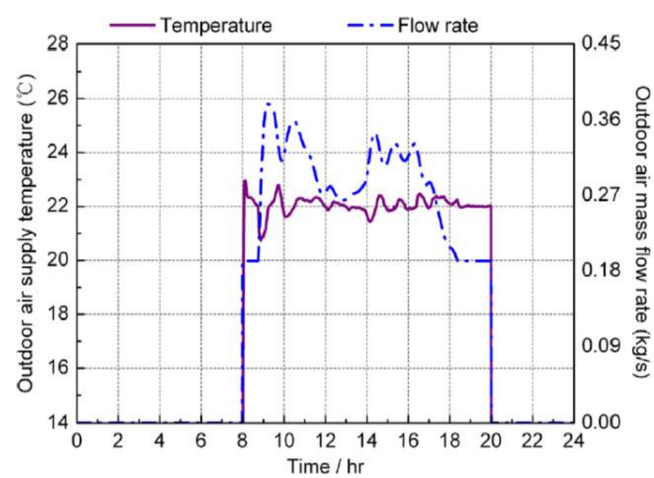

Fig11. OA mass flow rate and supply air temperature.

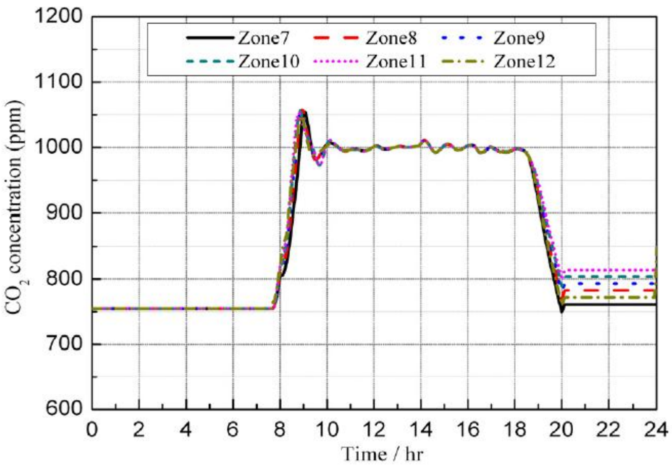

Fig12. CO_2 concentration of the zones.

VI. CONSLUSION

This project presents a simulation of a new air conditioning system combining VRF with OA processing unit in heating mode. After the illustration of the combined system and its control strategies, simulation models are developed and validated. The simulation model is validated using the experimental data reported in literatures. The simulation model accuracy to predict daily heating capacity, energy consumption and COP are about 7.87%, 12.45%, 6.19%, respectively. Moreover, it is found that when the accuracy of heating capacity is increased or decreased, the accuracy of simulated energy consumption is also increased or decreased following, which indicates that more attention should be paid on the relative error difference between the heating capacity and energy consumption, rather than the relative error itself. The simulation test results show that all the zones of the combined system can be maintained at their speci.c set-points, and the controls are also stable no matter the set-points change or not. Meanwhile, the indoor CO2 concentration of all zones can be well controlled below the limit to maintain acceptable IAQ. As the OA proportions are continuously monitored and controlled according to the demand, over ventilation is avoided and eventually the energy can be saved in the combined system.

VII. FUTURE WORKS

In this work, only the performance of the combined system under basic control strategies is simulated and analyzed. Future work could be carried out in several aspects such as optimal control of the combined system and comparison with other air conditioning systems, etc. In addition, the application of the combined system for the entire floor is also valuable for further researching.

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Author's Profile:

Md Tarique Anwar, have completed B.Tech (Mechanical Engineering) from JNTUH and have done Major Project on Air Conditioning Using Radiant Cooling System.Presently doing M.E(HVAC) from Nawab Shah Alam Khan College of Engineering and Technology, Hyderabad.