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The energy saving performance of heat recovery ventilation system in residential buildings in the summer of hot-summer and cold-winter zone in China

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ABSTRACT
The rapid increase in space cooling and heating demand in recent years in the hot-summer and cold-winter (HSCW) zone in China (the most developed area in China) requires technology to be as efficient as possible, consuming the lowest amount of energy necessary. Heat recovery ventilation (HRV) system can meet this demand by lowering the building energy demand by pre-heating or pre-cooling. However, the climate in HSCW zone is humid and rainy all the year round, which may affect the energy performance of HRV system. The current research focuses on field measurements of the performance of HRV system in a test building located in east China to study the actual energy saving performance of the HRV system in the HSCW zone. The actual performance of the HRV system is measured. The experiment reveals that the system can save 14.5% of air-conditioning energy consumption in summer and 4.96% of air-conditioning energy consumption during rainy season. There is no significant energy saving effect in transition seasons. EnergyPlus is used to calculate the energy performance of the HRV system under different operating conditions. The simulation is compared with the test data. Both the measurements and simulation indicate that the use of HRV system can significantly reduce the energy consumption of the air-conditioned buildings in summer in HSCW zone.

KEYWORDS
Heat recovery ventilation; Energy-saving; Field measurement

INTRODUCTION

Improving indoor air quality and reducing building energy consumption have become an important area of research in architecture and related disciplines. Good indoor air quality is a guarantee for the health, comfort and productivity of occupants. The introduction of fresh air into room is one of the necessary conditions to improve indoor air quality [1]. However, the introduction of fresh air may result in a large fresh air cooling/heating load. There is a contradiction between the improvement of indoor air quality and the reduction of building energy consumption. Setting up a heat recovery system to exchange heat between fresh air and indoor exhaust air, and preheating or precooling the fresh air to reduce the heating or cooling load is an effective energy saving measure.

Many studies have been carried out to study the energy-saving effect of the heat recovery ventilation (HRV) system. For example, Roulet et al. [2] developed the evaluation method of heat recovery effect for different countries and regions based on energy gain method. However, the research on the energy-saving effect of HRV system for hot summer and cold winter zone in China mainly based on theoretical calculation or numerical simulation. Few experimental verifications have been carried out. Taking a library in Shanghai as an example, Feng[3] calculated hourly energy recovery of HRV system and obtained energy-saving heat recovery modes and air conditioning modes for different conditions during the whole year.

The HSCW zone is one of the most developed areas in China, which has a hot and humid summer and a mild winter. Cooling is required through the summer season, but there is no central heating in winter. It is of great importance to verify the applicability of HRV system in summer in this area. Field measurements of the energy performance of HRV system in a test building located in east China has been carried out in this research. Results from experiments and numerical simulation have been compared and discussed in the paper.

METHODS

Evaluation method of heat recovery ventilation system

This paper selects HRV system with plate-type enthalpy exchanger as the research object. This exchanger is more suitable for the residential buildings and the HSCW zone.

·Heat transfer efficiency

The evaluation index system of heat recovery unit includes several important performance indexes, and the heat transfer efficiency [4] is one of them. The heat transfer efficiency includes three different types. The formula is shown in Table 1 as follows.

Table 1 Calculation formula of different heat transfer efficiency

Heat transfer efficiency	
Sensible heat recovery	$\eta_{ts} = \dfrac{m_s(t_2 - t_1)}{m_{\min}(t_3 - t_1)}$
Latent heat recovery	$\eta_{ds} = \dfrac{m_s(d_2 - d_1)}{m_{\min}(d_3 - d_1)}$
Enthalpy recovery	$\eta_{is} = \dfrac{m_s(h_2 - h_1)}{m_{\min}(h_3 - h_1)}$

Where t is dry-bulb temperature (°C), d is moisture content (g/kg) and h is enthalpy (kJ/kg). Subscript s means fresh air; 1 means supply-in air; *2* means supply-out air; *3* means exhaust-in air;4 means exhaust-out air.

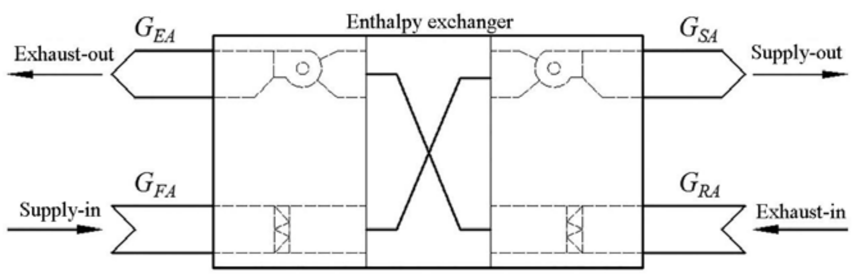

Figure 1 Energy test principle diagram of ventilation system

·Energy-saving evaluation method

According to the above enthalpy transfer efficiency, the heat energy recovered from HRV system is related to the fresh air volume, the enthalpy efficiency of the device, the enthalpy difference of air and the density of fresh air[5] Calculation formula for heat recovery is as follows:

$$E = G\eta\rho(h_3 - h_1) \tag{1}$$

Where, E is the energy recovered by HRV system (kW), G is the fresh air volume (m^3/s), η is the enthalpy efficiency of heat recovery unit, ρ is air density (kg/m^3).

When HRV system is running, the resistance of the recovery system is increased and the energy consumption is increased. The energy consumption of HRV system is mainly produced by the fan, so the energy consumption energy of the fan is used as the energy consumption energy of HRV system. The formula is as follows:

$$W = \frac{(G_1 + G_2)\triangle p}{\eta_f} \tag{2}$$

Where, G_1 is the supply-in air volume through HRV system (m^3/s), G_2 is the exhaust-out air volume through HRV system (m^3/s), Δp the resistance of the air through HRV system (kPa), η_f is the fan efficiency. The energy consumption is converted to cooling / heating production

$$E' = W \cdot COP \tag{3}$$

$$W = \frac{(G_1 + G_2)\triangle p}{\eta_f} \tag{4}$$

When and only E '< E HRV system is energy-saving, and the amount of cold (heat) recovery is Q=E- E'.

Experimental study

·The general information of the experiment site and the fresh air HRV system

The building used in the test is located in the Wujin District of Changzhou, Jiangsu province (HSCW). The test apartment consists of three main functional areas of the living room, the bedroom and the kitchen to simulate the ordinary residential space. The HRV system used in this test is plate-type HRV. The rated air volume is 250m^3/h, and the power of the fan is 80 W/h. Heating and cooling of the experimental residential are applied by the VRF system. The rated cooling capacity is 33500W. The rated heating capacity is 37500W.The COP coefficient is 6.0.

Figure 2 The test building

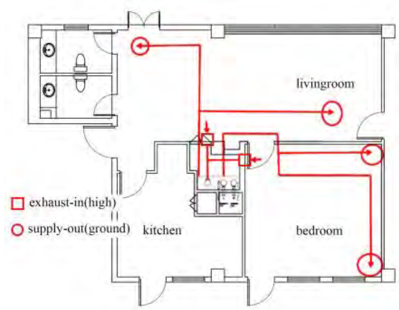

Figure 3 The plan of test apartment

·Experiment instrument and process

Main experimental instruments:

(1) temperature and humidity recorder(testo-174H)
 Accuracy Temperature:±0.5°C(-20~+70°C);
 Accuracy Humidity: ±3% RH(2% RH~98%RH);

(2) hot ball anemometer(TSI 9565-p): Accuracy: ±0.015m/s(0m/s~30m/s).

The experiment mainly includes two aspects: (1) to test the performance of the fresh air HRV system, which mainly includes air change rate, heat transfer efficiency, energy of the actual recovery etc.; (2) to measure the actual energy consumption of the test apartment, which includes energy consumption of all systems in the apartment. The heat gain or loss through the building envelope is also measured. Test process [6]~[8] is as follow:

(1) start the HRV system / air conditioning preheating operation for 30min; keep the system running under the steady air volume.
(2) fix the temperature and humidity recorder at a distance of 15cm from the air outlet and inlet; record the data every 5min;
(3) use the hot ball anemometer to measure the air volume of the fresh air fan and record the wind speed of the cross section; calculate the air volume of the duct, and use the air volume hood to measure the air volume of the air conditioner;
(4) Use power meter to test HRV system and air conditioning energy consumption separately;
(5) keep the length of each working condition at the length of 2 hours.

RESULTS

·Experimental results

Air conditioning + mechanical ventilation with fresh air bi-directional flow in summer

HSCW zone is hot and humid in the summer, the daily average temperature is between 25-30ºC, and the highest daily average temperature is over 30℃. The test condition is set as air conditioning temperature 26ºC for cooling mode. The ventilation system keeps stable operation and the HRV system is on. The air enthalpy method is used to test the efficiency and energy consumption of summer air conditioning, and at the same time test the cooling load of the heat transfer, air infiltration and indoor heat source under the condition of air conditioning. The results are shown in Table 2 and 3.

Table 2 Test results of the ventilation system

Ventilation system	Temperature (℃)	Relative humidity (%)	Airflow (m^3/h)	Enthalpy (kJ/kg)	Heat transfer efficiency
Exhaust-in	28.7	58.0	177.7	65.6	0.65(sensible heat)
Supply-in	35.4	63.0	166.3	95.2	0.52(latent heat)
Exhaust-out	33.3	57.5	175.1	86.1	0.55(enthalpy)
Supply-out	31.0	65.2	154.4	78.7	
Bedroom	26.6	48.7	/	/	
Living room	27.8	63.5	/	/	
Outdoor	35.0	58.0	/	/	

Table 3 Test results of the air conditioning

Air-conditioning	Temperature (℃)	Relative humidity (%)	Airflow (m^3/h)	Enthalpy (kJ/kg)	COP
Bedroom（supply）	11.3	92.6	479.2	30.9	2.3
Bedroom（exhaust）	27.1	44.9	/	52.9	
Living room（supply）	22.6	87.2	/	60.9	
Living room（exhaust）	26.2	69.6	1545.0	64.4	
Energy consumption	5.8kwh=20880kJ				

Dehumidification by cooling + mechanical ventilation with fresh air bi-directional flow in plum rain season.

The plum rain season is a continuous phenomenon of rainy days in the middle and lower reaches of China's Yangtze River in June and July. In this period, the relative humidity is always over 90% during the whole month. Therefore, the dehumidification load of the air conditioner is huge. In the test, the condition of air conditioning is set as dehumidification mode, and the ventilation system is on. The results are shown in Table 4 and 5.

Table 4 Test results of the ventilation system

Ventilation system	Temperature (°C)	Relative humidity (%)	Airflow (m^3/h)	Enthalpy (kJ/kg)	Heat transfer efficiency
Exhaust-in	23.4	64.9	175.0	53.3	0.62(sensible heat)
Supply-in	25.6	73.8	165.3	64.7	
Exhaust-out	25.4	67.2	177.1	60.5	0.33(latent heat)
Supply-out	24.2	67.2	152.4	56.7	
Bedroom	22.3	51.4	/	/	0.70(enthalpy)
Living room	22.4	72.	/	/	
Outdoor	23.3	97.0	/	/	

Table 5 Test results of the air conditioning

Air-conditioning	Temperature (℃)	Relative humidity (%)	Airflow (m^3/h)	Enthalpy (kJ/kg)	COP
Bedroom (supply)	10.9	90.7	552.2	29.5	5.8
Bedroom (exhaust)	20.3	65.8	/	45.2	
Living room (supply)	16.9	96.0	/	46.3	
Living room (exhaust)	21.1	78.2	1604.6	55.0	
Energy consumption	3.1kwh=11268kJ				

Simulation of energy consumption by EnergyPlus

Numerical simulation is also carried out in the study. The EnergyPlus model adopted in this paper is built strictly according to the actual size of the test apartment. The indoor air conditioning system is simulated by using the VRF system in EnergyPlus. The modelling of HRV is based on the sensible and latent heat exchange efficiency of the enthalpy exchanger. Air change rate in modelling condition is 0.5. The outdoor conditions for simulation is obtained from the weather station on site.

Simulation results

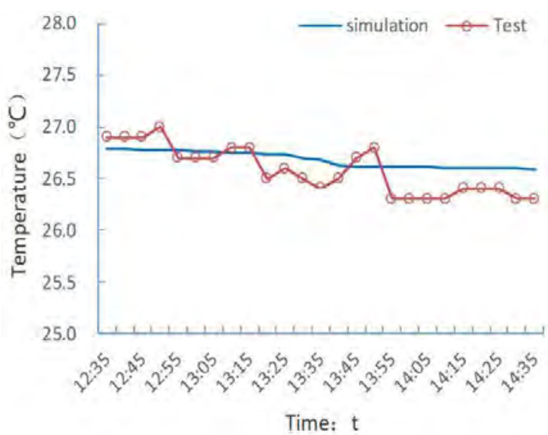

Figure 5 Temperature change curve of bedroom in summer

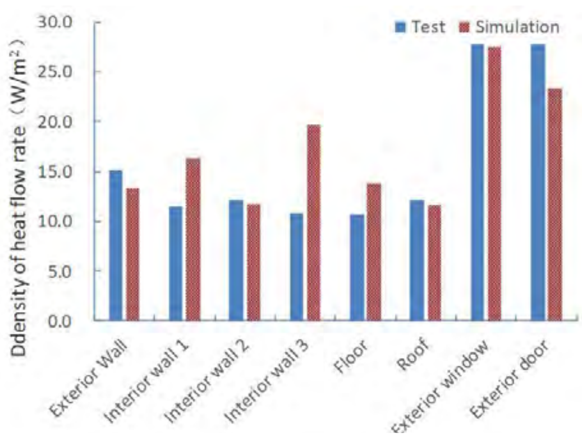

Figure 6 Comparison of average heat flux density of enclosure structure in summer

According to the measured and simulated results, the calculated value and the measured value are in good agreement with the accurate setting of the heat transfer and outdoor weather conditions. The relative error between the measured temperature and the simulated value of bedroom is 0.4%, the relative error of envelope heat transfer is 7%, and the heat transfer error of envelope is related to the actual construction quality and accuracy of the structure. In order to verify the accuracy of the model, a longer verification experiment was conducted during the transition period.

CONCLUSION

The energy consumption of a residential building with HRV system in HSCW zone in China is measured experimentally. The energy saving effect of HRV system in the transitional season, summer season and plum rainy season is analysed(The accuracy of the instrument has a certain influence on the energy saving value.). The numerical model of a typical residential building with HRV system in HSCW zone is also established. The accuracy of the model is verified through the comparison of simulated and experimental results. This research draws the following conclusions:

1) In the summer of the HSCW zone, both indoor temperature and humidity are high, the room requires cooling and dehumidification by air conditioning system. Due to the big difference between the indoor and outdoor enthalpy, fresh air HRV system has a significant effect on the enthalpy recovery. The field measurements show that the HRV system can save energy 7059.68kJ within 2 hours and reduce 14.5% of the cooling load.
2) In the plum rain season, indoor air humidity is very high, which will cause large energy consumption for dehumidification. The fresh air HRV system has a great latent heat recovery effect. The experimental results show that the fresh air HRV system can save energy 3459.92kJ and reduce 4.96% of the dehumidification load within 2 hours.
3) Through the simulation results, it can be seen that the use of HRV system can significantly reduce the energy consumption of the air-conditioned buildings in summer. Compared with the natural ventilation, the energy consumption of the cooling system was reduced by 13.9% in summer after the introduction of the HRV system.
4) In hot summer and cold winter areas, air conditioning needs to be turned on in summer and winter, and the use of HRV system can save more energy.

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