Thermal environment and behavioural adaptation in semi-outdoor cafeteria

Toshitaka Shimoda*, Masashi Noguchi, Junta Nakano, and Shin-ichi Tanabe

Department of Architecture, Waseda University, Japan

ABSTRACT
In this study, a semi-outdoor cafeteria was selected to investigate the behavioural adaptation of occupants in relation to environmental condition. Field surveys were conducted from the autumn of 2002 to winter of 2003, twice every week. The ratio of occupants choosing to sit in semi-outdoor space and those choosing to sit indoors was observed by counting the number of occupants every 15 min. Clothing insulation was also recorded by observation. Questionnaire survey was conducted separately to investigate psychological responses. Many occupants were considered to be staying voluntarily. Although the purpose of stay was similar in both semi-outdoor and indoor, the reasons for choosing the place were different. Environment was generally perceived as acceptable except for extreme cases. Air temperature of the occupied zone was found to have a large effect on clothing insulation and selection of occupancy environment.

INDEX TERMS
Thermal comfort; Field survey; Semi-outdoor space; Behavioural adaptation; Voluntary staying

INTRODUCTION

The environmental design philosophy today aims to create and control the thermal environment to be thermally neutral for the occupants in a given environment. However, in semi-outdoor environments such as atrium or open structured cafes where the main objective is to provide the occupants with outdoor elements in an architectural environment, an alternative design strategy would be necessary. Occupants in semi-outdoor environments are considered to be expecting thermal environment different from indoors, and factors such as sunlight and wind need not be kept under the criteria specified by existing thermal comfort standards for indoors. Moreover, the effect of behavioural adaptation, especially personal adjustment, is considered to be more prominent during the process of achieving comfort in semi-outdoor environment. It includes adjustment of clothing, activities and posture. Selection of the occupancy environment is also considered to be a form of behavioural adaptation, and the present study aimed to examine the influence of thermal environment on visitors' selection of occupancy environment, when given the two choices where factors other than environment were identical.

METHODS

Survey Area

In this study, a cafeteria where the eating area was divided into indoor space and semi-outdoor space adjacently was selected. The photos of the cafeteria are given in Figure 1, and the plan is depicted in Figure 2. This cafeteria is located within the grounds of the Waseda University, and the main users are students. The area is about 900 m^2, and has

* Corresponding author. E-mail: Shimoda@tanabe.arch.waseda.ac.jp

600 seats. Indoor space equipped with 300 seats is air-conditioned, and the side facing the semi-outdoor space is a glazing wall. Semi-outdoor space is non-air conditioned atria equipped with 300 seats, and the side is opened to outdoors. A part of the glass ceiling was covered with screens to diffuse direct sunlight. After the lunch hours when the number of occupants reaches its peak, the occupants could choose freely where to sit from abundant vacant seats.

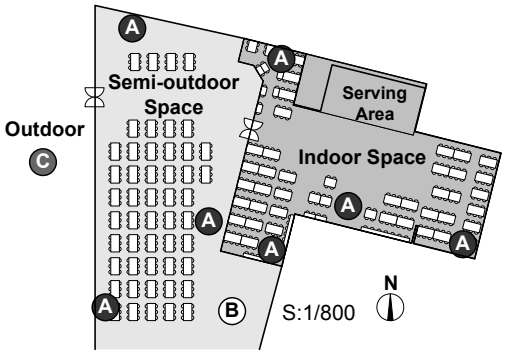

Figure 2 Plan of cafeteria.

Survey Periods

Surveys were conducted from autumn of 2002 to winter of 2003 for a total of 17 days when the university was open on a regular schedule. In order to avoid the crowding hours when selection of the seats would be limited regardless of the environmental conditions, surveys were carried out from 14:00 to 20:00. Moreover, It is thought that the occupancy conditions change with days of the week, every survey was conducted on Tuesdays and Fridays.

Survey Procedure

Three types of measurements were conducted for the survey.

Measurement of the Thermal Environment

Measurement items are given in Table 1. On points A, air temperature and humidity recorders were attached to the wall in order avoid the disturbance of the users. On points B, air temperature, humidity, air velocity, solar radiation and total radiation were measured since the environmental condition in semi-outdoor space was considered to be unstable. On points C, outdoor air temperature and humidity were measured separately. Each item was measured every 30 s. To examine the validity of the measurement in representative points, detailed measurement around occupants was also conducted randomly with the mobile measurement cart.

Table 1 Measurement items and height

	Mesurement items		Instruments	Height
Fixed points mesurement	Points A	Air temperature	Thermister	1.1m
		Humidity	RH sensor	
	Points B	Air temperature	C-C thermocouples	
		Humidity	RH sensor	
		Air velocity	Omnidirectional heated anemometer	
		Total radiation	Directional radio-meter (0.3-40μm)	
		Solar radiaiton	Silicon pyranometer (0.4-1.1μm)	
	Points C	Air temperature	Thermister	
		Humidity	RH sensor	
		Solar radiation	Pyranometer	

	Mesurement items	Instruments	Height
Mobile measurement cart	Air temperature	C-C thermocouples	1.1m
	Humidity	RH sensor	
	Air velocity	Omnidirectional heated anemometer	
	Total radiation	Directional radio-meter (0.3-40μm)	
	Solar radiaiton	Silicon pyranometer (0.4-1.1μm)	

Observation of the Occupants

Observers stationed in indoor and semi-outdoor spaces separately. Occupancy period was measured throughout the day by randomly selecting the occupants upon sitting in the area and recording the time he/she remained seated. The number of occupants sitting within the survey area was recorded every 15 min. Observation of occupants' clothing items was also conducted randomly with a garment checklist.

Questionnaire Survey for Occupants

In order to investigate the occupants' perception of environment, a voluntary questionnaire was conducted. The items of the questionnaire are given in Table 2. The questionnaire was summarized in one sheet of A4 paper. The occupants who volunteered to answer the questionnaire were handed a questionnaire sheet at the entrance of a cafeteria, and filled out this questionnaire during their stay. The sheet was returned on their way out and a small gift was given in exchange.

Table 2 The items on the questionnaire

Questionnaire	Background	Sex, Age, Smoke or not, Items of clothing
	Occupancy condition	Frequency of visit, Purpose of stay, Stay place, The reason for choosing the place
	Psychological responses	General comfort (7 scales, very comfortable– very uncomfortable), Thermal sensation (ASHRAE scale), Thermal preference (McIntyre scale), Thermal acceptability, Environmental satisfaction

RESULTS

All surveys were conducted regardless of the weather conditions. A total of 308 questionnaires were collected throughout the 17-day survey. Majority of the questionnaire respondents were university students. The ratio of males to females and semi-outdoor occupants to indoor occupants were approximately 50 to 50.

Thermal Environment

Temperature and humidity were recorded at indoor space, semi-outdoor space, and outdoors. Daily averages are given in Figure 3. Temperature was higher in the order of indoor, semi-outdoor, and outdoors. Indoor temperatures were mostly fixed at 23°C by air-conditioning system. On the other hand, temperature of the semi-outdoor space was greatly affected by the outside temperature since it was opened to the exterior. Absolute humidity was nearly the same in semi-outdoor space and outdoors. However, the value was higher by about 1g/kg in indoor space. In semi-outdoor, mean air velocity was almost less than 0.5m/s since it was walled-in space. In indoor, mean air velocity was almost less than 0.1m/s. But the draft was observed locally at indoor. Mean radiant temperature was generally equal to air temperature, except for the sunny place.

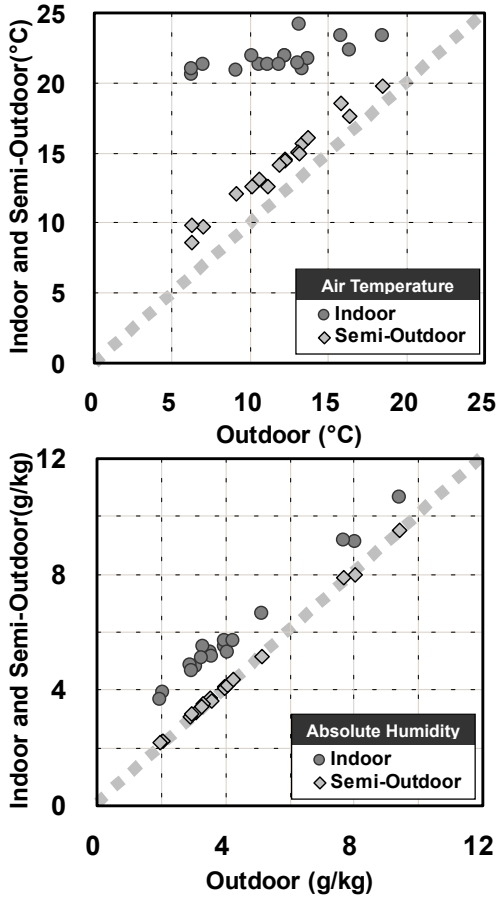

Figure 3 Daily mean temperature and humidity.

Purpose of Stay

The results of the questionnaire concerning the purpose of stay are shown in Figure 4. Respondents were asked to choose items which best described the purpose of their stay. The items were 'resting', 'eating', 'waiting', 'studying',

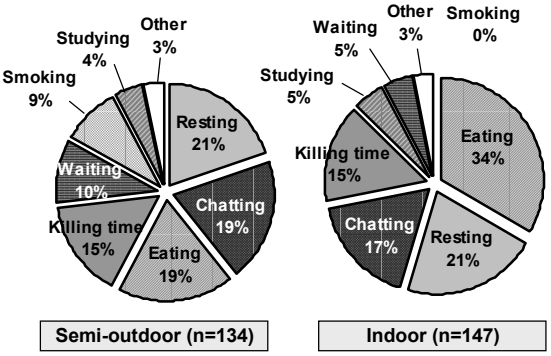

Figure 4 The purpose of stay.

'smoking', 'chatting', and 'killing time'. Greater number of replies of 'eating' was observed in the indoor space where the serving area of cafeteria was located. However, only minor difference was observed for other items. The purpose of stay was considered to be similar in both spaces. Moreover, since there were much answer of 'resting', 'eating', 'chatting', and 'killing time', many occupants were considered to be staying at their will.

The Reasons for Choosing the Place

The result of the questionnaire concerning the reasons for choosing the place is shown in Figure 5. Respondents were asked to chose items which best described the reason for choosing the place. The items are given in Figure 5. Many occupants answered 'openness', 'smoking', 'presence of others' in semi-outdoor space, and 'temperature', 'vacancy', 'non smoking' in indoor space. Although the purposes of stay were similar, the reasons for choosing the place were various.

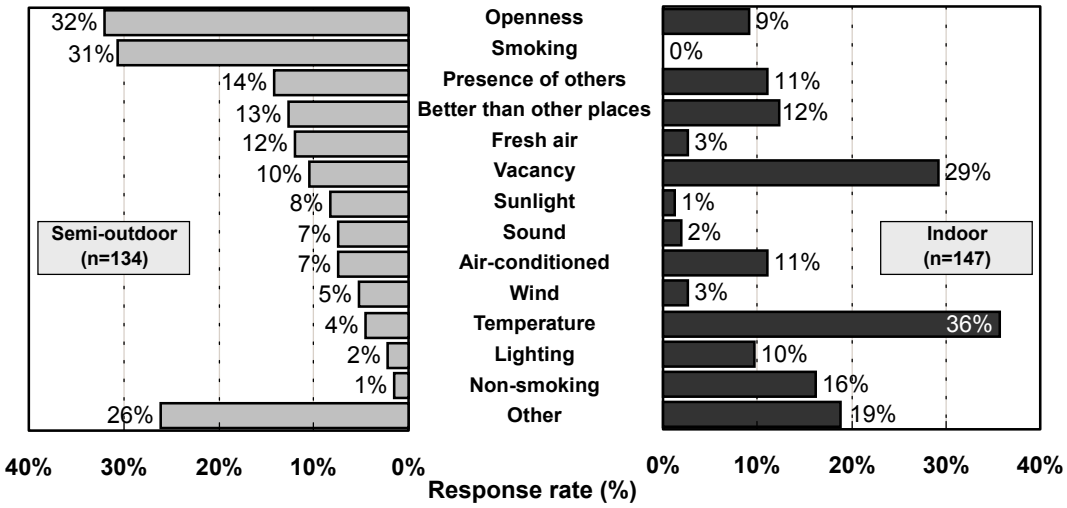

Figure 5 The reasons for choosing the place.

Thermal Sensation, Thermal Acceptability and Thermal Preference

For the question 'Is the present thermal environment acceptable?' the response rate of 'yes' is shown in Figure 6-1. Moreover, for the question 'How do you want the temperature to be?' the response rate of 'No change' is shown in Figure 6-2. No response of 'hot' for thermal sensation vote was observed in semi-outdoor space. Within the range of –2 to 2 of thermal sensation, nearly all occupants answered the thermal environment to be 'acceptable'. Environment was generally perceived as acceptable except for extreme cases. In semi-outdoor space, the frequency of 'no change' response rate was symmetric. However, in indoor space, it was larger on the warm side. Since investigation was conducted during cold seasons, occupants were considered to be asking for warmth in indoor spaces.

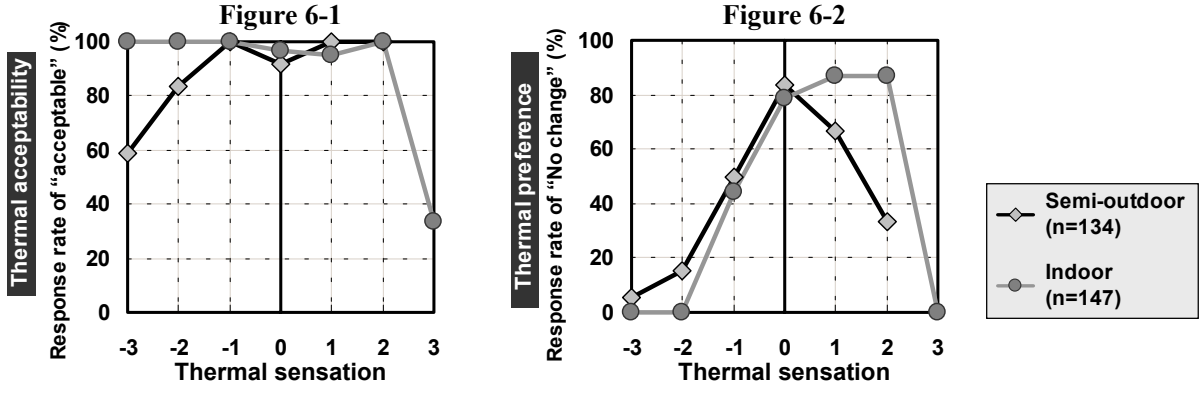

Figure 6 Thermal sensation, acceptability and preference.

Environmental Satisfaction and General Comfort

In order to investigate the factors that occupants think are comfortable, environmental satisfaction rating was included in the questionnaire. Occupants were asked to answer the degree of satisfaction in scales of 0 to 4 on six items of 'temperature', 'brightness', 'spaciousness', 'sound', 'furniture', and 'overall satisfaction'. General comfort sensation vote, not confined to thermal aspects, was also asked in scale from –3 to 3. Mean values and results of the t-test conducted between semi-outdoor space and indoor space are shown in Figure 7. Satisfaction for 'temperature' was high in indoor and 'spaciousness' was high in semi-outdoor space. This result was in agreement with the reasons for choosing the place. General comfort in semi-outdoor space was significantly smaller than that of indoor space, while the difference in 'overall satisfaction' was insignificant. The degree of the expectation for the environment of each space was confirmed to be different.

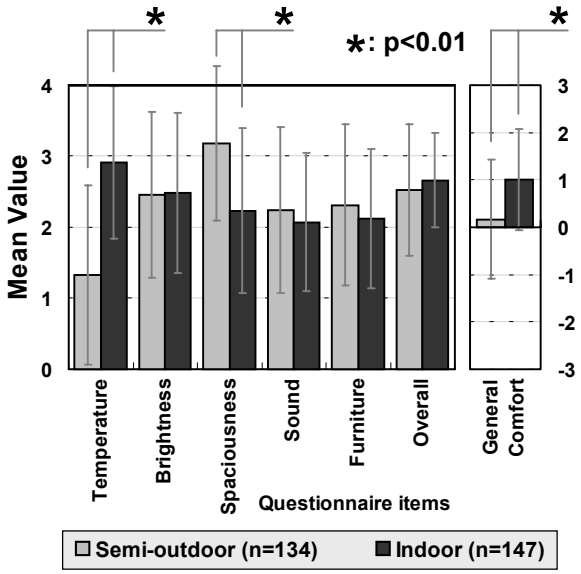

Figure 7 Environmental satisfaction and general comfort.

Air Temperature and Clothing Insulation

Occupants' clothing items were recorded on a garment checklist by observation. Daily mean air temperature and clothing insulation is shown in Figure 8. Difference between males and females was small. The average value was 1.01 clo in semi-outdoor space and 0.83 clo in indoor space. Clothing was linearly correlated with the air temperature. The occupants were adjusting there the clothing according to surrounding environment. However, the coefficient of determination (R^2) was comparatively low at indoor space. Since there are some occupants who just arrived indoor space from outdoor, it is thought that adjusting clothing was not fully performed. It turns out that the clothing insulation in indoor is influenced by the temperature of both indoor and outdoor.

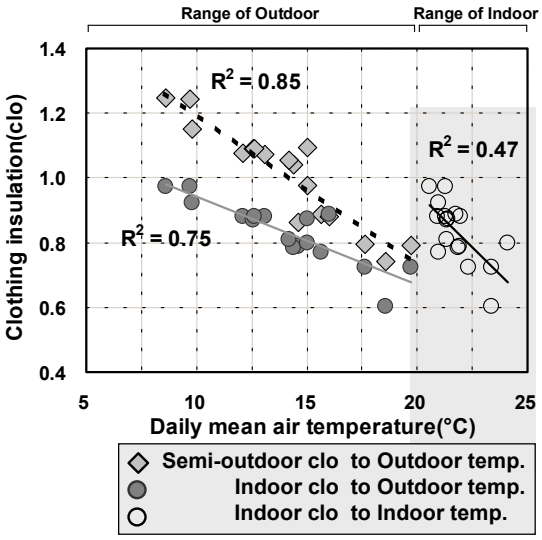

Figure 8 Air temperature and clothing insulation.

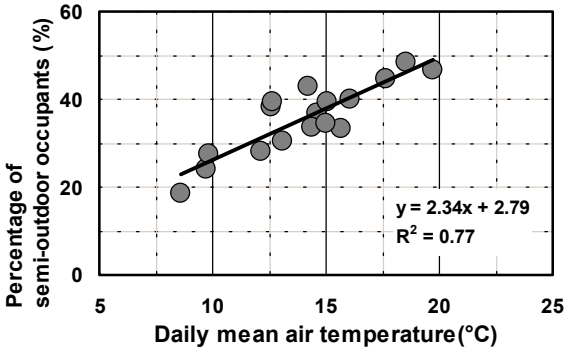

Figure 9 Air temperature and percentage of semi-outdoor occupants.

Air Temperature and Percentage of Semi-outdoor Occupants

Daily mean air temperature and percentage of semi-outdoor occupants to the whole is shown

in Figure 9. The total number of occupants measured every 15 min throughout the day was nearly constant at 4000 persons. The percentage was confirmed to have a strong relationship with the air temperature, showing that thermal environment had a large influence on selection of occupancy environment. When air temperature increased by 1°C, the percentage increased by 2%. Moreover, the linear regression showed that the number of semi-outdoor occupants to the indoor occupants would be the same at mean daily air temperature of around 20°C.

DISCUSSION

In order to assume the thermal environment at the time of the reply, the respondents were asked to write the time and place they sat down on a questionnaire. However, environment is unstable in semi-outdoor space, and it is difficult to confirm the relationship between thermal environment and psychological responses for each reply. Furthermore, since it was also difficult to confirm clothing insulation and metabolic rate for each questionnaire respondent, analysis was conducted on relationship between behavioural adaptation and thermal environment for group of occupants.

Since many occupants of this cafeteria were staying at their will, they were given higher adaptive opportunity than office environments designed for working. Clothing insulation and the number of occupants were found to correlate to air temperature. Moreover, as shown in Figure 7, majority of occupants answered the environment to be acceptable although they preferred to be warmer or cooler at the same time. The difference in expectation for the environment of each space contributed to broaden the acceptable thermal environment range. In such semi-outdoor space, tight air-conditioning control is not always required, and thermal environment control only to avoid extreme conditions would be sufficient. Spring and summer surveys are underway in 2003, and observation in cool and hot seasons is expected to further the understanding of behavioural adaptation in semi-outdoor spaces.

CONCLUSION

Field survey on behavioural adaptation was conducted in a cafeteria where the eating area was divided into indoor space and semi-outdoor space adjacently. Thermal environment of semi-outdoor space was greatly affected by the outdoor conditions while indoor space was kept nearly constant. Semi-outdoor temperature was generally lower than that of indoor, since the investigation was conducted from autumn to winter. Majority of the occupants were university students staying for arbitrary purpose, such as resting, eating and chatting. The behavioural adaptation in this cafeteria was confirmed by clothing insulation and percentage of semi-outdoor occupants in relation to air temperature. In each space, thermal acceptability rate was above 80% except for extreme cases although they preferred to be warmer or cooler at the same time. The degree of the expectation for the environment was considered to be different.

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