ISES 1997 Building Application
Proceedings of the International Solar Energy Society (ISES) 1997 Solar World Congress
Taejon, Korea, August 24-29, 1997, Vol.4, pp.266-273

THERMAL ENVIRONMENT OF A NATURALLY VENTILATED OFFICE SPACE DURING AUTUMNAL SEASON

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Abstract -- This paper describes the results of the survey of the thermal environment of the office space being naturally ventilated for cooling in autumnal season. The measurement and questionnaire were made in terms of daytime and nighttime ventilations. We found that the indoor air temperature in the morning before the office is occupied after the nighttime ventilation was made was about 1 °C lower than the case without nighttime ventilation; and that the indoor thermal environment while the windows and the doors were open was almost the same as that while those were closed. Both of nighttime and daytime ventilation strategies were confirmed to work well.

1. INTRODUCTION

Over the last several decades, the thermal environment of office buildings has been controlled by mechanical air-conditioning systems for all seasons. The same applies to their luminous environment.

It is very important to utilize various potentials to be found in our immediate outdoor environment for controlling the indoor environment; this is realized by bio-climatic design of buildings. There are many case studies that bio-climatic design can bring about reductions in fossil fuels and electric power supplied to the air-conditioning and lighting systems (Asada and Shukuya, 1997; Nishikawa and Shukuya, 1996; Mathew, 1986).

What was found in such case studies has helped the emergence of bio-climatically designed buildings. It is necessary not only to promote bio-climatic design but also to survey how bio-climatically designed built environment works so that goods and bads found by the survey reflect the future design.

The purpose of this study is to survey the thermal environment of the office building, "Kouhoku-NT-Building" constructed with the concept of bio-climatic design which was completed in the spring of 1996. This paper describes the results of the survey of the thermal environment of the office space being naturally ventilated for cooling in autumnal season.

2. VENTILATION STRATEGY

Figure 1 is a north-eastern view of the building. It has an atrium in the north and the offices in the south. As can be seen in Figures 2 and 3, the south facing window is devised with lightshelves, insulated glass panes, and automatically operable clerestory windows for ventilation. The windows for ventilation are also located at the top and bottom of the atrium. The doors located at the both sides of the corridors at the third and the fourth floors are also automatically opened for ventilation. The top of the partition walls between the office and the atrium on the third and the fourth floors are open for ventilation. The staircases located at the both sides of the corridors are expected to work as a chimney.

During daytime, the windows and the doors are opened if the outdoor air temperature is between 15 °C and 24 °C and unless the outdoor air velocity is over 10 m/s and it is rainy outside. In the conditions other than this, the windows and the doors are closed and the air conditioning system is operated. In the conditions that the air-conditioning system is operated, if the outdoor dew point temperature is between 5 °C and 20 °C and the enthalpy

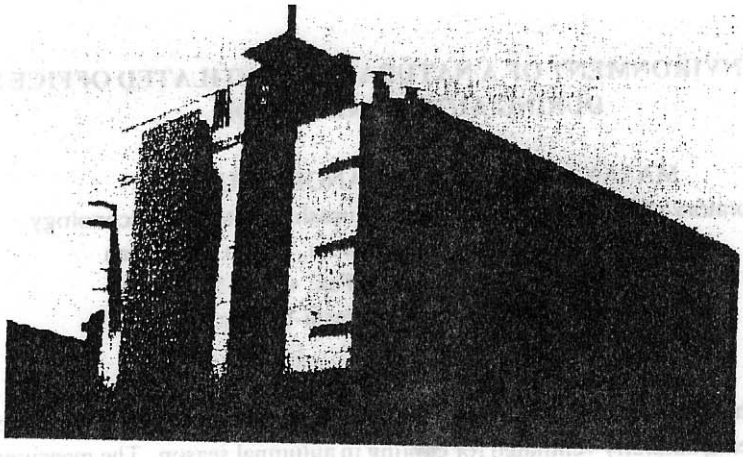

Figure 1 A north-eastern view of "Kouhoku-NT Building".

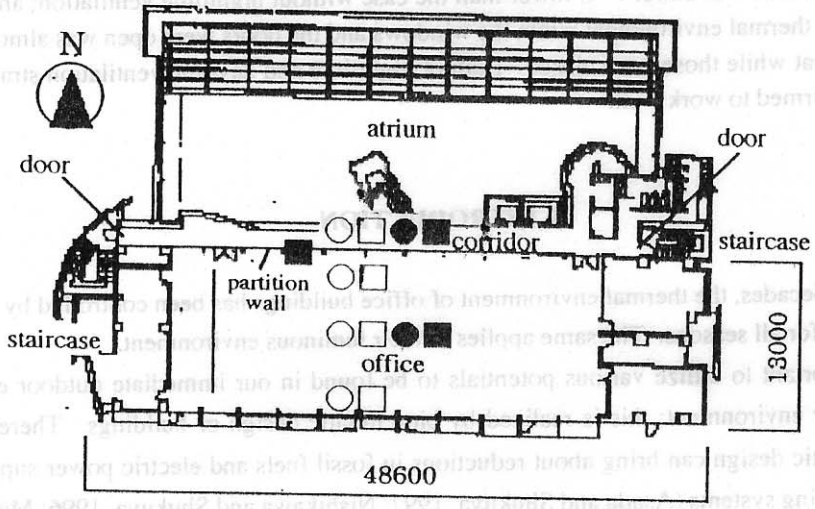

Figure 2 Fourth floor plan

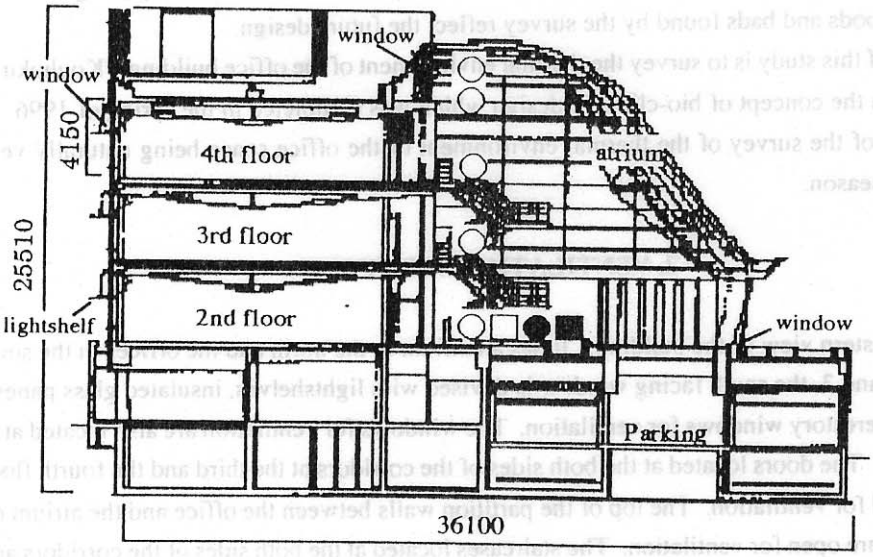

Figure 3 Section

○ Air temperature □ Relative humidity
● Glove temperature ■ Air velocity

Table 1 Open and close patterns of the openings

pattern	nighttime	daytime
1	open	close
2	close	open
3	open	open
4	close	close

*Nighttime is from 8:00 PM to 6:00 AM.
*Daytime is from 8:00 AM to 8:00 PM.

of the indoor air is greater than that of the outdoor air, free cooling is made.

During nighttime, the windows and the doors are opened for nighttime ventilation from 8:00 PM to any time, by which the room space is cooled with outdoor air and thereby the room air temperature at 8:30 AM in the following morning comes between 20 °C and 25 °C.

3. MEASUREMENT AND QUESTIONNAIRE

The measurement and questionnaire were made in terms of four combinations of daytime and nighttime ventilations from the 10th to the 26th of October in 1996. Table 1 shows open and close patterns of openings. Air and globe temperature, relative humidity, and air velocity at the points shown Figures 2 and 3 were measured and recorded at ten-minute intervals. Solar radiation, outdoor air temperature, humidity, air velocity and the pieces of information such as rain, and open/close condition of the openings were obtained from the data acquisition system originally installed in this building.

The copies of form of questionnaires on the thermal sensation and comfort were distributed to about forty occupants per day and we had them fill out the form. The questionnaire also asked the age, sex, clothing condition and the time the occupants filled out the form. The form was distributed for six days within the whole period of the present survey. All the answers were obtained between 0:00 PM and 5:30 PM.

4. RESULTS AND DISCUSSION

4-1. Nighttime ventilation

Figure 4 shows the air temperature variations of the fourth floor with outdoor air temperature variation on the 10th through the 11th of October and Figure 5 on the 12th through the 13th of October. Figures 6 and 7 show the air temperature variations of the atrium with outdoor air temperature variation in the corresponding periods, respectively. Nighttime ventilation was made from 8:00 PM on the 10th to 6:00 AM on the 11th to realize pattern 3. Nighttime ventilation was not made on the 13th to realize pattern 2.

As can be seen from Figure 4, the outdoor air temperature goes down from 19.5 °C to 16 °C for the period of 10 hours of nighttime ventilation and the average indoor air temperature goes down from 21 °C to 19 °C for the same period. On the other hand, as can be seen from Figure 5, the indoor air temperatures remain rather unchanged though the outdoor air temperature goes down more sharply on the 12th through the 13th than it did on the 10th through the 11th. The average air temperature of the fourth floor at 8:30 AM on the 11th versus on the 13th were 20.5 °C versus 21.5 °C, even if on the both days, daytime ventilation were started from 8:00 AM. This is because all the windows and the doors were closed during the nighttime on the 12th through the 13th. The same applies to the air temperature variation of the atrium. As can be seen from Figures 6 and 7, the average air temperature of the atrium at 8:30 AM on the 11th versus on the 13th were 20 °C versus 21 °C.

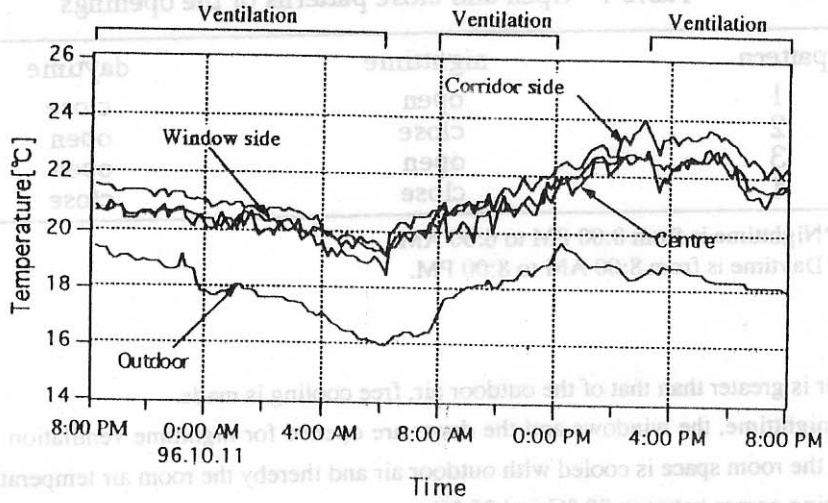

Figure 4 The air temperature variations of the fourth floor with outdoor air temperature variation on the 10th through the 11th of October to realize pattern 3.

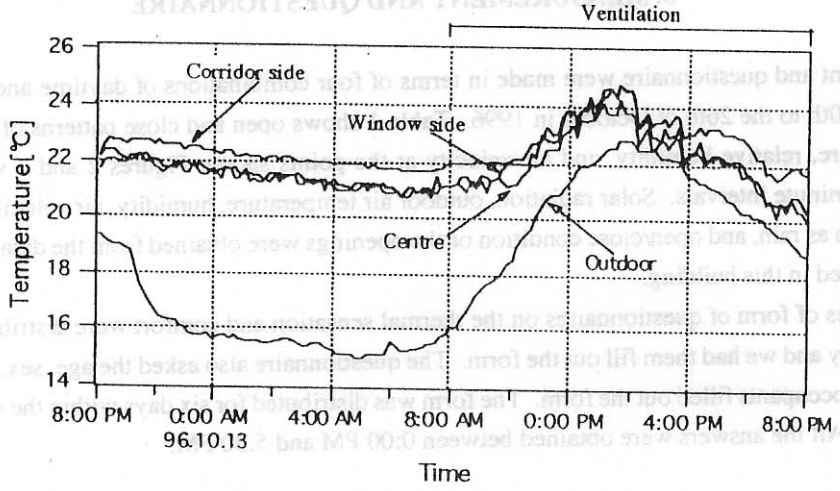

Figure 5 The air temperature variations of the fourth floor with outdoor air temperature variation on the 12th through the 13th of October to realize pattern 2.

The macro air flow of the fourth floor office on the 10th through the 11th is considered to be from the window side to the corridor side since the corridor side air temperature was about 1 °C higher than window side. For a similar reason, the macro air flow in the atrium can be considered to be from the bottom to the top. On the 10th through the 11th, the air temperature at the bottom of the atrium is the lowest among the air temperature at different heights. This is because the cool and heavy air coming from the outdoor to the bottom of the atrium is stay at the bottom and the warm and light indoor air up to upper space.

4-2. Daytime ventilation

Figure 8 shows the air temperature variations of the fourth floor with outdoor air temperature variation on the 17th through the 18th and Figure 9 on the 22nd through the 23rd. On both days, nighttime ventilation wasn't made. During daytime on the 18th, the windows and the doors were closed to realize pattern 4 and the outdoor air was taken for free cooling. On the 23rd, daytime ventilation was made from 10:00 AM to 8:00 PM to realize pattern 2. The weather conditions of both days were fine.

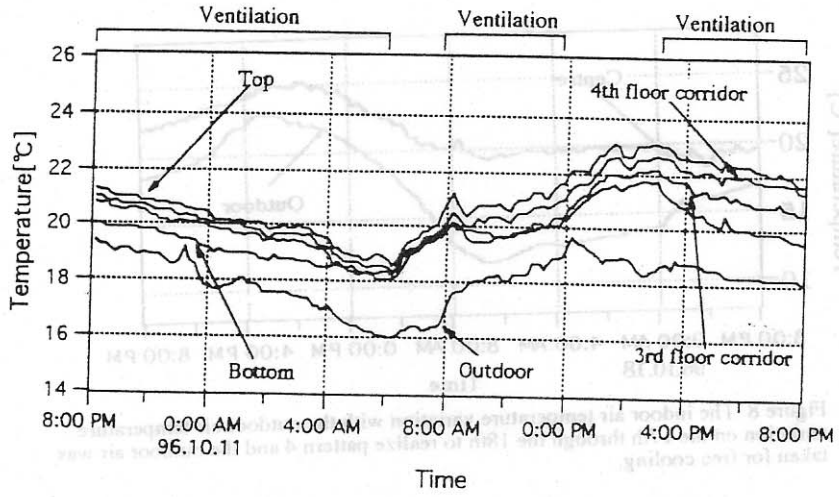

Figure 6 The air temperature variations of the atrium with outdoor air temperature variation on the 10th through the 11th of October to realize pattern 3.

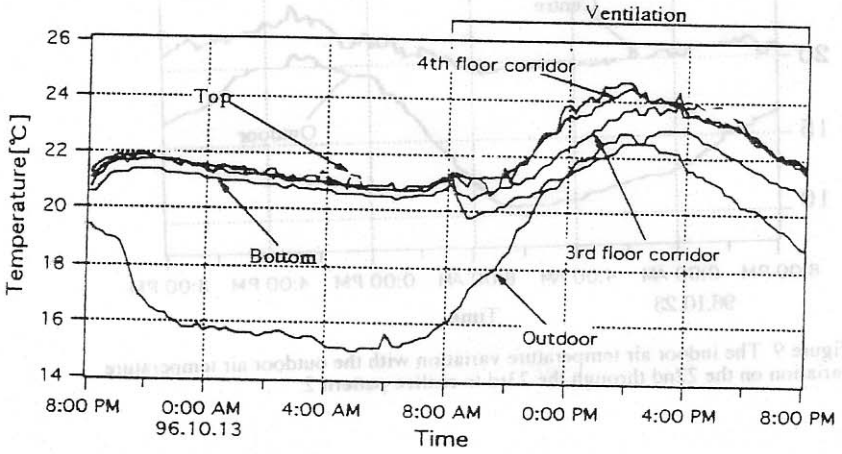

Figure 7 The air temperature variations of the atrium with outdoor air temperature variation on the 12th through the 13th of October to realize pattern 2.

The outdoor air temperature variation on the 18th is almost the same as that on 23rd. The same is true in the case of indoor air temperature.

Figure 10 shows the air velocity variations above the partition wall between the forth floor office and the corridor on the 18th versus on the 23th. The average air velocity on the 18th is about 0.1 m/s. On the other hand, that on the 23rd is about 0.2 m/s to 0.3 m/s. The air velocity on the 23rd is larger than that on the 18th. This is because outdoor air was taken to the indoor while the windows and the doors opened.

Figure 11 shows the relationship between the thermal sensation of the occupants and the equivalent uniform temperature. The open circles denote the results while the windows and the doors were opened, namely while the daytime ventilation was made and the closed circles denote the results while those were closed, namely while the air-conditioning system was operated.

We obtained these two groups of the results from the pieces of information such as open/close condition of the openings available from the data acquisition system of this building.

The equivalent uniform temperature is defined simply as the uniform temperature of an imaginary enclosure

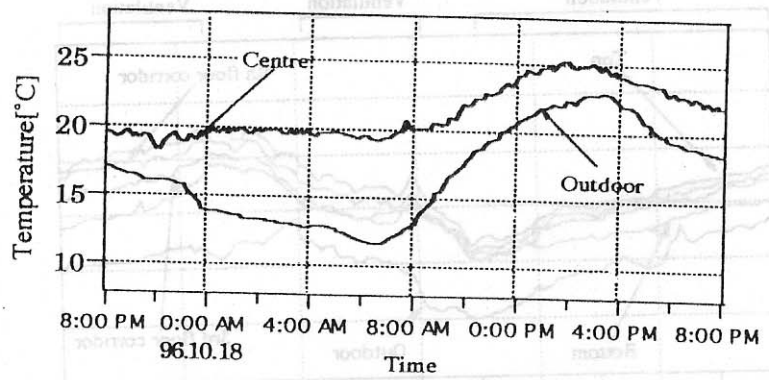

Figure 8 The indoor air temperature variation with the outdoor air temperature variation on the 17th through the 18th to realize pattern 4 and the outdoor air was taken for free cooling.

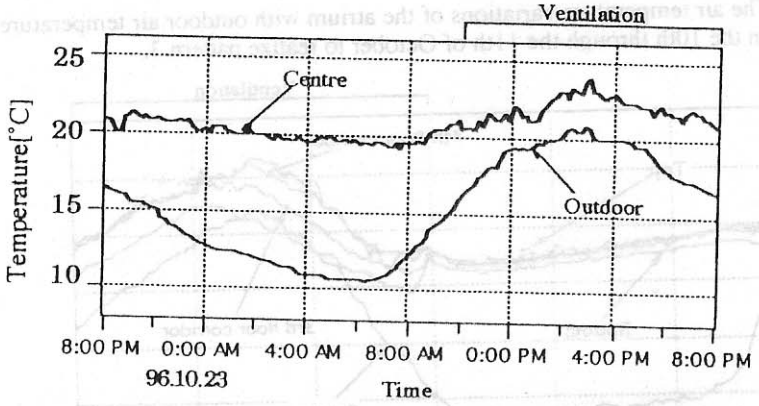

Figure 9 The indoor air temperature variation with the outdoor air temperature variation on the 22nd through the 23rd to realize pattern 2.

in which a person will experience the same degree of thermal comfort as in actual non uniform environment (Wrey, 1980; Rohles, 1987). For the calculation of the equivalent uniform temperature, the data of the air temperature, relative humidity, air velocity, mean radiant temperature, the clothing insulation values, and the metabolic rates were necessary. The air temperature, relative humidity and air velocity were obtained from the measured data recorded at the time the occupants filled out the form. The mean radiant temperature were calculated from the empirical equation for globe thermometer using the measured globe temperature, the air temperature, and the air velocity. We estimated the clothing insulation values from an equation given by Hanada et al (1981, 1983). The metabolic heat production and the external work performed were assumed to be 70 W/m^2 and 0 W/m^2.

Most of the calculated equivalent uniform temperature range was between 22 °C and 25 °C, while most of the thermal sensations were between neutral and slightly hot. There is no significant difference in the results between open windows and closed windows. This means that the indoor thermal environment while the windows and the doors were open was almost the same as that while those were closed.

5. CONCLUSION

The effect of natural ventilation on the thermal environment in a office newly built with the concept of a couple of bio-climatic design was measured in the autumn of 1996. We found that the indoor air temperature in the morning before the office is occupied after the nighttime ventilation was made was about 1 °C lower than the case without nighttime ventilation; and that the indoor thermal environment while the windows and the doors were open was

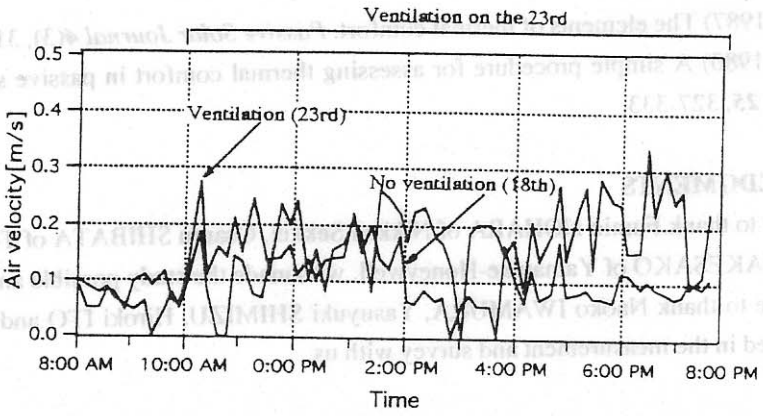

Figure 10 The air velocity above the partision wall between the fourth floor and the corridor on the 18th to realize pattern 4 versus on the 23rd to realize pattern 2.

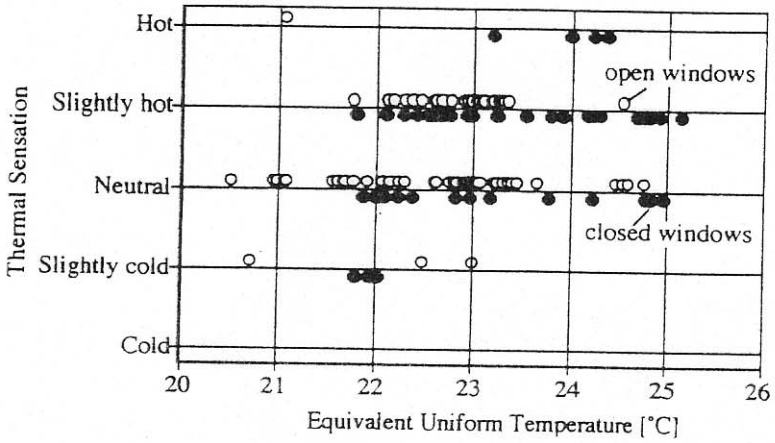

Figure 11 The relationship between the thermal sensation of the occupants and the equivalent uniform temperature while the windows and the doors were open versus while those were closed.

almost the same as that while those were closed. Both of nighttime and daytime ventilation strategies were confirmed to work well.

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ACKNOWLEDGMENTS

We would like to thank Fumio NOHARA of Nikken Sekkei, Osamu SHIBATA of Tokyo Gas, Toshiya OKUBO and Masashi TAKESAKO of Yamatake-Honeywell, who made the study possible and gave us variable data. We would also like to thank Naoko IWAMURA, Yasuyuki SHIMIZU, Hiroki ITO and Toshimitsu SHINOHARA, who participated in the measurement and survey with us.