DETERMINATION OF THERMAL SENSATION ON TRANSIENT CONDITIONS

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ABSTRACT

The objective of this study is to investigate the difference in thermal environment and human response between air-conditioned closed space and a semi-open space. The thermal response of the subjects in transitional space as they experienced step changes in temperature when moving from outdoor environment to indoor air-conditioned and back to outdoor was examined. The thermal sensation was investigated using a questionnaire and a comprehensive package of micro-metrological instruments. Experiment was conducted to examine the immediate thermal sensation of the subjects when walking from one set of thermal condition to another. Subjects were exposed to three different environmental conditions for 5 to 20 minutes (semi-outdoor, indoor and semi-outdoor). Skin temperature, subjective thermal sensation and comfort were recorded throughout the experiment. Results showed that there is variation in skin temperature as observed in sensation scores between the sequences. The predicted mean vote overshoot all through the sequence as the subjects move from one location to another. Since PMV is widely used as a tool to predict thermal comfort in steady-state environment, it may not be applied to predict thermal sensation in a transient environment. The result of this study can help to improve the PMV model to be applied in a transient environment. This outcome would be suitable in circumstances such as movement in a lobby which is semi-outdoor to predict thermal sensation.

Keywords: thermal sensation, thermal comfort, transition, predictive mean vote

1. INTRODUCTION

Thermal comfort research in buildings has primarily focused on steady-state conditions [1,2] while the thermal environment is often transient and dynamic over time (e.g., when moving from outdoor to indoor or moving from indoor to outdoor, and taking a plane, train, boat where air-conditioning is most frequently used to adjust thermal environment to accommodate hot or cold climate). Neither ASHRAE standard 55-2010 nor ISO 7730 give detailed description on thermal comfort in transient environment [3].

While, ASHRAE standard 55-2004 (ASHRAE 2004) lacks the description of predicting thermal comfort in a transient process during temperature step change. When boarding or getting off a plane, people experience a step-change process from high temperature to a neutral one or from neutral temperature to high temperature. Such thermal stimulus can also be experienced in daily life. In summer and winter, the temperature differences between indoor air-conditioned and outdoor natural environment always exists. When the temperature step-change exceeds the regulation ability of human body, the passengers may feel discomfort [4].

The concept of comfort is dynamic and is related to the way people perceive, interact and adapt with the environment rather than a static condition that should satisfy the majority of the population. Individuals do not always have the same thermal sensations and preferences over a short or long period of time therefore thermal comfort cannot be considered, studied and provided as a static condition [5].

The subject of thermal environment and human comfort has been extensively studied with regard to finding comfortable indoor thermal conditions [6,7]. The long history of research results became the standard for comfortable indoor thermal conditions [8]. Several recent studies have examined the topic of outdoor comfort [9]. However, there are many places, which are not completely indoor or completely outdoor. Research studies about thermal comfort in these transitional spaces are very few. Jitkhajornwanich [10] surveyed occupants' thermal comfort at both indoors and outdoors and put a transitional space between them. He compared thermal comfort between naturally ventilated buildings and air-conditioned buildings. Potvin [11] measured the thermal environment of arcades using a portable sensor array from the view of pedestrian [11].

Many researches suggest that when a person moves from one environment to another, the experience of the new environment is affected by their sensation from the previous environment [12, 13, 14, 15]. There is conflicting evidence as to the type and extent of this affect for instance studies have found that there is a lag in sensation and that it can take at least half an hour to reach a steady-state condition. Conversely it is also suggested that there can be an 'overshoot' in sensation when entering a new environment, for instance, when entering a cold environment from a previously warm environment, sensation is cooler than PMV would predict [16,14].

1.1 Transitional Spaces

Researchers use a variety of terms when referring to environmental conditions within a space. The expression transitional, however, is often used synonymously with the term transient, leading to confusion about whether we are talking about the architectural space, the response and behavior of the human occupant, the physical conditions, or some combination of these meanings [17].

Indoor spaces connected by large openings to the outdoor environment, such as downtown shopping centers, shopping malls or pedestrian passages are found in Europe and Asia In Japan, a hantogaikukan is defined as a semi-outdoor urban facility located between buildings [18] much like the covered streets, arcades, or passages in Western Europe [11]. Similarly, thermal response and physical measurements were taken in half-opened spaces, which have open entries and do not rely on HVAC systems, such as underground shopping malls and train-station malls are common for everyday life in Japan [13].

Measurements were taken in what researchers called "defence zones," the continuous spaces from the inside to the outside of building, such as an entry foyer space in a hotel lobby. The middle area refers to a covered balcony, porch, veranda, or sunroom. These spaces are adjacent to a dwelling or serve as a passage between multiple dwellings [19,20]. Further refinement of the architectural definition of a transitional space in the Japanese language describes tyukan ryouiki as the space where uchi and Soto meet [21]. Uchi (inside) refers to the interior space having the concept of being related, belonging, or possessing adjacent outdoor space, and Soto (outside) is conversely related to uchi. Transient conditions in indoor spaces and in what we define as transitional spaces are characterized by dynamic, variable, unstable, or fluctuating conditions [22].

Transient conditions are quite complicated and compounded by the effects of many variables such as temperature differentials, solar radiation, wind, and localized microclimates. The implications for improving comfort within transitional spaces are significant for maintaining and promoting active businesses and improving the quality of life. Though transient conditions may occur within any interior space, direct solar radiation, draft, or temperature swings would not be desirable. In transitional spaces, transient conditions are simply a consequence of outdoor conditions, where people expect and encounter different climate conditions and comfort offers more adaptive opportunities [17].

2. METHODOLOGY

2.1 Experiment Setup

The survey was conducted at UPM's post graduate study area of Faculty of Design and Architecture (FDA) located in the northern part of the UPM. The faculty was established in 1996, starting with a few numbers of students. The mentioned location was chosen for the survey due to the closeness of the survey points (veranda and indoor) so as to maximise the accuracy of the study. The total area of post graduate office is about 144m2. And the width of veranda is 2.9 m. The indoor temperature of the study area was also maintained at 24°C, while the outdoor hot humid temperature was recorded at 36°C.

2.2 Instrumentation

Three instruments are used in conducting the research work of which both are in line with ASHRAE recommended, those are Questionnaire form, Micrometeorological monitoring and Radian Asymmetry measurement instrument fluke 561 infrared thermometer.

2.3 Questionnaire Form

The questionnaire form is divided into three parts, namely, Part 1: Personal detail, Part 2: Thermal comfort votes and Part 3: Objective measurements. Only Part 3 is to be completed by the researcher.

Thermal comfort assessments are conducted using questionnaires forms. Personal details of each respondent including his/her gender, age, weight and height are required in the first part of the questionnaire form. In second part thermal comfort vote is determine by the following questions in accordance with ASHRAE seven point sensation scale and three-point Mclntyre Scale, The subjective thermal responses used for the sensation enquiry:

2.4 Micrometeorological Monitoring and Infrared Thermometer

Micrometeorological sensors were selected in accordance with the specifications outlined in ASHRAE's Handbook of Fundamentals. The OHM Delta Thermal Microclimate HD32.2 were used for monitoring microclimate environmental condition, such as air temperature (Ta), relative humidity (RH), air velocity (Va) and mean radiant temperature (MRT). The instrument was stationed on site and mounted on a tripod in both veranda and indoor. The detail information about OHM Delta Thermal Microclimate HD32.2 is described as; Analysis of hot environments through WBGT index (Wet Bulb Globe Temperature) in presence or absence of solar radiation. Analysis of moderate environments through PMV index (Predicted Mean Vote) and PPD index (Predicted Percentage of Dissatisfied).

The instrument is provided with three inputs for probes with SICRAM module, the probes have an electric circuit that communicates with the instrument and the sensor calibration data are saved in its Permanent memory. All the SICRAM probes can be inserted in one of the inputs which are automatically recognized when the instrument is switch on. The main important features of the instrument are: Logging acquisition and memorization of data inside the instrument, measuring the unit of temperature visualized (°C, °F, °K), recording date and hour of the system, visualization of maximum, minimum and medium statistic parameters and their cancellation of the system and the transfer speed of the data through the serial port RS232.

The Radian Asymmetry measurement instrument fluke 561 infrared thermometer was used to measure the forehead and hand (dossal) skin temperature of the respondent during the experimental

Overall data collection was conducted using indoor and outdoor climate measurement instrument namely HD32.3 WBGT-PMV Index, made by Delta Ohm SRL, and Radian Asymmetry measurement instrument fluke 561 infrared thermometer, The HD32.3 WBGT-PMV

Index, made by Delta Ohm SRL was placed at the two points of the survey.

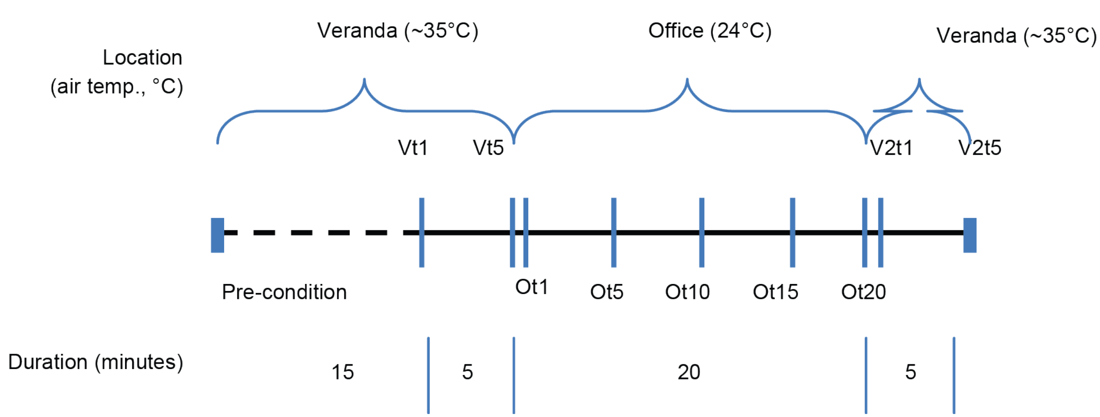

Figure 1: Participants' activity according to experiment sequence

Each of the 36 subjects was given 9 questionnaires to fill. The respondents were given 15mins to sit and relax for their temperature to be normal as is expected for positive output of the experiment, before the beginning of the test. This waiting period is referred to as Pre-Conditioning. The first questionnaire, Vt1 was filled upon arrival at the veranda (around the measurement instrument Ohm Delta machine), after 5 minutes the second questionnaire, Vt5 was filled at the same location.

The questionnaire Ot1 was filled at the moment the subject was indoor and 5 minutes later, another questionnaire Ot5 was filled at the same point. Three more questionnaires, Ot10, Ot15 and Ot20, were filled at 5 minutes interval. The subjects were returned to the veranda, where the Delta Ohm machine is placed and the last two questionnaires, V2t1 and V2t5 were filled at the same intervals of 5 minutes. The diagrammatic representation of the sequence is shown in figure 1.

3. RESULT

3.1 Environmental Condition Based on Sequence

Table 1. Shows a statistical summary of environmental condition based on sequence. The mean air temperature (Ta) at Vt1 and Vt5 (Veranda 1) are 34.9 and 34.80C. The mean air temperature of indoor air conditioned office was 24.3 for Ot1 to Ot15 while Ot20 has a mean value of 24.20C. For the Veranda 2, the mean air temperature has a mean value of 35.1 and 35.00C respectively. The mean values recorded for the relative humidity (RH) of the sequence in Vt1 and Vt5 were 42.3% and 42.5%, for the Ot1, Ot5, Ot10, Ot15 and Ot20, the relative humidity recorded were 52.2%, 51.6%, 51.9%,50.9% and 50.6% respectively. But for the Veranda 2, (V2 t1 and V2 t5) their mean RH were 43.2% and 42.4%.

Mean values of air velocity (Va) obtained were 0.3 (ms-1) and 0.5(ms-1) for Veranda 1 (Vt1 and Vt5). For the indoor air-conditioned office, the mean Va values obtained were 0.9(ms-1) for Ot1, while Ot5 to Ot20 had same mean value as 0.4(ms-1). The Veranda 2 (V2 t1 and V2 t5) also had the same mean air velocity as 0.5(ms-1). The mean radiant temperatures (MRT) for the sequence were 36.600C and 36.400C for Vt 1 and Vt 5. The values obtained for Ot1, Ot5, Ot10, Ot15 and Ot20 were 26.50C, 26.60C 26.70C, 26.60C and 26.70C respectively. However, V2 t1 and V2 t5 maintained the same MRT value as 36.40C. The mean values of operative temperature (T.op) recorded were 35.50C and 35.40C for Vt 1 and Vt 5. For the Ot1, Ot5, Ot10, Ot15 and Ot20, the mean values were 25.10C, 25.20C, 25.30C, 25.20C and 25.20C respectively. In the case of Veranda 2, T.op mean of the V2 t1 and V2 t5 were recorded as 35.50C and 35.70C respectively.

The overall details of environmental conditions once participants had entered the Veranda and indoor office with air-conditioned had been presented. The table show changes in environmental conditions within the sequence; from Veranda to indoor office with air-conditioned and back to the Veranda again. The variation occurred as a result of the conditions in the thermal transition between the Verandas and office. This also indicated that there is changed during transition mostly within the two Verandas which both are outdoor non-air conditioned. The change is attributable to the short term stay in the indoor before exiting to the Veranda again. This revealed that thermal sensation notice short changes while on transition.

3.2 Skin Temperature of Hand and Forehead

It can be seen that in each of the conditions, skin temperature either increases or decreases while in transition. Hand skin temperature was lower than that of forehead. However both of them exhibited a similar pattern of temperature

Table 1. Mean and standard Deviation (SD±) of Environmental Condition According to Sequence

Variables	Vt1	Vt5	ot1	ot5	ot10	ot15	ot20	Vt2 1	Vt2 t5
Ta (^{0}C) (±)	34.9 (2.3)	34.8 (2.2)	24.3 (0.8)	24.3 (0.7)	24.3 (0.5)	24.3 (0.2)	24.2 (0.3)	35.1 (2.1)	35.0 (1.9)
RH (%) (±)	42.3 (6.7)	42.5 (6.7)	52.2 (7.6)	51.6 (7.6)	51.9 (7.6)	50.9 (6.9)	50.6 (6.4)	43.2 (6.8)	42.4 (7.5)
Va (ms^{-1}) (±)	0.3 (0.2)	0.5 (0.4)	0.9 (1.0)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.4 (0.1)	0.5 (0.4)	0.5 (0.3)
MRT (^{0}C) (±)	36.6 (3.0)	36.4 (2.7)	26.5 (1.7)	26.6 (1.2)	26.7 (0.9)	26.6 (1.1)	26.7 (0.6)	36.4 (3.1)	36.4 (2.8)
T.op (^{0}C) (±)	35.5 (2.6)	35.4 (2.3)	25.1 (1.1)	25.2 (0.9)	25.3 (0.6)	25.2 (0.5)	25.2 (0.3)	35.7 (2.6)	35.5 (2.2)

change. Figure 2, Show differences in skin temperatures at different sequence. Result of the analysis shows that mean skin temperature difference at first Veranda (Vt1 to Vt5) was 0.650C. For the indoor air conditioned office, the mean temperature difference was 1.420C which is Ot1 to Ot20, while the mean temperature difference in the second Veranda (V2 t1 and V2 t5) was 1.050C. Thus, the result show differences in skin temperature at the start of each sequence.

3.3 Mean Thermal Comfort Vote.

Figure 3, shows the overall mean thermal comfort in relation to sequence. In Vt 1 and Vt 5 the respondents mean vote were -0.3 and -0.2. But in Ot1 to Ot20 which is indoor air-conditioned office the mean shows that the respondents voted between slightly comfortable and comfortable.

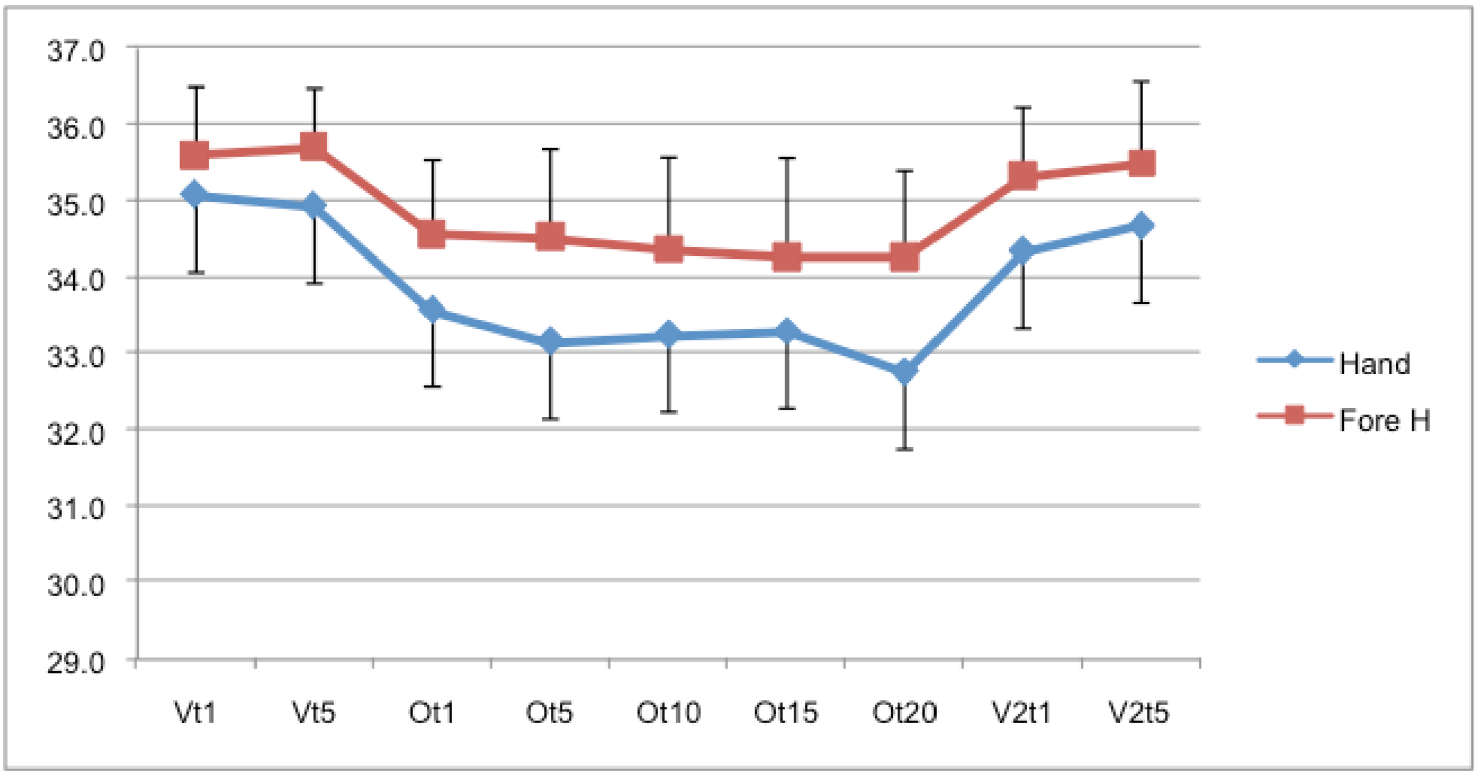

Figure 2: Skin Temperature for (Hand and Forehead)

during the transition from indoor to Veranda 2 (V2 t1 and V2 t5) the mean chart shows that the respondents voted slightly uncomfortable. The overall mean thermal comfort indicate short changes during the transition within the sequences, especially from the indoor air-conditioned space to outdoor non-air-conditioned, which is Veranda 2.

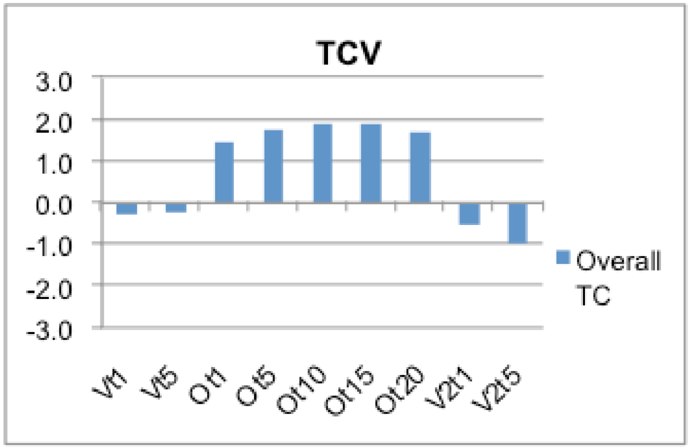

Figure 3: Mean Thermal Comfort Vote vs. Sequence

3.4 Variation in Predicted Mean Vote (PMV) and Thermal Sensation Vote (TSV)

In Figure 4, the result has shown that when moving from outdoor non-air conditioned to indoor air conditioned and another outdoor non- air conditioned space, there is a rapid variation in sensation which cannot be predicted by PMV. When moving from outdoor non-air conditioned (warmer) space to indoor air-conditioned space, PMV overshoots the thermal sensation vote value. However, this outcome did not conform to the ASHRAE standard which could be attributed to the differences in geographical locations. The Fanger PMV model was designed and tested based on America and European environment that are usually cooler. The coldness of these environments could have been the reason for over-shooting of the PMV values in every sequence. The PMV is widely used as a tool to predict thermal comfort; however, it was developed for use in steady-state environments and may not be applicable when predicting thermal sensation in a transient environment. Data from the current study will be used to improve the PMV for use in transient environments. This would then be applied to circumstances such as; journeys in a train to predict sensation immediately after boarding to enable thermal sensation throughout a train journey to be predicted. This condition is similar with the research conducted by other researchers [23,24].

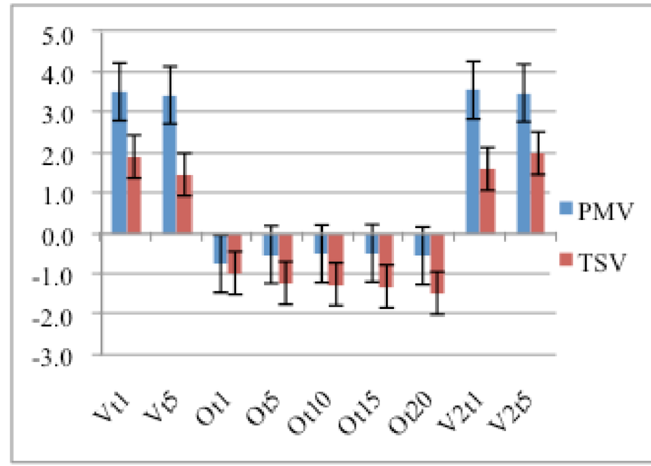

Figure 4 Predicted Mean Vote (PMV) and Thermal Sensation Vote (TSV)

4. CONCLUSION

In this study, experiments were performed to determine the thermal comfort and thermal sensation among people in transitional spaces. The thermal sensation was recorded throughout and it was observed that there is an immediate change in thermal sensation which is associated to the earlier environment. While moving from a hotter environment to a cooler environment, predicted mean vote (PMV) overshoots the thermal sensation (TSV) to a higher value.

Temperature measured for skin (Hand and forehead) either increases or decreases (according to conditions) while in transition. Hand skin temperature was found to be lower as against that of the forehead. However, the overall mean thermal comfort indicated a shot changes during the transition within the sequence especially from indoor air conditioned spaces to semi-outdoor non-air conditioned.

5. REFERENCE

Jing, S., Li, B., Tan, M., & Liu, H. (2012). Impact of Relative Humidity on Thermal Comfort in Warm Environment. Indoor and Built Environment, 1420326X12447614.

Nevins, R. G., Rohles, F. H., Springer, W., & Feyerherm, A. M. (1966). A temperature-humidity chart for thermal comfort of seated persons. ASHRAE transactions, 72(1), 283-291.

AC08024865, A. (Ed.). (2005). Ergonomics of the thermal environment-Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. ISO.

Liu, H., Liao, J., Yang, D., Du, X., Hu, P., Yang, Y., & Li, B. (2014). The response of human thermal perception and skin temperature to step-change transient thermal environments. Building and Environment, 73, 232-238.

Nicol, F., & Stevenson, F. (2013). Adaptive comfort in an unpredictable world.Building Research & Information, 41(3), 255-258.

De Dear, R., & Brager, G. S. (1998). Developing an adaptive model of thermal comfort and preference.

Fanger, P. O. (1970). Thermal comfort. Analysis and applications in environmental engineering. Thermal comfort. Analysis and applications in environmental engineering.

AC04472789, A. (Ed.). (2004). Thermal environmental conditions for human occupancy. Ashrae.

Raja, I. A., & Virk, G. S. (2001). Thermal comfort in urban open spaces: a review. Proceedings of moving thermal comfort standards into the 21st century, 342-52.

Jitkhajornwanich, K., Pitts, A. C., Malama, A., & Sharples, S. (1998). Thermal comfort in transitional spaces in the cool season of Bangkok. ASHRAE Transactions, 104, 1181.

Potvin, A. (2000). Assessing the microclimate of urban transitional spaces. Proceedings of Passive Low Energy Architecture, 581-6.

Chun, C., Kwok, A., Mitamura, T., Miwa, N., & Tamura, A. (2008). Thermal diary: Connecting temperature history to indoor comfort. Building and Environment, 43(5), 877-885.

Chun, C. Y., & Tamura, A. (1998). Thermal environment and human responses in underground shopping malls vs department stores in Japan. Building and Environment, 33(2), 151-158.

Dear, R. J., Ring, J. W., & Fanger, P. O. (1993). Thermal sensations resulting from sudden ambient temperature changes. Indoor Air, 3(3), 181-192.

Jones, B. W. (1992). Transient interaction between the human and the thermal environment. ASHRAE transactions, 98(2), 189-195.

Arens, E., Zhang, H., & Huizenga, C. (2006). Partial-and whole-body thermal sensation and comfort—Part II: Non-uniform environmental conditions. Journal of Thermal Biology, 31(1), 60-66.

Chun, C., Kwok, A., & Tamura, A. (2004). Thermal comfort in transitional spaces—basic concepts: literature review and trial measurement. Building and environment, 39(10), 1187-1192.

Tsujihara, M., Nakamura, Y., & Tanaka, M. (1999). Proposal of evaluation method of thermal environment inside semi-outdoor space in city from viewpoint of geographical difference. JOURNAL OF ARCHITECTURE PLANNING AND ENVIRONMENTAL ENGINEERING, 101-108.

Nakano, J. H., Tsutsumi, S., Horikawa, S. T., & Kimura, K. (1992). Field investigation on the transient thermal comfort buffer zones from outdoor to indoor. Indoor Air, 99, 172-7.

Zintani, N., Suda, M., & Hatsumi, M. (1999). Transitional space and common contact in apartment house. In Proceedings of Annual AIJ Conference, Architectural Institute of Japan (pp. 139-40).

Yamazaki, K., Sato, T., & Horiuchi, Y. (1996). Research on design method for transitional space in Hokkaido house. In Proceedings of Annual AIJ Conference, Architectural Institute of Japan (pp. 79-80).

Hensen, J. L. M. (1990). Literature review on thermal comfort in transient conditions. Building and Environment, 25(4), 309-316.

Underwood, P. (2006). A Practical Model for the Assessment of Thermal Comfort in Train Carriages (Doctoral dissertation, MPhil thesis, Loughborough University).

Stennings, P. (2007). Thermal Comfort of Railway Passengers (Doctoral dissertation, MPhil thesis, Loughborough University).