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Field Study of Thermal Environment Acceptability Using Ostracon Voting Device

Masanari Ukai[1], Yuta Ichikawa[2] and Tatsuo Nobe[3]

1 Kogakuin University, Tokyo, Japan, dm12011@ns.kogakuin.ac.jp
2 Kogakuin University, Tokyo, Japan, dm13003@ns.kogakuin.ac.jp
3 Kogakuin University, Tokyo, Japan, nobe@cc.kogakuin.ac.jp

Abstract

This study aims to assess the thermal conditions of an indoor environment deemed unacceptable by workers. For this purpose, Ostracon, a voting device, was developed to record the physical environment at the time a worker presses a button to express a complaint. Ostracon was used to record the opinions of 90 workers about their thermal environment in six offices during the summer. The results show that workers found the indoor thermal environment unacceptable even when the static thermal conditions were within a range that was predicted to be comfortable. Moreover, most of the workers' complaints were expressed moments after returning from tasks performed outside the office. This suggests that the workers' complaints were influenced by factors other than the indoor environment such as thermal history.

Keywords: Acceptability, Thermal comfort, Ostracon, Workplace, Thermal environment

1 Introduction

Thermal comfort is a topic under considerable debate because of the rapid progression of air-conditioning technology. The thermal index of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) uses two pairs of antonyms: 'hot–cold' and 'warm–cool.' However, such nomenclature is problematic in Japanese; ASHRAE describes 'warm' and 'cool' environments as uncomfortable for daily living, but such environments are sometimes considered comfortable in Japan. Moreover, 'neutral' is not always comfortable. The results of a 1975 survey conducted by ASHRAE showed that no single thermal environment satisfied all respondents. Therefore, the environmental condition and physiology referred to as 'neutral,' rather than 'warm' or 'cool,' was determined by ASHRAE as the definition of comfort. Currently used air-conditioning systems improve the thermal comfort of the indoor environment on the basis of this concept. The two indices typically used to evaluate thermal comfort, predicted mean vote and standard new effective temperature, evaluate only the steady states of thermal sensation. The index of predicted percentage of dissatisfaction based on the predicted mean vote is used to evaluate the steady-state environment. Such a restriction is problematic because in reality, the indoor thermal environment is evaluated on the basis of the acceptance of office workers, as expressed through complaints, and there is no established index to evaluate this acceptability. This study aims to clarify the mechanism to determine in the case of workers consider the thermal environmental acceptable in an actual office. This paper shows the characteristics of the complaints of actual workers as shown by data captured by Ostracon, which is a voting device developed to record the physical environment at the time a worker presses a button to

express a complaint. Furthermore, the study examines the process by which a worker determines whether a thermal environment is acceptable.

2 Ostracon device

The term ‘Ostracon’ originated in ancient Greece and describes a shard of pottery used by voting public to prevent the election of a dictator. The authors adopted this name for an acceptability-voting device developed for the present study to record the conditions of the physical environment deemed unacceptable by workers. The specifications of Ostracon are summarized in Table 1. Workers can push a button on the device located on their desks to record a complaint when they feel that the thermal environment is unacceptable. The Ostracon sends a signal to a pulse recorder when the button is pressed, activating the attached thermo-recorder and humidity recorder.

Table 1. Ostracon device used to vote on acceptability of the environment.

Acceptability-voting device	
Appearance	
Installation	Personal desk
Report of condition	Unacceptable
Measurement interval	10 min
Size	H 100 mm × W 70 mm × D 50 mm

Ostracon was used to determine whether the subjects deemed the environment comfortable in six offices during the summer. The conditions for each measurement location are shown in Table 2. The distribution of the types of job and preset temperature of the air-conditioning system differed for each office. Five workers of Office M each carried a pedometer to record their movement during this study.

Table 2. Conditions for each measurement location.

Office name	Term	Outdoor air temperature [°C] [Maximum]	Number of subjects	The type of job
S	2012/23/7 to 2012/6/8	35.4	10	Teachnical × 7 , Clerical × 3
E	1 : 2012/8/8 to 2012/14/8	34.5	10 × 3	Teachnical × 12 , Sales × 10 Clerical × 5 , Administrator × 3
	2 : 2012/16/8 to 2012/22/8	35.7		
	3 : 2012/24/8 to 2012/30/8	35.6		
O	1 : 2012/7/30 to 2012/8/9	34.7	10 × 2	Research × 13 , Clerical × 4 Teachnical × 1 , Unknown × 2
	2 : 2012/8/21 to 2012/8/30	35.6		
T	2012/21/8 to 2012/17/8	35.6	10	Teachnical × 7 , Clerical × 2 Unknown × 1
R	2012/6/9 to 2012/18/9	32.5	10	Teachnical × 9 , Clerical × 1
M	2012/13/9 to 2012/10/10	32.5	10	Teachnical × 5 , Clerical × 4 Unknown × 1

3 Results

3.1 Indoor thermal environments of offices

Fig. 1 shows the data from ASHRAE Standard 55-2004 within the indoor thermal environment in each office during operational hours. The environmental temperature was ascribed to the operative temperature because Ostracon cannot measure the radiation temperature. The shaded areas in the figure indicate the indoor thermal environments during office hours. The dashed red lines indicate the area within the comfortable temperature–humidity range in summer. The preset temperature and humidity set by the air-conditioning system differed for each office. The temperature and humidity were preset at a higher level than usual due to brownout restrictions set in the aftermath of the Great East Japan Earthquake.

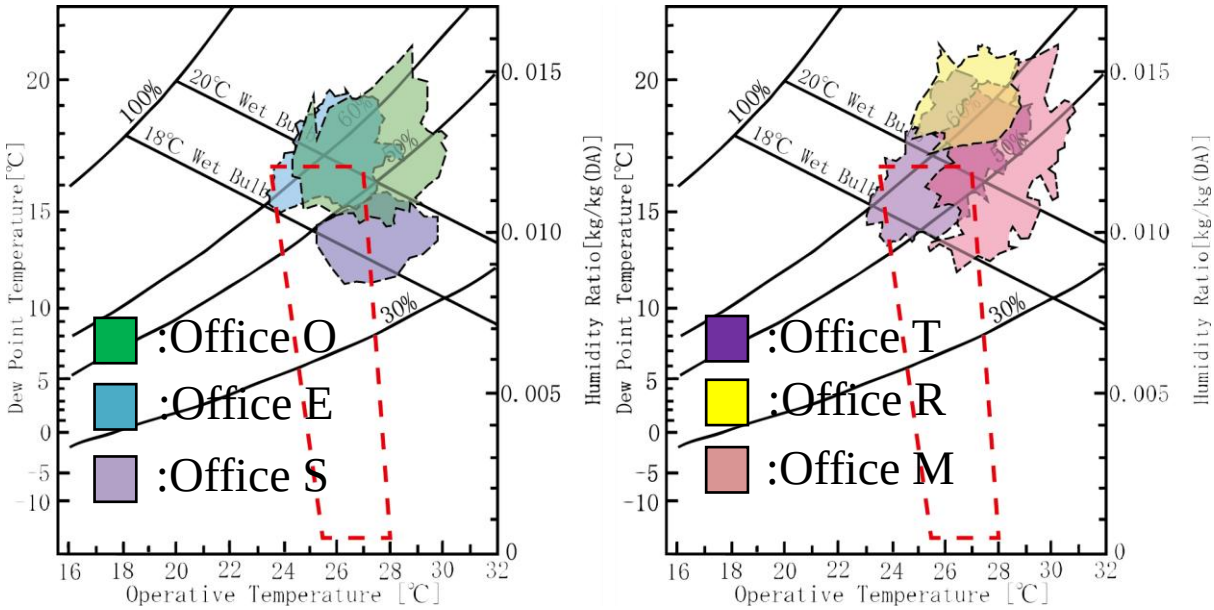

Figure 1. Indoor thermal environments of each office during operational hours.

Fig. 2 shows the occurrence frequency of the temperature and humidity in each office during operational hours. Office S used a ceiling radiant cooling system and desiccant air-conditioning unit. Therefore, its preset humidity was low. The humidity in Office R was high because it lacked dehumidification from a variable refrigerant flow system.

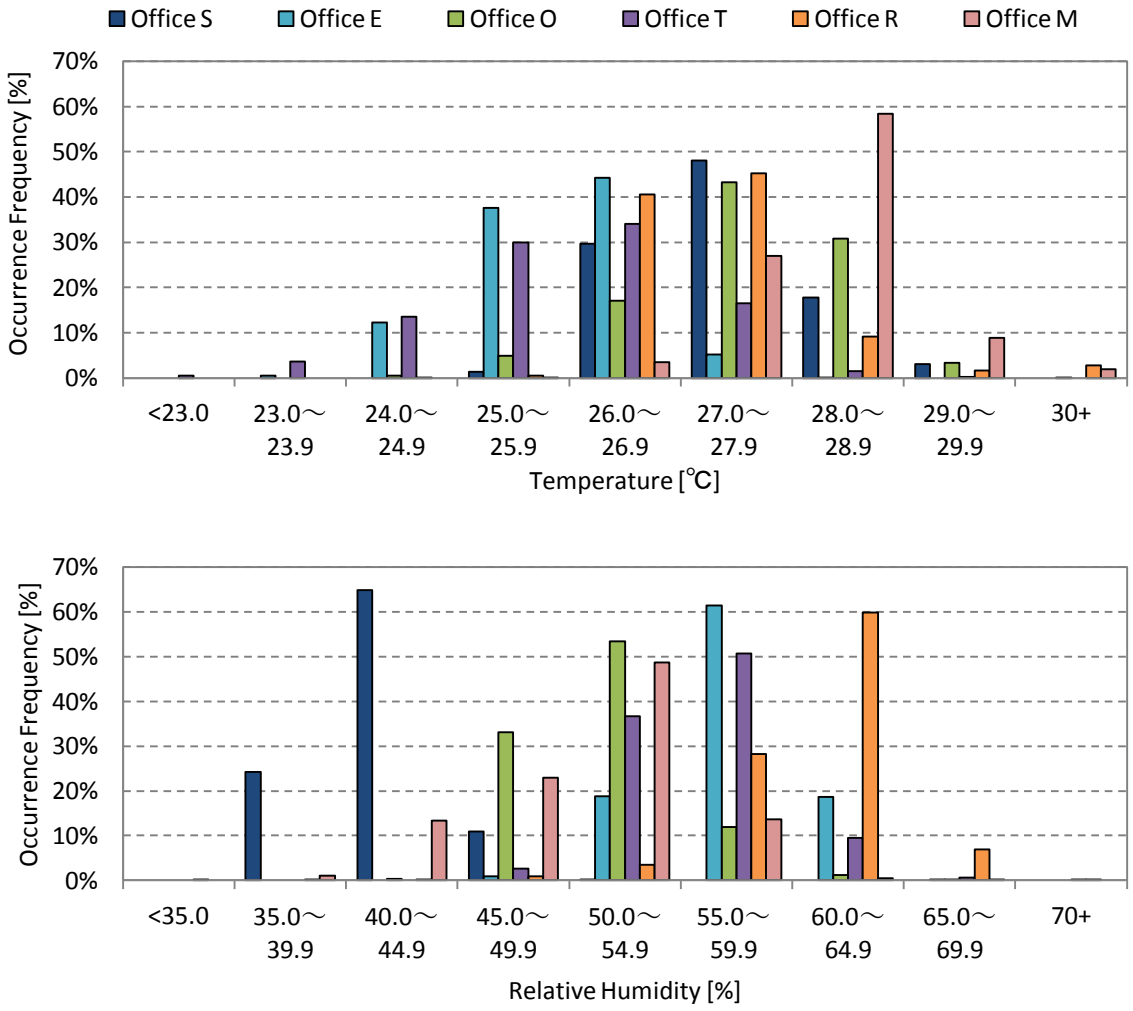

Figure 2. Occurrence frequency of the temperature and humidity in each office during operational hours.

3.2 Trend in the number of votes indicating unacceptable environment

Fig. 3 shows a decreasing trend in the number of votes indicating an unacceptable environment during the five days after the installation of Ostracon at each office. The number of votes indicating an unacceptable environment showed a decreasing trend during the five days. The data captured during a national holiday and a weekend were excluded. Moreover, because less than five days of data were recorded from Office E-1, these data were also excluded. Fig. 4 shows the predicted voting cumulative frequency according to the Gompertz curve and the voting cumulative frequency per worker at Office T. The voting cumulative frequency predictor by the Gompertz curve is

, (1)

where K, a and b are estimators of a parameter from the actual measured value, and x is the number of elapsed days. The results show that the number of votes deeming the environment as unacceptable was uniform during the first 10 days and showed a decreasing trend during the next nine days. A possible explanation for this behaviour is that the workers were likely

more interested in Ostracon at the beginning of the survey and the votes decreased as workers grew accustomed to their environments. However, this study was the first survey of using ostracon. Also, the decreasing trend of number of unacceptable votes was different with each worker. Therefore, the data were analyzed without considering such subjective human behaviour, and the data from Ostracon for Day 1 were analyzed.

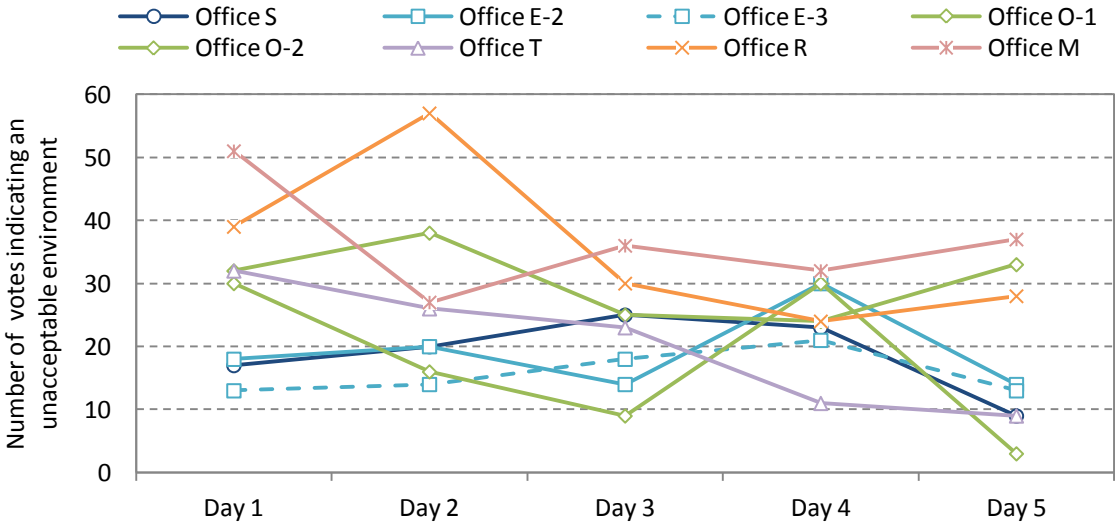

Figure 3. Changes of in the number of votes indicating unacceptable environment during the five-day period after the installation of Ostracon.

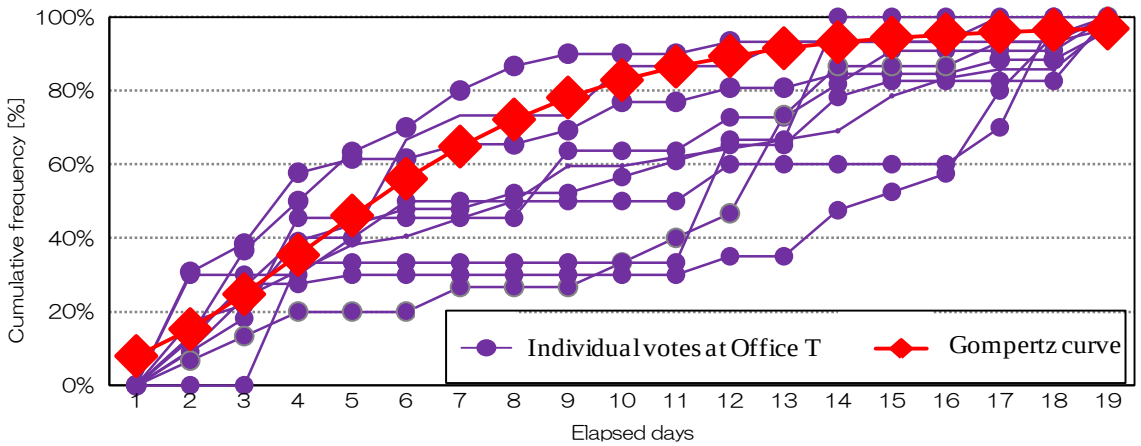

Figure 4. Predicted voting cumulative frequency according to the Gompertz curve.

3.3 Typical example of unacceptable votes

Fig. 5 shows the typical example of votes indicating unacceptable thermal environment at Office T. The dashed lines show the data for field workers and the continuous lines show the data for non-field workers. The results show that the number of votes indicating an unacceptable environment was different each day. The dashed lines in the figure show that a large number of votes came from field workers. Therefore, it is considered that the workers' complaints were influenced such as changes in their metabolic rates and personal sequence of thermal environment.

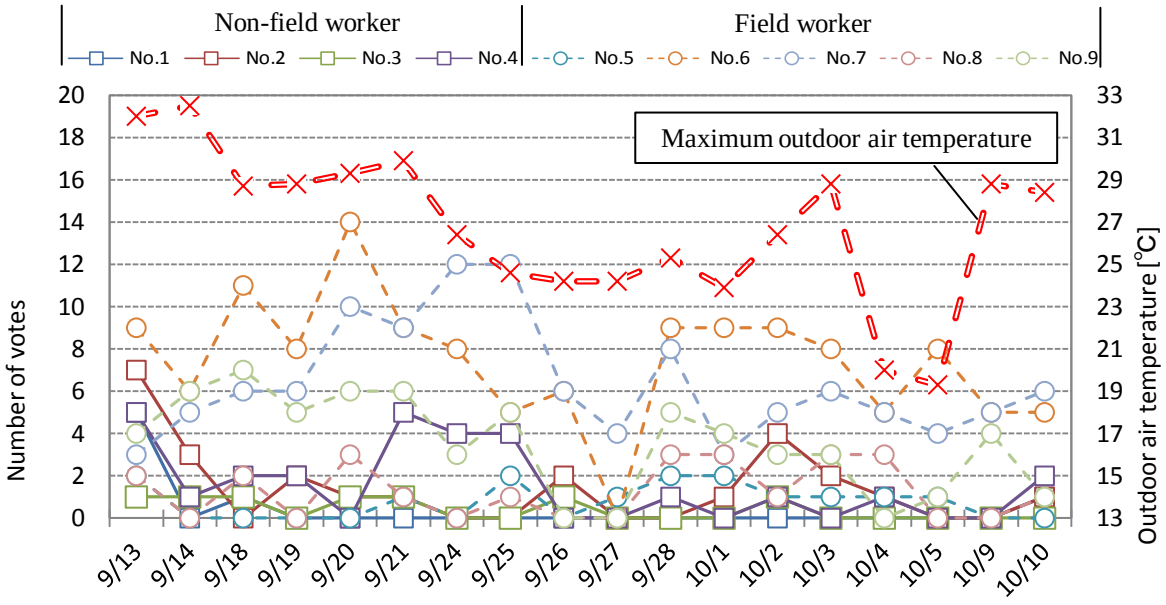

Figure 5. Typical example of votes by workers in Office T.

3.4 Temperature–humidity range deemed unacceptable

Fig. 6 shows the data based on ASHRAE Standard 55-2004 indicating the temperature and humidity range deemed unacceptable in each office. The environmental temperature was ascribed to the operative temperature because Ostracon cannot measure the radiation temperature. The shaded areas in the figure indicate the indoor thermal environments during office hours. The red dashed lines indicate comfortable temperature–humidity ranges in summer. These results show that 1599 votes indicated an unacceptable environment. Although the preset temperature and humidity differed among offices, 23.3% of the temperature and humidity values recorded in all offices were within the range deemed comfortable as per the ASHRAE Standard 55-2004.

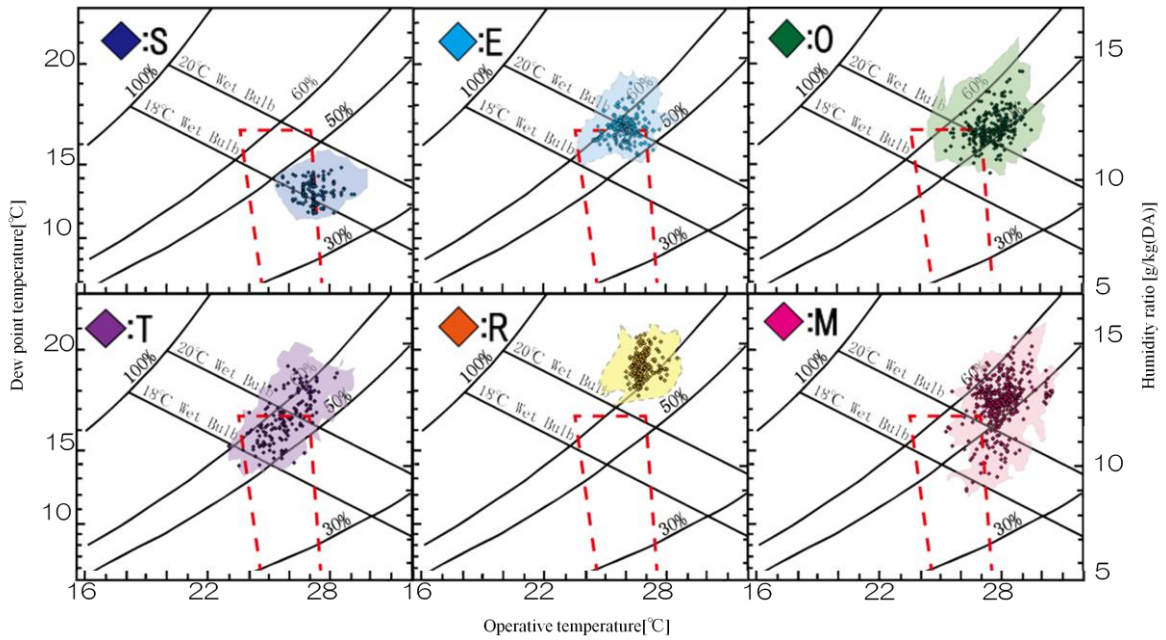

Figure 6. Votes indicating unacceptable environments and comfortable temperature–humidity ranges (ASHRAE Standard 55-2004).

3.5 Occurrence frequency of the temperature at which the environment was deemed unacceptable

Fig. 7 shows the occurrence frequency of the temperature deemed unacceptable by the workers. Dashed lines in the figure indicate the occurrence frequency of the temperature during office hours on the desk by ostracon. In these results, the occurrence frequency of the votes indicating unacceptable environment is similar to that of the temperature during office hours. Therefore, the data do not show a relationship between the temperature and acceptability of the thermal environment.

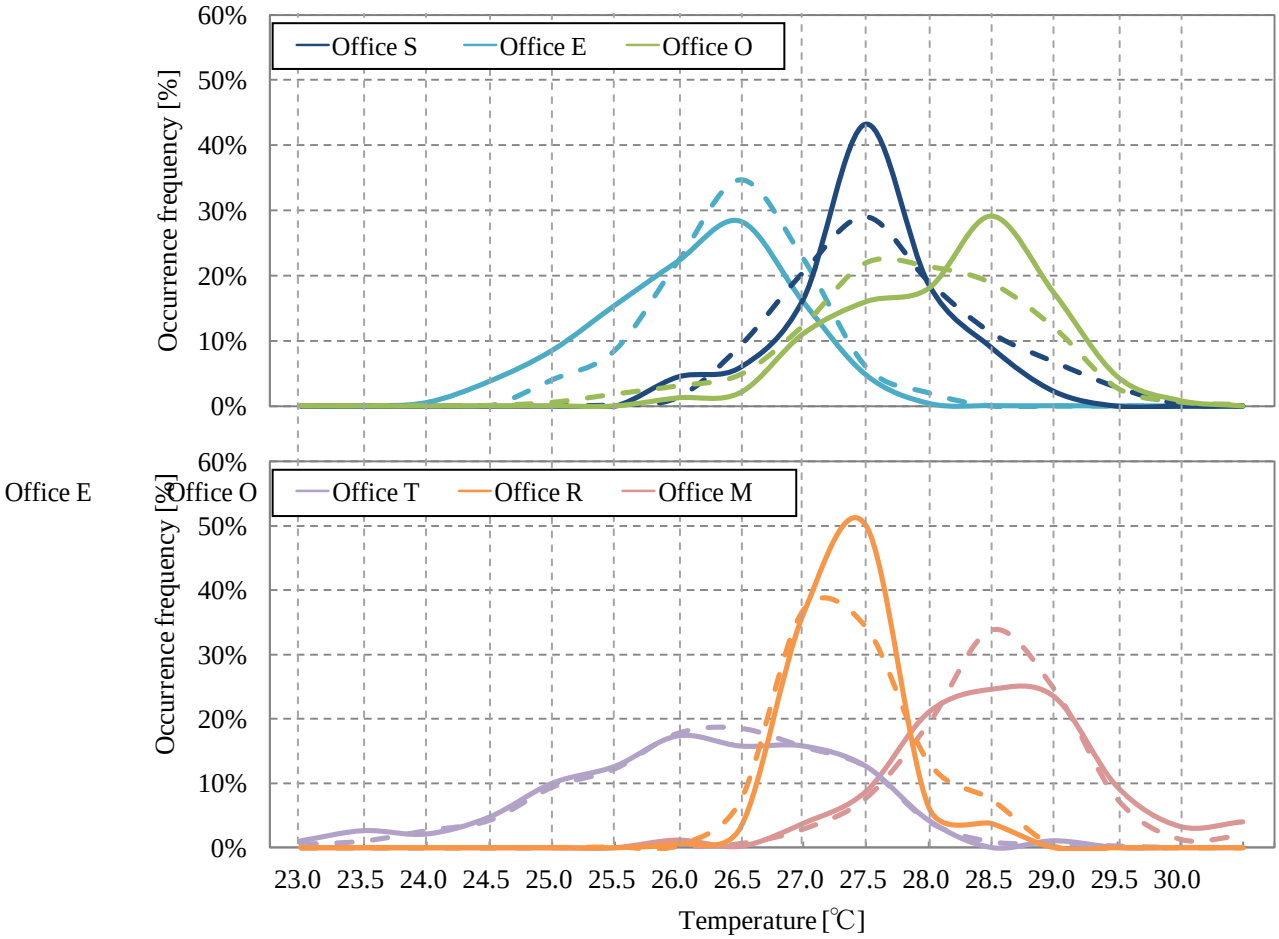

Figure 7. Occurrence frequency of the temperature at which the environment was deemed unacceptable by the workers.

3.6 Specific enthalpy and unacceptable votes

Fig. 8 shows the relationship between the specific enthalpy at the time someone voted unacceptable environment and the specific enthalpy difference 10 min prior to the voting. In general, when a thermal environment continues to improve, individuals deem the thermal environment comfortable. However, in these results, the votes indicating unacceptable environment occurred independently of the specific enthalpy difference 10 min prior to voting in the actual office environment. Therefore, it is considered that thermal environmental acceptability is not determined simply by physical environment conditions.

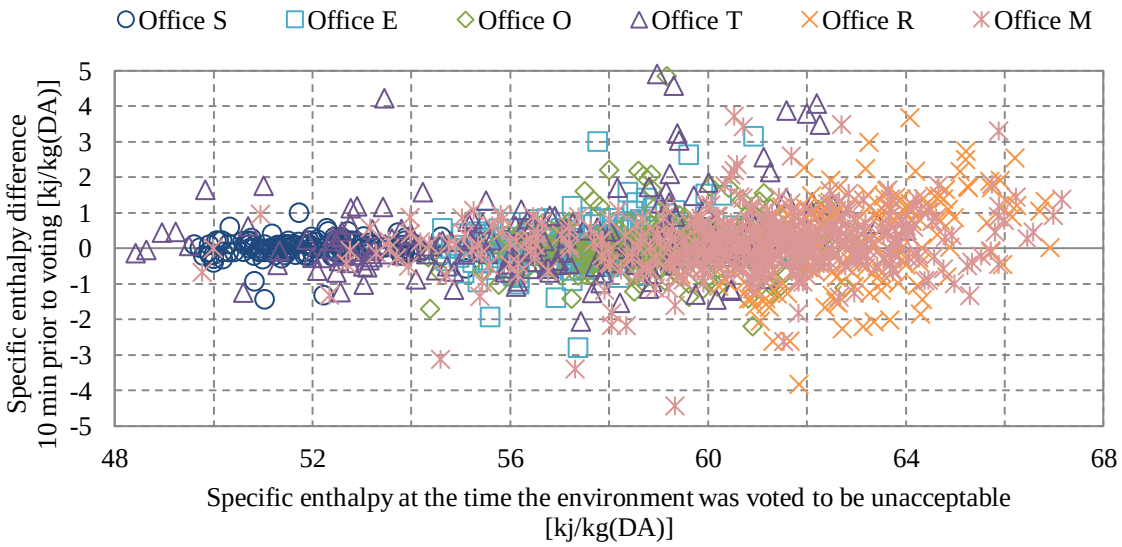

Figure 8. Specific enthalpy at the time of unacceptable votes.

4 Discussion

Fig. 9 shows that the number of votes was affected by the walking distance to Office M. A walking distance of more (less) than 500 metres per hour was assumed to correspond to movement outside of (within) the office. The results show that a high number of votes indicating unacceptable environment was affected by movement outside the office. Fig. 10 shows the average number of votes recorded during each hour at each office. In these results, the votes indicating unacceptable environment were concentrated in the morning and evening. These hours correspond to the times at which workers enter the office in the morning and return back from outside tasks in the evening. These results suggest that workers' complaints about the office environment are affected by changes in metabolic rates, such as those occurring when a worker returns to the office after leaving for lunch or performing job tasks outside of the office.

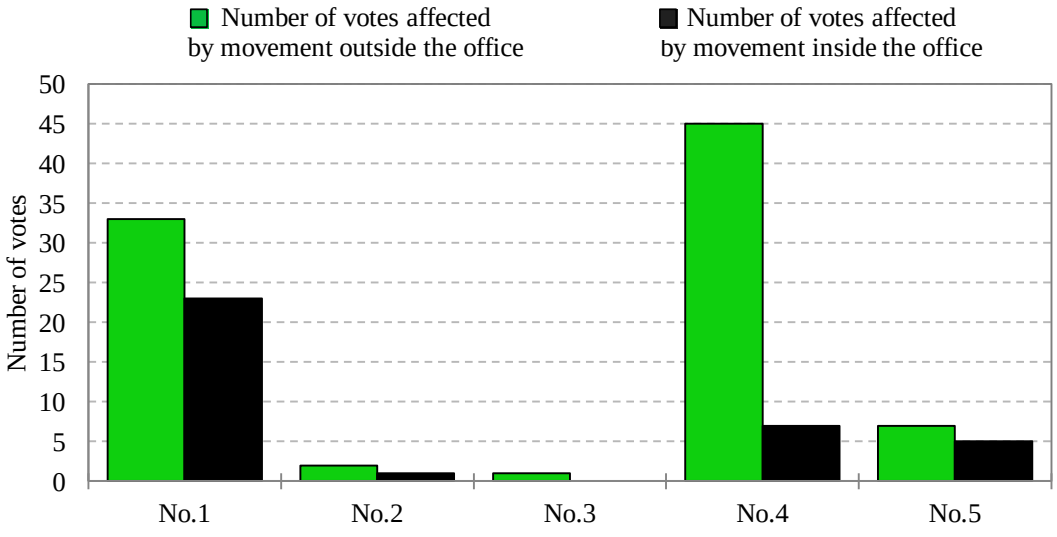

Figure 9. Number of votes affected by walking distance to Office M.

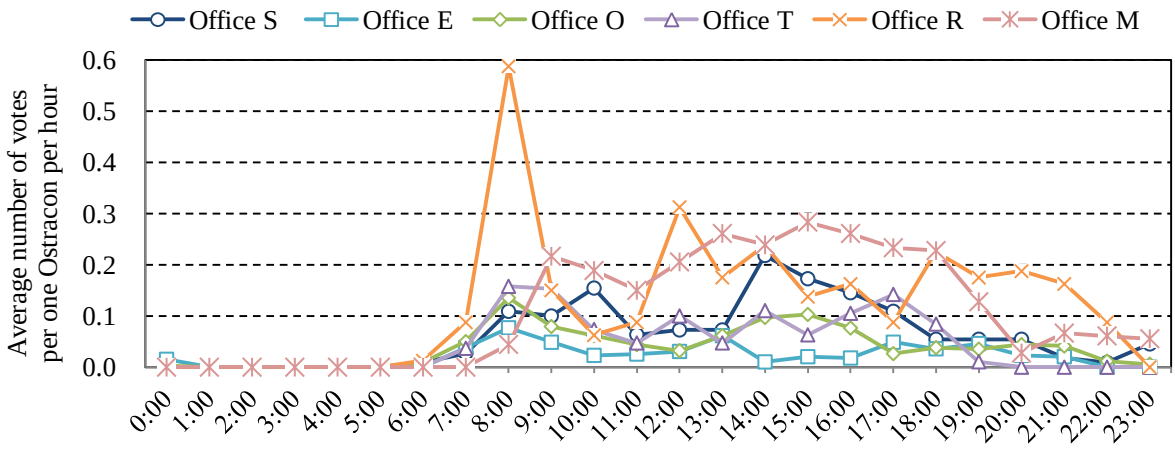

Figure 10. Average number of votes recorded during each hour at each office.

4 Conclusions

This study aimed to clarify the characteristics of the complaints and the mechanism by which workers consider the thermal environmental acceptable in an actual office. For this purpose, the authors developed a device called Ostracon that can record the physical environment when the workers feel that the thermal environment is unacceptable. Ostracon was used to record the environmental conditions at the time workers in offices felt the office environment to be unacceptable during the summer. The results are summarized in the following points:

1) Votes indicating an unacceptable environment were recorded even when the thermal environment was consistently maintained at comfortable levels according to ASHRAE standards. Even when the environmental conditions were set at a comfortable temperature–humidity range, 23.3% of the votes indicated that the environment was unacceptable.

2) The data did not show a relationship between the physical environment and the occurrence of votes deeming the environment as unacceptable. Therefore, it is considered that acceptability of the thermal environmental is not determined simply by temperature and humidity.

3) The votes indicating an unacceptable environment were concentrated in the morning and evening. These hours correspond to times at which workers enter the office in the morning or return in the evening from performing tasks outside the office. Moreover, a high rate of unacceptable votes was affected by movement outside of the office.

4) Therefore, it is considered that worker complaints registered in this study are a result of environmental factors such as the individual's thermal history and changes in metabolic rates that result from returning to the office after performing activities outside of the office.

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