The Influence of Operation Modes, Room Temperature Set Point and Curtain Styles on Energy Consumption of Room Air Conditioner

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Abstract: A field investigation was carried out in an office building of Changsha city in winter and summer, the influence of different running modes, curtain styles and room temperature set point on energy consumption of room air conditioner (RAC) was studied. The results show that: In summer automatic speed mode consumes the least refrigerating energy in different running modes, compared with low speed and high speed modes, it can conserve energy for 27.3% and 15.8%, respectively. In the same running mode, setting outer curtain can conserve energy for 40.9% and 20.4% compared with no curtain and inner curtain states, respectively. In winter high speed mode is the most efficient for saving energy which can decrease 40.3% and 30.9% compared with low speed and automatic speed modes. In the same running mode, setting inner curtain state makes the least heating energy consumption in cloudy day, about 10.8% and 2.7% less than no curtain and outer curtain states. However, it is not obvious when the day is fine. The heating energy consumption decreases as room temperature set point falls, compared with the energy consumption at 20.5℃ and 19.5℃, it is decreases for 34.1% and17.0 % at 18.5℃, respectively. All the results will be the reference of environment design and control for air conditioning room.

Key words: room air conditioner; influence factors; energy consumption; energy conservation.

1. INTRODUCTION

With the improvement of people's living standards, thermal comfort demands of people on indoor environment are higher and higher. The room air conditioners for space cooling along with reversible heat pumps for all-year round space conditioning have been widely used in China since the 1990s [1-3],. This has led to the rapid increase of electricity demand for air conditioning. Take the statistics of Shanghai from 1999 to 2003 as an example: The amount of RACs, which were just 76 per 100 families in 1999 in Shanghai city, rise to 132 per 100 families in 2003, and the highest daily electricity consumption, was from 9.03 million kW up to 13.62 million kW. This makes it an urgent matter to promote consciousness of energy conservation aiming at upgrading the efficiency of RAC.

However, there are many factors that influence the energy consumption of RAC, it's important to know the influence degree of these factors, which can help us optimize the operation, decrease the energy consumption and improve the indoor thermal comfort. For the purpose of decreasing energy demand and increasing energy efficiency of air-conditioner, many researches have been conducted to enable the RAC running economically.

In summer, temperature has evident impact on energy consumption of air conditioner system, about 6%-8% increase as the indoor temperature falls 1℃ [4]; air speed is another significant factor on energy consumption, studies revealed that the rising of air speed can broaden the range of acceptable temperature [5-8]. The cooling load can be decreased to a great extent if the overshadow characteristics of window is improved, about 16%~29% energy will be reserved [9].

In winter, however, the impact of room temperature set point, air speed and shading conditions on the energy consumption of RAC have been studied little, and the related articles that carries on the whole year to study are also not a great many. In this paper, a field investigation was carried out in an air-conditioning room of one office building in

Changsha city in winter and summer, the purpose was aimed at the influence of running modes, curtain styles and room temperature set point on energy consumption of RAC.

2. METHODS

2.1. Field Study

The field investigation was carried out in an office building of Changsha city in September and December of 2005，the tested room locates in the north of the second floor，The areas of the room and window are about 9.7 m^2(length × width=3.6m ×2.7m) and 2.1 m^2 (length × width=1.45m ×1.45m), respectively. A dark yellow chemical fiber material curtain is setting both inside and outside of the window. The KFR-35W/R RAC with the rated refrigerating capability of 3500W and heating capability of 3800 (4100) W is equipped in the office room. Two persons were in the room, and no other indoor heat sources were existed during the investigation.

The investigation was carried out when the outdoor environment parameter values were almost the same, parameters measured in the investigation included both indoor and outdoor mean radiant temperature, dry-bulb temperature and wet-bulb temperature, as well as indoor air speed, and energy consumption of RAC. The vertical height of the indoor testing point located at working position was about 1.1 m; outdoor testing point was 0.5m far from the wall and 1.1m higher than indoor floor. Wet and dry bulb temperatures were recorded every ten minutes, the rest air parameters and energy consumption of RAC were recorded every half an hour.

Each investigation lasted two and a half hours and carried out at the same time of a day. The tests included different running modes of low speed, high speed and automatic speed and different curtain styles of no curtain, inner curtain and outer curtain in summer, and besides, different indoor room temperature set points of 20.5℃, 19.5℃ and 18.5℃ were also conducted in winter. During the investigations, thermal environment of adjacent rooms were basically the same. Before test, the door and windows were closed and the RAC had been running for an hour.

2.2. Instruments

The instruments of measurement included WQC-12 thermometer of ventilated psychrometer, black-bulb thermometer; QDF-2 hot-bulb anemometer, GB/T15283-1994 kilowatt-hour meter. The model, measurement rang and accuracy of each instrument are presented in table 1.

3. RESULTS AND DISCUSSION

3.1 Energy Consumption Analysis in summer

3.1.1 Refrigerating energy consumption in different RAC running modes

The RAC was running in three different modes including low speed, high speed and automatic speed, the mean values of indoor and outdoor thermal parameters and energy consumption of RAC are shown in table 2. This table implies that indoor and outdoor thermal parameter values could be considered as the same among the three running modes. The variations of refrigerating energy consumption with time of ACR in low speed, high speed and automatic speed are shown in Fig.1.

Tab.1 Instrument parameter schedule

Parameter	Instrument	Type	Measurement rang	Accuracy
Dry-bulb temperature	Thermometer of ventilated psychrometer,	wqc-12	-36℃~+46℃	±0.2℃
Wet-bulb temperature	Thermometer of ventilated psychrometer,	wqc-12	-36℃~+46.℃	±0.2℃
Radiation temperature	Black-bulb thermometer	—	0℃~50℃	±0.1℃
Air speed	Hot-bulb anemometer	qdf-2	0.05~5m/s	±0.01m/s
Energy consumption	Kilowatt-hour meter	gb/t15283-1994	—	±0.01kwh

Tab. 2 Mean values of indoor and outdoor thermal parameters and refrigerating energy consumption in different RAC running modes

running modes of RAC	Indoor				Outdoor			refrigerating Energy consumption (kWh)
	dry-bulb temp. (℃)	wet-bulb temp. (℃)	radiation temp. (℃)	air speed (m/s)	dry-bulb temp. (℃)	wet-bulb temp. (℃)	radiation temp. (℃)	
Low speed	26.5	24.8	27.3	0.42	33.7	28.0	34.7	0.66
High speed	25.8	24.5	26.1	0.60	33.4	28.2	34.1	0.57
Automatic speed	25.9	24.2	26.1	0.49	33.9	27.1	35.3	0.48

It is clearly to see from Fig.1 that Low speed mode of RAC consumed the most refrigerating energy, high speed mode consumed moderately, minor for automatic speed mode. Energy consumptions of the three modes during the test time were 0.66 kWh 、 0.57 kWh and 0.48 kWh, respectively. Compared with low speed and high speed modes, automatic speed mode could conserve energy for 27.3% and 15.8%, respectively. The energy consumption fluctuation is great in automatic speed mode, small in low speed mode and almost strictly linear in high speed mode.

Reasons may be that different circulating air speed makes different circulating air volume, the mean air speed in low speed, high speed and the automatic speed modes were 0.42m/s, 0.60 m/s and 0.49m/s, respectively. In low speed mode, the temperature difference between outlet air and refrigerant is small because of the relatively less circulating air volume which decreases the efficiency of evaporator and takes a long time to reach the stable state, so that the energy consumption and running time will be increased. Compare with low speed mode, high speed mode can accelerate air circulation and shorten the time of heat exchange between air and refrigerant, which is in favor of improving the refrigerating efficiency of the refrigerant and reducing the energy consumption. Automatic speed mode could be predominant to carry on adjusting to control air speed according to the room temperature and better economize electric power， which may cause the energy consumption fluctuated more greatly. In this study, the air speed of automatic mode was from 0.36 m/s to 0.65 m/s.

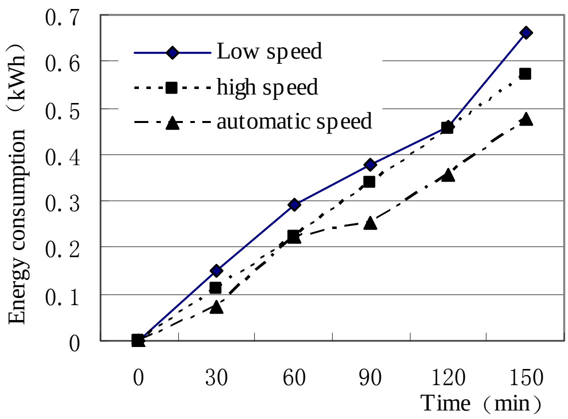

Fig.1 The time variations of refrigerating energy consumption in different RAC running mode

3.1.2. Refrigerating energy consumption of RAC in different curtain styles

The RAC was running in low speed running mode all the time, no curtain, inner curtain and outer curtain were set respectively in the same running mode, under similar conditions presented in table 3. The time variations of energy consumption in no curtain, inner curtain and outer curtain styles of the same RAC running mode are show in Fig. 2, which are based on the same thermal parameter values indoor and outdoor.

From Fig. 2 we can see that no curtain state consumed the highest refrigerating energy，setting inner curtain was secondly, outer curtain was the least.

Tab. 3 Mean values of indoor and outdoor thermal parameters and refrigerating energy consumption in different curtain styles

curtain styles	Indoor			Outdoor			refrigerating Energy consumption (kWh)
	dry-bulb temp. (℃)	Wet-bulb temp. (℃)	Radiation temp. (℃)	Dry-bulb temp. (℃)	Wet-bulb temp. (℃)	Radiation temp. (℃)	
No curtain	26.5	24.8	27.3	33.7	28.0	34.7	0.66
Inner curtain	26.8	25.2	27.7	34.2	27.4	35.7	0.49
Outer curtain	26.8	24.8	27.3	34.4	28.1	34.9	0.39

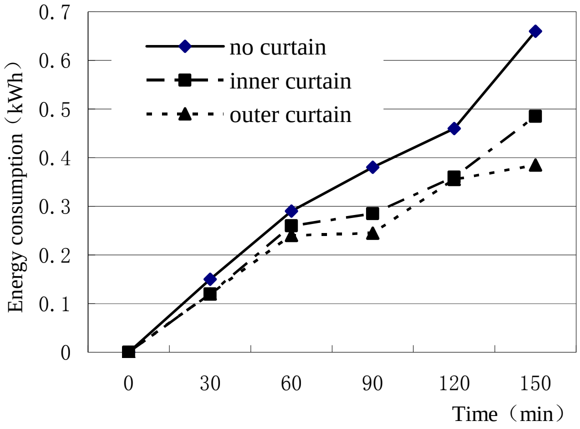

Fig.2 The time variations of refrigerating energy consumption in different curtain styles

Energy consumptions of the three states, during the test time, were 0.66 kWh, 0.49 kWh and 0.39kWh, respectively. Compared with no curtain and inner curtain states, refrigerating energy consumption of RAC could decrease 40.9% and 20.4% when setting outer curtain. we concludes that conduction and convection heat transfers from outdoor to indoor because of the temperature difference in summer, the overall transfer heat is the most when without curtain, which induces the cooling load and the energy consumption will be enlarged. Setting curtains can not only minimize the radiant heat entering in the room but also reduce conduction and convection heat exchange between indoor and outdoor. The energy consumption of RAC with outer curtain was less than with inner curtain, because the outer curtain absorbs the radiation heat and then emits outdoors through convection and radiation which is different from the inner curtain.

3.2 Energy Consumption Analysis in winter

3.2.1. Heating energy consumption in different RAC running modes

Low speed, high speed and automatic speed modes were set respectively, mean values of each parameter were presented in table 4, outdoor mean dry-bulb temperature was around 8.5 and indoor mean dry-bulb temperature was around 19.5 , so we regard the thermal parameter values of indoor and outdoor as the same in the three running modes.

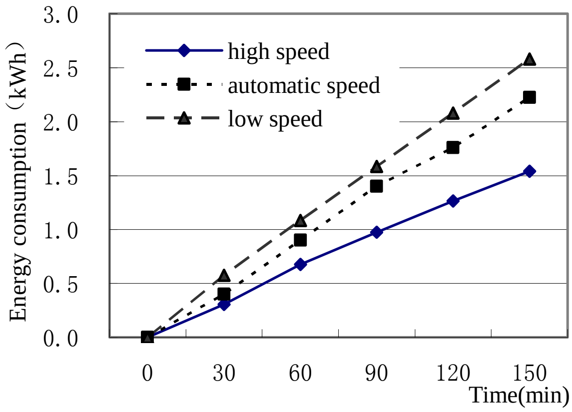

Fig.3 The time variations of heating energy consumption in different RAC running modes

The variations of heating energy consumption with time in low speed, high speed and automatic speed modes are displayed in Fig. 3. It is quite clear from the results presented in this figure that low speed mode of RAC consumed the most heating energy, the following was automatic speed mode, and the least was high speed mode. Energy consumptions of three modes，during the test time, were 2.58 kWh、2.23 kWh and 1.54kWh respectively. Compared with low speed and automatic speed modes, high speed mode could conserve energy for 40.3% and 30.9% respectively. The reasons is that high speed can accelerate the circulating air volume and enhance the heat exchange capability, which advance the efficiency of the heating, therefore the electric power consumption of RAC in high speed mode is the least; and vice versa, low speed consumes the highest.

Tab. 4 Mean values of indoor and outdoor thermal parameters and heating energy consumption in different RAC running modes

running modes of RAC	Indoor				Outdoor			refrigerating Energy consumption (kWh)
	dry-bulb temp. (℃)	wet-bulb temp. (℃)	radiation temp. (℃)	air speed (m/s)	dry-bulb temp. (℃)	wet-bulb temp. (℃)	radiation temp. (℃)	
Low speed	19.4	13.1	15.8	0.17	8.4	5.3	9.4	2.58
High speed	19.4	13.7	16.3	0.24	8.7	5.9	9.8	1.54
Automatic speed	19.6	13.2	16.3	0.21	8.1	5.2	8.6	2.23

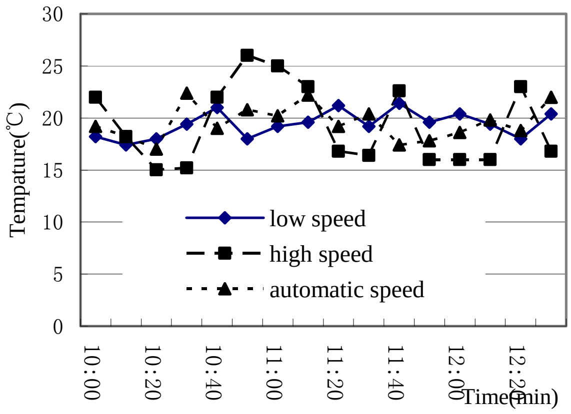

Fig.4 The distribution of indoor temperature with time in different RAC running modes

Fig. 4 is the distribution of indoor temperature with time during the test, the mean values of the temperature in the three modes were19.4℃, 19.6℃ and 19.4℃, respectively, approximately the same. The indoor temperature fluctuation was from 17.4℃ to 21.4℃ was in low speed mode, and air speed fluctuated from 0.05 m/s to 0.32 m/s, the mean running time was 8 minutes and pausing time was 3 minutes, which made human body feel comfort at most of the time. The indoor temperature fluctuation was larger in automatic speed mode, the highest temperature was 22.4 and lowest was 17.0 , indoor air speed rang was from 0.05 m/s to 0.40 m/s during the test, the RAC was running for 6 minutes and then pausing for 4 minutes. In high speed mode, the highest temperature was 26 and the lowest was 15 , that means the indoor temperature fluctuation was the maximum and the indoor air speed variation was up to 0.48 m/s from 0.05 m/s, running time was short and pausing time was long, the longest pausing time reached 12 minutes, which made people exposed in the cold environment long time and uncomfortable.

3.2.2. Heating energy consumption of RAC in different curtain styles

In winter, because of the temperature difference between human body and surroundings, heat transfer from human body to surroundings, which makes the body feel chilly. Setting curtain can reduce heat transfer from indoor to outdoor and keep room a high temperature, but on the other hand, it can also decrease the radiant heat from outdoor to indoor simultaneously. The solar radiation intensities are not the same in sunny and cloudy day, so this part is focus on the overall heat transfer between indoor and outdoor in different outdoor climates.

(1) Heating energy consumption of RAC in different curtain styles in sunny day

The test was carried out on three similar days, similar outdoor temperature and relative humidity, similar solar radiation intensities. The RAC was running in low speed mode all the time. No curtain, inner curtain and outer curtain were set respectively in this running mode, indoor and outdoor thermal parameter values are summarized in table 5. Each corresponding environmental parameter values can be assumed to be approximate the same among the three conditions during the test.

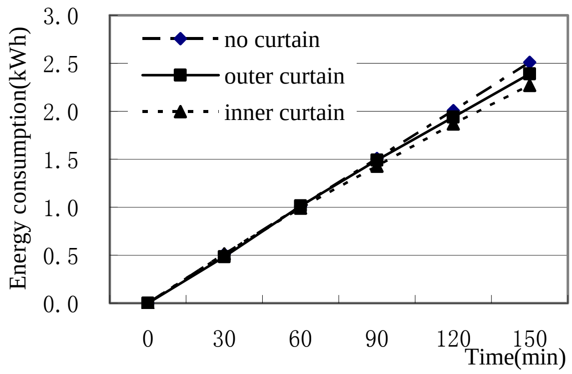

Fig.5 The time variations of heating energy consumption in different curtain styles in sunny day

Tab. 5 Mean values of indoor and outdoor thermal parameters and heating energy consumption in different curtain styles in sunny day

curtain styles	Indoor			Outdoor			refrigerating Energy consumption (kWh)
	dry-bulb temp. (℃)	Wet-bulb temp. (℃)	Radiation temp. (℃)	Dry-bulb temp. (℃)	Wet-bulb temp. (℃)	Radiation temp. (℃)	
No curtain	19.9	14.1	16.4	9.0	5.5	9.9	2.51
Inner curtain	19.9	14.2	16.8	9.3	5.7	10.0	2.27
Outer curtain	19.7	13.4	16.8	9.1	5.2	9.6	2.39

The variations of heating energy consumption with time in no curtain, inner curtain and outer curtain states in sunny day are shown in Fig. 5. The figure indicates that energy consumptions among the three different states were almost the same. The RAC consumed 2.51 kWh during the test in no curtain state, 2.39 kWh in outer curtain state and 2.27 kWh in inner curtain state, inner curtain state made a little energy saving. The little difference between no curtain and with curtain states can be attributed to the north direction of the office room which induces the heat transmitted from indoor to outdoor is approximately the same with the solar radiation heat entered from outdoor to indoor.

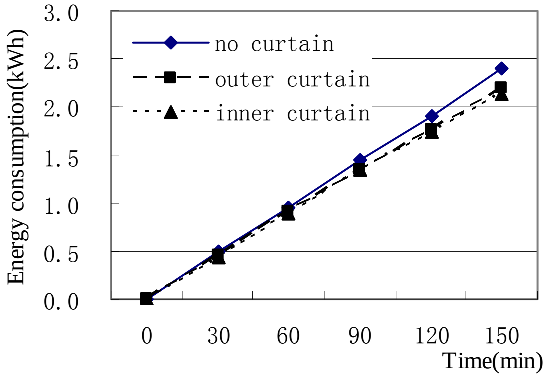

Fig.6 The time variations of heating energy consumption in different curtain styles in cloudy day

(2) Heating energy consumption of RAC in different curtain styles in cloudy day

No curtain, inner curtain and outer curtain states were tested in turn in low speed mode of RAC under similar outdoor weather conditions in cloudy climate. Values of indoor and outdoor thermal parameters are listed in table 6. The variations of heating energy consumption with time in different curtain styles are provided in Fig. 6.

In this figure heating energy consumptions of RAC were 2.40 kWh, 2.14 kWh and 2.20 kWh in no curtain, inner curtain and outer curtain styles, which implies that energy consumption in inner curtain state is the least, which can save energy for 10.8% and 2.7% compared with no curtain and outer curtain states. The reasons may be that: the heat transmitted from indoor to outdoor because of temperature difference which could be reduced by the curtain is lesser than the solar radiation heat entered from outdoor to indoor which is relatively weak in cloud day. But solar radiation can enter indoors when with inner curtain, which can increase the gain heat of indoor and decrease the energy consumption of RAC.

3.2.3. Heating energy consumption of RAC at different room temperature set points

The RAC was running in low speed mode all the time, heating energy consumption of different room temperature set points were tested under similar ambient conditions presented in table 7. Indoor temperatures controlled within the national standard of China (limited value range is from18℃ to 22℃).

Fig. 7 shows the heating energy consumption variations with time when the room temperature set points were 20.5 , 19.5 and 18.5 , respectively. It clearly demonstrates that energy consumption decreases as temperature falls, the heating energy consumption was 3.40 kWh when room temperature set point was 20.5 , and it was down to 2.70kWh when room temperature set point decreased to 19.5 , it was just 2.24 kWh when 18.5 . Compared with the energy consumption of RAC at 20.5 and 19.5 , it is just 65.9% and 83.0 % of that at 18.5 , that is to say it could be decreased for 34.1% and 17.0%, respectively, which indicates that decrease of temperature based on thermal acceptable can save the energy consumption of RAC in winter largely.

Tab. 6 Mean values of indoor and outdoor parameters and heating energy consumption in different curtain styles in cloudy day

curtain styles	Indoor			Outdoor			refrigerating Energy consumption (kWh)
	dry-bulb temp. (℃)	Wet-bulb temp. (℃)	Radiation temp. (℃)	Dry-bulb temp. (℃)	Wet-bulb temp. (℃)	Radiation temp. (℃)	
No curtain	19.3	15.1	17.3	9.4	8.7	9.6	2.40
Inner curtain	19.5	14.7	17.3	9.5	8.0	10.3	2.14
Outer curtain	19.3	14.8	17.2	9.1	8.0	10.2	2.20

Tab. 7 Mean values of indoor and outdoor thermal parameters and energy consumption of RAC at different temperature

Indoor				Outdoor			Energy consumption (kWh)
dry-bulb temp. (℃)	wet-bulb temp. (℃)	radiation temp. (℃)	air speed (m/s)	dry-bulb temp. (℃)	wet-bulb temp. (℃)	radiation temp. (℃)	
18.5	14.4	15.8	0.14	5.6	4.6	8.9	2.24
19.5	14.6	16.3	0.16	5.9	4.9	8.6	2.70
20.5	15.4	16.8	0.18	5.8	4.6	9.9	3.40

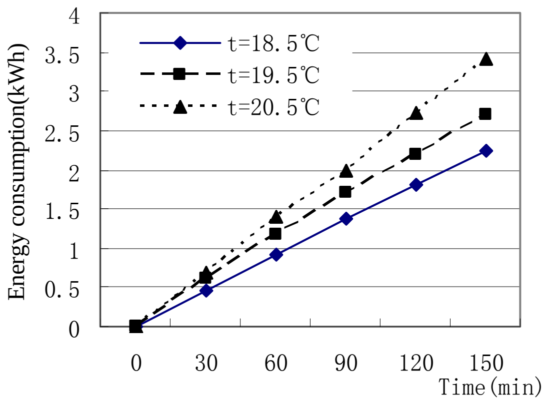

Fig.7 The time variations of heating energy consumption at different room temperature set points

4. CONCLUSIONS

The field study of the influence of running modes, room temperature set point and curtain styles on energy consumption of RAC was carried out in an office room in Changsha city. Prior to this study, limited operation parameters of RAC in summer and winter were available. In this study, descriptive statistics were obtained. Additionally, the energy consumption of each circumstance was also investigated.

In summer, low speed mode of RAC consumes the most refrigerating energy, high speed mode consumes moderately, minor for automatic speed mode. Compared with low speed and high speed modes, automatic speed mode can conserve energy for 27.3% and 15.8%, respectively. The curtain has great impact on the refrigerating energy consumption of RAC, and the outer curtain state is better than inner and no curtains states and refrigerating energy consumption decrease 40.9% and 20.4% compared with no curtain and inner curtain states, which indicates that setting outer curtain is an effective way to reduce the energy consumption of RAC.

In winter, low speed mode of RAC consumes the most heating energy, the following is automatic speed mode, and the least is high speed. Compared with low speed and automatic speed modes, high speed mode can conserve energy for 40.3% and 30.9% respectively. In cloudy day, setting inner curtain state consumes the least heating energy, about 10.8% and 2.7% less than no curtain and outer curtain states; however, it is almost the same when the day is sunny. The heating energy consumption decreases as room temperature set point falls, compared with the energy consumption at 20.5℃ and 19.5℃, it is decreases for 34.1% and17.0 % at 18.5℃, respectively, which implies that energy consumption of RAC can be diminish with the decrease of room temperature set point within the comfort zone.

REFERENCES

[1] Zhihao Li, Ning Li. Trends of t he Development of Room Air -Conditioners in China [J], Journal of Xuzhou institute of architectural technology, Jun. 2001, 1 (2):1-4 .(In Chinese)

[2] Takao Nishimura. ''Heat pumps — status and trends'' in Asia and the Pacific. International Journal of Refrigeration 25 (2002) 405–413

[3] Cunyang Fan, Weiding Long. Application and the prospect of the ASHP, HV&AC, 1994, vol. 24, No.6. (In Chinese)

[4] Ping Yin. Effects of indoor air design conditions on first investment and operating costs of air conditioning systems [J]. HV&AC, 2002, 32 (2):21-25. (In Chinese)

[5] Humphreys M A. Outdoor temperature and comfort indoors. Building research and practice, 1978, 6(2):

92-105

[6] Yanjun Zhou, Runbai Wei. The reach of environmental air speed and temperature under thermal comfort condition [J]. Ergonomics, 1998, 4(1):16-20. (In Chinese)

[7] Xiang Huang, Caihang Liang, Yuhui Di. Thermal comfort and evaporative cooling air conditioning [J]. Building energy and environment, 2004, 23(22):13-17. (In Chinese)

[8] Zanjie Ji, Yi Gao, Xiaojie Wang, Gangbei Tu. The impact of air speed on thermal comfort [J]. Journal of Lanzhou University (Natural Sciences), Apr.2003, 39(2):95-99. (In Chinese)

[9] Qibiao, Lin. Building Heat Insulation [M]. Guangzhou: south china university of technology publishing company, 1997, 127-140. (In Chinese)