STUDY ON THE CONTROL STRATEGIES AND PARAMETERS FOR CLIMATE RESPONSIVE ELEMENTS

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Abstract

In this paper, thermal characteristics and operating condition of one kind Climate responsive elements so-called Wall-mounted Solar Air Collector (WSAC) was experimentally and theoretically analyzed. Proposed a Optimal operating condition of time-vary Variable Air Volume (VAV) for WSAC with consideration of building energy consumption by studying the relation of solar irradiance and air flow with WSAC transient thermal efficiency and net efficiency. Operation mode of Constant air volume air supply, variable air volume air supply and intermittent air volume air supply was studied in Physical experiments room to explore the WSAC thermal performance and energy-saving effect, results showed that: In considering of the WSAC net efficiency, the operation of variable air volume air supply net efficiency is more than other air supply means, and compare to Constant air volume air supply savings energy 63%, also available a best control operation mode along with the changing of solar irradiance.

1. Introduction

Wall-mounted Solar Air Collector (WSAC）is a building-combined Climate responsive elements. At present, studies on WSAC is mainly focusing on the improvement of single WSAC performance, including heat transfer performance of WSAC itself and structural optimization, etc.[1]~[4] With the deepening research and development of technology in solar thermal and integration of building field, control strategy optimization of heat transport process in building integrated solar air heating system has attracted increasing attention. Researches are mainly in the following perspectives: 1）control strategies in preventing cold air flowing back [5]；2）optimal control of heat transport system[6]；3）optimal and combination control of WSAC mass flow and internal temperature rise [7], etc. By studying on the optimal control of heat transport process, TIAN Hao[5] concluded that under the intermittent mandatory circle, the indoor temperature rising effect of WSAC is obvious. However, he did not propose a suitable operating period of fans and air volume. On this basis, CHEN Bin[6] studied the relationship between thermal supply and mass flow rate of a porous WSAC experimentally and theoretically; and stated that thermal supply under intermittent operating condition was higher than constituent operating condition. However, she failed to conclude the control strategies of major influential factors, for instance, solar irradiance and outdoor temperature. Afterward, SUN Ya-feng[7] studied the intermittent control strategy of porous WSAC, results showed that the average thermal efficiency is high during operating period, however, the indoor temperature fluctuation was large and the best operating point has not been achieved due to the limit in air rate adjustment range of the fan.

Based on the above-mentioned research background, by experiments and theoretical analysis of WSAC's instantaneous efficiency with solar irradiance and the air rate changes, and by introducing the concept of net efficiency, the operating results of porous Variable Air Volume (VAV) control method under actual outdoor weather conditions has been deeply studied.

2. Experiment

2.1. Experiment facilities and test methods s

Experiment facilities are shown as Fig.1. Construction area of the test room is about $9m^2$, WSAC is installed on the north-facing wall. The dimension of WSAC is 2044mm×540mm×120mm. Collector plates are installed in the central of WSAC; they are 1mm-thick white iron plate with type 15-1 holes in; the diameter of the hole is 5mm; the distance between is 5mm. After polished, the specific friction resistance of the surface of white iron plate is increased. The absorbing layer is chosen selective-absorption dark color, whose absorption rate is larger than 0.9, and the emissivity is about 0.45~0.5.

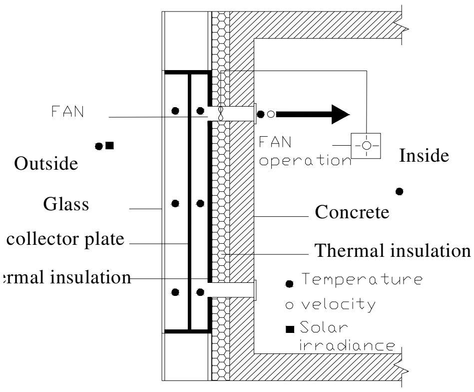

Fig.1 WSAC structure and arrangement of testing points

A centrifugal round pipeline fan (Ck-100A) is installed between WSAC and indoor. The diameter of the pipe is 100mm; rated speed is 1730r/m; maximum air volume is $260m^3/h$; the distance between axis and ground is 1.8m; WSAC is able to change the heat supply by changing air volume supply of the fan. In order to maintain the accuracy of the experiment, logarithm-linear method is used when measuring at the entrance, and when checking the result at the exit. For getting the accurate indoor temperature, thermocouples are set in different places, and are wrapped with sun-shade aluminum foil to enhance the accuracy of experiment result. Testing points have also been set in the indoor side tuyere and inside the WSAC. Meanwhile, outdoor weather data, including solar irradiation, temperature, moisture, air flow rate and wind direction, are collected by PC-3 Portable Weather Station, which can circuit test automatically. All the test data are recorded by circuit testing data system of computer automatically, and data collection time interval is 10 minutes. The whole test is conducted from January to March, 2010.

2.2. Performance test for fans under operating condition

This experiment mainly studies the influence of air volume adjustment on optimizing the thermal characteristics of WSAC, for example, instantaneous thermal efficiency, net efficiency and thermal supply. The whole experiment process is able to be divided into two sections: section one focuses on the variable thermal properties of WSAC under different air volume; based on the studies in section one, section two mainly analyzes WSAC’ s property of air supplying by choosing reasonable air volume supply.

3. RESULTS AND DISCUSSION

3.1. WSAC Thermal performance Analysis

3.1.1 Transient thermal efficiency

The regulation of WSAC’s air supply rate is 4 successive calibration of Fan stall air supply rate, which is $43m^3/h$、$86m^3/h$、$105m^3/h$ 和 $154m^3/h$, respectively. The transient thermal efficiency is calculated as equation (1)[8]：

$$\eta = \frac{mc_p(T_{out} - T_{in})}{A*G} \qquad (1)$$

Where

G: Transient solar radiation(W/m^2)

T_{out}: the WSAC outlet temperature(℃)

T_{in}: the WSAC inlet temperature(℃)

m: mass flow rate(kg/s)

c_p: specific heat capacity (J/(kg ·℃))

A: WSAC area (m^2)

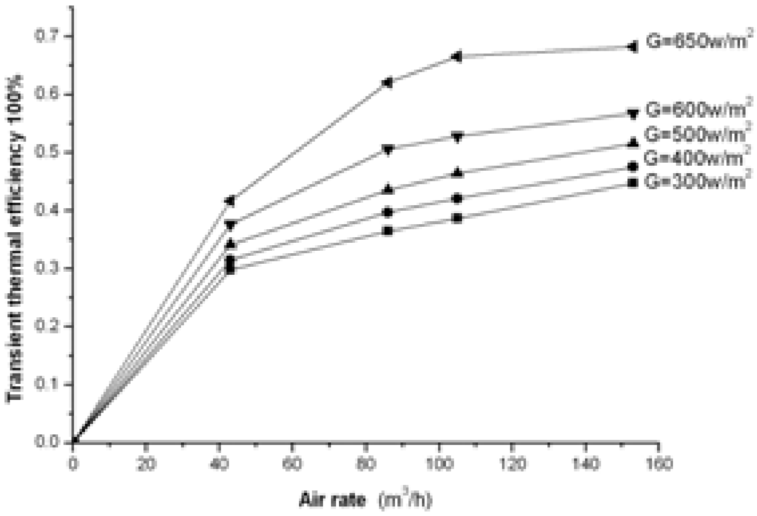

Fig.2 Variation of Transient thermal efficiency with air rate and solar irradiance

The variation of transient thermal efficiency with air rate and solar irradiance is shown in Fig. 3. The results showed that with the air rate increasing, transient thermal efficiency increase. When the air rate increased to 154m³/h the Transient thermal efficiency decreased significantly, especially in a high solar irradiance. Meanwhile, from Fig.2 can be found that transient thermal efficiency get a maximum rate of increase, when the solar irradiance reached from 600 W/m^2 to 650 W/m^2. Thus, when the solar irradiance is greater than 600 W/m^2, the increasing of air rate can significantly improve the WSAC transient thermal efficiency.

3.1.2 Net efficiency

The above analysis shows that, under a same solar irradiance conditions, continue to increase the air rate only lead to a high electricity consumption instead of the increasing of transient thermal efficiency, when the air rate raised to a certain value. Therefore, the net efficiency should be considered as a parameter in the case of WSAC performance analysis. According to reference[9], the net efficiency is calculated as equation (2)：

$$\eta' = \frac{mc_p(T_{out} - T_{in}) - P}{A*G} \qquad (2)$$

Where

P: fan power (W)。

Fan power could be calculated by reference[10], see equation (3):

$$\frac{Q}{Q_m} = (\frac{P}{P_m})^{1/3} \quad (3)$$

Where
Q: Air rate (m^3 /h)
Qm: Rated air rate (m^3 /h)
Pm: Fan rated power (W)

Table 1 lists the fan power, unit electricity consumption calculated by different air rate 43m^3 /h, 86m^3 /h, 105m^3 /h and 154m^3 /h.

Table.1 Test results of fan characteristics

Air rate Q/ $m^3 \cdot h^{-1}$	Fan power P/W	Unit electricity consumption W.h.m^{-3}
154	8.5	5.5×10-2
105	2.72	2.5×10-2
86	1.48	1.7×10-2
43	0.185	0.4×10-2

As shown in Fig.3, When the air rate is small, the transient thermal efficiency and net efficiency are almost same; with the air rate increasing, the difference between net efficiency and the transient thermal efficiency increases. The solar irradiance had a powerful influence on the net efficiency. Increasing the solar irradiance from 300 W/m2 to 650 W/m2, the difference between net efficiency and transient thermal efficiency could be decreased from 12.7% to 3.8%, under a constant air rate 154m^3 /h.

From above results, a large volume air supply will reduce the net efficiency of WSAC, when the solar irradiance is below 300 W/m2, thus air rate below 86m^3 /h is recommendable. At the same time, a large volume air supply will enhance the net efficiency, when the solar irradiance is above 650 W/m2. Continue to increase the air rate, however, will have little contribution for increasing net efficiency. Thus, using of variable air rate(VAV) can increase the net efficiency of WSAC during the daytime.

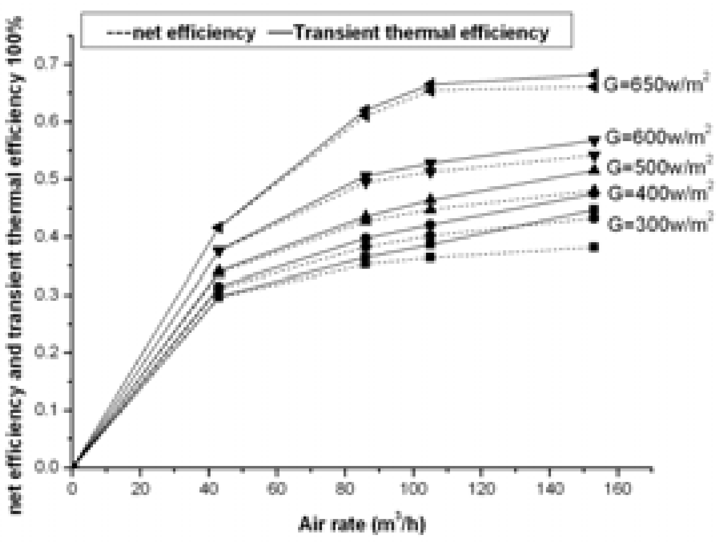

Fig.3 Variation of Transient thermal efficiency and net efficiency with air rate and solar irradiance

3.2. Variable air rate control strategy

3.2.1 Test modes

To further understand the advantages of VAV, this study compare the thermal performance of VAV with constant air rate (CAV) and intermittent air rate (IAV). Test modes are shown in Fig. 4 in which two different types VAV are designed to compare with each other.

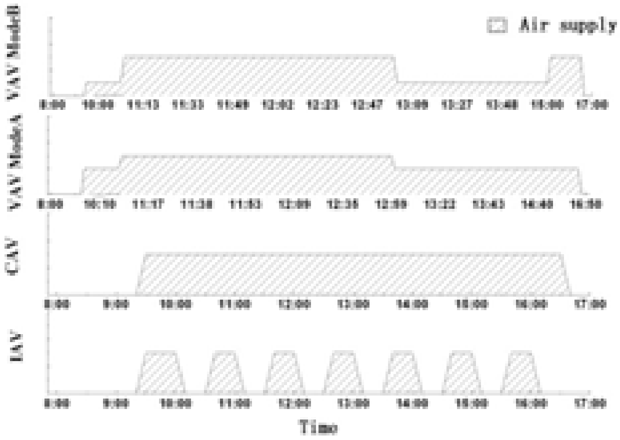

Fig. 4 Test modes

3.2.2 VAV thermal performance

The calculated and measured average transient thermal efficiency, net efficiency, fan power of the four kinds modes are listed in Table 2. Known from the Table 2, CAV reached the best average thermal efficiency, on the other hand, IAV have the worst average thermal efficiency. Meanwhile, VAV mode A have the best average net efficiency, which is mainly due to CAV continuous operating under 154m^3 /h, yet VAV mode A operating based on the variation of solar radiation.

Table. **2** Thermal performance of test modes

Mode	Average thermal efficiency %	Average net efficiency %	Heating kJ	Electricity consumption kW • h
CAV	0.69	0.676	10786.2	0.0916
IAV	0.408	0.408	9464.84	0.0495
VAV A	0.687	0.679	11007.5	0.0577
VAV B	0.457	0.451	7214.04	0.0558

VAV mode A is also running better than VAV mode B, as shown in Fig.5, Fig.6 and Table 2. Because at the beginning of operation, the WSAC had been sunning for a long time, although the solar irradiance was below than 500W/m2, the inside average temperature was higher than 50℃, which could be approximated as the WSAC at the high solar irradiance. As in the pervious analysis, a lower air rate was not conducive to improve the thermal performance. Thus, the VAV mode B was worse than mode A, for the low air rate of 43m^3 /h at the beginning. Meanwhile, the VAV mode B had a high air rate of 154m^3 /h, which was also not conducive to improve the thermal performance, on the other hand, it could reduce the net efficiency directly.

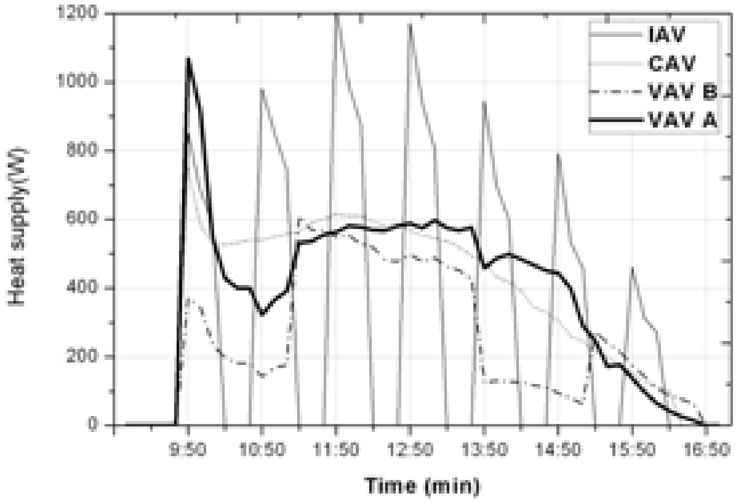

Fig. 5 Heat supply in different climate responsive component

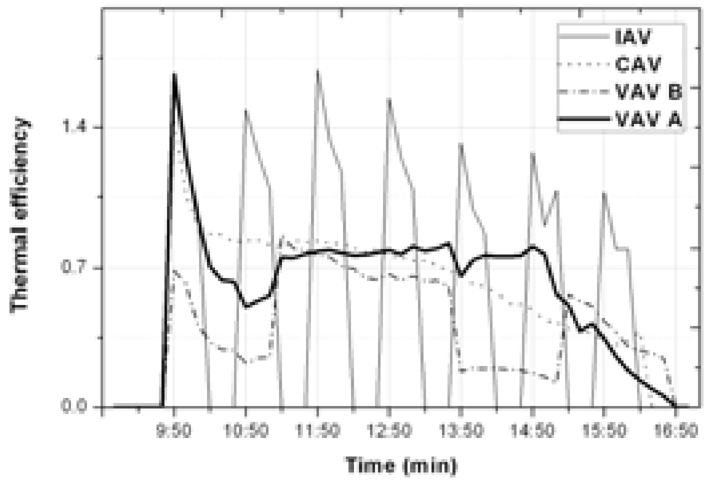

Fig. 6 Thermal efficiency in different climate responsive component

Moreover, it is discovered that, when WSAC is operating in VAV mode, the major factor that lead to electricity consumption of fan is the air volume of $154m^3$ /h, which accounts for less air supply time. It is shown by Table 1 that, when air rate is $154m^3$ /h, the electricity consumption is more than twice of those when the air rate is $105m^3$ /h; however, the former air rate is only 1.5 as much as the latter condition. Meanwhile, compare the beginning period of A mode, the VAV mode, with that of B mode, the continuous constant volume air supply, it can be discovered that WSAC' s thermal supply property can be fully utilized due to high inside temperature of WSAC, no matter under the air volume of $105m^3$ /h or $154m^3$ /h. Therefore, excessive air volume could not enhance the performance of heat collecting.

In conclusion, at the beginning period of air supplying, WSAC should make use of the standard constant air supply volume of $105m^3$ /h; when irradiation reaches at the crest, take $154m^3$ /h as air supply volume; when about sunset, take $43m^3$ /has the air supply volume.

5. Conclusion

In this paper, WSAC was experimentally and theoretically analyzed. The relation of air rate, solar irradiance and transient thermal efficiency, net efficiency was discussed. Based on these relation of parameters, optimal control strategy was designed, and the results showed that：

1) Transient thermal efficiency increased with the increase of air rate, but as the air rate continues increase the rate of increase in thermal efficiency decreases.

2) In considering the case of the fan energy consumption, with the air rate increases, net efficiency and the difference between the transient thermal efficiency increased. Increasing the solar irradiance from 300 W/m2 to 650 W/m2, the difference between net efficiency and transient thermal efficiency could be decreased from 12.7% to 3.8%, under a constant air rate $154m^3$ /h.

3) From the study, strategies of enhancing WSAC operating efficiency are: ①at the beginning period of air supplying, WSAC should make use of the standard constant air supply volume of $105m^3$ /h; ②when irradiation reaches at the crest, take $154m^3$ /h as air supply volume; ③when about sunset, take $43m^3$ /has the air supply volume.

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