Analysis of the Energy-Saving Potential of a Three-Rotary Wheel Fresh Air-Handling Unit

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Abstract : To evaluate the energy-saving potential of a proposed three-rotary wheel fresh air-handling unit (TRWFAHU), it is numerically simulated with weather data of Changsha by using a mathematical model. Compared with a conventional fresh air-handling unit, TRWFAHU can save 10.2% of primary energy and greatly decrease the energy consumption of chiller. If waste heat is available for regenerating the desiccant, the system can achieve greater energy savings. It is feasible to improve indoor air quality (IAQ) by increasing ventilation while without increasing energy consumption.

Keywords: TRWFAHU; Mathematical model; Numerical simulation; Energy saving; IAQ

1 INTRODUCTION

Comprehensive field investigations show that improving indoor air quality (IAQ) can improve the occupants' working and learning performance as well as decreasing their risks of illness [1-4]. Therefore, creating a comfortable and healthy indoor environment for occupants can bring about enormous potential benefits for society. Indoor air quality is closely related to ventilation rate. Increasing ventilation rate can improve indoor air quality and consequently improve productivity and promote health of occupants. However, increasing ventilation rate usually brings about more energy consumption and thus a very high energy costs. In developed country, approximately one-third of the primary energy is consumed by the space conditioning system. And a great part of this energy consumption is used for outdoor air handling. Depleting energy resources, deteriorating environmental quality and rising energy cost often make it prohibitive to increase ventilation rate. Therefore, it is desirous to develop new technologies which can provide buildings with more outdoor air while without increase of energy use. For the purpose of increasing ventilation rate but without increasing energy consumption, a novel fresh air handling unit, three-rotary wheels fresh air handling unit (TRWFAHU), was proposed[5]. With a mathematical model, the energy saving potential of the proposed AHU is numerically investigated with annual weather data of Changsha in this paper.

2 PRINCIPLE OF THREE-ROTARY WHEELS FRESH AIR HANDLING UNIT

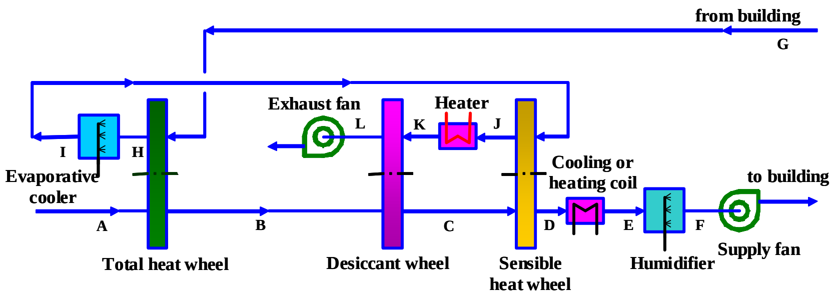

Fig.1 Schematic of three-rotary wheels fresh air handling unit

Fig.1 is the schematic diagram of a three-rotary wheels fresh air handling unit (TRWFAHU). In this unit, the total heat wheel is used for recovering the cool or heat energy from exhaust air to handle the outdoor air preliminarily. The desiccant wheel is for the purpose of dehumidifying incoming air while without overcooling of supply air. Sensible heat wheel is used for cooling incoming air with exhaust air to save cooling energy consumption. The three rotary wheels are all in operation under summer mode while only the total heat wheel works and the two others will be turn off under winter mode.

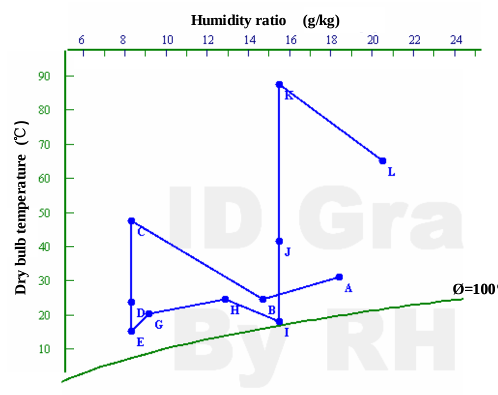

Fig.2 Psychrometric processes under summer operation mode

Fig.2 shows the psychrometric processes of three-rotary wheels fresh air handling unit under summer operation mode. Ambient air at state A firstly flows through a total heat recovery wheel where it transfers heat and moisture into exhaust air. Precooled and predehumidified incoming air at state B is deeply dried by desiccant wheel and is simultaneously heated by latent heat released by moisture and sensible heat transferred by desiccant wheel. Then, dried and hot air at state C is sensibly cooled preliminarily by exhaust air via sensible heat wheel and secondarily by chilled water via cooling coil. After that, the cold and dry fresh air at state E is transported by supply fan and distributed into conditioning space via diffusers. After absorbing the building latent load and small amount of sensible load, the air is exhausted. Exhaust air at state G firstly entries into total heat wheel where it is heated and humidified by supply air and then flows through an evaporative cooler where it is cooled and humidified. The cold and wet exhaust air at state I is preheated to state J by the sensible heat wheel. To regenerate desiccant, exhaust air at state J is then heated to higher temperature by a heater. After regenerating desiccant, warm and humid air at state L is exhausted to the surrounding.

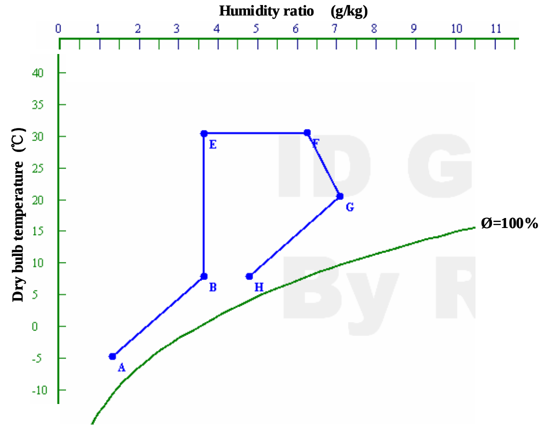

Fig.3 Psychrometric processes under winter operation mode

Different from summer operation, desiccant wheel doesn't work in winter due to no requirement for dehumidification. In addition, sensible heat wheel, heater, and evaporative cooler will also be turn off to save energy. Fig.3 shows the psychrometric processes in winter. Cold and dry outdoor air at state A is firstly preheated and prehumidified by exhaust air from building via total heat wheel. Preheated and prehumidifed fresh air is then heated by heating coil from state B to state E. According to demand for supply air, fresh air is humidified by humidifier from state E to state F and then is transported into building by supply fan to meet the requirement for space conditioning. Suctioned by exhaust fan, exhaust air flows through total heat wheel where part of its thermal energy is recovered and is finally released into surrounding air.

3 SIMULATION OF THREE-ROTARY WHEELS FRESH AIR HANDLING UNIT

To simulate the operation of the proposed AHU and evaluate its energy saving potential, the three-rotary wheels fresh air handling unit is annually simulated using proposed mathematical model [5]. The weather data of Changsha, the capital of Hunan Province in China, is used in this case study. The critical outdoor air dry bulb temperature in Changsha is up to 39 in summer and is 0 in winter. The critical outdoor air humidity ratio is 28g/kg in summer and 1g/kg in winter. The annual mean outdoor air dry bulb temperature and humidity ratio are 17.4   and 10.6g/kg respectively. Fig.4 and Fig.5 show the hourly variations of outdoor air dry bulb temperature and humidity ratio, respectively.

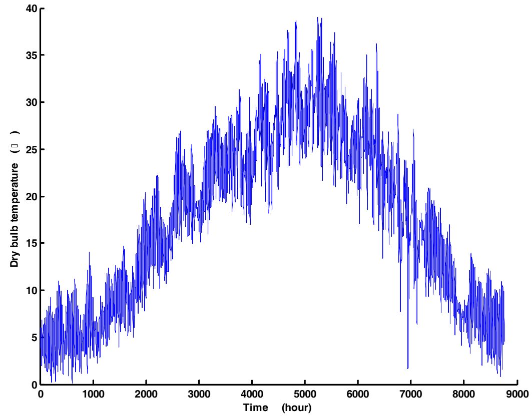

Fig.4 Hourly variations of outdoor air dry bulb temperature in Changsha

The designed indoor air condition is dry bulb temperature of 25   and relative humidity of 50% in summer and dry bulb temperature of 20   and relative humidity of 50% in winter. Supply air temperature is 17   in summer with a supply air temperature difference of 8   and is 30   in winter with a supply air temperature difference of 10 . To save energy, AHU is turn off if outdoor air state is between designed winter indoor air condition and designed summer indoor air condition.

Sensible heat recovery effectiveness and moisture recovery effectiveness of the total heat wheel is assumed to be 0.8 and 0.7 respectively. Sensible heat exchange effectiveness of the sensible heat wheel is 0.85. Saturation effectiveness of evaporative cooler is 0.9. According to analysis result of Niu and Zhang, an optimized desiccant wheel can achieve an effectiveness η_{f1} of 0.3 and an effectiveness η_{f2} of 0.85 [6]. The heater and coil is assumed to be well sized and controlled to meet the requirement for heating or cooling of reactive air or process air. Humidifier is also assumed to be well designed to content the demand for humidifying of air.

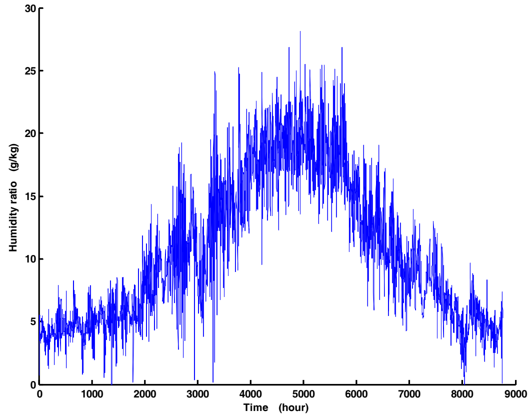

Fig.5 Hourly variations of outdoor air humidity ratio in Changsha

To evaluate the energy saving potential of TRWFAHU, conventional fresh air handling unit (CFAHU) is investigated and compared with the presented system. The schematic diagram and the air handling process of conventional AHU are shown in Fig. 6 and Fig.7 respectively. In conventional AHU, the supply air parameters are the same as those in three-rotary wheels fresh air handling unit.

Energy required by the primary equipments is calculated with constant indexes of performances: the COP of chiller is 3.31; the boiler efficiency is 0.85 and fan efficiency is 0.8; the pressure rise of fan is 1400Pa. In comparing total energy consumption, electricity consumption is converted into equivalent primary energy by multiplying a factor of 3. The energy used by motor driving rotary wheels is neglected. Energy consumed by pumps is thought to be equal.

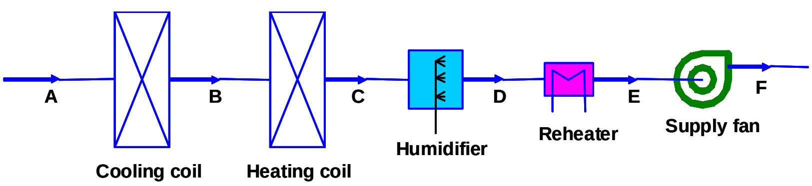

Fig.6 Schematic diagram of conventional AHU

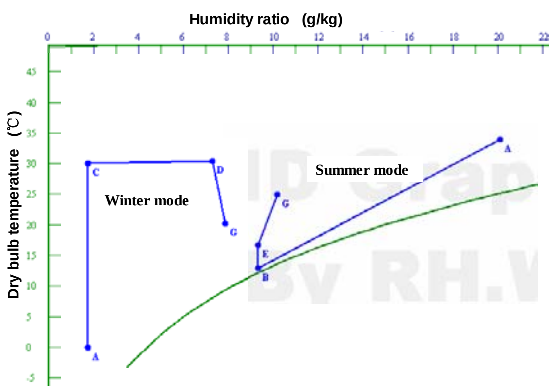

Fig.7 Psychrometric processes of conventional AHU

4 RESULT AND DISCUSS

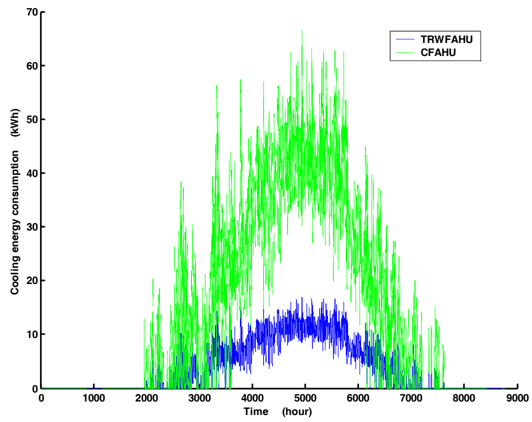

Fig.8 Hourly cooling energy consumptions per kilogram air of two different kinds of AHU

Fig.8 shows hourly cooling energy consumption per kilogram air of the two kinds of AHU. From Fig.8, it can be found that the presented AHU can greatly decrease cooling energy consumption compared with conventional AHU and thus TRWFAHU can help in shaving electricity peak load caused by comprehensive application of electricity-driven chiller. Cooling capacity saving mainly benefits from the utilization of three rotary wheels, which can fully recover cooling energy from exhaust air while avoiding overcooling of supply air. Besides saving cooling energy, the presented AHU can almost save half of heating energy of conventional system, which is illustrated by Fig.9. Fig.10 shows hourly regenerating energy consumption of three-rotary wheels fresh AHU and reheating energy consumption of conventional fresh AHU. Though TRWFAHU can save much cooling energy in summer, it also consumes much thermal energy to regenerate desiccant, which can discount the energy saving potential of TRWFAHU. If waste heat, such as exhaust of combined heating and power (CHP) system, can be used to regenerate desiccant, energy saving potential of presented system will be greater.

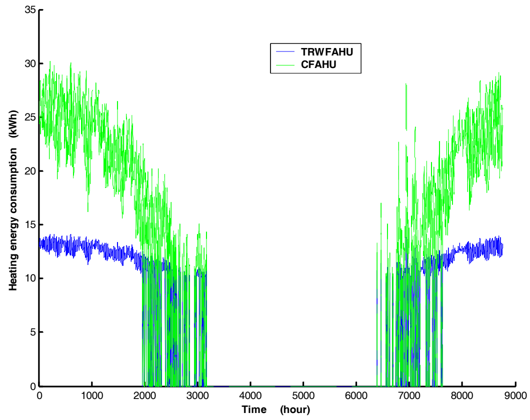

Fig.9 Hourly heating energy consumptions per kilogram air of two different kinds of AHU

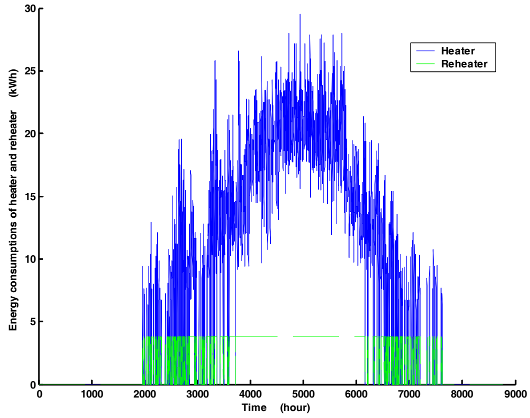

Fig.10 Hourly energy consumptions per kilogram air of heater and reheater

Fig.11 compares the yearly total energy consumption per kilogram air of primary equipments. Compared to conventional AHU, three-rotary wheels fresh AHU can save 73.4% of chiller energy while increase 12.4% of boiler energy and about one time of fan energy, which results in a total primary energy saving of 10.2%. It means that it can increase ventilation rate by 10%, thus can improve indoor air quality, without increase of energy consumption if the presented AHU is used to handle fresh air. Moreover, electricity consumed by presented system is about 28.9% less than that by conventional system. If waste heat can be utilized to regenerate desiccant in summer, the three-rotary wheels fresh AHU can save up to 38.6% of primary energy in comparison with conventional AHU.

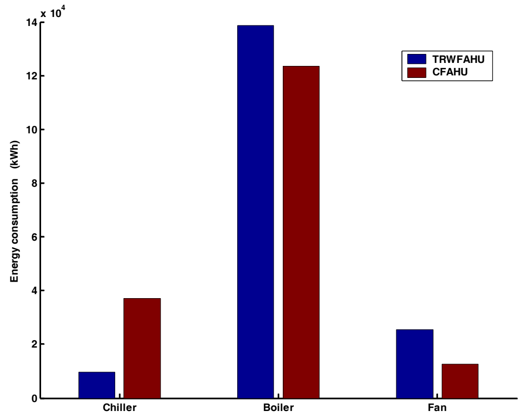

Fig.11 Comparison of yearly total energy consumptions per kilogram air of primary equipments

5 CONCLUSIONS

The proposed fresh air handling unit is numerically investigated and compared with conventional fresh air handling unit. Compared with conventional system, the novel AHU can save 10.2% of primary energy. If low temperature waste heat is available to regenerate desiccant, the proposed AHU can achieve a primary energy saving of up to 38.6%. In addition, TRWFAHU is helpful in shaving summer peak electricity load due to greatly reduce energy consumption of chiller.

The proposed AHU is feasible in hot and humid climate like Changsha. With this fresh air handling unit, it can increase fresh air rate by 10% while without increase of energy consumption. Therefore, the presented three-rotary wheel fresh air handling unit is beneficial for improving indoor air quality.

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