Behavioural adaptation in semi-outdoor environment

Junta Nakano*, Shin-ichi Tanabe

Department of Architecture, Waseda University, Japan

ABSTRACT
The term 'semi-outdoor environment' refers to an architectural environment where natural outdoor elements are designedly introduced with the aid of environmental control. As the thermal environment is not intended to be fully controlled in semi-outdoor environments, behavioural adaptation is expected to play a major role in the process of achieving thermal comfort. Behavioural adaptation in forms of occupancy conditions and clothing adjustment was investigated in four semi-outdoor spaces by four seasonal surveys. Short-term occupants in the present semi-outdoor environments were mainly engaged in arbitrary activities, and were able to choose their occupancy conditions. Occupants in non-air-conditioned spaces were more responsive to thermal environment of the occupied space than those in air-conditioned spaces. Occupancy period and the number of occupants showed a linear relationship with daily mean air temperature of the occupied zone. Clothing was closely related to daily mean outdoor temperature, regardless of the difference in environmental control.

INDEX TERMS
Thermal comfort; Field survey; Semi-outdoor environment; Behavioural adaptation

INTRODUCTION
The term 'semi-outdoor environment' refers to an architectural environment where natural outdoor elements are designedly introduced with the aid of environmental control. Semi-outdoor environment falls in between the environmental engineering categories of 'indoor environment' where thermal environment is controlled to satisfy thermal comfort of the occupants, and 'outdoor environment' where occupants need to adjust themselves to achieve thermal comfort. As the thermal environment is not intended to be fully controlled in semi-outdoor environment, behavioural adaptation, especially personal adjustment, is expected to play a major role in the process of achieving thermal comfort. Personal adjustment includes adjustment of clothing, activity, posture, or selection of occupancy conditions (Brager and de Dear, 1998). Clothing is the most documented form of adjustment in indoor environment. However, form or process of adjustment may change depending on circumstances. For example, if the thermal environment did not match their expectation and other forms of adaptation were not sufficient to maintain their comfort, occupants may choose not to stay at all under arbitrary occupancy conditions. Knowledge on adaptation characteristics is required for different design objectives, and short-term occupancy lasting no more than an hour was considered to be the main purpose of occupancy for semi-outdoor environment such as atrium buildings or terraces. Seasonal observation was conducted in semi-outdoor environments designed for resting and roaming of the visitors. The results of the behavioural adaptation in relation to thermal environment will be discussed in this paper.

METHODS
Survey Procedure
Four semi-outdoor architectural environments located in Tokyo, Japan were selected for the survey, spaces P and B that were air-conditioned atria (HVAC spaces) and spaces O and T that

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

were non-air-conditioned spaces (non-HVAC spaces). In addition to occupant questionnaire and measurement of the immediate thermal environment, behavioural adaptation was examined from summer of 2001 to spring of 2002 for four days per space per season. The description of the entire survey is given in detail elsewhere (Nakano *et al*., 2003), and measurement items concerning behavioural adaptation will be described in this paper. A short-term occupant was defined as a visitor who actually sat down in the survey area, and a passer-by or a standing person was left out of scope. Two forms of behavioural adaptation, occupancy conditions and clothing adjustment, were investigated.

Occupancy period was measured throughout each survey day from 10:00 to 18:00 hours by randomly selecting the visitors sitting in the area and recording the time he/she remained seated. Daily mean occupancy period was derived from approximately 100 observations per day. Number of occupants sitting within the survey area was also counted every 10 min. Questions concerning the background information, purpose of stay and frequency of visit were included in the questionnaire.

Field studies on clothing are typically conducted by surveyor's visual observation or by asking the occupant to choose their clothing items on a garment checklist. A combination of both methods was employed in this survey for precise examination of clothing adjustment. The questionnaire sheet included a checklist presented in Figure 1, asking specifically on the clothing items worn 'at the moment' to observe the correspondence with the immediate thermal environment. However, mistakes could happen especially in short-term occupancy spaces where a respondent may have worn a coat prior to occupancy and removed it at the time of questionnaire. In order to avoid apparent mistakes, visual observation of a surveyor was also recorded simultaneously using the same checklist. Each clothing item in the questionnaire was assigned an insulation value according to ISO 9920 (1995) and summed for total insulation. A total of 2248 questionnaires were collected throughout the survey.

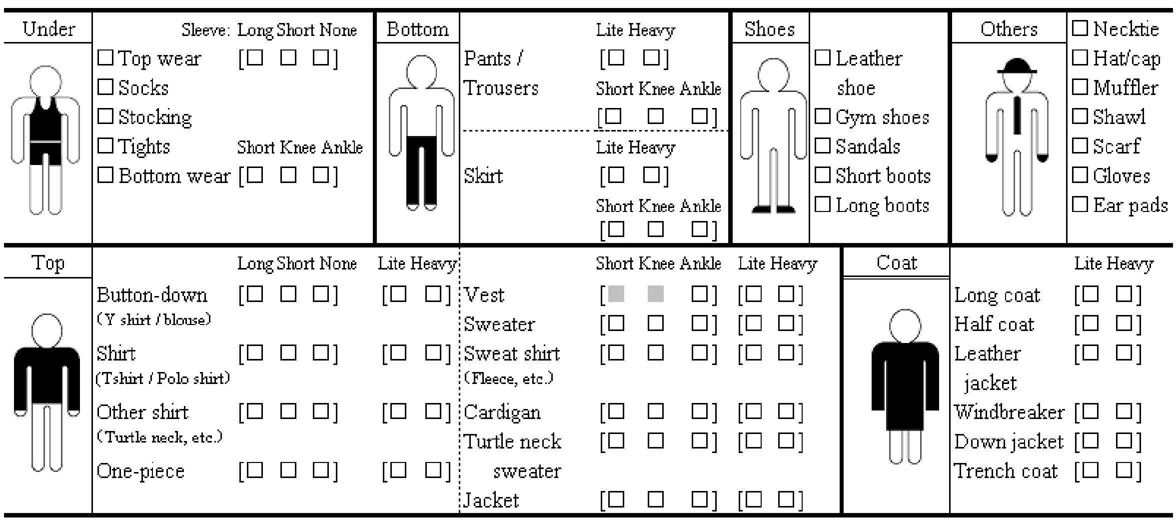

Figure 1 Garment checklist.

RESULTS

Outdoor Climate

Many researchers have pointed out that outdoor conditions cast a large influence on adaptation. Figure 2 shows the daily mean outdoor temperature and humidity of all survey days extracted from the meteorological database. Tokyo area belongs to the temperate climate zone having four distinctive seasons. The climate is hot and humid in summer, cold and dry in winter, and intermediate during spring and autumn. The general seasonal description agreed well with the seasonal characteristics of the present survey.

The daily mean variation of outdoor temperature from the minimum temperature of the day was calculated for each season from the meteorological data of survey days. The results are given in Figure 3. Daily minimum temperature was generally observed at around 6:00 and maximum at 14:00 hours. Difference in daily maximum and minimum temperature was approximately 5.5°C in autumn and winter and 4°C in summer and spring, showing that daily temperature fluctuation was larger in autumn and winter seasons.

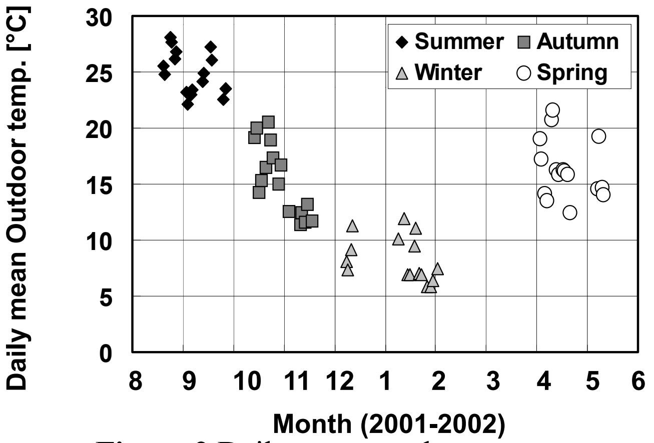

Figure 2 Daily mean outdoor temperature of the survey days.

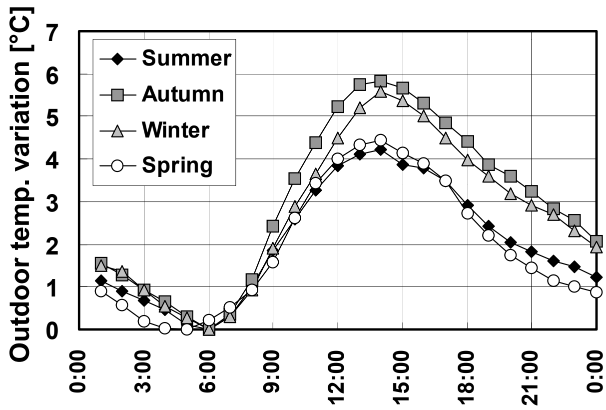

Figure 3 Daily variation of outdoor temperature from the minimum value of the day.

General Occupancy Conditions

Analysis of questionnaires showed that the percentage of males to females was equal in non-HVAC spaces while 60% were females in HVAC spaces. More than 80% of the total occupants were engaged in arbitrary activities such as 'resting' and 'eating'. The contrary would be 'waiting', where an occupant is required to wait in the environment regardless of his/her comfort condition. The percentage of 'waiting' plus 'others' was less than 20%, implying that the majority of occupants were staying at their will.

A distinctive daily peak in number of occupants was observed around 12:30 in office buildings O, P and B when office workers occupied the area for lunch. A unique profile was confirmed in department store T where the number grew from morning towards the afternoon, and remained constant or even higher until the end of the survey. Yearly average occupancy periods in non-HVAC spaces were approximately 10 min in both spaces O and T. The values were not consistent in HVAC spaces, 20 min and 15 min for spaces P and B, respectively. The average occupancy period was longer in space P where a section of the survey area was equipped with lounge chairs compared to metal meshed benches in space B. Quality of furniture may have an impact on the occupancy period in closed HVAC spaces, while the effect could be considered to be smaller in open structured semi-outdoor environment where installation of high quality comfort chairs would be unrealistic.

Thermal Environment and Occupancy Conditions

The daily total number of occupants counted for each survey day is plotted against the daily mean air temperature of the occupied zone in Figure 4. Exceptional data of rainy days in unroofed non-HVAC spaces and exhibition days in all spaces were excluded. The number of occupants was confirmed to have a strong linear relationship with the air temperature of the occupied zone in non-HVAC spaces while no correlation was found in HVAC spaces.

The occupancy period was also linearly correlated with the air temperature of the occupied zone in non-HVAC spaces as presented in Figure 5. The gradient was similar for both spaces, which approximately equalled to a 1 min decrease in average occupancy period for each 3°C decrement in daily mean air temperature. No correlation was found for HVAC spaces.

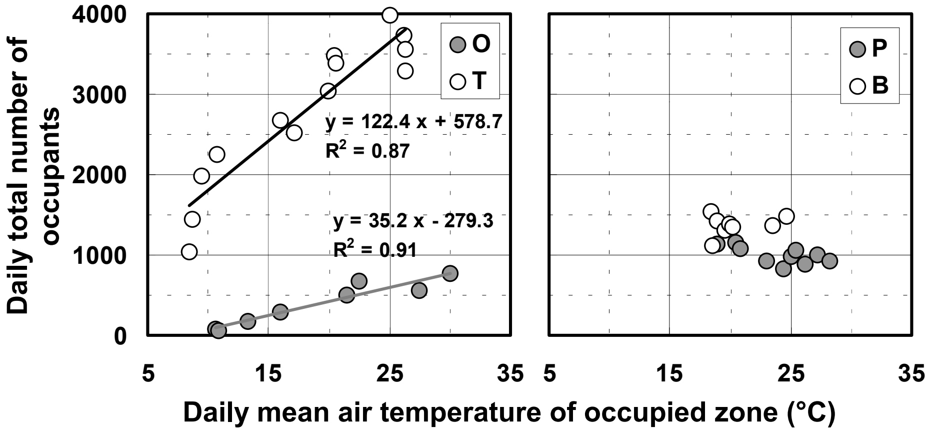

Figure 4 Daily mean outdoor air temperature and daily total number of occupants.

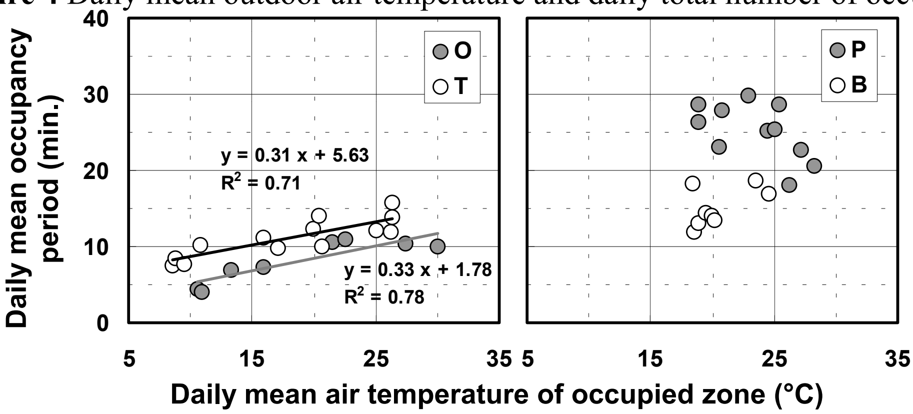

Figure 5 Daily mean outdoor air temperature and daily mean occupancy period.

Clothing Adjustment

Immediate air temperature of the occupied zone recorded for each questionnaire respondent were rounded off to 0.5°C increments and corresponding mean clothing insulation values were calculated to examine the clothing adjustment for a given thermal environment. The results are presented in Figure 6. The size of the plot represents the size of the population used to calculate each mean value. Weighted linear regression was applied for each season. Significant relations ($p < 0.01$) were found for clothing and air temperature of the occupied zone in both non-HVAC and HVAC spaces for all seasons. Seasonal differences in the gradient of linear regression were found for both non-HVAC spaces and HVAC spaces. The gradient of linear regression describes the degree of clothing change against air temperature change of the occupied zone. Summer and spring showed a similar gradient as well as autumn and winter. Gradients were found to be larger in HVAC spaces.

Relationship was sought among mean clothing insulation and mean outdoor temperature for each day, since the profile of HVAC spaces appeared quite similar to that of non-HVAC if the temperature range was stretched to that of non-HVAC spaces. The results are presented in Figure 7. Clothing adjustment in relation to outdoor temperature was almost identical in HVAC spaces and non-HVAC spaces. A decrease of 2.5°C in daily mean outdoor temperature was equivalent to a 0.1 clo increment in clothing insulation.

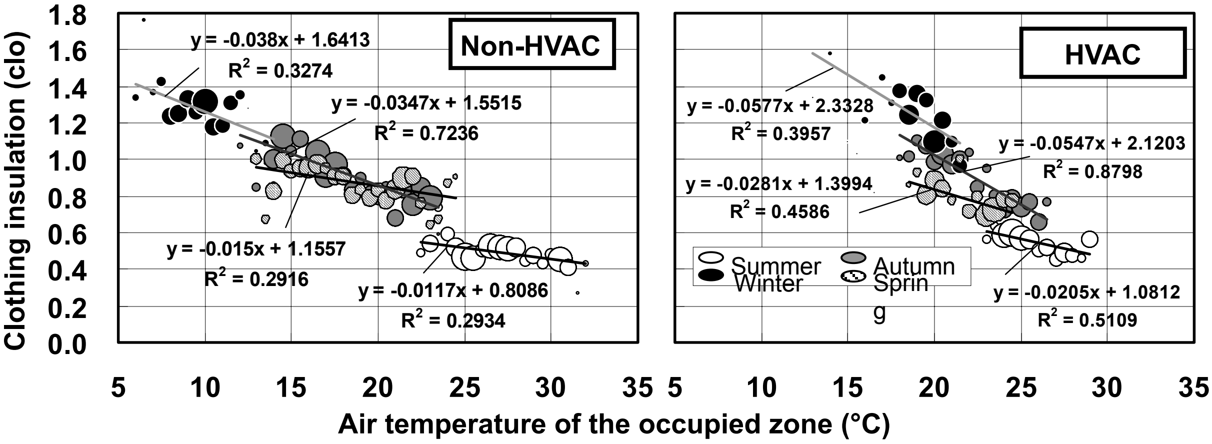

Figure 6 Clothing insulation and air temperature of the occupied zone.

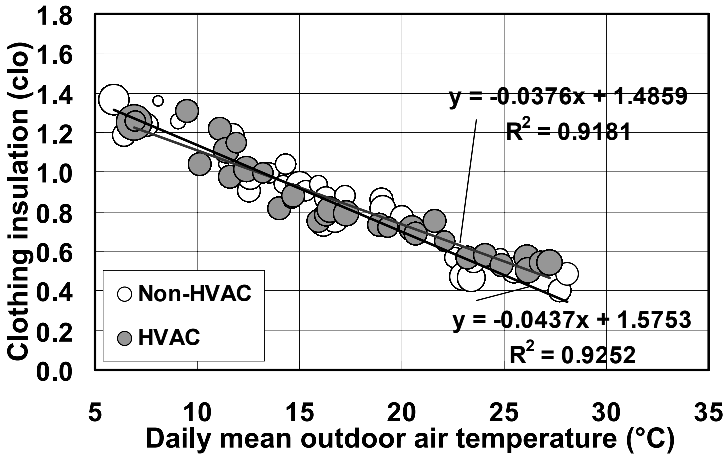

Figure 7 Clothing insulation and daily mean outdoor temperature.

DISCUSSION

The instantaneous effect of environmental change such as solar radiation and wind on occupancy conditions could not be analysed from the present results, due to large daily fluctuation in number of occupants in all spaces. The results illustrate that occupants in non-HVAC semi-outdoor environments were more responsive to thermal environment, and preferred warmer weather to cooler for short-term occupancy. Nikolopoulou *et al*. (2001) reported similar results on a link between the number of occupants and instantaneous globe temperature from the UK field survey in urban outdoor spaces, analogous to non-HVAC semi-outdoor environment in this study. The present survey started from the middle of August, and extremely hot conditions in summer, generally observed from July to August, could not be measured. Though linear regression was applied in the analysis, an inflection point in number of occupants may be present under hot weather conditions. While non-HVAC spaces showed a linear fit for number of occupants even within the narrow temperature range of HVAC spaces, this was not the case for HVAC spaces. The purpose of use was confirmed from the questionnaire to be similar between the two types of spaces, and the prominent difference lies in the level of environmental control and occupants' expectation for the environment. The cause for variation of occupancy conditions in HVAC spaces could not be specified from the survey, but factors other than thermal environment is supposed to have had a greater impact.

Outdoor conditions are reported to be the most influential factor on clothing adjustment by various researchers. This also applied to the results of the present survey, showing that occupants were dressed primarily for outdoors regardless of the degree of environmental control in semi-outdoor spaces. The year-round gradient of clothing change against outdoor temperature rise was approximately –0.04 clo/°C for both types of spaces, and this value is in close agreement with the results of de Dear *et al.*(1998) derived from indoor operative temperature and office workers' clothing. Significant correlation was also observed for clothing and air temperature of the occupied zone in air-conditioned atria, due to the fact that thermal environment within the atria itself was strongly affected by outdoor conditions.

The gradient of seasonal clothing change against air temperature could be divided into two groups, summer–spring and autumn–winter. The gradient was larger for the autumn–winter group, suggesting a greater clothing adjustment for a given temperature change. Figure 3 for the average daily air temperature variation illustrates that temperature changes are larger in autumn and winter during the day. Occupants, accustomed to seasonal differences in diurnal fluctuation characteristics, were assumed to be dressed for the lower end of the daily temperature range. Humphreys (1977) have pointed out the serial effect of outdoor conditions on clothing adjustment, but this could not be tested from the present survey due to discrete survey days. Seasonal climatic characteristics, not only in terms of mean outdoor temperature, should be considered for a finer prediction of clothing.

CONCLUSION

Behavioural adaptation in forms of occupancy conditions and clothing adjustment was investigated in semi-outdoor environment by four seasonal surveys. Short-term occupants in the present semi-outdoor environments were mainly engaged in arbitrary activities, and were free to choose their occupancy conditions. Occupants in non-air-conditioned spaces were more responsive to thermal environment of the occupied space than those in air-conditioned spaces, and the occupancy condition in terms of occupancy period and number of occupants were linearly correlated with the daily mean air temperature of the occupied zone. Clothing adjustment showed a close correlation with daily mean outdoor temperature, regardless of the difference in level of environmental control. Seasonal climatic characteristics, not only in terms of mean outdoor temperature, should be considered for a finer prediction of clothing.

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