THERMAL SENSATION AND COMFORT IN TRANSIENT CONDITIONS IN HOT-HUMID ENVIRONMENT

YAKUBU YAU GITAL

FRSB 2016 6

THERMAL SENSATION AND COMFORT IN TRANSIENT CONDITIONS IN HOT-HUMID ENVIRONMENT

By

YAKUBU YAU GITAL

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, In Fulfilment of the Requirements for the Degree of Master of Science

March 2016

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DEDICATION

This thesis is dedicated to my late mum, Hajiya Maryam and my family.

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Master of Science

THERMAL SENSATION AND COMFORT IN TRANSIENT CONDITIONS IN HOT-HUMID ENVIRONMENT

By

YAKUBU YAU GITAL

March 2016

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The study was conducted to identify affective and sensory responses observed as a result of hysteresis effects in transient thermal conditions consisting of warm-neutral and neutral-warm outside of a laboratory setting. Air-conditioned building interiors in hot/humid areas have resulted in thermal discomfort and health risks for people moving into and out of buildings. Reports have shown that the immediate change in air temperature can cause unexpected thermoregulation responses. Thermal Sensation Vote (TSV) and Thermal Comfort Vote (TCV) assessments as a consequence of moving through spaces with different thermal conditions were conducted in an existing single-story office in a hot-humid microclimate, maintained at an air temperature of 24°C. Subjective assessments consisting of sensations, preferences and thermal comfort votes were correlated against a steady state PMV model. Local skin temperatures on the forehead and dorsal left hand were included to observe physiological responses due to thermal transition. Sensory and affective responses as a consequence of thermal transition after travel from warm-neutral-warm conditions did not replicate the hysteresis effects of brief, slightly cool, thermal sensations found in previous laboratory experiments.

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PENYELIDIKAN TERHADAP SENSASI TERMAL DAN KESELESAAN DALAM KEADAAN TRANSIEN DALAM PERSEKITARAN PANAS-LEMBAP

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Kajian ini dijalankan bagi mengenal pasti respon afektif dan sensori yang dicatatkan akibat kesan histeresis dalam keadaan termal transien yang terdiri daripada seting suam-neutral dan neutral-suam di luar seting makmal. Penyamanan udara interior bangunan dalam kawasan panas /lembap telah menyebabkan ketidakselesaan termal dan risiko kesihatan bagi orang yang keluar dan masuk ke sesebuah bangunan. Laporan telah memperlihatkan bahawa penukaran serta merta dalam suhu air boleh menyebabkan respon termoregulasi mendadak. Penaksiran vot sensasi termal (TSV) dan vot keselesaan termal (TCV) sebagai akibat pergerakan melalui ruang beserta keadaan termal berlainan telah dijalankan di dalam pejabat setingkat dalam mikrocuaca panas-lembap, suhu angin dikekalkan pada 24°C. Penaksiran subjektif yang terdiri daripada keutamaan sensasi dan vot keselesaan termal berkorelasi dengan model PMV berkeadaan mantap. Suhu kulit lokal di atas dahi dan dorsal tangan kiri juga terlibat bagi meneliti respon fisiologikal disebabkan transisi termal. Respon afektif dan sensori disebabkan transisi termal selepas melalui dari keadaan suam-neutral-suam tidak menandakan kesan histeresis bagi sensasi termal yang singkat, agak sejuk yang diperoleh dari eksperimen makmal terdahulu.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Master of Science. The members of the Supervisory committee were as follows:

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LIST OF ABBREVIATIONS

ASHRAE	American society of heating, refrigerating, and air-conditioning engineers.
ISO	International standard organization
PPD	Predicted percentage of dissatisfied
RH	Relative humidity
Ta	Air temperature
Va	Air velocity
MRT	Mean radiant temperature
T.op	Operative temperature
PMV	Predicted mean vote
TSV	Thermal sensation vote
TCV	Thermal comfort vote
HVAC	Heating, ventilation and Air conditioning
ASHVE	American society of heating ventilates engineers

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CHAPTER 1

INTRODUCTION

1.1 Background

Thermal comfort research in buildings has primarily focused on steady-state conditions (Jing et al., 2012; Nevins et al., 1966). 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 or boat where air-conditioning is most frequently used to adjust thermal environment to accommodate hot or cold climate). Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation (ASHRAE, 2013b).

It is believed that 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 neutral one or from neutral temperature to high temperature. Such thermal stimulus disturbance can also be experienced in our daily life. In summer and winter, the temperature difference between indoor air-conditioning and outdoor natural environment always exists. When the temperature step-change exceeds the regulation ability of human body, people may feel discomfort (Liu et al., 2014).

In 1994, ASHRAE proposed comfort index for developing countries in hot-humid regions and is supported by (Humphreys, 1992; Tanabe, 1988). According to these studies, the building occupants are acclimatized to and therefore are able to tolerate both higher and lower temperatures.

In the studies conducted in hot-humid South East Asian region in the 1930s, the proposed neutral temperature is higher than 24.5^{o}C as recommended by ASHRAE Standard 55. The results of these studies suggest a wider thermal comfort range for these regions as proposed by ASHRAE Standard 55, which indicates that Malaysians are acclimatized to much higher environmental temperatures. Adopting the international standards for comfort condition for Malaysians who are in hot-humid tropical climate may lead to overcooling and energy wastes (Ahmad and Ibrahim, 2003). Research in this direction therefore would help in determining thermal sensation within the transient environment which will help in reducing energy waste due to over-cooling or warming as postulated by (Ahmad and Ibrahim, 2003)

Buildings isolate people from external temperatures and limit their ability for thermal adaptation due to fixed temperatures. Interestingly, some authors claim that people look for temperature differences as a way to reach thermal comfort. Temperature

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deviations do not always cause discomfort; on the contrary, fixed temperatures provoke people's discomfort to some extent (Nicol, 2011).

The subject of thermal environment and human comfort has been extensively studied with regard to finding comfortable indoor thermal conditions (De Dear and Brager, 1998; Fanger, 1970).The long history of research results became the standard for comfortable indoor thermal conditions (ASHRAE, 1992a). Several recent studies have examined the topic of outdoor comfort. However, there are many places which are not completely indoor or completely outdoor. Recent comfort standards are not suitable to assess comfort conditions in spaces that are neither outdoor nor indoor (Raja and Virk, 2001).

Studies about thermal comfort in these transient conditions are very few. Jitkhajornwanich et al. (1998) surveyed occupants' thermal comfort in indoors, outdoors including a transitional space between them. They compared thermal comfort between naturally ventilated buildings and air-conditioned buildings. On the other hand, measurement of thermal environment of arcades using a portable sensor array from the view of pedestrian was also conducted (Potvin, 2000).

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 (Chun et al., 2008; Chun and Tamura, 1998; de Dear et al., 1993; Jones, 1992b). There is conflicting evidence as to the type and extent of this effect, for instance Jones and Ogawa (1993), state 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 usually lower than how PMV would predict (Arens et al., 2006b; de Dear et al., 1993). But only few studies investigated the thermal comfort of same peoples moving from one place to another (Pérez-Lombard et al., 2008).

Architects and engineers use thermal comfort standards, such as thermal environment conditions for human occupancy by the American Society of Heating, Refrigeration, and Air-conditioning (ASHRAE, 1992b; Standard, 1992) and moderate thermal environments determination of PMV and PPD indices and specification of the condition for thermal comfort by International Standard Organization (ISO, 1994), to design system to provide a physical environment appropriate for thermal comfort. According to ASHRAE 55-2004 and ISO 7730 standard, the environment that is acceptable for 80% of the residents would be defined as comfortable thermal environment, the measured temperature with percentage people dissatisfied (PPD) 20% would be the comfortable temperature. This research set out to investigate the responses of occupants moving from outside hot- humid climate to air conditioned office in tropical microclimate.

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1.2 Problem Statement

Heating, ventilation, and air-conditioning technologies and systems are typically used to provide desirable indoor thermal environments for human occupancy. However, if occupants go through spatial transitions involving noticeable temperature differences, typical thermal comfort evaluation schemes which are geared toward thermally adapted individuals for example, ASHREA Standard 55 (ASHRAE, 2004). may not apply. Temperature differences from one space to another, temperature sequences and direction are the main factors affecting people's thermal memory in the short term (Vargas and Stevenson, 2014).

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 (Nicol and Stevenson, 2013).

People are frequently exposed to such transitient conditions, for example when they enter or exit a building or when they move through differentially temperate rooms within a building, conduct of thermal assessment processes pertaining to transitient conditions may result in inappropriate temperature settings, inefficient thermal controls, and poor thermal comfort conditions (Wu and Mahdavi, 2014b).

Opinions have varied that PMV cannot be used for transient conditions thermal comfort predictions because of its unstable and dynamic physical and MET value. Neither ASHRAE standard 55-2010 nor ISO 7730 give comprehensive description on thermal comfort in transient environment (ISO, 2005). The transitient condition is an independent dynamic space which has various physical conditions and behavior. Future investigation in this direction will help to identify subjective responses of users' thermal sensations in this dynamic space type (Chun et al., 2004). Hence, the focus of this study is to investigate the human sensation and comfort in transient conditions.

1.3 Background of Study Area

Malaysia is a hot and humid tropical country that lies between 1^{o} and 7^{o} North's and 100^{o} and 120 east. The capital city, Kuala Lumpur is situated at a latitude 3^{o} 7, above the equator at 101^{o} 33^{o}. Most locations have a relative humidity of 80% to 88% rising to nearly 90% in the highland areas and never falling below 60% the mean maximum daytime temperature recorded was 29^{o}C to 32^{o}C while the minimum temperature is 23^{o}C to 26^{o}C with rainfall 1000mm per year (Ahmad and Ibrahim, 2003).

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The Department of Occupational Safety and Health Malaysia (DOSM) recommended indoor design temperature range from 23^{o}C to 26^{o}C with relative humidity 60% to 70% (Ahmad and Ibrahim, 2003) as above the required temperature and humidity perimeters are lower than outside air, full acclimatization is to satisfy optimal normal requirement for the working areas in order to satisfy human comfort and working condition (Standard) MS 1525 2001).

Malaysia has a hot and humid climate. Air conditioning during office hours is very important so as to provide thermal comfort in to a building (Ismail et al., 2009) However in the years, sick building syndrome have become common issues in Malaysia. This is due to the construction of building designed to be energy-efficient with air conditioning system, but poor maintenances and services of HVAC system resulting in increasing of indoor air pollutant level(Berardi et al., 1991). Also this is a close to the equator, It has plentiful sunshine but it is occasional to have a full day with completely clear sky.

The study was conducted at a one floor office building with an area of 144M^{2}. A corridor is built around the office with a width of 2.9m. In this work the researcher explores how people respond to temperature derivation and repeated short term experiences. In the present study, thermal sensations and comfort assessments as a consequence of moving through spaces with distinct thermal conditions (i.e., from semi-outdoor to indoor and vice versa).

1.4 Aim of the Research

The aim of this research is to identify the human response on environmental transient conditions between semi-outdoor space and air conditioned environment.

1.5 Objectives of the Research

1. To determine whether or not thermal sensation response of thermally acclimatized participants who are experiencing distinct semi-outdoor and indoor transitions agree with predictions of standard thermal comfort models.
2. To examine the effects of temperature differences on participants' thermal sensation and comfort responses.

1.6 Research Questions

The following research questions were designed in order to achieve the research objectives:

1. Do changes in thermal sensation and thermal comfort votes after moving from outdoor to indoor and vice versa correlate with temperature difference?

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2. Is there any difference between transient condition during the transition with respondents' skin temperature,thermal sensation vote (TSV),and predicted mean vote (PMV)?
3. Can skin temperature (i.e. on hand and forehead) influence participants' thermal sensation vote?

1.7 Research Methodology

To achieve the above research methodology thermal transient response experiments were conducted. But field research is the most appropriate for observing and evaluating a range of response.

i. Objective measurement: According to Fanger for calculating PMV, four environmental variables (ambient temperature, mean radian temperature, relative humidity, and air velocity) should be measured by a device and two personal variables (i.e. clothing insulation value and metabolic rate) should be estimated according to standards (Fanger, 1973).
ii. Subjective Measurements: This was conducted in survey and filled questionnaire about thermal sensation, thermal comfort, thermal preference, thermal acceptance and air preference.

The research framework contains the problem statement on different thermal sensation perceptions, thermal comfort in transient condition that requires different assessment method in the light of the reality that people are experiencing non-uniform/dynamic thermal comfort.

At the same time the framework looked at the objectives of physical or physiological occurrences when moving between spaces through answering questionnaires and micro climate monitoring to compare with the Predicted Mean Value (PMV). On the other hand, the thermal acceptability, thermal preference, air preference and air acceptability are used to determine whether 24^0C is sufficient in an office not. The data was analysed through data analysis, descriptive statistics, and one-way anova and Pearson correlation.

1.8 Scope and Limitations

This reseach is focused on investigating thermal comfort under transient onditions aspect, such as how moving from one place with a certain operative temperature to another place that has a different operative temperature can effect people's thermal comfort and thermal sensation assessments were taken into consideration. The two subject assessments were validated using skin temperature at two local point that is forehead and hand. However, other physiological measurements such as core temperature and heart beat reading were not included due to limited funding and man power to assist the reseserchер duing the quasi-experiment.

Our theoretical knowledge concerning thermal comfort in transient conditions is still limited. At present, results of thermal comfort experiment seems to be the only

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source of information on thermal acceptability in changing environmental condition. This present study is limited to condition characteristic of postgraduate office of Faculty of Design and Architecture.

In addition, the instruments used were limited to adopted questionnaire and measurement instruments were limited to the use of an indoor climate-measuring instrument (HD32.3 – WBGT- PMV index) and a radiant asymmetry-measuring instrument (fluke 561 infrared thermometer). Moreover, meteorology measurements were limited to KLIA weather station, data that were acquired from the Malaysia Meteorology Department. The validity of the survey questionnaire and measurements was in accordance with the ASHARE 55 and ISO 7730 requirements. Finally, evaluation of thermal environment followed ISO 7730 procedure.

1.9 Significance of Study

Transient thermal environment can be established by changing air temperature and or air velocity. Comparatively, air velocity change is easier and can be used to offset higher air temperature in transient conditions in warm climate.

Indoor Air Quality evaluation consisted of 20% of the overall Green Building Index using Malaysian rating tool. Correlation between thermal perceptions and the ambient air-conditioned indoor temperatures may serve as important guides for building services engineers and researchers who are intending to minimize energy usage in heating, ventilating and air conditioning systems in offices operating in the tropics with acceptable thermal comfort level and to improve the performance and well-being of its workers.

Understanding how humans subjectively perceive the environment following a step-change in conditions can aid the design of that space. For instance, if it is cold and wet outside and warm inside, persons entering may experience a build-up of condensation on clothing. This may be perceived as discomfort with the space until the body has adapted to the new conditions. Understanding the relationship between the physical (condensation build-up) and the subjective (ratings of discomfort) enables designers to select environmental parameters that can adapt to the occupant's needs.

Hence, the thermal comfort survey to be embarked upon, would not only provide a guide for the utilization and comfort of the rooms occupants (international student from various countries) but will assist in setting up standards as well as ensuring that faculty comfort lobby accommodate all its postgraduate students from different environments. Also, the study would greatly assist in ensuring as well as minimizing energy usage in the building located within Malaysia being a tropical country with the view of maintaining an acceptable thermal comfort of outdoor transitient environment in accordance with best practices.

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Future investigation in this direction will be made, including subjective responses for user thermal sensations in this dynamic space type.

1.10 Thesis Structure

Chapter one of thesis shed light on the thesis introduction, background of the study, problem statements, aims and objectives, research questions and significance of the study. The second chapter is all about literature review which results in the identification of the itemised issues in chapter one. Chapter three discussed the research methodology and the instruments employed in the research. The findings of the research were captured and discussed in chapter four. Summary, conclusion and recommendations are the points covering chapter five.

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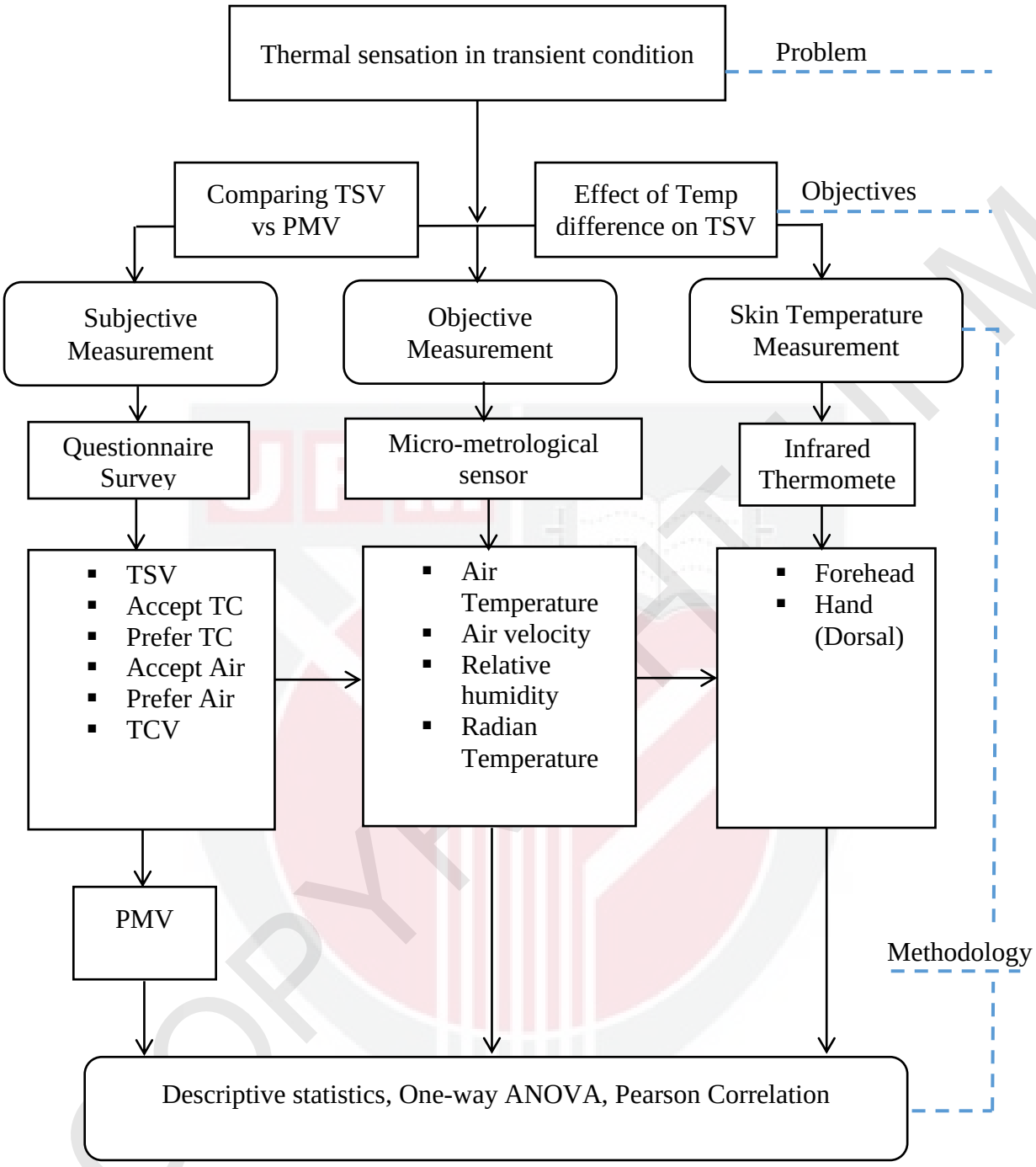

Figure 1.1 Research framework

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