

Experimental study on the indoor temperature variation characteristics and energy conservation potentialities in winter

LONG Enshen, WANG Yong, FU Xiangzhao

College of Urban Construction and Environmental Engineering, Chongqing University, Chongqing 400045, P.R. China

Abstract: This paper conducts an experiment on the starting and stopping of an indoor air-conditioner in winter, and obtains a series of experimental data of the indoor environmental temperature. With these data, it makes a further calculation of the indoor PMV index during the start-up and shutdown of the air-conditioner. On condition that the human body's thermal comfort is basically guaranteed, an optimal combination mode of time is worked out to start and stop the air conditioner that operates intermittently in the experimental room. If the starting and stopping of the air-conditioner is managed in this way, the maximum energy-saving potentiality can be 41% compared with the traditional continuous operation.

Key words: air-conditioned room; intermittent operation, energy conservation potentiality; starting and stopping management of air-conditioner; thermal comfort.

1. Foreword

With the development of our country's economy and the continuous improvement of people's living standard, the building energy consumption is taking up an ever-increasing proportion in the total energy consumption, and the building energy conservation has become an important link in our country's energy conservation. The methods to practice building energy conservation mainly fall into taking measures and using high-performance equipment. The energy conservation based on measures includes adopting the thermal insulating and energy-saving materials and strengthening the management on the energy conservation of building equipment. At present, the building area up to the building standard of energy conservation is taking up a very small proportion of the total building areas, approximately 1% [1-3]. Therefore, to reduce the consumption of non-energy-conserving buildings and increase the proportion of energy-conserving buildings has become the focus of building energy conservation. For the non-energy-conserving buildings already in existence, since their building envelope, forms of doors and windows, area ratio of window to wall, and the shape coefficient of building are already fixed, the ways to the energy conservation of these buildings should be approached from the research on strengthening the management of energy conservation of the cold-and-heat source equipment. Literature [4] measures the temperature variation of the chilled water after the chiller of the air conditioning

system is stopped in some emporium, evaluates the effects of the air-conditioning which is stopped ahead of time to make use of the surplus cold, and shows the extent to which the energy conservation can be achieved on condition that the thermal comfort is guaranteed during the business hours. However, at present, there are few reports on the research of air-conditioners or systems operating intermittently. This paper carries out an experiment of starting and stopping an indoor air-conditioner in winter that operates intermittently, with the aim of finding out the optimal working program and energy-saving effects when the air-conditioner is under intermittent operation on condition that the human body's thermal comfort is ensured.

2. Experimental method and process

On January 2 & 3, 2003, an experiment of starting and stopping the air-conditioner was conducted in an air-conditioned office in Chongqing University. The experimental room is on the first floor of a five-story building. Its east and south walls are adjacent to the outdoors; the west wall is adjacent to a non-air-conditioned room and the north to an interior corridor. The room is 9.6m in length, 6.3m in breadth and 3.5m in height. On the south wall are installed three mono-layer push-and-pull windows made of aluminum alloy, whose area is $(2.05 \times 2.35) \text{ m}^2$. The inside of the north and east walls are covered with a wooden file that extends from the ground to the ceiling, with a thickness of 0.45m. The size and arrangement of the

experimental room are shown in Fig.1.

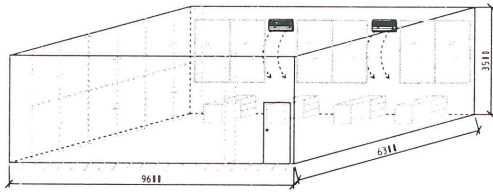


Fig.1 schematic diagram of the experimental room

In the experimental room sixteen copper-constantan thermocouples (numbered 101-116) are installed to measure the environmental temperature indoors and outdoors, and the thermocouples are calibrated prior to the experiment. All the thermocouples are connected to a thermal data-collecting meter for building use. The data of temperature at all measuring points collected by the meter are fed into the computer and then processed. Meanwhile, an infrared thermometer is adopted to measure the surface temperature variation of the building envelope, and an environment-testing meter of artificial intelligence is used to measure the variation of air temperature and airflow velocity indoors and outdoors. The data gained from these two meters act as a supplement or verification to the data from the thermal data-collecting meter for building use. The heat-releasing equipments in the room are illuminating lights of 360W and a computer of 80W. The heat sources of the room are two hanging-type split air-conditioning systems with fixed heating power of 4200W.

3. Results of experiment

Fig.2 shows us the temperature variation laws of the air and building envelope surface inside the room after the start-up of the air-conditioner on Jan. 2. It can be seen from the figures that the indoor air temperature rises the fastest after the air-conditioner is started. Fig. 1 shows that there is a 10°C increase in air temperature 10 min after the start-up of air-conditioner, and 15 minutes later, the air temperature levels off at about 25 °C. The tendency of air temperature variation in Fig. 2 is similar to that in Fig. 1. The temperature variation of the indoor building envelope surface is comparatively mild compared with the that of indoor air. After the start-up of the machine, the temperature of the building envelope rises slowly and roughly levels off 25 min later. The temperature of the west wall finally levels off at about 16 °C and the surface temperature of the inside north wall at about 18 °C. The

reason for the difference is that the north wall is covered by the wooden file, thus the temperature measured by the thermocouples is the surface temperature of the file. Besides, the north wall faces the air outlet of the air-conditioner. On the other hand, the west wall has a mortar surface, hence the thermal capacity of the two walls are different. In the measuring process, there is little change in the ground temperature, only a slight increase.

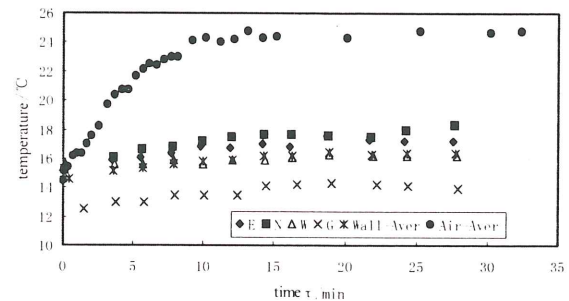


Fig.2 Indoor air temperature's variation with time while machine on (Jan.2)

Fig.3 shows us the temperature variation laws of the building envelope surface and the indoor air after the shutdown of the air-conditioner on Jan. 2. It can be seen from the figures that the indoor air temperature declines rapidly after the air-conditioner is stopped, and within 15 minutes there is a 10 °C decrease in temperature at the two times of stopping the machine. On the other hand, the temperature of the building envelope does not decline so significantly as the air temperature does. This is because the thermal capacity of the building envelope is larger than that of the air. When the temperature finally levels off, the air temperature becomes the lowest while there is no remarkable change in the ground temperature.

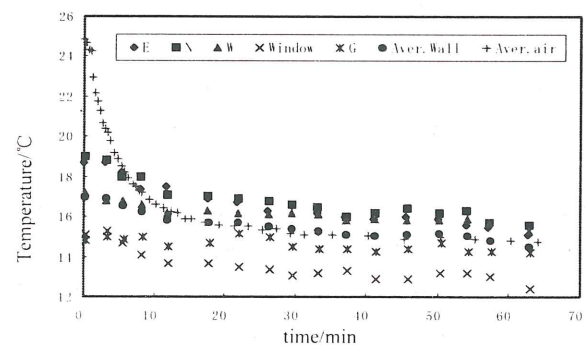


Fig.3 laws of indoor air temperature's variation with time while machine off (Jan.2)

It can be found out from the indoor temperature variation curve during the start-up and shutdown of the air-conditioner that the changing of the indoor

environmental temperature follows a certain rule, and that the temperature variation laws at different times of starting and stopping the machine present good repeatability generally. Next, we try to predict the characteristics of indoor air temperature variation by making theoretical analysis and establishing a mathematical model.

Literature[5] establishes a theoretical analytic model of indoor air's heat transfer and gets an analytic solution of indoor temperature's changing with time by means of making an analysis of the air's heat gain and loss in the room, which is caused by multiple factors such as various kinds of interior or exterior disturbance and the thermal characteristics of the building envelope. The value of $t_{\square}$ and B in the theoretical analysis can be got from the experimental data. With the data obtained from the experimental room, we acquire the laws of indoor temperature's changing with time.

Fig.4 shows the comparison between the theoretical predictive curve and the experimental data of indoor air's mean temperature on Jan. 2 and 3 after the start-up of the machine. Fig.5 shows the comparison between the theoretical predictive curve and the experimental data of indoor air's mean temperature on Jan. 2 and 3 after the shutdown of the machine. It can be seen from the figures that the theoretical curve fits in very well with the experimental data.

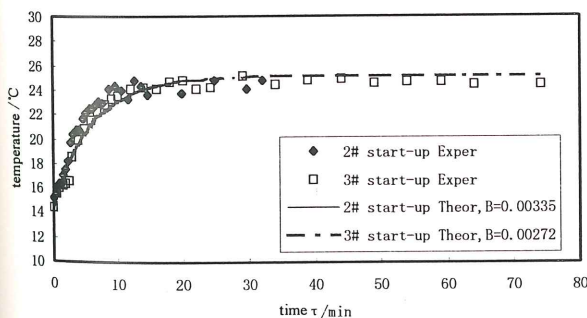


Fig.4 comparison between the theory and experiment while machine on

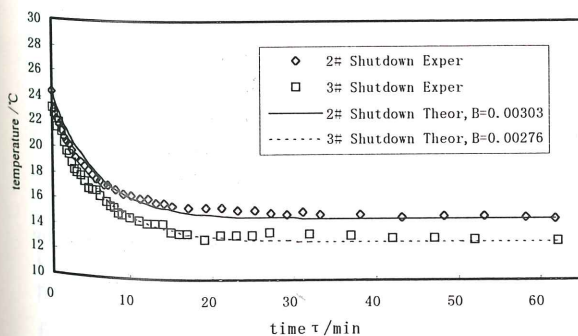


Fig.5 comparison between the theory and experiment while machine off

4. Research on the indoor comfort and energy conservation potentiality when the machine is in intermittent operation

The prerequisite of the air-conditioner's energy conservation by way of intermittent start-up and shutdown is that the human body's thermal comfort is basically guaranteed. The present international standard of thermal comfort is based on the thermal comfort model established by Prof. Fanger, using PMV (Predicted Mean Vote) as the evaluation of thermal comfort.

According to the thermal comfort model of Prof. Fanger, in calculating human body's heat load, the following items are taken into consideration: ① metabolic rate of human body's energy (M). ② mechanical work of human body. (W) ③ heat emitted from the exterior of human body by way of convection (C). ④ heat emitted from the exterior of human body by way of radiation (R). ⑤ heat lost by way of sweat evaporation and exhaled vapor (E) [6]. In a stable environment, the thermal equilibrium equation of human body is:

$$M - W - C - R - E = 0 \quad (1)$$

The calculation formula of PMV is

$$PMV = [0.303 \exp(-0.036M) + 0.0275] TL \quad (2)$$

$$TL = M - W - 3.05 \left[5.733 - 0.007(M - W) - P_a \right] - 0.42(M - W - 56.15) - 1.73 \times 10^{-2} M (5.867 - P_a) - 0.0014M(34 - t_a) - 3.96 \times 10^{-8} f_{cl} \left[(t_{cl} + 273)^4 - (t_r + 273)^4 \right] - f_{cl} h_c (t_{cl} - t_a) \quad (3)$$

The value of PMV can be worked out with the experimental data, such as the indoor air temperature, the surface temperature of various building envelope, clothing and facilities inside the room. Thus we can find an optimal combination mode of time to start and stop the air-conditioner operating intermittently. Through repeated calculation, a program of the air-conditioner's intermittent operation is worked out under the condition that the human body's thermal comfort is ensured in the experimental room. That is, to stop the machine for 12 minutes and start for 18 min.

Fig.6 shows the experimental curve of indoor air temperature's changing with time during two times of typical start-up and shutdown of the air-conditioner. After the machine is stopped, the air temperature declines. When it drops to a certain level, the air-conditioner is restarted. When the air temperature rises

to a certain level, the air-conditioner is stopped again, and this process is repeated many times. The experiment shows that in the process of intermittent operation, although there is comparatively a wide range of variation of the indoor air temperature, the inner surface temperature of the room varies mildly, and the variation does not bring distinct influence to people's comfort indoors. In the process of starting and stopping the air-conditioner, the indoor air temperature varies from 24.3°C to 15.5°C. Fig.7 shows the curve of PMV value changing with time in the process of starting and stopping the machine that operates intermittently. The PMV value is worked out with the experimental variation curve of the indoor air temperature and with the data like the surface temperature of various building envelope and facilities in the process of starting and stopping the machine, which are shown in Fig. 7.

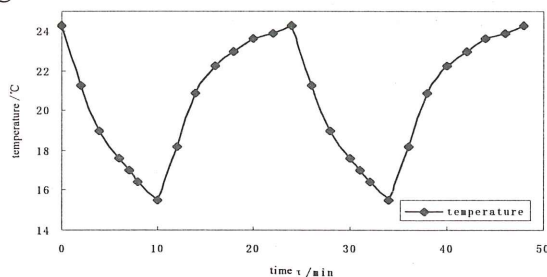


Fig.6 experimental curve of indoor air temperature's

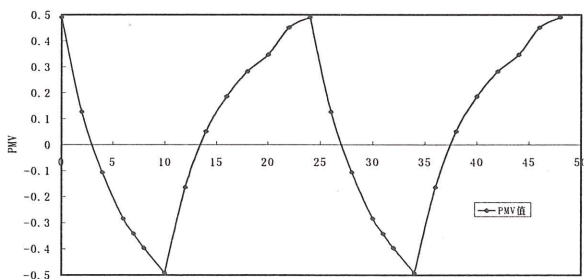


Fig.7 curve of indoor PMV's variation with time under intermittent operation

It can be seen from Fig.7 that after the machine is stopped, the PMV value declines from 0.490558 to -0.49155 within 10 minutes. The indoor air temperature rises from 15.5°C to 24.3°C within 14 minutes after the machine is started, and the PMV value also goes up from -0.49155 to 0.490558. If the air-conditioner operates in this way, theoretically it can save 41% of energy compared with continuous operation.

The author experiments with this intermittent way of operation and makes investigation among the people in

the room. It shows that the influence on human body's thermal comfort can be ignored if the air-conditioner is started and stopped in this way.

5. Conclusions

1) From the experiment on the indoor air temperature and the surface temperature of various building envelopes and facilities in an air-conditioned room in winter by way of starting and stopping the machine four times, we can reach the conclusion that the laws of temperature variation have repeatability.

2) Through the analysis of the data of interior environmental temperature obtained from the experiment on starting and stopping an indoor air-conditioner in winter, we can see that the indoor temperature varies with time and the variation presents a regular pattern of exponent. What is more, when the time is long enough, the indoor temperature tends to be stable. The theoretical analysis fits in well with the experimental results.

3) The intermittent operation of the air-conditioner is a very effective program of energy conservation. Through the calculation of the experimental data, we get an optimal combination mode of time to start and stop the air-conditioner that operates intermittently in the experimental room. If the air-conditioner is started and stopped in this way, the maximum energy-saving potentiality can be 41% compared with the traditional way of continuous operation.

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