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Long-term field survey on thermal adaptation in office buildings in Japan

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Abstract

A long-term field survey was conducted with six buildings in order to investigate how the occupants adapt to the indoor climate in office buildings in Japan. More than 5000 questionnaires and corresponding indoor temperatures were collected. Clothing adjustment was observed to be related to outdoor temperature and indoor temperature, as well as dress codes. No considerable differences were found on the thermal perceptions between two groups of buildings, which provided different levels of opportunity for controlling indoor climate. With both groups, the preferred SET* was always close to 26 °C. The comfort temperature was estimated from the results of clothing adjustment and the preferred SET*. The gradient of the comfort temperature to outdoor temperature was found to be between the adaptive model for centralized HVAC and for natural ventilation. It could be caused by that the major part of the occupants in the present study had more opportunity to control their thermal conditions than in the centralized HVAC buildings (i.e. operable windows, controllable HVAC or personal fans).

Keywords: Thermal comfort; Field survey; Adaptation; Clothing insulation; Office building

1. Introduction

A great number of thermal comfort studies have been done with laboratory methods in climate chambers, and heat balance models, e.g. the PMV model [1], were developed and supported by those laboratory studies. On the other hand, comfort studies with field methods in actual buildings have also been done by several researchers, as reviewed by Brager and de Dear [2]. People in actual buildings can modify their thermal comfort by behavioral adaptation, e.g. adjusting clothing insulation or increasing air movement, and it has considerable impact on the comfort temperature and energy consumption in the buildings. The field studies have demonstrated the evidence of the behavioral adaptation. Furthermore, some of the field studies suggested the possibility of other adaptation processes [3–5]. More recently, de Dear and Brager [6] developed adaptive models for centralized HVAC buildings and natural-ventilated buildings. In particular, the adaptive model for natural-ventilated buildings indicated that the comfort temperature cannot be fully explained by the heat balance model, even if the effects of the behavioral adaptation are included in the heat balance. It was concluded that the comfort temperature is also affected by psychological adaptation, i.e. expectation and habitation.

Such an adaptive approach is expected to improve the existing design and control strategy of thermal environment for energy conservation. Thus, the latest revised ASHRAE standard 55-2004 [7] includes the adaptive model for naturally ventilated buildings as an option. However, the option is very restricted to apply in practice, because no mechanical cooling system is allowed. Almost

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all office buildings in Japan are installed with mechanical cooling systems. They do not satisfy the eligibility requirement of the adaptive standard, even if they have operable windows.

Many field studies have been done also in Japan. Isoda and Minamino [8] and Naruse and Minamino [9] conducted field surveys in offices and schools, and they showed the comfort temperature ranges and the clothing insulation for each season. In the 1990s, field surveys in many offices were done to develop and examine the post occupancy evaluation (POE) system [10] for office environment, but they provided little information on the effects of thermal adaptation. Recently, Nakano and Tanabe [11] conducted field surveys in semi-outdoor spaces and it was found that the comfort range is affected by the types of the spaces (i.e. indoor or semi-outdoor) and the types of the environmental control (i.e. HVAC or non-HVAC).

As mentioned above, almost all office buildings in Japan are installed with mechanical cooling systems. However, there are still some differences of the ‘‘adaptive opportunity’’ [2] in those buildings (Is the HVAC system centralized or controllable? Are the windows operable? Is there a dress code?), and these differences may affect the adaptation processes. Additionally, it is not sure whether the adaptation processes are independent of regional climate conditions and cultures, although de Dear and Brager's adaptive models were derived from the global database regardless of climates and cultures. Thus, a long-term field survey was carried out to investigate how the occupants adapt to the environment in usual office buildings in Japan.

2. Methods

The survey was carried out with six office buildings from July 2003 to May 2005. The characteristics of the buildings and occupants are shown in Table 1. These buildings are located at Sendai, Tsukuba and Yokohama cities, which are distributed in the eastern area of Honshu Island. Buildings A and C were surveyed during the period of 2003–04, and buildings D–F were surveyed during the period of 2004–05. Only building B was surveyed repeatedly in both periods. Buildings A and D had centralized air-conditioning systems and no operable windows. Thus, the occupants in these buildings could not control the indoor climate by themselves. The occupants in the other buildings could control the air-conditioning systems and windows, but the possibilities were considered to be different between the buildings. The number and age of the surveyed occupants are summarized in Table 2. These occupants usually engaged in typical office work.

This survey included indoor climate measurement and a questionnaire survey. For simplified indoor climate measurement a small data logger, with temperature and humidity sensors, was stuck on each occupant's desk, and it was located at the height of 0.6 m from the floor. In order to understand the indoor climate in more detail, another measurement was also done every season with a mobile instrument cart. This cart could measure air temperature and air velocity at three different heights (i.e. 0.1, 0.6 and 1.1 m above floor), and globe temperature and relative humidity (Table 3). The detailed measurements were done beside each occupant for approx. 10 min until the globe temperature became stable.

About 20 occupants in each building participated in the questionnaire survey. The questionnaire survey was conducted for one or 2 weeks in every month. A web server was installed for this survey. The participants accessed this server through the Internet in order to answer the questionnaire. The participants were requested to access the server every 12:00 and 17:00 by E-mail. In this questionnaire, the situation of mechanical cooling/heating, the situation of windows, and the frequencies of adaptive behaviors (i.e. modifying clothing, controlling windows, etc.) were asked as shown in Fig. 1. The other questions

Table 1
Summary of the surveyed buildings

Building code	Location	Survey period	Mechanical cooling and heating	Operable window	Dress code male/female
A	Sendai	Jul. 2003–Feb. 2004	Central control	No operable window	Business suit/uniform
B	Sendai	Jul. 2003–Feb. 2005	Zone control by occupants Aprox. 15 occupants/zone	Aprox. 5 operable windows per 100 m^2 floor space	Free/free
C	Tsukuba	Jul. 2003–Jun. 2004	Zone control by occupants Aprox. 5 occupants/zone	Aprox. 10 operable windows per 100 m^2 floor space	Free/free
D	Sendai	Jun. 2004–May 2005	Central control	No operable window	Business suit/free
E	Yokohama	Jun. 2004–May 2005	Zone control by occupants[a] Aprox. 10 occupants/zone	Aprox. 6 operable windows per 100 m^2 floor space	Business suit/free
F	Yokohama	Jun. 2004–May 2005	Zone control by occupants Aprox. 20 occupants/zone	Aprox.3 operable windows per 100 m^2 floor space	Business suit/free

[a]Centralized perimeter cooling and heating system was used together.

Table 2
Summary of the surveyed occupants

Building code	Surveyed number		Age category			
			21–30	30–40	41–50	51–60
A	Male	12		4	5	3
	Female	8	5	2		1
	Male and female	20	5	6	5	4
B	Male	19	17	2		
	Female	7	5	2		
	Male and female	26	22	4		
C	Male	10	4	6		
	Female	8	2	3	3	
	Male and female	18	6	9	3	
D	Male	17	6	4	7	
	Female	3	2	1		
	Male and female	20	8	5	7	
E	Male	14	2	8	4	
	Female	4	1	3		
	Male and female	18	3	11	4	
F	Male	11	1	8	2	
	Female	10	5	5		
	Male and female	21	6	13	2	

Table 3
Indoor climate measurements

	Items	Height (+ floor level)			Observation
		0.1 m	0.6 m	1.1 m	
Simplified measurement	Air temperature		O		Continuous
	Humidity		O		
Detailed measurement	Air temperature	O	O	O	Every season
	Air velocity	O	O	O	
	Humidity		O		
	Globe Temp.		O		

were related to clothing insulation, metabolic rate and thermal perceptions. A clothing garment checklist was prepared to estimate clothing insulation. The duration of continuous sedentary state was sought to substitute for the assessment of metabolic rate, because the question must be as easy as possible to answer regularly through the year. The thermal perceptions included thermal sensation, thermal acceptability and temperature preference, and these scales are shown in Fig. 1.

3. Results

3.1. Indoor climate

The average air temperature and humidity during surveyed periods are shown in Table 4. The average air temperature was distributed from 20 to 27 °C. There was little temperature difference between summer and winter seasons at 12 pm in buildings A and D, while those in the other buildings were about 2 °C. The average humidity was 40–70% in summer and 20–30% in winter. The observations of detailed measurements are also summarized in Table 4. The air velocity was averaged across three heights. The average air velocity in summer tended to be higher than in winter. Fig. 2 shows the distribution of the air velocity observations with different occupants. The most of the observations were distributed lower than 0.2 m/s in all buildings. The higher observations close to or over 0.3 m/s were caused by personal fans, which brought into the buildings by occupants. However, the high air velocities observed in building A were attributed to diffusers of mechanical cooling/heating, which were located close to

Please answer your circumstances and behaviors during past hours (9:00-12:00 *or*13:00-17:00).

• *Was mechanical cooling/heating running at least temporarily?* ○ Yes ○ No ○ I'm not sure.

• *Were windows openat least temporarily?* ○ Yes ○ No ○ I'm not sure.

• *If you were doing the following actions to control your hot /cold discomfort, please answer the frequencies.*

(a) Modifying clothing	◉ Never	○ Once ortwice	○ More frequently
(b) Controlling window ordoor (open, close and adjust)	◉ Never	○ Once ortwice	○ More frequently
(c) Controlling window shade	◉ Never	○ Once ortwice	○ More frequently
(d) Using personal fan or heater(d)	◉ Never	○ Once ortwice	○ More frequently
(e) (Controlling mechanical cooling or heating (on,off and adjust)	◉ Never	○ Once ortwice	○ More frequently
(f) Taking cold or hotdrink	◉ Never	○ Once ortwice	○ More frequently
(g) Fanning yourself	◉ Never	○ Once ortwice	○ More frequently

Pleaseanswer about the thermal environment at this moment.

Pleaserate your thermal sensation at this moment	*Please rate the thermal environment atthismoment*	*At this moment, would you prefer the temperature to be*
○ 3: Hot	○ Acceptable	○ Higher
○ 2: Warm	○ Not acceptable	○ No change
○ 1: Slightlywarm		○ Lower
○ 0: Neutral		
○ -1: Slightlycool		
○ -2: Cool		
○ -3: Cold		

Fig. 1. Questionnaire (partially extracted).

the occupants. Temperature differences between 0.1 and 1.1 m heights were lower than 3 °C in all buildings, and it satisfied the comfort level of ASHRAE standard 55 [7]. Globe temperature was close to air temperature but slightly higher, in most of the buildings. The daily mean outdoor temperature was obtained from the local weather stations of Japan Meteorological Agency.

3.2. *Operation of mechanical cooling/heating and windows*

Results of the questionnaire survey concerning operation of mechanical cooling/heating and operable windows are shown in Figs. 3 and 4, respectively. Buildings A and D almost always used mechanical cooling/heating. Buildings B and C used mechanical cooling/heating less frequently than buildings A and D, and windows were often used. Building E had more operable windows than buildings B and F, but the windows were hardly operated. This could be the reason why the centralized perimeter cooling/heating system was usually kept running. With building F, mechanical cooling/heating was usually used and sometimes windows were operated. Fig. 5 shows the incidences of windows opened in buildings B and C as a function of indoor air temperature. It is likely that higher indoor temperature caused occupants to open windows especially in building C. However, it could not be confirmed because the indoor temperature was affected by mechanical cooling as well as opening windows.

The mechanical cooling in summer appears to be used more frequently than mechanical heating in winter in most

Table 4
Summary of the indoor climate measurements

Building code	Season	Daily mean outdoor temp. (°C)		Simplified measurement								Detailed measurement		
		AVE	SD	Air temp. (°C) at 9 am		Air temp. (°C) at 12 pm		Air temp. (°C) at 5 pm		Relative humidity (%)[a]		Air velocity (m/s)	Vertical temp. difference (°C)	Diff. between globe and air temp. (°C)[b]
				AVE	SD	AVE	SD	AVE	SD	AVE	SD	AVE	AVE	AVE
A	Spring	—	—	—	—	—	—	—	—	—	—	—	—	—
	Summer	21.9	3.2	23.9	1.1	24.6	0.9	24.9	0.9	67.4	5.9	0.18	0.0	0.1
	Autumn	14.1	1.3	23.4	1.1	23.7	1.3	24.4	1.0	39.7	3.9	0.12	0.2	0.0
	Winter	2.6	1.6	23.0	1.0	23.8	0.7	24.3	0.7	28.4	2.7	0.11	0.1	0.1
B	Spring	13.7	4.5	24.4	1.2	25.3	0.9	25.7	1.0	33.9	8.8	0.08	1.5	−0.1
	Summer	20.8	2.1	26.0	0.8	26.5	0.8	26.5	0.8	45.3	6.1	0.07	1.1	0.4
	Autumn	12.2	3.0	24.0	1.1	25.3	0.8	25.9	1.0	35.0	5.7	0.07	1.6	0.2
	Winter	3.4	2.6	23.0	1.4	24.8	1.5	25.4	1.4	25.1	1.8	0.04	2.4	0.1
C	Spring	14.5	4.5	22.2	1.8	23.9	1.7	24.0	1.8	40.9	10.8	0.14	0.0	0.3
	Summer	21.2	2.6	24.8	1.5	25.6	1.4	25.8	1.3	57.5	8.3	0.15	0.5	0.5
	Autumn	14.1	3.2	23.9	1.1	25.4	1.1	25.2	1.1	42.1	10.3	0.09	1.2	0.2
	Winter	5.3	2.3	20.9	1.5	23.8	1.4	23.8	1.2	32.6	7.1	0.09	1.3	0.0
D	Spring	14.1	4.3	24.9	1.2	25.3	0.8	25.7	1.2	31.6	6.1	0.05	1.3	0.0
	Summer	21.2	2.1	25.4	1.0	25.7	0.9	25.9	0.8	44.7	5.5	0.10	0.3	0.2
	Autumn	10.8	4.1	24.4	1.3	25.4	1.1	25.0	1.2	31.4	8.2	0.09	0.6	0.1
	Winter	3.6	2.1	23.7	1.6	25.1	1.2	25.5	1.3	24.0	0.8	0.07	0.7	0.2
E	Spring	16.1	2.7	22.9	1.5	24.1	1.0	24.5	0.8	37.4	7.9	0.07	1.1	0.0
	Summer	26.4	2.5	25.5	0.8	25.4	0.7	24.9	0.8	56.0	5.3	0.13	0.4	0.6
	Autumn	16.8	3.9	22.9	1.7	24.2	1.2	23.8	1.0	45.5	10.2	0.03	1.3	−0.1
	Winter	7.7	2.4	21.3	1.6	23.8	1.2	24.4	1.0	27.2	3.4	0.09	1.7	—
F	Spring	16.1	2.7	24.9	0.9	25.8	0.6	25.9	0.6	39.0	5.1	0.17	0.3	0.7
	Summer	26.4	2.5	26.5	0.5	26.9	0.7	26.9	0.7	46.8	4.6	0.13	0.6	0.7
	Autumn	16.8	3.9	25.0	0.9	26.0	0.7	25.9	0.9	42.1	6.3	0.16	0.6	0.7
	Winter	7.7	2.4	23.2	1.0	24.6	1.0	25.0	1.0	32.0	4.6	0.09	1.8	0.1

—No data.
[a]Average and standard deviation during 8 am–8 pm.
[b]Globe temperature−air temperature.

of the surveyed buildings, because people, lighting, personal computers and other electrical appliances generated plenty of heat in the buildings.

3.3. Frequencies of behaviors

The answered frequencies of adaptive behaviors are summarized in Table 5. Taking cold/hot drink and modifying clothing were found to be the most frequent behaviors, while the other behaviors were utilized almost less than 10%. The frequencies of the adaptive behaviors did not clearly correspond with adaptive opportunities. In particular, mechanical cooling/heating system was hardly controlled in buildings B, C and E, where the occupants could control the system. It did not indicate that there was no control in those buildings. It was possible that the mechanical cooling/heating was turned on and the thermostat was adjusted in the early morning. Moreover, there was a little doubt if the form of the questionnaire had affected the results. Because "never" had been selected as the default (Fig. 1) in order to minimize the efforts, which would be made by the occupants. However, it is not far from the fact reported by Heinemeier et al. [12]. They found that even if occupants had task air conditioning system, only 10% of them adjusted it daily.

3.4. Clothing insulation

Clothing insulation was estimated from the questionnaire survey. Clothing insulation of each garment was referred to ISO9920 [13]. The relation of clothing insulation to indoor temperature and outdoor temperature are shown in Table 6. It was found that the clothing insulation was more related to outdoor temperature than indoor temperature. The clothing insulation of each dress code was averaged every 5 °C of daily mean outdoor temperature and is shown in Fig. 6. For the case of no dress code, the clothing insulation of females was observed to be approximately 0.05 clo lower than that of males. The clothing insulation in the case of business suits changed similarly to that in the case of no dress code, but it was stabilized above 20 °C of outdoor temperature. The clothing insulation of uniforms (building A, female) was also varied with temperature change by adding or removing some optional garments, but is observed to be always higher than the other conditions.

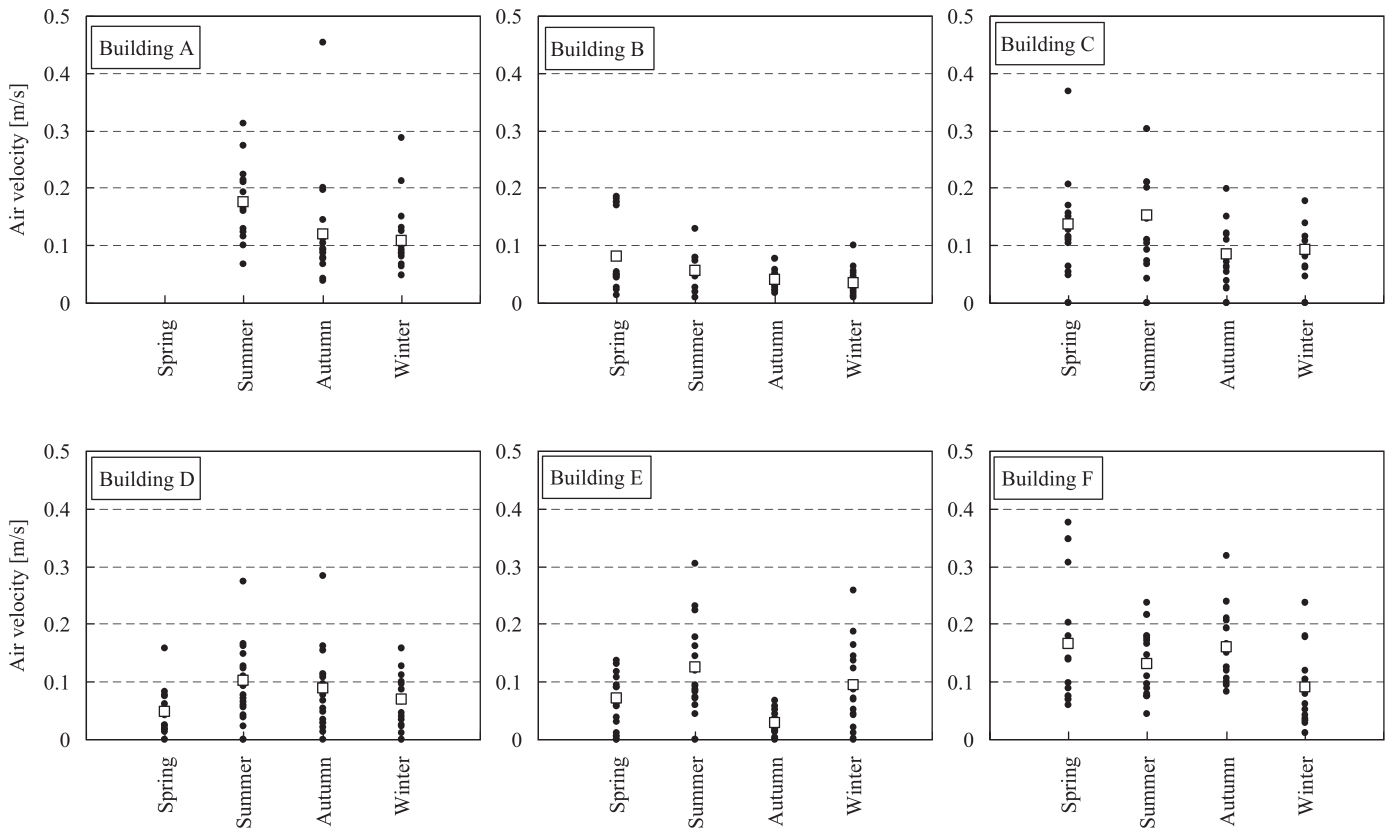

Fig. 2. Distribution of air velocity observations (hollow square: mean).

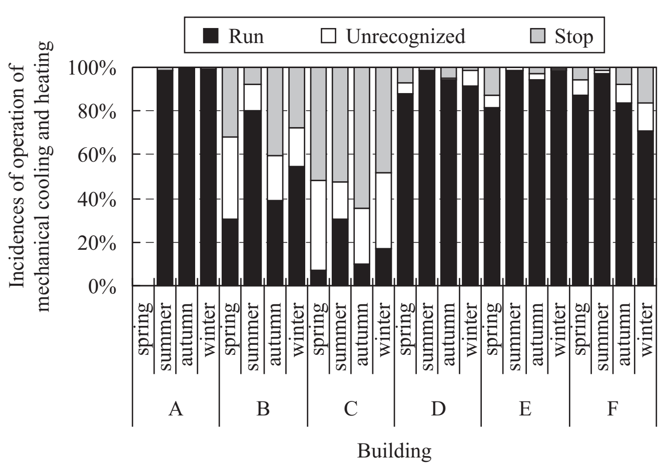

Fig. 3. Incidences of operation of the mechanical cooling and heating.

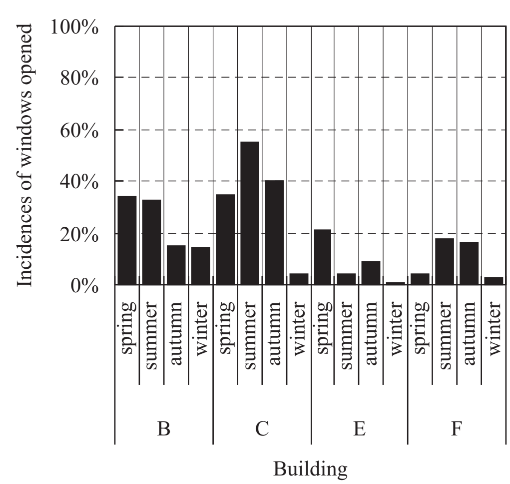

Fig. 4. Incidences of the windows opened.

Fig. 7 shows the average clothing insulation except for the female/uniform, with variations of indoor temperature. The clothing insulation decreased by approximately 0.05 clo every 5 °C increase of outdoor temperature when the clothing insulation was higher than 0.5 clo. The clothing insulation was also adjusted with indoor temperature, and the adjustment was more obvious in winter than in summer because there were more garments to adjust in winter than in summer.

Fig. 8 shows the mean clothing insulation in each building as a function of outdoor temperature at the certain indoor temperatures (i.e. 24 and 26 °C). The plots with less than 10 samples were excluded in the figures, and the mean clothing insulation in building A was determined without female data. It was found that the clothing insulation patterns with buildings D and F were different from the other buildings at low outdoor temperatures, while those in the other buildings were similar. It is well corresponding to the result on the frequency of modifying clothing (Table 5). The buildings D and F had the same characteristics. In both buildings, the indoor temperature was relatively high all through the year (Table 4), and the male occupants dressed in business suits. Moreover, both buildings provided less possibility to control mechanical cooling/heating and windows. However, each of them was not the exclusive characteristic of the buildings D and F. Therefore, it was not identified which characteristic caused this clothing insulation patterns.

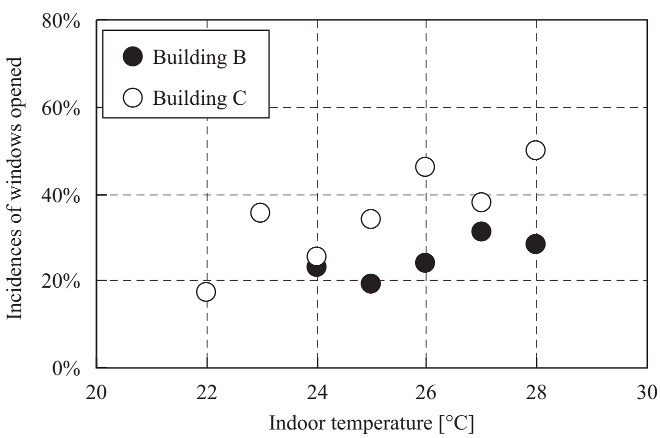

Fig. 5. Relationship between incidences of the windows opened and the indoor temperature.

3.5. Activity

The duration of continuous sedentary state was sought in this survey to substitute for the assessment of the metabolic rate. The duration was sought as 7 category scales, and very short standing work in the same room for less than 1 min was included in the sedentary work. The results are shown in Fig. 9. Over 70% of the occupants of all the buildings were doing continuous sedentary work for 15 min or longer duration. In the previous study, Goto et al. [14] have shown subjective thermal responses approximated the steady-state response after 15–20 min under constant activity.

3.6. Thermal perception

The analysis was conducted to investigate the relationship between thermal perception and indoor climate. For this analysis, the surveyed buildings were divided into two groups: one was the buildings B, C and E, and the other was the buildings A, D and F. The data sets of the buildings in the same group were analyzed together, because the number of data points for each building was insufficient when out of the prevalent air temperature range, even though there were many accumulated within the prevalent air temperature range. The groups were defined by the possibility of controlling the indoor climate (i.e. mechanical cooling/heating and windows).

Table 5
Percentage of frequencies of adaptive behaviors

Adaptive behavior	Frequency	Building code					
		A	B	C	D	E	F
(a) Modifying clothing	Never	78.2	85.9	79.5	93.2	81.9	91.1
	Once or twice	21.2	13.6	20.1	6.1	17.6	7.1
	More frequently	0.7	0.5	0.5	0.7	0.5	1.8
(b) Controlling window or door (open, close and adjust)	Never	—	94.5	89.7	—	98.5	97.7
	Once or twice	—	5.0	10.0	—	1.2	2.0
	More frequently	—	0.5	0.3	—	0.3	0.3
(c) Controlling window shade	Never	100.0	98.5	97.0	98.9	98.6	97.7
	Once or twice	0.0	1.5	3.0	0.8	1.4	2.3
	More frequently	0.0	0.0	0.0	0.3	0.0	0.0
(d) Using personal fan or heater	Never	99.8	96.6	99.1	96.4	93.8	90.2
	Once or twice	0.2	2.0	0.2	0.9	3.9	3.0
	More frequently	0.0	1.4	0.8	2.7	2.3	6.7
(e) Controlling mechanical cooling or heating (on, off and adjust)	Never	—	98.3	99.5	—	99.2	91.6
	Once or twice	—	1.6	0.5	—	0.8	6.7
	More frequently	—	0.1	0.0	—	0.0	1.7
(f) Taking cold or hot drink	Never	71.8	96.2	81.3	72.1	89.2	71.3
	Once or twice	24.3	3.4	18.7	27.6	10.7	27.3
	More frequently	3.8	0.4	0.0	0.3	0.1	1.4
(g) Fanning yourself	Never	97.0	99.1	94.0	96.8	96.1	88.5
	Once or twice	2.5	0.9	4.2	2.8	3.5	8.7
	More frequently	0.5	0.0	1.8	0.4	0.4	2.8

Table 6
Relationship of clothing insulation (Icl) to the indoor and outdoor temperature

	Regression equation	R^2	p
Indoor temperature (Ta)	Icl = 1.972–0.052*Ta	0.134	<0.001
Outdoor temperature (Tout)	Icl = 0.842–0.013*Tout	0.307	<0.001

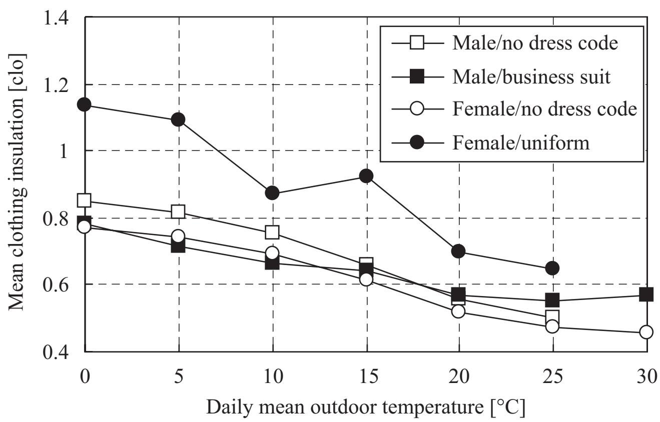

Fig. 6. Comparison of the clothing insulation with different dress codes.

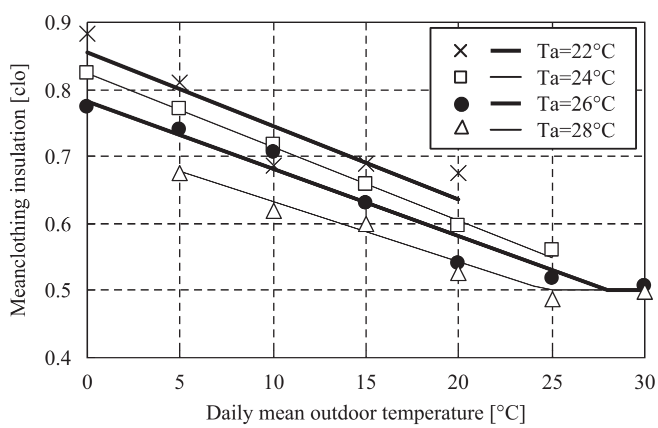

Fig. 7. Relationship between the clothing insulation and the outdoor/indoor temperature (except for female/uniform).

As mentioned above, the frequencies of adaptive behaviors did not correspond clearly to the possibilities of those. However, Heinemeier et al. [12] and Bauman et al. [15] had indicated that it is more important for occupants' satisfaction to be possible to control their thermal conditions than to actually make a large number of adjustments. Therefore, we paid more attention to whether the occupants were possible to control their thermal conditions in this analysis.

There were differences in clothing insulation between the buildings. In order to standardize the effect of the clothing insulation, the SET* was calculated for all buildings. When the SET* was calculated, the monthly mean clothing insulation of each building was used instead of the individual clothing insulation, and 0.1 clo was added to it as the increase of clothing insulation by chair [16]. The air velocity and globe temperature were not measured continuously in the survey. Therefore, the air velocity and MRT were assumed to be 0.1 m/s and equal to the air temperature. These assumptions were close to the observations in detailed measurements as shown in Table 4. The metabolic rate was assumed to be a constant of 1.2 met for all the occupants.

Fig. 10 compares the average thermal sensations answered after different durations of being in a sedentary state. The thermal sensations after less than 15 min of being in a sedentary state were significantly higher than those after a long time of being in a sedentary state. It agrees well with our previous study [14], and the metabolic rate during this period should not be assumed to be constant. Thus, the data sets during this period were excluded from the following analysis.

The data sets were divided into two groups as mentioned above (i.e. buildings B, C and E vs. buildings A, D and F). On each group, linear regression analysis and probit analysis were done to get the relationship of the thermal sensation to the SET* and the temperature preferences to the SET*, respectively. The fitted lines of these are shown in Figs. 11 and 12. The lines of the temperature preference, which increase along with the SET*, represent preference for lower temperature, the opposite lines represent preference for higher temperature.

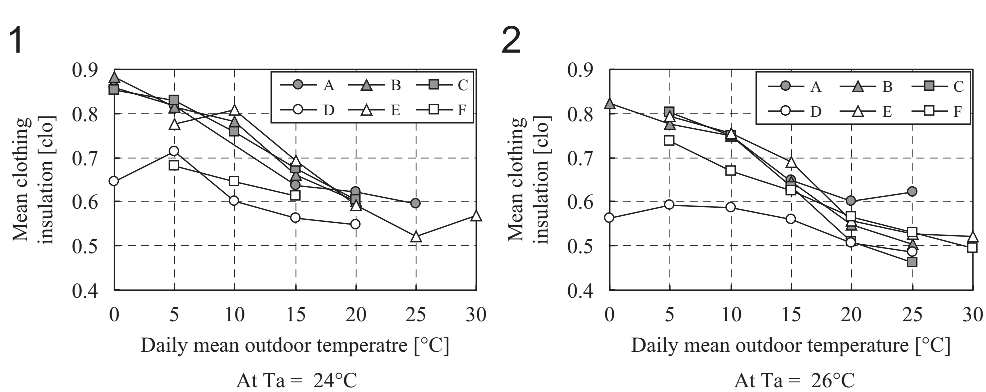

Fig. 8. Comparison of the clothing insulation with different buildings (except for female data from building A).

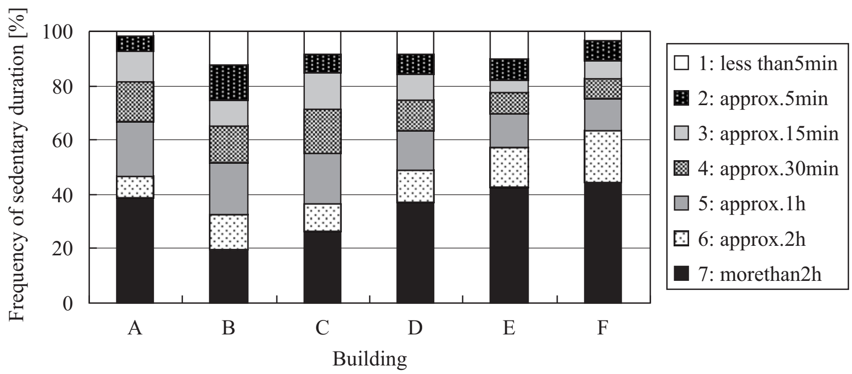

Fig. 9. Duration of a continuous sedentary state.

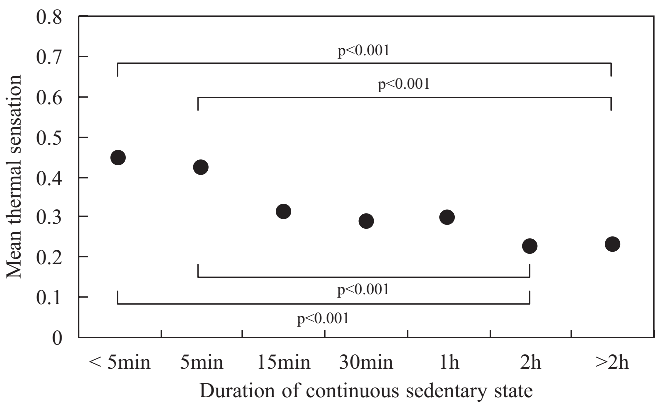

Fig. 10. Comparison of average thermal sensations answered after different durations of being in a sedentary state.

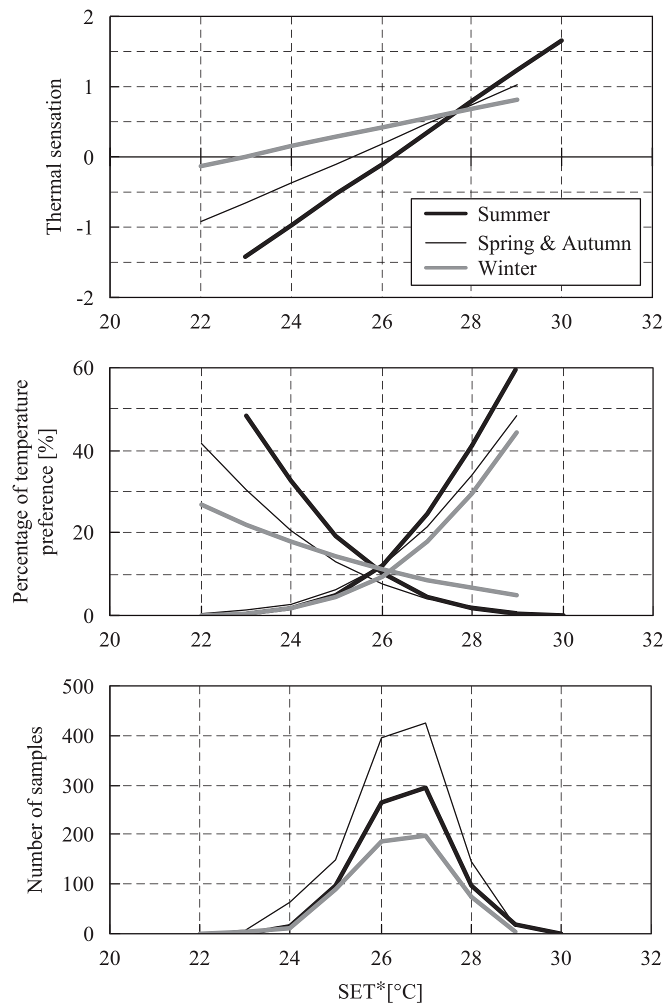

Fig. 11. Thermal sensation and temperature preference of buildings B, C and E (more opportunity to control the indoor climate).

As comparing Fig. 11 with Fig. 12, there were no considerable differences. The slopes of the thermal sensation and the neutral SET* varied between the seasons. However, the preferred SET*, which was determined from the intersection of the temperature preference lines, did not change, and it was always close to 26 °C. The percentage of thermal acceptability was almost always higher than 80% in both the groups unless the SET* was higher than 29 °C.

4. Discussions

In the present study, there were no considerable differences on the thermal perceptions between the two groups. One was the group of buildings where occupants had more opportunity to control the mechanical cooling/heating and windows, and the other was the group of buildings where the occupants had less opportunity to control those. It is possible that the assumption of the constant air velocity had disturbed to see the differences. Actually, 10 out of 61 occupants in the buildings A, D and F had brought personal fans by themselves, and used at least temporally (10 out of 62 occupants used personal fans in the buildings B, C and E). In addition, those occupants with the personal fans extended the opportunity to control their thermal conditions. Thus, it was supposed that the difference between two groups had been smaller than we expected.

With both the groups, the preferred SET* was always close to 26 °C, although the neutral SET* varied between the seasons. The variation of the neutral SET* could be due to semantics artifact as described by de Dear and Brager [6]. Thus, the preferred SET* is more appropriate

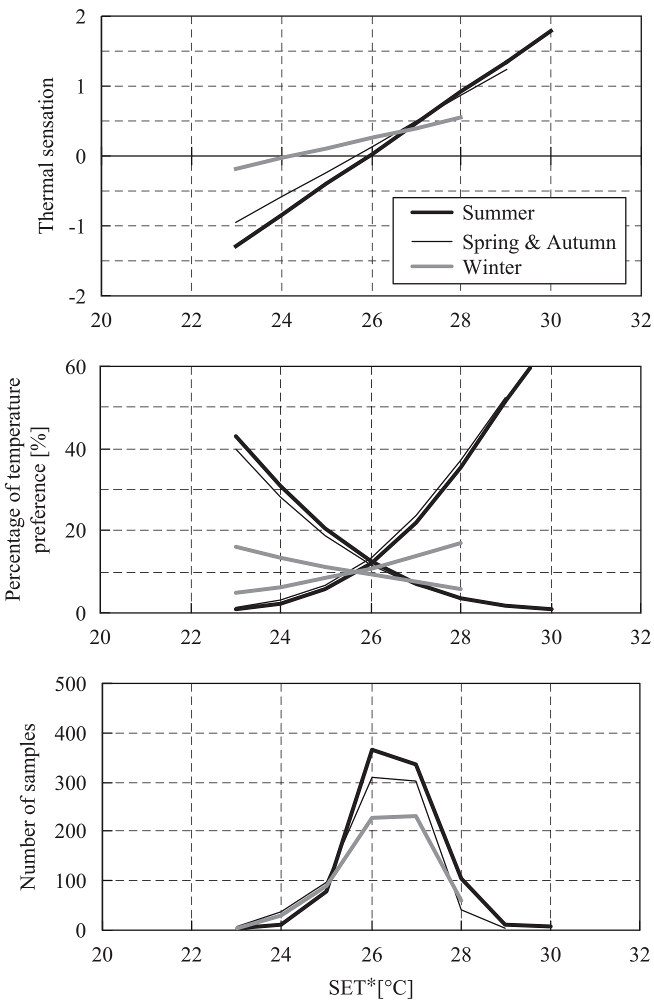

Fig. 12. Thermal sensation and temperature preference of buildings A, D and F (less opportunity to control the indoor climate).

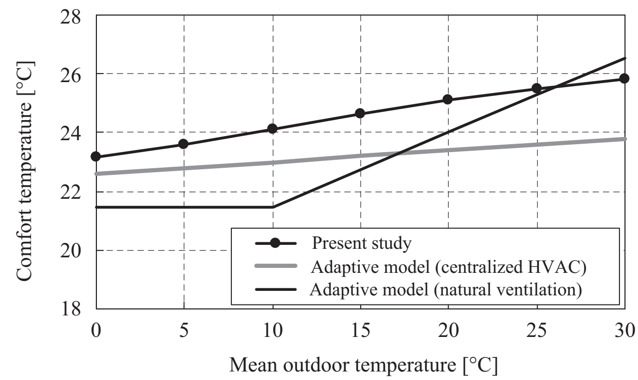

Fig. 13. Comparison of comfort temperature between the present study and de Dear's adaptive models.

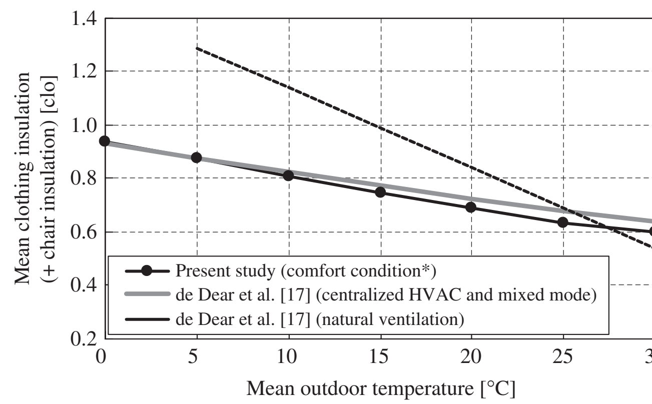

Fig. 14. Comparison of mean clothing insulation between the present study and de Dear's database (* clothing insulation determined with comfort temperature).

for occupant's optimum thermal condition. On the other hand, the clothing insulation adjusted with the outdoor and indoor temperatures was depicted in Fig. 7. Therefore, the comfort indoor temperature at a certain outdoor temperature can be determined from the preferred SET* and Fig. 7.

With assuming 1.2 met, MRT = Ta, 0.1 m/s, 50%RH and 0.1 clo increase in clothing insulation by chair, combination of indoor temperature and clothing insulation, which satisfies SET* = 26 °C as well as the relations depicted in Fig. 7, was found for each outdoor temperature by iterative calculation. Fig. 13 shows the determined comfort temperature, and compares with de Dear's adaptive models [6], even though the definition of mean outdoor temperature is different. The comfort temperature determined in this study was always higher than the adaptive model for centralized HVAC. The gradient of the comfort temperature was greater than the adaptive model for centralized HVAC, but smaller than the adaptive model for natural ventilation only.

Fig. 14 compares the mean clothing insulation between the present study and de Dear's database [17]. It was found that the clothing insulation in the naturally ventilated buildings varied much steeper with outdoor temperature than that in the present study. It must be a major reason for the difference in the gradient of comfort temperatures. On the other hand, the clothing insulation in the centralized HVAC and mixed mode buildings was almost equal to the present study. It indicated that the difference in the comfort temperatures was not caused by the clothing insulation. However, the major part of the occupants in this study had more opportunities to control the thermal conditions, i.e. operable windows, controllable HVAC and personal fans, than in centralized HVAC buildings. It is possible that those factors had affected to the comfort temperature physically and/or psychologically; therefore, the gradient of the comfort temperature appeared between the adaptive model for centralized HVAC and for natural ventilation.

5. Conclusion

A long-term field survey was conducted in six office buildings in Japan. The adjustment of clothing was observed and the relationship with the outdoor and indoor temperatures, as well as the dress codes, was determined. Within the present survey, no considerable differences were found on the thermal perceptions between the two groups of buildings, which provided different levels of opportunity for controlling the indoor climate, and the preferred SET* was 26 °C for both groups. It is possible that the rough assumption of air velocity had disturbed to see the differences. In addition, it was supposed that the difference in the opportunity for controlling the indoor climate had been reduced by the personal fans, which brought into the buildings by occupants.

On the other hand, the comfort temperature, which was estimated from the analysis of the clothing adjustment and the preferred SET*, was different from the adaptive model developed by de Dear and Brager. The comfort temperature estimated in this study was always higher than the adaptive model for centralized HVAC buildings, and the gradient of that was greater than the adaptive model for centralized HVAC, but smaller than that for natural ventilation only. The clothing insulation was found to be a major reason for the difference with the adaptive model for the natural ventilation only, but could not be the reason for the difference with that for centralized HVAC because it was almost equal to each other. However, the major part of the occupants in the present study had more opportunities to control the thermal conditions (i.e. operable windows, controllable HVAC and personal fans) than in centralized HVAC buildings. It could be a reason why the comfort temperature in this study varied greater than in the centralized HVAC buildings.

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