

# Relationship between Thermal Environmental Acceptability and Individual Characteristics in an Office

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**Abstract** – We examine the acceptability of the thermal environment to office workers using data recorded with the Ostracon voting device. Although temporal changes in the overall indoor thermal environment were seemingly small, the spatial distribution of the thermal environment changed. Unacceptable votes in the middle of the thermal environment occurred regardless of the perimeter thermal environment, suggesting that temperature was less relevant to acceptability in the middle of the thermal environment.

**Keywords** – Thermal Comfort, Office, Acceptability, Ostracon.

## I. INTRODUCTION

Indexes, such as predicted mean vote and standard effective temperature have been used to evaluate thermal comfort. With these indexes, however, indoor thermal environment is measured not by its acceptability to occupants but as a simple temperature measurement. Although these indices allow stable evaluation of the indoor thermal environment, each occupant experiences the thermal environment differently and acceptance varies in offices even though thermal comfort is highly rated. In this study, we examine which conditions lead workers to find the thermal conditions of an indoor environment unacceptable. For this purpose, we developed the ‘Ostracon’ voting device, which records the physical environment when workers press a button on their desk to complain that the thermal environment is unacceptable [1]-[3]. This study analyzes the effects of various factors on thermal environmental acceptability to office workers.

## II. SURVEY OUTLINE

Table I shows a survey outline. The survey was carried out from November 25 to December 6, 2014, the building was an office, and the number of test subjects was 40. The air conditioning system was a linear air blow-off port with variable air volume in the interior zone, and a fan coil unit was placed in the perimeter zone. Ostracon devices were installed on each office worker’s desk and a seat-occupancy sensor was also developed and used, which recorded the temperature at the chair seat.

## III. OSTRACON DEVICE



‘Ostracon’ is an ancient Greek word that refers to a shard of pottery used by the electorate as a ballot. We used this name for our acceptability voting device developed for this study to

record the characteristics of the physical environment deemed unacceptable by workers. The device specifications are summarized in Table I. Workers pushed a button on the device, which was located on their desks, to record a complaint when they felt that the thermal environment was unacceptable. The Ostracon sent a signal to a pulse recorder, activating the attached thermo-recorder and humidity recorder. A seat-occupancy sensor was also developed to record the temperature of the chair seat. The Ostracon was used to determine whether the subjects deemed the office environment thermally comfortable. The conditions for each measurement location are shown in Table II.

TABLE I  
CONDITIONS FOR EACH MEASUREMENT LOCATION

<b>Study days</b>	<b>November 25 to December 6 2014</b>	
<b>Air conditioning</b>	Variable air volume	
<b>Number of subjects</b>	Ostracon	40
	Seat occupancy sensor	40

TABLE II  
OSTRACON VOTING DEVICE USED TO  
INDICATE THERMAL ACCEPTABILITY OF THE ENVIRONMENT

	<b>Acceptability voting device</b>
<b>Appearance</b>	
<b>Installation</b>	Desk
<b>Condition report</b>	Unacceptable
<b>Measurement interval</b>	10 min
<b>Size</b>	125 × 85 × 50 mm
	<b>Seat occupancy detection device</b>
<b>Appearance</b>	
<b>Installation</b>	On chair
<b>Condition report</b>	Not applicable
<b>Measurement interval</b>	4 min
<b>Size</b>	420 × 280 mm

IV. RESULTS

A. Questionnaire Survey

Fig. 1 shows the results of the questionnaire survey. The collection rate for the questionnaires was poor because the ratio of unknowns was high. The number of men was twice that of women, and the majority of respondents were in their forties and in clerical occupations. Most people wore long-sleeved suits because this survey was carried out in fall and winter. The percentage of 'very comfortable' and 'very uncomfortable' responses was 0%, whereas that for 'slightly uncomfortable' was 26%. The thermal sensation of the indoor temperature varied, although 'slightly comfortable' was the most common response for indoor thermal comfort. There were more 'comfortable' than 'slightly uncomfortable' responses for indoor thermal comfort, although the number of 'slightly uncomfortable' responses increased. For overall acceptance, the ratio of acceptance was six times that of unacceptance.

B. Spatial Distribution and Change in Thermal Environment

Fig. 2 shows the spatial distribution and change in the thermal environment in the office over time divided into three patterns: 09:00–11:00, 12:00–14:00, and 15:00–18:00. The south-facing windows are shown at the top of Fig. 2. The red dots indicate 'too hot' unacceptable votes, the blue dots indicate 'too cold' votes, and the number of dots corresponds to the number of votes. The temperature difference between the hot and cool areas was about 3 °C. As expected, 'too cold' unacceptable votes occurred in cool areas, such as around desk No. 3; however, they were also recorded in warm areas, such as around desk No. 31. Similarly, 'too hot' votes occurred in warm areas, such as around desk No. 40, and also in cool areas, such as around desk No. 6. Moreover, particular people voted many times. This suggests that the uncomfortable votes were affected by airflows affecting individual locations.

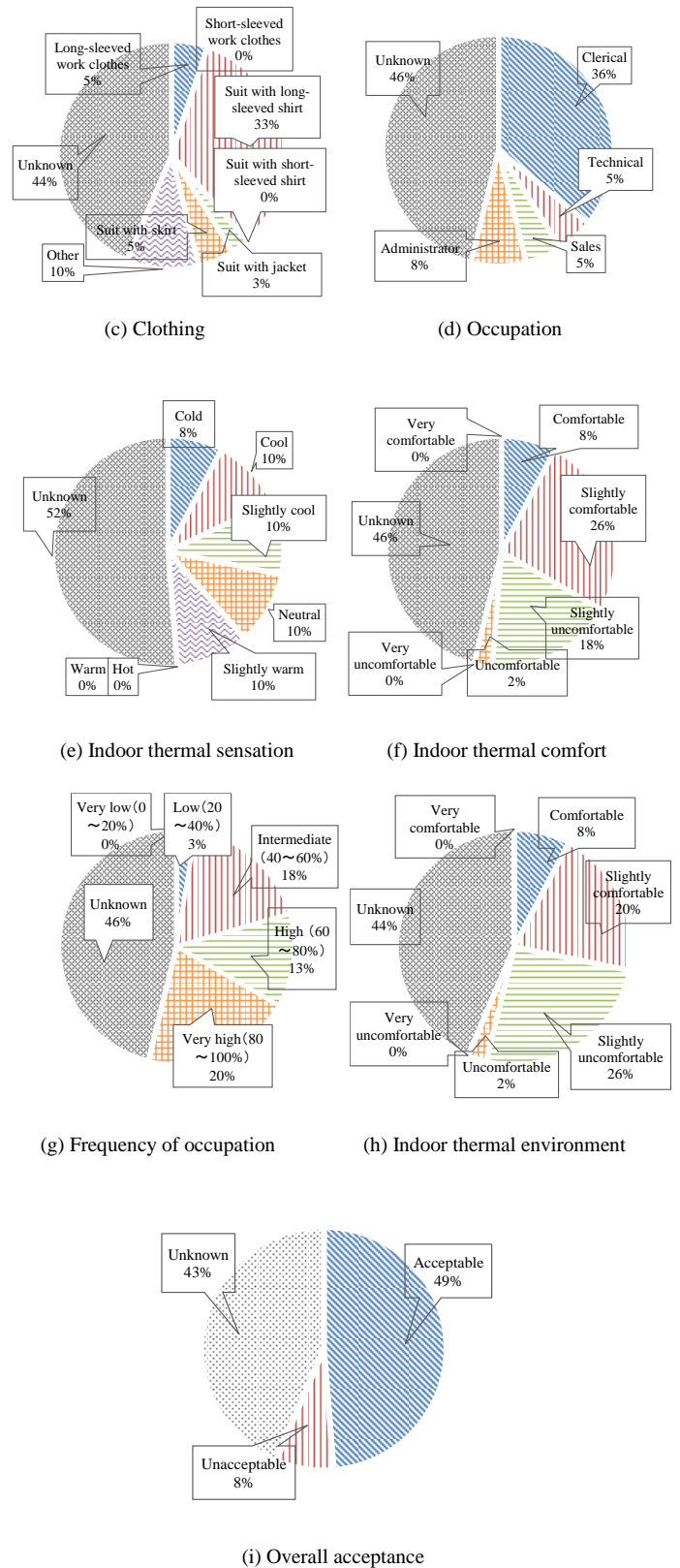


Fig. 1. Questionnaire survey results.

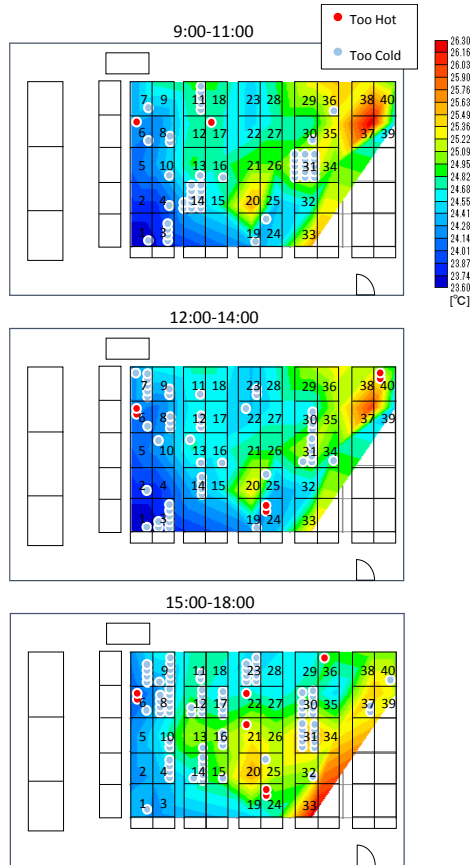


Fig. 2. Time course of the thermal environment and unacceptable votes.

### C. Distribution and Change of Thermal Environment According to Standard Effective Temperature\*

Fig. 3 shows the distribution of the standard effective temperature\* in the office divided into three patterns as in Fig. 2. Fig. 3 shows the measured dry bulb temperature. The Ostracon measurements were taken at 10 min intervals; therefore, one point represents 10 min. Furthermore, the region shown in purple in the figure represents the intermediate region between the summer and winter comfort zones. The thermal environment in the study area distributed for both of inside and outside of the comfortable range. The thermal environment distribution in study area showed a wider distribution at 9:00–11:00, although the variation of the thermal environment over time was smaller. Fig. 4 shows that the 'too cold' and 'too hot' unacceptable votes appeared inside and outside the comfortable region.

### D. Unacceptable Votes for Each Day

Fig. 5 shows the number of unacceptable votes, average outside temperature, and the maximum outside temperature for each day. Many unacceptable votes occurred early in the study, and the most votes were cast on November 26 and there was no large increase or decrease in votes during the latter half of the study. On November 26, the largest number of 'too cold' unacceptable votes was cast, even though the average outside temperature was the highest.

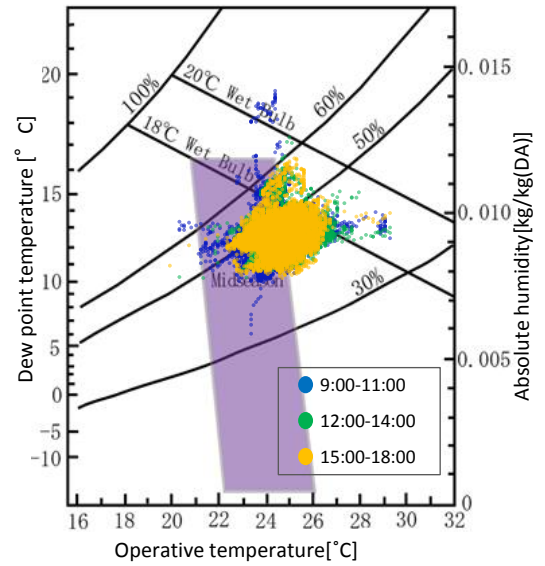


Fig. 3. Standard effective temperature\* distribution in the office.

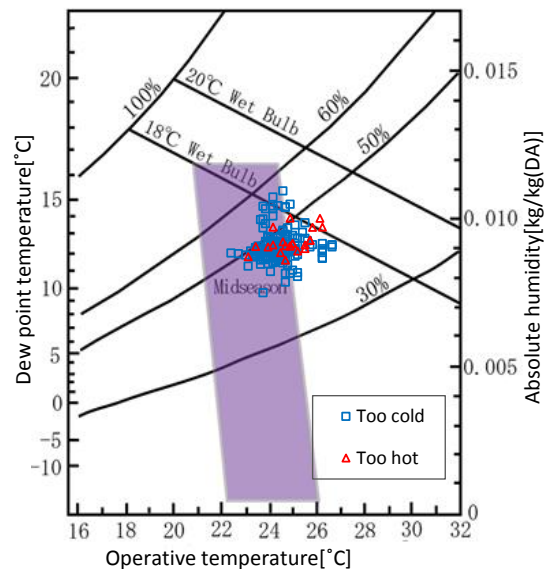


Fig. 4. 'Too cold' (blue points) and 'too hot' (red points) unacceptable votes as a function of standard effective temperature\*.

### E. Unacceptable Votes for Each Time

Fig. 6 shows the number of unacceptable votes for each time with the average outside temperature. Although the average indoor temperature in the early morning was low, it was about 25 °C in the afternoon. Numbers of 'too cold' unacceptable votes near the average were recorded from 10:00 to 15:00, and the most such votes were recorded at 16:00, with a higher than average number recorded at 17:00. 'Too hot' unacceptable votes increased in the mid-afternoon, although there were fewer votes.

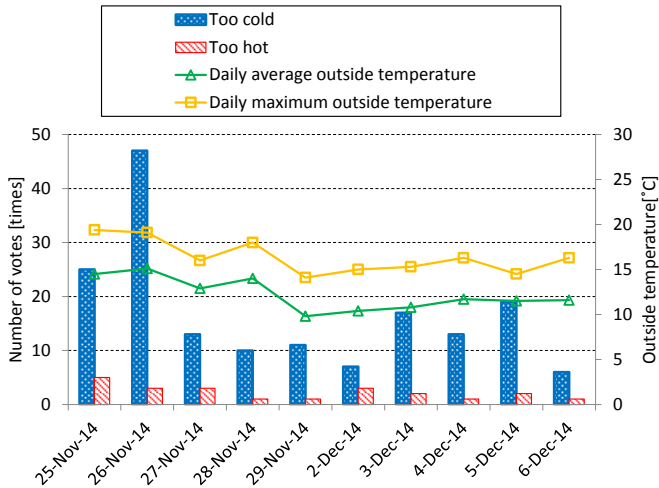


Fig. 5. Number of unacceptable votes for each day.

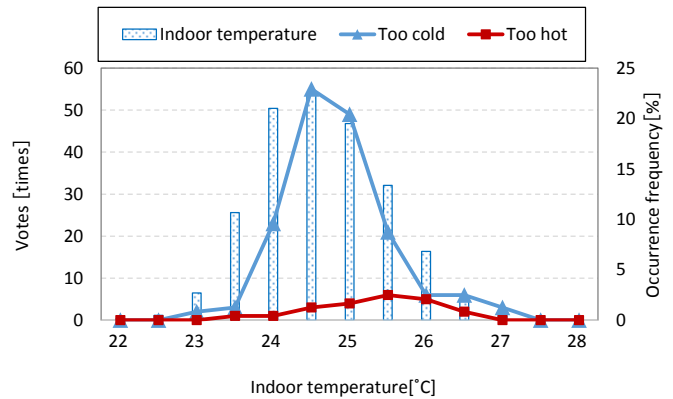


Fig. 7. Frequency of indoor temperature and number of unacceptable votes.

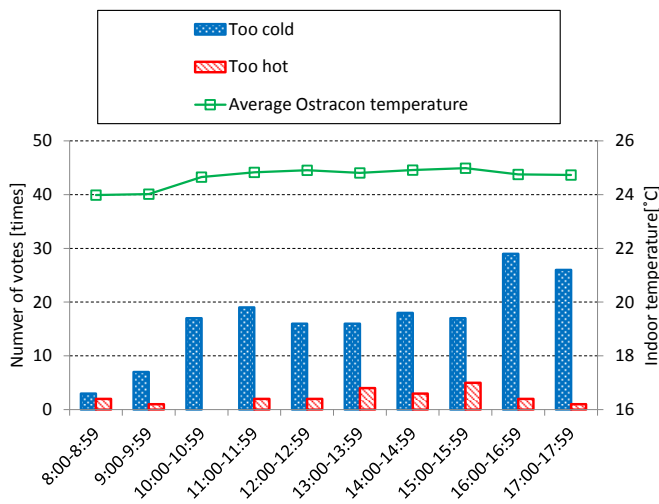


Fig. 6. Number of unacceptable votes for each time.

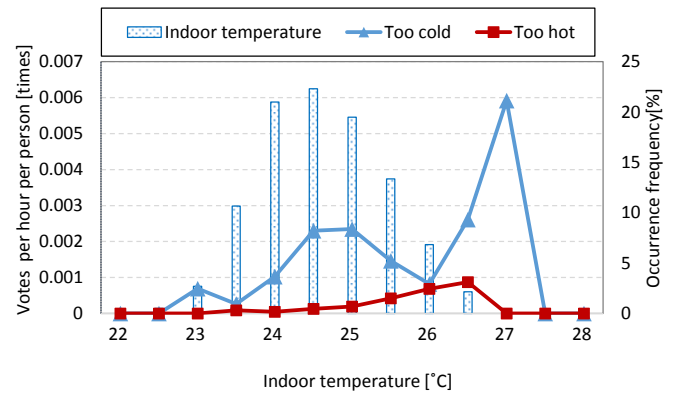


Fig. 8. Number of votes per hour per person and indoor temperature frequency.

#### F. Thermal Distribution of Times When Unacceptable Votes Occurred

Fig. 7 shows the indoor temperature frequency and the number of unacceptable votes as a function of time. The number of 'too hot' unacceptable votes was much lower than 'too cold' votes, and the indoor thermal temperature remained around 25 °C. The maximum indoor temperature frequency was the same as the maximum number of 'too cold' unacceptable votes. 'Too hot' unacceptable votes occurred infrequently during the warm period from 22 to 24 °C.

#### G. Unacceptable Votes Per Hour Per Person

Fig. 8 shows the number of votes per hour per person and the frequency with which each indoor temperature occurred. The distribution of 'too cold' votes increased as the indoor temperature increased, suggesting that unacceptable votes occurred despite the indoor thermal environment being regarded as generally comfortable. 'Too hot' votes occurred in the very warm environment. Therefore, 'too cold' and 'too hot' unacceptable votes were both cast in same indoor thermal environment. Additionally, the distribution of 'too cold' votes at 27 °C is the largest whereas the frequency at which an indoor temperature of 27 °C occurs is very low.

H. Specific Enthalpy when Unacceptable Votes Occurred

Fig. 9 shows the specific enthalpy and specific enthalpy difference between a vote cast 4 min previously. Generally, although environments that are measured as being warm feel warm when the temperature increases, 'too cold' votes were cast regardless of the change in the distribution of the comparison between the specific enthalpy and the value measured 4 min before the 'too cold' vote.

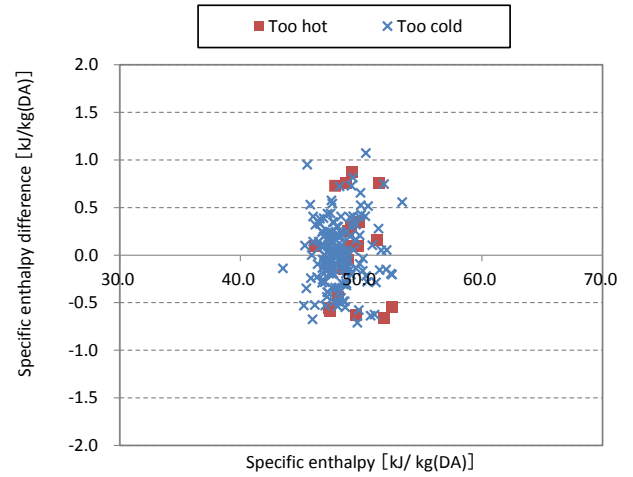


Fig. 9. Specific enthalpy and specific enthalpy difference between the current vote and the vote 4 min previously.

V. ANALYSIS OF INDIVIDUAL CHARACTERISTICS

A. Continuous Sitting

Fig. 10 shows the continuous sitting conditions of the subjects during the day. Continuous sitting for 5 min occurred most frequently, and the frequency decreased gradually. Continuous sitting over 60 min did not reach 5 %, suggesting that the office workers moved around frequently.

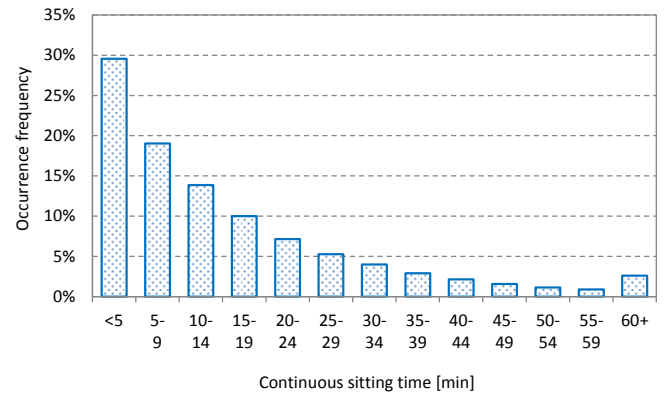


Fig. 10. Continuous sitting times for all workers.

B. Unacceptable Votes Occurrence by Occupation

Fig. 11 shows the occurrence of continuous sitting by occupation. The distribution of continuous sitting for clerical workers was similar to that of sales staff, because short and long periods of continuous sitting occurred. However, for technical and administrative workers, there were few periods of continuous sitting of up to 10 min and no periods over 31 min, suggesting that these workers moved around most frequently. Fig. 12 shows votes per person per day by occupation. It confirmed that only technical workers cast 'too hot' votes more than 'too cold' votes; it was the opposite for all other workers. These results are related to the amount of time spent sitting, suggesting that metabolic rate was increased by frequent movement.

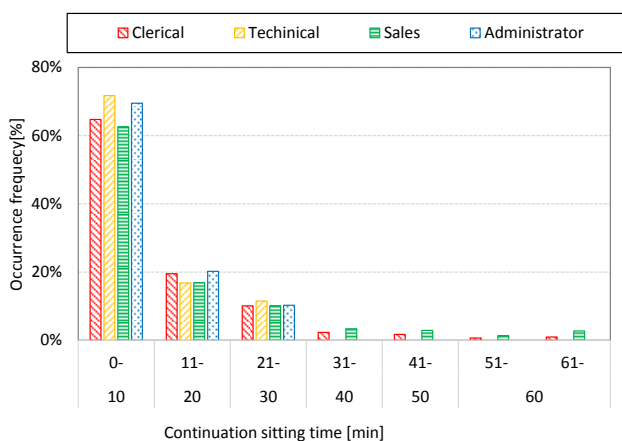


Fig. 11. Continuous sitting times by occupation.

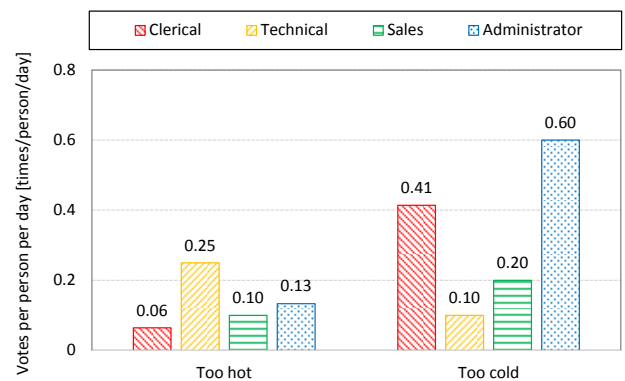


Fig. 12. Votes per person per day by occupation.



Figs. 13 and 14 show the number of 'too cold' votes cast by clerical and administrative workers by gender and by age group. Ninety-six percent of the clerical workers were in the forties and fifties age groups, and about 25 % were women. Fig. 11 suggests that clerical workers sit for long periods of time, particularly women in the forties and fifties age groups (Fig. 13(b)). This suggests basal metabolic rate per surface area is 10% lower in women than men, and female-specific thermal insulation performance was reduced in low-temperature environments; compared with men, women produce less heat in response to a reduction in skin temperature [4]. Although there were only four administrators, who were in the forties and fifties age groups, the 'too cold' votes for the forties age group accounted for about 90% of the 'too cold' votes.

### C. Unacceptable Votes by Age Group

Fig. 15 shows continuous sitting by age group. There was little difference across age groups, although continuous sitting for periods of less than 10 min was slightly more common. Fig. 16 shows the number of 'too hot' and 'too cold' unacceptable votes per person per day for each age group. The number of 'too cold' votes for the forties and fifties age groups was high, whereas the number of 'too hot' votes was quite high. Fig. 17 shows the breakdown of the 'too cold' votes for periods of continuous sitting of less than 10 min by age group. The forties and fifties age groups accounted for 80% of the votes. Thus, when thermal environment changed, the reaction was slower in older groups. This was likely to be caused by the effect of the thermal history.

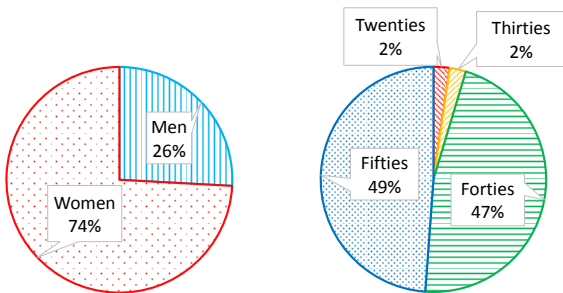


Fig. 13. Proportion of 'too cold' votes for clerical workers. (a) Proportion of men and women. (b) Proportion of age groups.

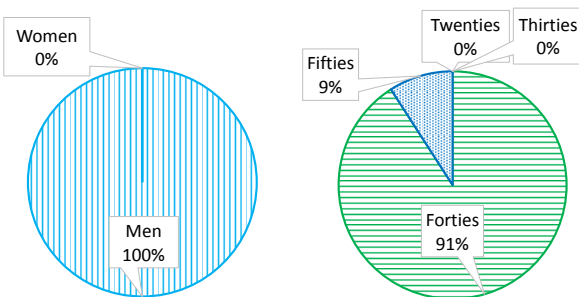


Fig. 14. Proportion of 'too cold' votes by administrative workers. (a) Proportion of men and women. (b) Proportion of ages.

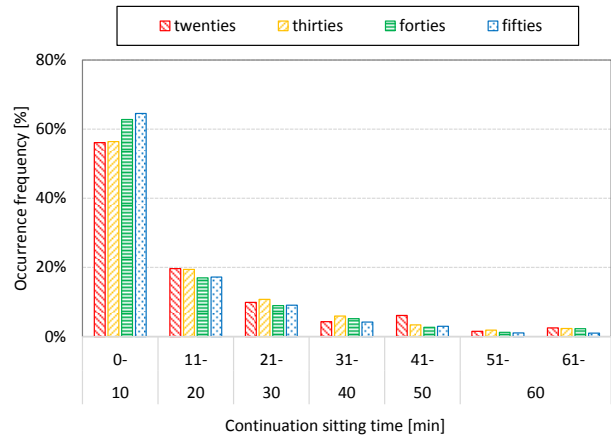


Fig. 15. Frequency of continuous sitting by age group.

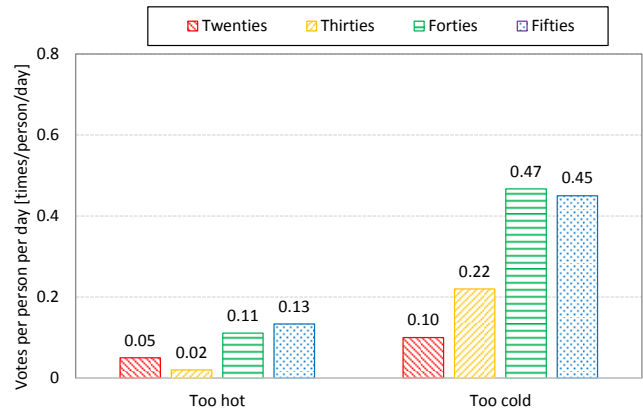


Fig. 16. Votes per person per day by age group.

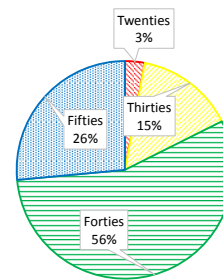


Fig. 17. 'Too cold' votes as a function of continuous sitting for less than 10 min.

## VI. DISCUSSION

Fig. 18 shows the number of unacceptable votes from all office workers per number of periods of continuous sitting. Fig. 19 shows the number of unacceptable votes by gender per number of periods of continuous sitting. The number of unacceptable votes per person per day for men was 0.37 times and for women it was 0.66, and the number of unacceptable votes by women (dashed lines) was large. Overall, the number of 'too cold' unacceptable votes was affected by the number of 'too cold' votes from women. The effect of continuous sitting for long periods increased the number of 'too cold' votes, and this trend was particularly pronounced in women. In addition, there were no 'too hot' unacceptable votes from woman, and only a few from men. In general, women have a thicker layer of subcutaneous fat than men, and this layer provides thermal insulation [4]. However, women cast more 'too cold' votes. This suggests that clothing and the smaller increase in heat production in women may be a factor in the difference in the number of 'too cold' unacceptable votes [4]. In addition, there were fewer unacceptable votes immediately after sitting, and 'too cold' votes by woman occurred frequently during long periods of sitting. In the fall, people do not sweat greatly, which is a factor in complaints about thermal environment, there were fewer unacceptable votes because of the effect of the thermal history, thus the unacceptable votes caused by long periods of sitting were noticeable.

## VII. CONCLUSION

Although changes over time in the overall indoor thermal environment appeared small, the spatial distribution of the thermal environment changed. Here, unacceptable votes in the middle of the thermal environment occurred regardless of the perimeter thermal environment, suggesting that temperature was less relevant to unacceptability in the middle thermal environment. Differences in the votes related to the office workers' occupation was caused by increases in the metabolic rate of technical workers resulting from frequent movement, as inferred from the short time spent sitting. Differences in votes by age arose because many unacceptable votes were recorded within the first 10 min from individuals sitting continuously, because the strong effect of the individual thermal history resulted in a delayed reaction to changes in the thermal environment. In the middle of the thermal environment, there were fewer uncomfortable votes from men than from women. Women in particular frequently complained that the environment felt too cool, and no women complained that the environment felt too hot; therefore, the reason for

unacceptability may have been caused by longer periods of sitting and differences in clothing.

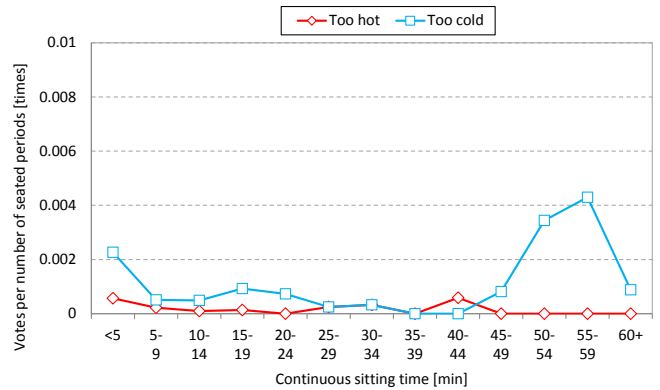


Fig. 18. Number of unacceptable votes from all office workers per number of continuous seated periods. Discussion.

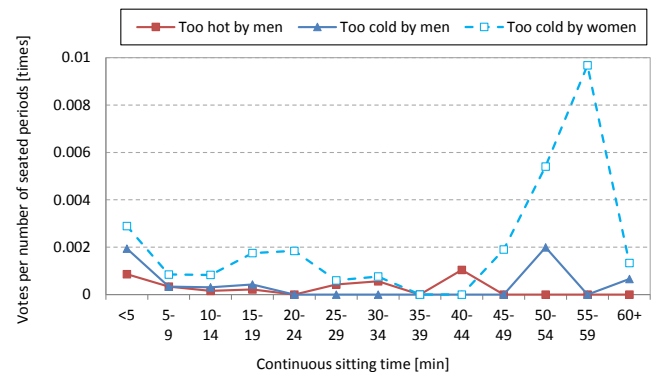


Fig. 19. Number of unacceptable votes by gender per number of continuous seated periods.

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