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HUMAN ADAPTIVE THERMAL COMFORT INSIDE NATURALLY VENTILATED BUILDINGS FOR RELIGIOUS PRACTICE IN THAILAND

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Abstract

The adaptive model of thermal comfort considers non-thermal variables as mediators and moderators which can vary building users' thermal perception. Therefore, the adaptive approach has drawn global attention from researchers due to its potential to reduce energy requirements in buildings. In tropical climates such as Thailand, characterised by high heat and humidity, architectural solutions *generally focus on passive shading and cooling techniques utilising ventilation. Although many studies have surveyed various types of buildings, there is a lack of attention to religious buildings, despite extended hours of indoor thermal exposure* affecting users' wellbeing and practice qualities. This research considers adaptive thermal comfort in Buddhist meditation buildings in the tropical climate of Thailand, with particularly consideration of the physiological and psychological benefits of meditative activities, and the sense of space, in the context of an inherited rich Buddhist culture with regard to users' thermal perception. This field survey, which employed qualitative and quantitative research methods, collected 517 datasets from three Thai meditation buildings from 2016 to 2017. The main aims of this research are to: (i) explore a suitable thermal environment; (ii) examine if the neutral temperature (T_n) is perceived as thermal comfort; and (iii) to investigate users' most performed thermal adaptive solutions in meditation halls. The findings indicate that the subjects have more extensive ranges of thermal acceptability with a more exceptional adaptive ability than considered in the ASHRAE standards. Additionally, the results demonstrate that the current T_n state is capable of providing the subjects with thermal comfort, but it is not the most comfortable temperature in order to experience enhanced meditative qualities, and subjects performed a combination of adaptions. Thermal sensation votes were affected by non-thermal factors, including meditation experiences and ventilation profiles.

Keywords: Adaptive Thermal Comfort, Neutral Temperature, Meditative Qualities, Religious Practice Buildings, Thermal Acceptability, Thermal Adaptation

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Nomenclature

ΔS	:	A sum of the heat balance of human body (W/m^2)
AC	:	Air conditioned
ACT	:	Acceptance and commitment therapy
A_{du}	:	Body area of Dubois's calculation (m^2)
A_{eff}	:	Effective radiation area (m^2)
AIVC	:	Air infiltration and ventilation centre
ANS	:	Automatic nervous system
APD	:	Actual percentage of dissatisfaction (%)
aPMV	:	Adaptive predicted mean vote
APV	:	Actual thermal perception vote
ASHRAE	:	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASP	:	Actual thermal perception
ASV	:	Present actual sensation vote
ASV_{exp}	:	Actual thermal sensation of the experienced subjects
ASV_{inexp}	:	Actual thermal sensation of the inexperienced subjects
ASV_{past}	:	Past actual sensation vote
A_{sw}	:	Body surface exposed to environment and covered by sweat film (ºC)
BD	:	Feeling moody, bored and dissatisfied
CAMS-R	:	Cognitive and affective mindfulness scale
CBE	:	Centre for the built environment
C_d	:	Conduction (W/m^2)
CIBSE	:	Chartered institution of building services engine
CLO	:	Clothing insulation value
CLO_{all}	:	Clothing insulation value of all the subjects
CLO_{female}	:	Clothing insulation value of the female subjects
CLO_{male}	:	Clothing insulation value of the male subjects

CNS	:	Central nervous system
C_p	:	Specific heat (j/kg.K)
C_{resp}	:	Convective heat loss (W/m^2)
CT	:	Continuous thought
CTS	:	Comfortable thermal sensation
C_v	:	Convection (W/m^2)
d	:	Diameter of the globe sphere
D/S ratio	:	Distance-to-spot ratio
DBT	:	Dry bulb temperature (ºC)
$DBT_{av\text{-}in}$	:	Average indoor dry bulb temperature of three WBGT devices (ºC)
DBT_{in}	:	30-minute average indoor dry bulb temperature (ºC)
DBT_{out}	:	Outdoor dry bulb temperature (ºC)
D_p	:	Hall density preference
DR	:	Difficulty in relaxation
E	:	Evaporation (W/m^2)
E_{diff}	:	Heat loss by vapour diffusion of human skin (W/m^2)
EEG	:	Electroencephalogram
E_{max}	:	Maximum evaporative of the human body (W/m^2)
E_{resp}	:	Evaporative heat loss from respiratory system (W/m^2)
E_{rsw}	:	Heat loss by evaporation of skin sweat (W/m^2)
E_{sk}	:	Heat loss through skin surface (W/m^2)
E_{sw}	:	Sweat secretion (W/m^2)
ET	:	Effective temperature (ºC)
*ET**	:	New effective temperature (ºC)
ε	:	Emissivity of the globe surface
F_{cl}	:	Burton clothing efficiency factor
f_{cl}	:	The clothed body surface area to the hide body surface area
F_{fan}	:	The percentage of fan function (%)
FFMQ	:	Five mindfulness questionnaire

FG	:	Wishing the practice will end soon
FMI	:	Freiburg mindfulness inventory
F_{pcl}	:	Efficiency of vapor permeation of body skin to the atmosphere
F_{window}	:	The percentage of window function (%)
G	:	Griffiths slope
GSR	:	Galvanic skin response
h	:	A result of combination of *hr* and *hc* (W/m^2k)
h_c	:	Convective conductance (W/m^2k)
h_{cl}	:	Convective heat transfer coefficient (W/m^2k)
h_r	:	Radiation conductance (W/m^2k)
I_{cl}	:	Thermal resistance of the whole clothing applied (clo) (m^2K/W)
IEQ	:	Indoor environment quality
IFA	:	Impaired instruction-following ability
IR	:	Infrared radiation
ISO	:	International organization for standardization
K	:	Heat transfer from of human skin to surface of clothing(W/m^2)
KIMS	:	Kentucky inventory of mindfulness scale
L	:	Sensible heat loss by respiration (W/m^2)
LTM	:	Long-term memory
LT_p	:	Day lighting preference
m	:	Permeability of skin
MAAS	:	Mindfulness attention awareness
MBSR	:	Mindfulness-based stress reduction
MEDEQ	:	Meditation depth questionnaire
MEDI	:	Meditation depth index
MET	:	Metabolic rate
MRT	:	Mean radiant temperature (ºC)
M_{sk}	:	Energy loss from the respiratory system

N	:	Number of subjects
NV	:	Naturally ventilated
ONAB	:	Natioan office of buddhism
p	:	Statistically significant value
P	:	Pulmonary ventilation
P_a	:	Pressure of the ambient air (Pa)
PET	:	Physical equivalent temperatures (ºC)
PHLMS	:	Philadelphia mindfulness
PMV	:	Predicted mean vote
PPD	:	Predicted percentage of dissatisfaction (%)
Ps	:	Saturated vapour of skin pressure (Pa)
P_{sa}	:	Saturated vapour pressure (Pa)
P_{sk}	:	Pressure at skin (Pa)
R_a	:	Radiation (W/m^2)
R	:	Correlation coefficient
R^2	:	Coefficient of determination
R_{cl}	:	Heat transfer resistance of clothing from skin to the outer surface of clothing ($m^{2o}C/W$)
RCTs	:	Random control clinical trial
RH	:	Relative humidity (%)
$RH_{av\text{-}in}$	:	Indoor average relative humidity of three WBGT devices (%)
RH_{in}	:	30-minute average indoor relative humidity (%)
RH_{out}	:	Outdoor relative humidity (%)
RH_p	:	Relative humidity preference
SD	:	Semantic discrepancy (ºC)
SET	:	Standard effective temperature (ºC)
SI	:	The international system of units
SMQ	:	Southampton mindfulness questionnaire
SNS	:	Sympathetic nervous system
SP	:	Feeling sleepy while meditating
std	:	Standard deviation

STM	:	Short-term memory
T_a	:	Air temperature (ºC)
TAS	:	Tellegen absorption scale
T_c	:	Comfort temperature (ºC)
$T_{c\text{-}APV}$	:	Comfort temperature of actual thermal perception vote (ºC)
$T_{c\text{-}Bedford}$	:	Bedford's comfort temperature (ºC)
$T_{c\text{-}Griffith}$	:	Griffith's comfort temperature (ºC)
T_{cl}	:	Outside surface temperature of clothing (ºC)
TCS	:	Thermally comfortable sensation
TCV	:	Thermal comfort vote
T_{ex}	:	Exhaled air temperature (ºC)
T_g	:	Globe temperature (ºC)
$T_{g\text{-}av\text{-}in}$	:	Indoor average globe temperature of three WBGT devices (ºC)
TGBI	:	Thai green building institute
$T_{g\text{-}in}$	:	30-minute average indoor globe temperature (ºC)
$T_{g\text{-}out}$	:	Outdoor globe temperature (ºC)
T_i	:	Indoor globe or air temperature (ºC)
T_{in}	:	Inhaled air temperature (ºC)
T_{it}	:	Target indoor temperature (ºC)
TM	:	Transcendental meditation
$T_{monthly\text{-}av\text{-}out}$	:	Monthly mean outdoor dry bulb temperature (ºC)
TMS	:	Toronto mindfulness scale
T_n	:	Neutral temperature (ºC)
$T_{n\text{-}AC}$	:	Neutral temperature of the subjects with *ac* ventilation background (ºC)
$T_{n\text{-}ASHRAE}$	:	Neutral temperature of ASHARE adaptive model (ºC)
$T_{n\text{-}exp}$	:	Neutral temperature of the experienced subjects (ºC)
$T_{n\text{-}inexp}$	:	Neutral temperature of the inexperienced subjects (ºC)
$T_{n\text{-}NV}$	:	Neutral temperature of the subjects with *NV* ventilation background (ºC)

$T_{n\text{-}PMV}$	:	Predicted mean vote neutral temperature (ºC)
T_{oi}	:	Outdoor temperature index (ºC)
T_{op}	:	Operative temperature (ºC)
T_p	:	Preferred temperature (ºC)
T_r	:	Radiant temperature (ºC)
TREES	:	Thai's rating of energy and environmental sustainability
TREES-NC	:	Thai's rating of energy and environmental sustainability for new construction
T_{rm}	:	Weighted running mean outdoor temperature (ºC)
T_s	:	Skin temperature (ºC)
TSA	:	Thermal acceptability question
T_{sk}	:	Different temperature of skin (ºC)
T_U	:	Turbulence intensity (ºC)
T_w	:	Water temperature (ºC)
v	:	Airspeed (m/s)
v_p	:	Airspeed preference
WBGT	:	Wet bulb globe thermometer (ºC)
WBT	:	Wet bulb temperature (ºC)
W_{rsw}	:	Skin wettedness
ε	:	Average emittance of clothing
λ	:	Constants of latent heat of vapour evaporation at 35°C
μ	:	Efficiency of the work
σ	:	Stefan-Boltzman constant (W/m^2k^4)

Chapter 1

Introduction

Chapter 1: Introduction

This research investigates subjects' suitable indoor thermal environment and thermally adaptive solutions in naturally ventilated meditation buildings. This chapter briefly discusses the research background, describing research progress concerning human thermal comfort in terms of physiological and adaptive models. This short introduction reveals research gaps that lead to the formulation of three major research questions, with a series of sub-problems. The research aims and objectives are also stated and the scope of research and limitations are discussed. At the end of this section, the structure of the remainder of the thesis is presented.

1.1 Background of study

Human thermal comfort is determined by subjective evaluation of a current thermal environment (Humphreys & Nicol 2006; ASHRAE Standard-55:2010 2010). When humans perceive their environment to be amenable, including in terms of thermal comfort, this enhances productivity in workplaces, and improves health and wellbeing (Romana, Palella and Riccio 2011). Thermal comfort has been widely investigated in well-controlled laboratory settings and realistic dynamic environments based on two approaches: steady-state and adaptive models.

Controlled experiments normally examine respondents under given clothing and task conditions in carefully regulated environments. The derived results are developed and applied to assess optimum indoor thermal conditions for building users in air-conditioned (*AC*) spaces. This approach were influenced by the pioneering two-node model by Gagge (1936), and the comfort equation by Fanger (1970). Under these paradigms, Predicted Mean Vote (*PMV*) and Predicted Percentage of Dissatisfaction (*PPD*) were established and later included in *ISO* (International Organization for Standardization) and *ASHRAE* (American Society of Heating, Refrigeration, and Air-Conditioning Engineers) standards.

Building users in *AC* environments are assured of ideal thermal comfort indoors, created by a stable, standard, set point of indoor thermal condition, with highly efficient building envelopes to minimise infiltration rate and energy demand. As a consequence, users in such confined, air-tight spaces are severed from the outdoor environment (and the natural world) by highly insulating materials. Such a constant thermal comfort space obviates the traditional necessity for humans to be thermally adaptive. This convenient way of living incurs the operational cost of active cooling systems.

However, when considering the past generations before the debut of mechanical active-cooling systems, how could they maintain thermal comfort in wider ranges of thermal conditions, with fundamental adaptive techniques? Vernacular architecture worldwide demonstrates examples demonstrating building users' indigenous solutions to environmental and climatic conditions, allowing them to live with wellbeing while being sensitive to the sustainability of local contextual settings and resources. In this regard, the adaptive approach has attracted researchers' interest in the field, particularly concerning how to live in a wide range of thermal environments without *AC* systems.

This school of thought is mentioned in the '*Adaptive Model*', which introduces an inclusive concept in which human thermal comfort may also vary according to non-thermal factors ignored by the steady-state model. Research findings under the adaptive approach demonstrate possibilities to reduce the operation of the *AC* system operation by encouraging adaptive activities. Based on past research in this approach, it is confirmed that users' optimum thermal environment is not only expressed by a single temperature set point, but also as acceptable thermal ranges.

Many studies following this approach have been conducted in various types of buildings, such as educational (Khedari *et al.*, 2000; Yamtraipat Khedari and Hirunlabh 2005), residential (Jitkhajornwanich 2006; Rangsiraksa 2006; Nuntasiri and Rasisuttha 2015) and office buildings (Busch 1990). It is reported that neutral temperature (T_n) varies according to building types and locations, and types of space, such as indoor, semi-outdoor, and outdoor

(Jitkhajornwanich 1997). Humphreys (1978) conducted a meta-analysis based on data collected from users in offices and residential buildings and found that subjects' T_n in *AC* spaces was limited under a narrower range than that of those living in free-running (*FR*) buildings, where T_n varied considerably according to outdoor temperature.

Subsequently, an RP-884 final report (DeDear *et al.*, 1997) presented a meta-analysis based on a global database, collecting 21,000 datasets from users in 160 buildings equipped with *AC*, *FR*, and naturally ventilated (*NV*) systems. The analytical results of the report showed agreement with Humphreys (1978) on a shift in subjects' T_n in *FR* buildings, and confirmed a relationship between T_n and daily average effective temperature (*ET*). The report, moreover, concluded that the *PMV* and *PDD* methods were unsuitable for assessing the thermal environment for occupiers in *NV* buildings. Consequently, the adaptive model was introduced at the end of the report (DeDear *et al.*, 1997). Results of the report were officially recognized and included in the ASHRAE Standard-55 version 2004 (ASHRAE Standard-55:2004 2004), which became the foundation of thermal comfort in the adaptive approach, and which was subsequently updated in the 2010 version (ASHRAE Standard-55:2010 2010).

Apart from physical variables, the adaptive approach considers non-thermal factors excluded from the physiological model. Subjective aspects including situational and contextual factors are considered as mediators or mediums that can encourage or discourage thermal adaptation and affect human thermal perception, as mentioned in a conceptual model of human thermal assessment by Knez *et al.* (2009). An impact of such unquantifiable variables has been widely investigated and discussed (Nikolopoulou & Steemers 2003; Knez and Thorsson 2008; Knez *et al.*, 2009; Shooshtarian 2015). Nikolopoulou and Steemers (2003) proposed roles for six psychological factors: perceived control, expectations, past experience, environmental stimulation, time of exposure, and naturalness.

Furthermore, human thermal adaption itself can be categorised into three modes: behavioural, physiological, and psychological adjustments, all of which

can vary according to subjective human thermal feedback (Brager and DeDear 1998). Such evidence indicates the complexity of human expression of thermal satisfaction, and affirms that personal interpretation of thermal environment does not rely only on heat-exchanging phenomena between physiological and environmental factors, but also non-thermal and personal stimuli existing in the actual context.

It should be noted that the steady-state model is partially adjustable, since it claims some benefits from human adaptation in terms of physiological and behavioural factors such as *MET* (metabolic rate) and *CLO* (clothing insulation value), as seen in Fanger's comfort equation. The adaptive approach agrees on such adaptabilities, while highlighting the importance of the psychological influence on personal thermal evaluations, which are ignored by physiological analyses. In this case, the question of whether a thermally neutral sensation is perceived as comfortable is challenged. In basic psychology, sensation and perception are clearly described and differentiated: the former is a process of signal transmission between the environment and human organisms, while the latter is not only a physiological process but also relates to how the information is subjectively interpreted, based on an individual's psychological background (Schiffman 2001).

In thermal comfort study, a range of '*Hot*' to '*Cool*' sensations is included in the *ASHRAE* thermal sensation scale (ASHRAE Standard-55:2004 2004) for the investigation of subjects' T_n. Such a series of derived subjective states seems not to directly express the subjects' perceptions, such as thermal comfort, attitudes, or pleasance in the environments. However, the RP-884 report defines a thermally comfortable sensation as occurring in Bedford's thermal comfort range, varying within ±1 *ASV* (DeDear *et al.*, 1997), and a state of thermal neutrality according to the heat-balance model.

As mentioned earlier, thermal environmental evaluation is not solely based upon the physiological phenomena, but also an association with the psychological process of the interpretation of information. Based on such a description, in addition to physical variables affecting human senses and

subjective thermal vote in a thermal evaluating process, other non-thermal factors existing in the actual environment can also influence thermal perception.

The adaptive thermal comfort field of research is commonly conducted in actual environments of *FR* and *NV* buildings, where users' subjective thermal votes can be collected and thermally adaptive behaviour can be observed. However, such adaptive activities may be limited when studied in investigations of *AC* spaces. Active cooling systems preserve the environment in the comfortable state of the narrow range of thermal condition where subjects are less adaptive. Consequently, human thermal adaptation seems to allow users to be more resilient to thermal variations and is considered one of the essential solutions to potentially lower energy demand (Brager and DeDear 2001).

In Europe, the adaptive approach developed based on the Smart Controls and Thermal Comfort (*SCATs*) database is included in EN15251 (Nicol and Humphreys 2010). In China, Adaptive Predicted Mean Vote (*aPMV*) was created for Chinese building standards (Yao, Li and Liu 2009; Parsons 2014). Similarly, in Thailand, the Thai Green Building Institute (*TGBI*), which is a non-profit organization, was established in 2009 to set up a rating system for buildings in Thailand called the Thai Rating of Energy and Environmental Sustainability (*TREES*). Although the Thai standard was specifically established to serve local requirements, its application to local conditions and its practical use remains questionable.

Section six of the Thai standard discusses Indoor Environmental Quality, where human thermal comfort is conceptualised according to ASHRAE Standard-55:2004 (TGBI 2010). Although this American standard was established based on a large global database of field surveys, it refers only five case studies of Thai buildings, of which two and three of them applied mechanically cooling and naturally ventilated solutions, respectively (DeDear *et al.*, 1997; ASHRAE Standard-55:2004 2004). Thus, it can be seen that the local standard seems to rely primarily on partial findings of the ASHRAE meta-analysis, which may not truly reflect the actual local requirements. Furthermore, human expectations and uses of buildings may have changed, given that it is almost two decades

since the data upon which the ASHRAE Standard is based was collected. Thus, the suitability for applying the standard in this region is still questionable, and further investigation is required.

Apart from the unsolved question regarding the applicability of the local thermal comfort standards, the literature review undertaken in this thesis reveals that the main focus of the adaptive thermal comfort study was on residential, educational, factory, and office buildings. However, it seems that religious buildings received a little attention, even though they are required to accommodate a large number of occupants for extended periods. Furthermore, religious buildings are usually linked to strong cultural and religious beliefs which might affect human adaptive behaviour and subjective interpretations of current stimuli in thermal environments.

In Buddhism, various forms of meditation are the core of Buddhist spiritual practice, emulating the route by which the Buddha achieved enlightenment (Gunaratana 1988). Buddhists consider meditation to be a path toward release from the cycle of suffering that comprises un-enlightened human existence. Meditation was originally the preserve of mendicants and ascetics, but soon became a universal and popular activity among the Buddhist masses (Cook 2010). Buildings specially designed for meditation by ordinary people are a new function in Buddhist architecture, with no precedent in scripture or classical Buddhist texts. However, nowadays, such buildings are widely constructed in Thailand and are commonly found in Buddhist monastery compounds. Such areas are considered holy spaces, designed according to Buddhist cosmology, which strongly relates to some syncretic Thai religious beliefs in both Brahmanism and Buddhism (Khanjanusthiti 1996). In this case, the cultural and organisational conditions of religious places seem to influence the local people's behaviour, and cause them to pay extra respect to the places and to the monks who provide and maintain them.

Although Buddhist meditation is fundamentally a religious activity of practicing Buddhists, it was popularised in the West as a lifestyle hobby since the 1950s (contemporaneous with the related Hindu-Buddhist phenomenon of yoga), and

it is currently widely known as mindfulness cultivation. The effects of this activity attracted the attention of psychotherapists, and in the 1960s it was widely investigated and was proposed as a solution for psychological interventions in mental healthcare, particularly to reduce stress (and thus to help treat numerous biomedical conditions associated with stress, such as coronary heart disease (Paul-Labrador et al. 2006)). Since then, a series of meditation-related research has been continuously published (*Keng et al.*, 2011).

Despite their enthusiastic adoption of the outward forms and supposed clothing of meditation, and even chanting mantras, Westerners omitted the religious philosophy associated with the rite, and they modified and developed some techniques for their own purposes (Shapiro *et al.*, 2002). Consequently, 'mindfulness activity' can now be regarded as a semi-independent field of study, and its experts argue that mindfulness can be cultivated to effect changes in the body and mind of practitioners. Regarding physiology, mindfulness practice can lower blood pressure and heart rate, and raise skin resistance (Akishege 1968; Fennell *et al*., 2016), and it can result in an improvement of mental qualities such as happiness, self-assurance, life satisfaction, and emotional flexibility (Beck 1967; Beck *et al*., 1979; Shapiro *et al.*, 2002; Keng *et al.*, 2011). Given its diverse and multi-faceted impacts on physiology and physical and mental health, the question arises of whether it can also affect subjects' thermal perception.

In terms of the research impact, religious buildings have not attracted researchers' interest, despite the important implications for users' wellbeing. In Thailand, where Buddhism is the national religion, 40,736 Buddhist monasteries exist nationwide (National Statistic Office 2017). According to Cook (2010), approximately 33,000 monasteries regularly organise meditation activities open to the public, and 1,001 meditation centres are officially registered with the National Office of Buddhism (2009). Meditation sessions organised by monasteries are usually open to the public. Some of them also provide free accommodation and food for participants, while some other private organisations run sessions which may incur some admission fees. The

meditation buildings are required to accommodate approximately 15 to over 150 people for long periods, with each training session lasting for 30 to 180 minutes. In this case, this extended thermal exposure may affect a large number of users indoors, and therefore field surveys of adaptive thermal comfort should be conducted to explore users' optimum thermal conditions including thermal adaptions.

1.2 Research gap

This research aims to fulfil a discrepancy in adaptive thermal comfort research by contributing a field survey of human adaptive thermal comfort in an area where no research has been yet conducted. As discussed in the previous section, thermal comfort in the adaptive approach has been widely conducted in three main areas: commercial, educational, and residential buildings. Negligible attention has been given to field research of human thermal comfort in religious buildings. This research selects meditation buildings as a location of study, since an extended period of thermal exposure in their spaces may affect users' wellbeing and practice qualities.

Buildings under intensively cultural and organisational influences may psychologically affect users' behaviour in their routine personal and environmental interactions. This indicates an opportunity to reveal alternative adaptive solutions which may not be discovered or employed by people in other types of space. Moreover, this research aims to fulfils the gap regarding the local Thai thermal comfort standard, since the current manual of the Thai building rating system directly adopts the thermal comfort standard of the ASHRAE Standard-55:2004 (2004) without amendment or consideration of local characteristics. Therefore, the suitability of the applied standard is still questionable in terms of if it truly reflects local needs. Thus, field-based research of human adaptive thermal comfort in religious buildings is necessary and useful, especially for *NV* meditation halls in Thailand.

1.3 Research hypothesis

The previous section highlighted the research gap addressed by the current inquiry, therefore this field research of human adaptive thermal comfort was conducted in three *NV* meditation buildings in the hot and humid climate of Thailand, in the context of intensive cultural and organisational influences from the prevailing Buddhist culture. With consideration of the benefits of meditative practices on practitioners according to previous studies, and the influential factors on human thermal comfort (both steady-state and adaptive approaches), certain physiological and psychological aspects are studied with regard to the context of human thermal perception during meditation practices. Figure 1 describes the formulation of the research hypothesis.

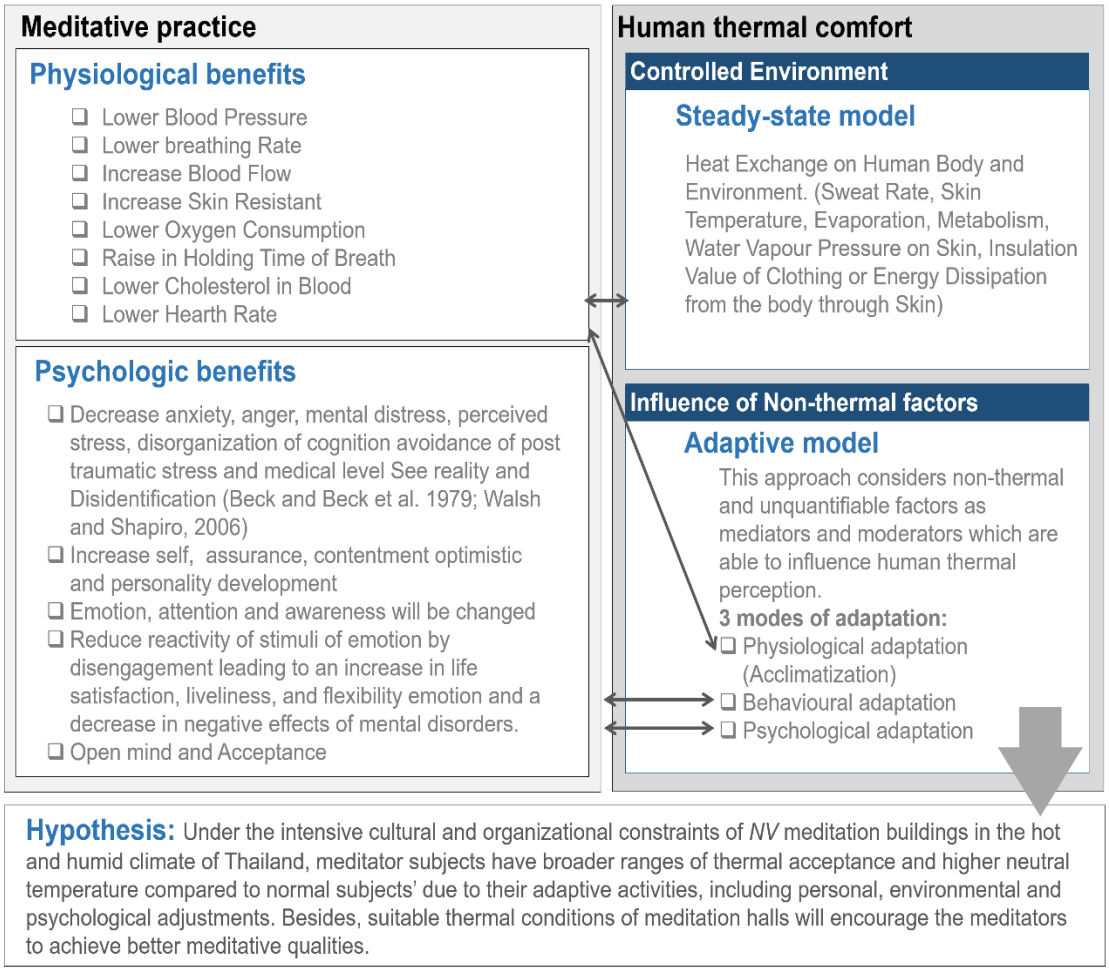


Figure 1: Summary of hypothesis formulation of this thesis

Therefore, the overarching hypothesis of this research is formulated as:

'Under the intensive cultural and organisational constraints of NV meditation buildings in the hot and humid climate of Thailand, meditator subjects have broader ranges of thermal acceptance and higher neutral temperature compared to normal subjects due to their adaptive activities. Besides, suitable thermal conditions of meditation halls will promote meditation activities which allow the meditators to achieve better meditative qualities.'

1.4 Research questions

Based on the formulated research hypothesis, three research questions mentioned in this section are set as follows;

1st major question: the set of questions aims to inquire about what suitable thermal environments for the subjects in meditation halls. Under this major problem, a series of sub-questions are listed as follows;

1.1. Can the steady-state model precisely predict subjects' thermal sensation in *NV* meditation buildings?
1.2. What are suitable thermal conditions for subjects in meditation buildings?
1.3. What is an adaptive equation and model for this building type? Compared with the ASHRAE adaptive model, to what extent do international standards reflect local needs?

2nd major question: does T_n provide the most thermally comfortable perception for the meditator subjects? In thermal comfort study, *ASHRAE* thermal sensation scale has been widely used to explore (T_n). However, the results obtained by this method are questionable in terms of whether the thermally neutral state provides the most thermal comfort for subjects. Therefore, the major set of the second problem inquires whether T_n provides the most thermally comfortable perception for the meditator subjects. Under this problem, the following sub-questions arise:

2.1. What thermal states may the subjects experience as thermally comfortable, and do the subjects perceive the T_n to be comfortable?

2.2. Does a shift of thermal environment relate to meditative qualities, and in which thermal condition can subjects achieve better meditative experiences?

3rd major question: thermal comfort in adaptive approach demonstrates that adaptive activities can extend acceptable thermal ranges. Thus, the suitable thermal conditions should not be proposed without discussing what subjects' adaptive solutions performed in the halls. Sub-questions related to this major problem are as follows:

3.1. What are the subjects' thermally adaptive actions performed in the halls and what are the subjects' three most-performed adaptations in different sequences of actions found in the meditation halls?

3.2. What are the subjects' most performed mode of adaptation in the first-three sequence actions while staying in meditation halls?

3.3. Regarding psychological adaptation, do different ventilation profiles result in a variety of subjects' thermal sensitivity and T_n outcomes?

3.4. What are relationships amongst environmental variables and environmental controls available in the halls?

1.5 Research aims

Research aims correspond to the three major research questions adumbrated in the previous section.

- **The first aim:** the first aim is to explore suitable thermal condition for the subjects in the meditation halls. Before presenting the data and the results, past relevant studies will be reviewed and discussed. The review includes lab-based and field-based studies of human thermal comfort, benefits of meditations on body and mind, and a description of the fundamentals Theravada meditation. The steady-state model, *PMV*, will be examined for its suitability for local applications by correlating it with

ASV results. Besides, T_n derived from *PMV* method ($T_{n\text{-}PMV}$) will be explored and compared with T_n based on the actual votes.

In terms of an exploration of the suitable thermal environment, subjective thermal terms, such as neutral temperature (T_n), preferred temperature (T_p), acceptable thermal ranges and Bedford's comfortable range ($T_{c\text{-}Bedford}$) are investigated and explored. T_n is analysed using four different analytical methods: *PMV*, bin method, linear regressions, and Probit analysis. Sematic discrepancy (*SD*) as mentioned in the RP-884 report is also explored. The adaptive equation and adaptive model are established and compared with those suggested by the ASHRAE Standard 55:2004. The results are presented as tables, graphs, and regression models. Finally, the analytical and comparative results are discussed before a conclusion is drawn.

- **The second aim:** this report differentiates thermal sensation and perception by comparing the data of the subjects' *ASV* and *APV* (Actual Thermal Perception Vote). This research creates an *APV* scale to test participants' thermal attitudes toward the current environment. The obtained results are examined to determine if such perceptions vary according to the thermal environment, to explore the subjects' most Comfortable Temperature ($T_{c\text{-}APV}$) and its range. Besides, thermal perception and sensation votes are compared in order to investigate the Comfortable Thermal Sensation (*CTS*). Finally, the derived subjective thermal terms ($T_{n\text{-}PMV}$, T_n, T_p, $T_{c\text{-}Bedford}$, $T_{c\text{-}APV}$) and 80% and 90% acceptable ranges of T_n are compared. Difficulty in Relaxation (*DR*) and Impaired Instruction-Following Ability (*IFA*) are correlated with T_{op} to examine relationships between subjects' meditation qualities and indoor environmental factors. The meditative qualities at $T_{c\text{-}APV}$ and T_n conditions are compared to reveal the thermal state in which the participants may experience better quality activities.

- **The third aim:** the thermal adaptations subjects are expected to perform and that they do perform are surveyed and observed. Three sequences of subjects' adaptive actions and the most performed solutions of each sequence are identified and reported. Furthermore, the subjects' internal driving force in environmental adaptation is investigated by an airspeed preference (v_p) scale. The obtained data is correlated with indoor *DBT* and *v* to explore the most relevant factor to a shift in the v_p proportion. Furthermore, operations of the environmental controls are observed, evaluated, and correlated with environmental factors to discover the strongest relations between the factors. The correlation results are summarized and presented in tables and diagrams.

1.6 Research objectives

The main research objective is to conduct an adaptive thermal comfort field study in Buddhist meditation buildings.

The first objective: To explore the most suitable thermal state for the building users and their thermal adaptive actions in *NV* meditation buildings. The following sub-objectives arise from this are:

- To critically review literature on relevant aspects regarding steady-state model theory and practice and adaptive thermal comfort, including discussions of fundamental Theravada meditation techniques and meditation research.
- To develop a survey method for thermal comfort study in a large-shared space of *NV* meditation halls with a number of subjects.
- To investigate the applicability of the steady-state model by comparing the predictive results of *PMV* with the subjects' thermal sensation votes.
- To explore the subjects' subjective thermal states based on adaptive thermal comfort approach such as preferred and comfortable temperatures.
- To establish an adaptive equation and adaptive model for the users in meditation buildings in Thailand.

- To compare the current adaptive model with the ASHRAE Standard 55: 2004 to investigate the extent to which this international model reflects actual local requirements in Thailand.

The second objective: To investigate if the thermally neutral state, as mentioned in the conventional studies of human thermal comfort, can provide the subjects for thermally comfortable perception. Based on this, there are sub-objectives as follows;

- To differentiate and compare two subjective thermal terms: thermal perception and thermal sensation. These two psychological terms in practice were applied synonymously in the research field.
- To examine if the neutral state of thermal sensation is perceived as thermal comfort, and to explore the most thermally comfortable sensation for volunteers.
- To explore thermal sensations, in which the subjects may perceive thermal comfort, and the most comfortable temperature for the subjects.
- To analyse relationships between variations of indoor thermal conditions and meditative qualities.
- To compare thermal subjective states derived from the previous analyses with a shift of meditative qualities and to investigate the most suitable thermal state for *NV* meditation buildings.

The third objective: To explore human thermal subjective technique performed in *NV* meditation halls. Sub-objectives of this final objective are listed below;

- To investigate what thermal adaptations and the most voted mode of adaptation volunteers commonly perform in existing meditation halls.
- To analyse if different ventilation profiles and meditation experiences influence the subjects' thermal sensitivity and thermal neutrality.
- To inspect relationships between the percentages of environmental control operations (windows and fans) and indoor and outdoor environmental factors and to explore the most influential factors on the functions of the environmental controls in *NV* meditation halls.

1.7 Research scope and limitations

According to the literature review of both online sources and hard copies, as presented in Chapters 3 and 4, no evidence of a field survey of human thermal comfort in meditation buildings has been found. This thesis collected and analysed relevant information regarding research methodologies and results before designing the research method and conducting the surveys. It should be noted that this research planned to refer and apply survey methods as published in past studies so that the derived results are comparable. However, some aspects may not be directly adopted, while some of them required some amendments due to research limitations. Thus, it is necessary to discuss the scopes and limitations of this study.

1.7.1 Research scope

- Unlike climate chamber studies, this field-based research focuses only on an investigation of subjects' subjective thermal states under the complexity of the actual real-life factors of *NV* meditation halls, where thermal environments and personal factors vary uncontrollably and unpredictably.
- This study focusses on users' behavioural and psychological adaptation, while physiological adaptation is excluded.
- Four main groups of meditation building users are un-ordained meditators, monks, instructors, and staff members. This study focuses only on the un-ordained meditators who comprise the majority of the users of the meditation halls.
- Regarding the area of survey, the meditation buildings comprise different functions, such as office, kitchen, storage, lecture room, common area, *WC* and accommodation facilities. This research limits the studied area only to the meditation halls.

1.7.2 Limitations of the research

- Based on the survey, the subjective thermal votes and the personal data were mainly contributed by actual female building users with various

demographic characteristics and backgrounds. In this case, it is noted that the male users are a minority group of the subjects in this study.

- This research did not measure the metabolic rate (*MET*) of each subject, assuming it as a constant factor. Thus, subjects' *MET* in the *PMV* calculation was assumed to be equal at 1.00 based on sedentary activities, as mentioned in ASHRAE Standard-55:2004 (2004).
- For a case study selection, it should be noted that there are a number of meditation centres in the country that vary in their style of practice, size of meditation halls, expected number of participants, and dates and plans of practice over the years. Case study selections were conducted based on criteria discussed in Chapter 5. Finally, only three consenting places were selected as case studies.
- Environmental measurement methods as suggested by ASHRAE Standard-55:2004 (2004) were used. However, this suggestion seems unsuitable to be applied in the large and sharing space of the meditation halls where indoor environmental factors varies unpredictably. Although this research considers such conditions, this might not wholly address all those challenges due to time constraints and limitations in the number of measuring instruments and assistants. Thus, the methods of the questionnaire survey and environmental measurement were designed and developed to better suit the research context, as mentioned in Chapter 5.
- The author is gracefully supported by the Dean of Engineering Scholarship for International Excellence of the University of Nottingham, which subsidises the tuition fee from 2015 - 2018. However, all expenses involving with research activities such as purchasing, calibrating measuring instruments and hiring research assistants are the author's responsibility. This financial condition becomes one of the research constraints, which significantly shapes the research method of this field survey.
- The environmental measuring method of ASHRAE Standard-55:2004 (2004) was considered. It is recommended to collect environmental data

as soon as possible after each subjective vote. However, due to a limitation of survey time, a large number of subjects, and a small number of measuring instruments, the survey and measuring methods need to be slightly amended. Thus, 30-minute average environmental data over the questionnaire-answering sessions was employed.

- It should be noted that *DBT*, *RH*, and T_g were measured at three locations in the halls, while there is only one location for *v* measurement. The details of the measuring method are further described in Chapter 5.

1.8 Thesis structure

This thesis consists of 11 major chapters, including those dealing with the introduction, literature review, research methodology, results, discussion, and conclusion, as briefly outlined below.

Chapter 1: Introduction

This chapter introduces readers to the background of the study, summarising general research concerning the steady-state model and the adaptive approach to identify the research gap addressed by this thesis. Relevant aspects of meditation, such as fundamental techniques of practice, benefits of meditative training, and physiological and psychological implications are reviewed. The research questions are presented to define the aims and objectives of this research. The research scope and limitations are discussed, prior to this outline.

Chapter 2: Physiological model of thermal comfort

This chapter discusses theories of human thermal comfort investigation in the steady-state model. An overview of human thermal comfort investigation is described, with a brief description of the human body and thermoregulatory systems. Moreover, the pioneering physiological works in this field are analysed, including Gagge's two-node model (Gagge 1936) and Fanger's comfort equation (Fanger 1970). These theories provide the foundation for the well-known physiological models examined in this thesis, *PMV* and *PDD*. Besides, subjective thermal assessment methods are reviewed and discussed.

Chapter 3: Adaptive thermal comfort

This chapter focuses mainly on the other perspective of human thermal comfort known as the adaptive thermal comfort, elaborating on why the physiological model cannot precisely predict thermal sensation in *FR* and *NV* buildings. Different aspects of the adaptive model are reviewed to establish readers' background on this approach and the stance of this research. Besides, it should be mentioned that the adaptive model was officially integrated into the ASHRAE Standard-55:2004 (2004) based on the RP-884 database.

This chapter summarises the analytical methods of the RP-884 final report and describes subjective thermal terms such as neutral temperature (T_n), preferred temperature (T_p) acceptable ranges, and semantic discrepancy (*SD*), as operationalised in the report. The report suggests evaluating methods for assessing suitable thermal environments for *AC* and *NV* buildings. Apart from the aspects discussed above, the relevant theory of the adaptive model is described, such as modes of adaptation. Fundamental psychological aspects referred to in adaptive thermal comfort studies, such as sensation and perception, short-term and long-term memories, schemata, and past experience are described and discussed. Before concluding the chapter, a literature review of Thai human thermal comfort related to the adaptive model is presented.

Chapter 4: Meditation studies

Apart from human thermal comfort theories, relevant meditation aspects are reviewed in this chapter. Broad definitions of meditation are discussed, which might vary according to different practice styles. Although meditation originated in Hindu-Buddhist traditions, such mind-practising activities have become a palpable phenomenon in Western communities and are applied in modern biomedical interventions and holistic therapies. However, the perspectives of average Westerners and Easterners toward meditative practices are rather different. In this chapter, Western points of view on meditation based on research such as the benefits of meditation on mind and body are discussed. Meditation depths and self-evaluating questions are briefly described, since

some of them are referred, developed, and applied in this research. Furthermore, Buddhism's fundamental technique of meditation practice and Buddhism monastery planning in Thailand are described. At the end of the chapter, positive psychology based on the principles of Buddhism are discussed, before concluding the chapter.

Chapter 5: Research methodology

This chapter describes the research methods applied in a pilot study and the main surveys. The first section of the chapter presents a design workflow of the research, from defining the research problem to the writing-up stage. Moreover, it describes the site selecting method, including explaining the physical information of these meditation halls, monastic surroundings, and training schedules. Furthermore, research ethics approval and acquisition of environmental, personal, and psychological data are explained. Besides, survey methods applied in the pilot study and main surveys, including the calculating and analytical methods employed in the analysis, are described.

Chapter 6: Results of the pilot study

This pilot study was conducted to examine the initial research method and instruments. The results and the difficulties found during the survey were considered and utilised in developing the final main surveys. The questionnaire survey method of this pre-test was amended on-site due to unexpected circumstances that arose on the survey day. Such difficulties and solutions to the problems are described in this chapter. A number of the subjective votes, thermal environmental measurements, behavioural observations, and thermal adaptations are presented and analysed.

Chapter 7: Summary of environmental, demographic, and subjective vote data

This chapter discusses fundamental information of the database of the main survey to allow readers to understand an overall picture of the environmental condition of meditation halls and subjects. The results presented in this chapter cover primary and secondary data collected from 2015 to 2017. A summary of

demographic data, such as subjects' age range, education level, experience of meditation, place of residence and indoor and outdoor thermal environments is presented. All data pertaining to subjective votes, such as *ASV*, *APV*, T_p or meditative qualities used in subsequent analysis are summarised and reported.

Chapter 8: Users' subjective thermal states and adaptive equation

Chapters 8, 9, and 10 present the results of the main survey which comprises the main contribution of this thesis. Chapter 8 explores the subjects' suitable thermal conditions based on data exhibited in the previous chapter. Different analytical methods of thermal comfort analysis are harnessed to investigate participants' suitable thermal conditions, such as *PMV*, thermal acceptability, T_n, T_p, and *SD*. Furthermore, an adaptive equation developed in this research is created and overlaid on that of the ASHRAE Standard-55:2004 (2004), to investigate the differences between the models.

Chapter 9: Users' thermal comfort sensation, and relationships between meditative qualities and indoor environmental factors

The subjective thermal terms discussed in the previous chapter reveal a different condition between thermal neutrality and the preferred thermal environment for meditative practice. However, T_n derived by *ASV* investigation is questioned if the subjects perceive thermal comfort in such a neutral state. This study created an actual perception vote (*APV*) scale to analyse users' comfort temperature ($T_{c\text{-}APV}$). The *APV* samples were also correlated with these of the *ASV* for exploring thermally comfortable sensation (*TCS*). Besides, all the derived subjective thermal terms such as T_n, T_p, T_c, acceptable thermal ranges, and T_c range are compared and discussed in this chapter to reveal differences between each state. This study lead to a suggested modification of the acceptable thermal ranges to reflect the need of the meditation building users. Moreover, relationships between meditation qualities and T_{op} are analysed.

Chapter 10: Thermally adaptive solutions of the meditators

This chapter focuses on thermally adaptive actions performed by the subjects in the meditation halls. The analytical results are presented by the methods of

data collection (questionnaire survey and observation). The results obtained from the former solution mainly concern subjects' thermal adaptive solutions in meditation halls. For the observation results, the main aim of this chapter is to investigate the relations between environmental controls and environmental factors. Twelve relationships between the environmental control operations and six environmental factors are analysed and presented as a table and diagram before concluding the chapter.

Chapter 11: Thesis conclusion

This is the last chapter of the thesis, summarising all the chapters discussed above. All the findings are concluded by addressing the research questions, as stated in the first chapter, based on the derived results. At the end of the chapter, suggestions for the local standard on thermal comfort in meditation buildings and for further field surveys of the adaptive thermal comfort in meditation halls are provided.

Chapter 2

Physiological Model of Thermal Comfort

Chapter 2: Physiological Model of Thermal Comfort

The importance of thermal comfort is recognised and it has been continuously researched. Two approaches were established: physiological and adaptive models. The former solution was established based on lab-based results derived where environmental and subject's personal variables were carefully controlled. This solution has gained acceptance in the field and included in ASHRAE and ISO standards for evaluating indoor thermal environments for users in *AC* spaces. This chapter focuses on thermal comfort in steady-state, based on a heat-changing effect involving physiological and environmental factors. Moreover, basic human thermoregulatory mechanisms and two models of major steady-steady state (two node models and thermal comfort equation) are described. At the end of this chapter, psychological assessment of thermal comfort study is discussed and subjective thermal scales employed in previous research are critically reviewed, before concluding the chapter.

2.1 Homeostasis by thermoregulation

Homeostasis, which is a fundamental condition for living organisms, combines the Greek terms 'homeo' and 'stasis', meaning 'similar' and 'stable' (respectively). Homeostasis regulation is a physiological regulation based on processes of osmoregulation, thermoregulation and chemical regulation to equilibrate cell and body conditions according to internal and external stimuli (Palaparthi 2017).

The activity of cells is controlled by a hormone regulated by stimuli before being discharged into the blood system. The physiological reaction to the hormonal inducement affects the internal balance of the body and results in a new stimulus. These subsequent internal actions comprise a self-altering system known as feedback regulation, comprising positive and negative channels.

- **Positive feedback** accelerates the physiological function in the same direction as the stimuli. For example, the lactation rate during breastfeeding stimulates the mammary gland and causes the prolactin-discharging process regulated by the pituitary gland. The discharging rate of the hormone varies proportionally according to the amount of milk loss.
- **Negative feedback** is a reverse reaction of the aforementioned mechanism, which is a crucial equilibrating process for endotherms to equilibrate internal conditions by osmoregulation, chemical regulation, and thermoregulation.

Osmoregulation is the maintenance of water in the body relating to biochemical processes occurring when the concentrations of the extracellular (e.g. blood plasma in a human organism) and intracellular fluids are different, causing osmosis and diffusion whereby water passes through the extracellular surface. Chemical regulation relates to the maintenance of chemical substances in the body. For instance, blood glucose regulation involves the negative feedback process. The concentration of the glucose increases after food intake, resulting in the generation of insulin by the pancreas to accelerate the process of glucose delivery to the selected tissues. When the concentration of the glucose in blood drops, this lowers the initial stimulus, which subsequently decreases the release of insulin. However, this research is not concerned with comprehensive biochemical mechanisms, rather it is focused on the heat-regulating system of the human body, called thermoregulation.

This section describes the thermoregulation mechanism that is activated when the body temperature deviates from the suitable setpoint, which in extremes can result in hypothermia or hyperpyrexia situations, as discussed later in this chapter. Thermoregulation is regulated by a hormonal activity from the hypothalamus, a small region of the brain. In addition to relating the internal physiological activities of the organism, thermoregulation also affects human behaviour, such as variations of activity intensity and posture, affecting the body surface area (among other outcomes).

2.2 Overview of human thermal comfort studies

Human thermal comfort is an individual, subjective, and physiological evaluation of the perceived experience of the thermal environment (Brager and DeDear 1998; Humphreys and Nicol 2006; ASHRAE Standard-55:2010 2010). It is acknowledged that indoor thermal conditions influence human well-being, and building designers have always considered thermal comfort to be a fundamental consideration; indeed, the original purpose of human structures is to protect people from the elements, particularly temperature. The number of human thermal comfort studies has been gradually increasing, as reported by Rupp *et al.* (2015). The literature search in this study involved searching for terms related to human thermal comfort using online search engines and academic publishers' websites, including Google Scholar, Web of Science, Scopus, and Science Direct. The search was conducted in 2015, and revealed an increasing number of published researches in this field. Google Scholar yielded more than 59,000 potentially relevant publications. There are two major approaches in thermal comfort study: steady-state and adaptive approaches.

The steady-state model mentioned in '*Thermal Comfort: Analysis and Applications in Environmental Engineering*' by Fanger (1970) was the most cited paper, with 4,690 citations (Rupp *et al.* 2015). This study focuses on a body heat balance study, which led to the establishment of the well-known *Predicted Mean Voted* (*PMV*) and *Predicted Percentage of Dissatisfied* (*PPD*) methods. Investigations of indoor thermal comfort states continue to be profoundly influenced by Fanger's physiological model. This method has gained international acceptance, and was included in the American and European standards as a predictive method for assessing users' thermal satisfaction in *AC* spaces.

The second approach is an adaptive model developed for *NV* or *FR* buildings. This evaluation method was developed based on the perspective in which building users are active recipients who can restore their comfort level when they perceive dissatisfying thermal stimuli. This approach demonstrates that the users' thermal comfort state or thermal neutrality in *FR* and *NV* buildings are

variable, and can be expressed as a relationship between T_n and outdoor environmental factors. Adaptive thermal comfort is considered an essential energy-saving solution. This approach has been officially integrated into the ASHRAE-standard 55 in 2004 and CEN EN 15251 in 2007. A key difference between the steady-state and adaptive models is that the latter approach considers the full-thermal adaptability of the users, while it is partially considered by the former method.

2.3 Human body and thermoregulatory systems

Before discussing the steady-state model focusing on a physiological process of heat exchange to the environment, the human body's thermoregulatory systems should be mentioned. The heat balance of human body describes a relationship between two different nodes, the core and the body surface or skin. The core of the human body produces heat energy from consumed food, and the skin (subsequent to internal metabolic processes) helps regulate temperature, by opening pores and enabling sweating when the body is too hot, or contracting pores to conserve heat when the body is cold. The human organism undergoes fluctuating temperatures throughout the day as part of normal metabolic processes (e.g. it is colder during sleep when the body is less active), but generally the body core temperature is maintained at 37.2°C, which is hotter than the ambient temperature in most cases. As the heat-exchanging intermediary between the core and the thermal surroundings, the skin temperature is cooler than the former and hotter than the latter, typically ranging from 31°C to 34°C in a thermally comfortable state (Auliciems and Szokolay 2007). The heat of body core can be raised by increasing metabolic rate (*MET*), which varies mainly according to activities.

The human body regulates its heat to maintain optimum core temperature; consequently, the skin, which senses ambient temperature, is a secondary priority for the body's thermoregulation, and it may feel cold or hot as a result of its activities relative to the core and external temperature, which ultimately determines the comfort of the person. To take a universal example, if the core is hot, the body will attempt to cool down by opening the pores and releasing

sweat, thus the person will latently feel hot, but will begin to feel cool, and may be more comfortable with air conditioning or fans to accelerate the body's cooling process. If the ambient temperature suddenly becomes significantly colder (e.g. due to a sudden wind or downpour), the person will consequently feel cold and the body will stop sweating and close the pores, but residual sweat on the skin may cause a chill.

More specifically, Nicol *et al.* (2012) referred to the heat-discharging phenomenon called 'vasodilation', whereby excessive heat accumulated in the body is emitted via numerous physiological processes involving the expansion of the veins and the increase of blood flow to peripheral (i.e. skin) tissues. The blood flow system is given a fillip by the body increasing blood supply around the skin surface, expanding blood vessels to increase heat loss to environment via the body surface, causing a higher skin temperature as the heat is transferred from internal (core) tissues to the surrounding environment. This is associated with the evaporative effect of sweat from the skin. While the human body can generally cope with normal parameters of heat discharge, if the core temperature is raised by 4 K, the body is at risk of hyperpyrexia.

In contrast, human body reacts differently when core temperature is lower than the threshold temperature (37.2°C). The converse of vasodilation occurs in such circumstances, known as vasoconstriction, which minimises heat loss by restricting the blood circulation, resulting in a drop in skin temperature. Moreover, the body will shiver and muscle tension will increase to elevate *MET*. If the core loses 2.5 K heat, it might be exposed to hypothermia. The energy-exchanging method between the body and its surroundings comprise the human physiological process to maintain body core temperature at 37.2°C, for optimum metabolic functions, health, and comfort (Fabbri 2015).

2.4 Principles of heat exchange in the human body

It should be noted that this research is not conducted under the physiological model, but adaptive approach. Thus, the data of physiological variables such as skin temperature (T_s), skin pressure, or evaporative heat loss in the human

respiratory system are not collected and discussed in the analyses. However, the steady-state model and its factors are important since they are considered a foundation of thermal comfort study. Therefore, it is necessary to mention two pioneering works in this regard: the two-node model by Gagge (1936) and the steady-state model by Fanger (1970), which are considered fundamental theories of human thermal comfort. These principles elaborate the phenomenon of heat transfer between human body and environment, and thermal comfort indices, which are further discussed in this section.

2.4.1 Two-node model by Gagge (1936)

Pharo Gagge (1936), a scientist working for the JB Pierce Laboratory, published the article '*the linearity of criterion as applied to partitional calorimetry*' presenting a sum of the heat balance of human body (ΔS) called the '*two-node model*'. The model expresses the relationship of body heat exchange to the environment. The body core automatically and continuously produces heat in the forms arising from basal metabolism and muscular metabolism. The body's skin operates as a transmittal medium for transferring heat to the surroundings via heat-exchanging phenomena involving radiative, conductive, evaporative, and convective processes. The five most influential factors in the energy transfer of the human body are Metabolism (M), Net Radiation (R_a), Convection (C_v), Conduction (C_d), and Evaporation (E), as shown in Eqn 1 below. It should be noted here that the unit of M in calculation is converted into Watts, as calculated by the function, M = 58.18 *MET*, where *MET* is metabolic rate. However, the C_d in the equation was ignored, since the effect of heat transfer by this factor is insignificant, due to insulation of clothing. Thus, based on this concept, the two-node model can be expressed as shown in Eqn 2.

$$M \pm R_a \pm C_v \pm C_d - E = \Delta S \qquad \textit{Eqn 1}$$

$$M \pm R_a \pm C_v - E = \Delta S \qquad \textit{Eqn 2}$$

The human body generates energy from the core for use in biological processes and muscular activity, while the rest is dissipated through the skin as heat. The

energy transforming to work is efficient and can be considered as shown in Eqn 3, in which η is the efficiency of the work.

$$\eta = \frac{Work}{M} \qquad \textit{Eqn 3}$$

Thus, energy released from the activity can be expressed as in Eqn 4:

$$M(1-\eta) \qquad \textit{Eqn 4}$$

That is the energy dissipated from the core and spread through the body surface (A_{du}), known as a DuBois's body surface, calculated by Eqn 5. This is possible energy that the body exchanges with the environment per square meter.

$$\frac{M(1-\eta)}{A_{du}} \qquad \textit{Eqn 5}$$

Eqn 2 presents the heat balance of human body, which involves *M*, *R*, C_v and *E*. *E*, which is the evaporative heat loss can be categorised into three major channels through respiration loss, evaporation of skin sweat, and vapour diffusion of the skin.

There are two losses via respiratory system, evaporative heat loss (E_{resp}) and convective heat loss (C_{resp}). The former process (E_{resp}) relates to evaporation caused by a pressure difference between the lung (5.87pa at 35°C) and the surroundings, as presented in Eqn 6 below. C_{resp} represents an energy exchange due to a temperature difference between the exhaled air (approximately 34°C) and the environment (T_a), as expressed in Eqn 7.

$$E_{resp} = 0.0173\, M\, (5.87 - p_a) \qquad \textit{Eqn 6}$$

$$C_{resp} = 0.0014\, M\, (34 - T_a) \qquad \textit{Eqn 7}$$

Thus, the total heat lost by the respiratory system (M_{sk}) is the heat generated from the body's activity deduced by the heat losses via the C_{resp} and E_{resp}, as described in Eqn 8:

$$M_{sk} = M(1 - \eta) - \ (0.0173M(5.87 - p_a)) - (0.0014M(34 - T_a)) \qquad \textit{Eqn 8}$$

However, the skin is the other heat-exchanging medium in which the heat is dissipated by latent-heat and sensible-heat losses. The latter phenomenon is caused by the effect of R_a and C_v; Eqn 9 shows a relation of different temperature of skin (T_{sk}) and the ambient air (T_a), clothing efficiency factor or dry heat exchange via clothing (F_{cl}), and h which is a result of combination of radiation conductance (h_r) and convective conductance (h_c).

$$R_a + C_v = h(T_{sk} - T_a)F_{cl} \qquad \textit{Eqn 9}$$

Where F_{cl} can be calculated by the Eqn 10 below. This is a sensible heat loss on human skin where *CLO* is a unit of clothing insulation value, while h is the combined effects of radiation (h_r) and convection (h_c) conductance.

$$F_{cl} = \frac{1}{1 + 0.155 \times h \times clo} \qquad \textit{Eqn 10}$$

The skin also exchanges energy via a latent heat loss by vapour diffusion (E_{diff}) and evaporation of skin sweat (E_{rsw}). The E_{rsw} is a function of skin wettedness (W_{rsw}) multiplied by the maximum evaporative rate of the human body (E_{max}) (Eqn 11). W_{rsw} can calculated by Eqn 12, which is a ratio of an environment-exposed skin area covered by a sweat film (A_{sw}) (wettedness) to the total body area (A_{du}) calculated by DuBios's equation. The E_{max} calculation requires different pressure between the ambient (p_a) and skin (p_{sk}) areas, combined with the effect of h_c and the efficiency of vapour permeation of body skin to the atmosphere (F_{pcl}) (Eqn 13).

$$E_{rsw} = W_{rsw} \times E_{max} \qquad \textit{Eqn 11}$$

$$W_{rsw} = \frac{A_{sw}}{A_{du}} \qquad \textit{Eqn 12}$$

$$E_{max} = \ 16.7 \ h_c \ (p_{sk} - p_a) \ F_{pcl} \qquad \textit{Eqn 13}$$

Those calculations define the magnitude of evaporative heat loss from uncovered skin on the body. To explore heat loss through areas of the skin covered by clothing, additional considerations are required pertaining to evaporation by diffusion (E_{diff}). This variable can be calculated by applying the ratio of covered area of body skin to the whole-body area multiplied by the maximum evaporative rate (Eqn 14).

$$E_{diff} = (1 - W_{rsw})0.06\, E_{max} \qquad \textit{Eqn 14}$$

It should be noted that in the condition where *RH* ranges from 40% to 60% and dry bulb temperature (*DBT*) is lower than 20°C, 20% to 25% of the *MET* is contributed by evaporation by diffusion and regulatory sweating (E_{diff} + E_{rsw}). Therefore, a total heat loss through skin surface (E_{sk}) can be expressed as the combined effect of E_{diff} and E_{rsw}, as shown in Eqn 15. If this function is substituted by the E_{diff} and E_{rsw} relations, it can be expressed as shown in Eqn 16.

$$E_{sk} = E_{diff} + E_{rsw} \qquad \textit{Eqn 15}$$

$$E_{sk} = 16.7\, h_c\, F_{pcl}\, (p_{sk} - p_a)(0.06 + 0.94 W_{rsw}) \qquad \textit{Eqn 16}$$

Finally, all of the above equations demonstrating the heat-discharging channels through the skin and respiration can be combined into one body heat-balance equation; this comprehensive formula is expressed in Eqn 17 (Auliciems and Szokolay 2007):

$$\Delta S = MET[(1 - \eta) - 0.0173(5.87 - p_a) - 0.0014(34 - T_a)] - [16.7(0.06 + 0.94 W_{rsw})\, h_c\, (p_{sk} - p_a) F_{pcl}] - [h(T_{sk} - T_a) F_{cl}] \qquad \textit{Eqn 17}$$

2.4.2 Fanger's steady-state model of thermal comfort (1970)

Fanger (1970) stands at the forefront of this research field contributing a pivotal point of thermal comfort study. He focused on physical environments, physiological factors, and people's sensations regarding their '*well-being expression*'. Fanger (1967) published an article entitled *"Calculation of Thermal*

Comfort: Introduction of Basic Comfort Equation", which included a rating scale of well-being perception, in the following year the book '*Thermal Comfort*' presented a new discipline for studying indoor comfort and well-being conditions. This book describes methods for predicting users' thermal comfort state based on environment-controlled results.

2.4.2.1 *Six influential factors of Fanger on thermal comfort*

Before describing Fanger's (1970) experiment and his heat balance model, six-basic variables of his work should be understood, which influence human thermal comfort and are used in calculating software for *PMV* and *PPD*: air temperature (T_a), airspeed (v), humidity, clothing insulation value (*CLO*), metabolic rate (*MET*), and mean radiant temperature (*MRT*).

Air temperature (T_a) is the ambient air surrounding the human body, which fundamentally affects the rate of heat transfer of human body to the environment. T_a can be measured using different instruments, such as a glass thermometer filled with mercury, thermocouple, thermistor, and platinum-resistant thermometer. Those sensors measure the air condition in actual environments where the obtained result is a combined effect of T_a and T_r. It is necessary to measure T_a at a location not too far from and not too close to the subjects, since T_a can vary by different thermal conditions of the actual settings. This research uses *DBT* to represent T_a.

Airspeed (v) is a velocity of air movement which has effect to human thermal comfort. It was traditionally measured manually by kata thermometer, but it can now be measured by hand-held propeller and cup type anemometers; however, these devices might be unsuitable for thermal comfort study due to unreliability in low v conditions. A pilot-tube, which is another type of anemometer, is commonly found in wind tunnel laboratories. A hot wire anemometer, on the other hand, is suggested for thermal comfort study, since it can detect low-speed air movement by evaluating the cooling rate of the hot wire.

Humidity is a fundamental environmental parameter, comprising the volume and proportion of vapour (mainly water vapour) in the air. This factor can be

measured using a whirling hygrometer, comprising two thermometers measuring *DBT* and wet bulb temperature (*WBT*). The web bulb thermometer normally presents a lower measured value than its counterpart due to an evaporative effect. The measuring results of *DBT* and *WBT* can be plotted on the psychrometric chart for exploring relative humidity (*RH*).

Humidity can cause dissatisfaction as perceived by human sensation. Low humidity (i.e. in arid environments) can result in dry skin and mucous membranes, while excessive vapour in the air restricts the evaporative capacity of the skin and affects the respiratory system, along with being conducive to bacterial infections and fungal growth. When the human body produces sweat on the skin this is an evaporative cooling technique, as explained previously, whose effectiveness depends on the sweat evaporating into the surrounding atmosphere; the rate of evaporation is directly determined by *RH* (with faster evaporation in low *RH* contexts, and vice-versa). Vapour in the air is commonly called *RH* and is expressed as a percentage (%). It is a ratio of vapour pressure in the air (p_a) to the saturated vapour pressure (p_{sa}) at one particular temperature (Parsons 2014).

Clothing insulation value (*CLO*) concerns the personal thermal resistance of clothing materials, which can prevent or assist humans' heat exchange with the surrounding environment. Clothing can be expressed in the unit *CLO*, whereby one unit of *CLO* can technically be converted to 0.155 $\frac{m^2 C^\circ}{W}$ (Fabbri 2015). *CLO* is also mentioned in different standards, including ASHRAE Standard-55:2004 (2004), CIBSE Guide A (Humphreys and Nicol 2006), and the ASHRAE Handbook - Fundamentals (2013). According to the ASHRAE Standard-55:2004 (2004), *CLO* can be calculated by three solutions:

- Referring to complete sets of clothing assembly presented in the standard.
- If the provided options are unsuitable given the actual clothing of the subjects, the insulation values can be directly added to or subtracted from the existing *CLO* value of the total sets of the assembly.

- Combining each single value of *CLO* of garment insulation for the clothing worn by respondents.

It should be noted that the standard *CLO* values available in the ASHRAE Standard-55:2004 are estimated numbers, and a 20% margin of error should be taken into account. Common summer and winter *CLO* values can vary between 0.35 to 0.60 and 0.80 to 1.00, respectively. The calculating methods mentioned above are for standing postures. For seated subjects, an extra *CLO* value for the chair should be factored in (e.g. an additional 0.15 *CLO* for an executive chair should be included in the total *CLO* for each office worker).

Metabolic rate (*MET*) is a unit of metabolic heat production varying depending on physiological activities. Generally, one unit of *MET* is equal to 58.15 $\frac{W}{m^s}$ (INNOVA 2002) and an activity of seated person (ASHRAE Standard-55:2004 2004). If *MET* is analysed with body surface area by DuBois (A_{du}), where *m* is the body mass and *l* is height, as Eqn 18 shows, one *MET* is equal to a 100W-heat generation.

$$A_{du} = 0.2025\, m^{0.425} l^{0.725} \qquad \textit{Eqn 18}$$

It should be noted that one single value of *MET* may not appropriate to apply in thermal comfort study where there is a combination of users' activities. Humphreys and Nicol (2006) suggested a method of time-weight average calculation to allow researchers to obtain a more accurate result. For instance, in one period, a sample may spend 50% of the time typing (*MET* = 1.1), 25% walking (*MET* = 1.6) and the other 25% sitting and filing (*MET* = 1.2). In this case, *MET* in such a scenario is 1.25, which can be derived from the calculation as (0.5 x 1.1) + (0.25 x 1.2) + (0.25 x 1.6).

Moreover, although in an actual space each building user may have particular *MET* for their current activity, Humphreys and Nicol (2006) suggest that *MET*-evaluating value should be individually considered for each sample, as one particular *MET* for all users in a space characterised by diverse activities would be inapplicable (in other words, there is no one-size-fits-all *MET*). Due to the

fact that levels of *MET* result from activities performed, the designed indoor temperature for each activity should be carefully considered. Humphreys and Nicol (2006) presented a set of T_a for different building functions. For example, activities in bedrooms are expected to have an *MET* of approximately 0.9 for a temperature range from 17°C to 19°C, with 2.5 *CLO* in winter and 23°C to 25°C with 1.2 *CLO* in summer. In contrast, users in living rooms are expected to perform approximately 1.1 *MET*. Therefore, the suggested minimum and maximum T_a values are 22°C and 23°C, with 1.0 *CLO* in winter, and 25°C and 25°C with 0.65 *CLO* in summer, as Table 2.1 presents. Additionally, Humphreys and Nicol (2006) described example values of *MET* for activities as listed in Table 2.2.

Table 2.1: Sample of suggested environmental and personal factors according to functions and seasons

Suggested environmental and personal factors for functions			
Function	T_a (ºC)	*MET*	*CLO*
Winter Bedroom	17.00 - 19.00	0.90	2.50
Summer Bedroom	23.00 - 25.00	0.90	1.20
Winter Living Room	22.00 - 23.00	1.10	1.00
Summer Living Room	23.00 - 25.00	0.65	1.10

Source: (Humphreys and Nicol 2006)

Table 2.2: Sample of MET for resting activities

Subjects of resting activities in CIBSE Guide A (2006)		
Activity	*MET*	Heat Generation ($W.m^{-2}$)
Sleeping	0.7	41
Reclining	0.8	45
Seated, Quiet	1	58
Standing, Relaxing	1.2	70

Source: (Humphreys and Nicol 2006)

Mean radiant temperature (*MRT*) expresses an average temperature of environmental surfaces which might cause radiative-heat exchange to recipients. *MRT* cannot be directly measured, but it can be calculated by the relationships of globe temperature T_g (explained below), *v*, *RH*, and T_a. Before discussing *MRT*, the measuring solution of T_g should be understood. T_g can be measured by a globe thermometer, commonly constructed with a copper ball of 150 mm diameter painted in matte black. A thermometer is placed inside at the centre of the sphere, to receive diffuse solar radiation from the globe at the same distance from each point on the circumference (Szokolay 2014). The globe must be painted in black or grey in order to represent human skin shaded by clothing, by which the body receives diffused solar radiation. In the construction of the globe, air leakage must be minimised as much as possible, as any air exchange between the inside of the globe and the environment might affect the measuring accuracy due to convection heat transfer interference (Parsons 2003). Encasing the sensor with an ellipsoid or cylindrical shape might be more accurate and representative of the shape of the human body than the traditional spherical globe.

Furthermore, different colours and materials have been examined for the spherical globe thermometer. Each material has different heat transfer properties; thus, it might take time for the globe temperature to reach the equilibrium stage before reading the temperature. A standard size of the black sphere is 150 mm in diameter, suitable for field survey due to its portability (Parsons 2003). A smaller dimension of the sphere can be used, but this could require some corrections in measuring results.

Regarding the T_g-measuring method, Humphreys and Nicol (2006) suggested that the instrument should be installed in the measured area for 5 to 20 minutes prior to each reading, to allow the equipment to acclimatise to the local climatic condition. Moreover, the tool needs be placed in the area with absence of direct solar radiation. The measuring results of T_g at the subjects' filling-out period are calculated with *RH*, *v*, T_a, diameter of the globe sphere (*d*), and emissivity of the globe surface (ε) for *MRT*. ISO 7726:1998 (1998) presents a calculating

method for *MRT* based on the magnitude of *v.* The calculating method is further discussed in Chapter 5.

2.4.2.2 *Fanger's experiment*

Fanger (1970) examined 128 Danish students with an average age of 23 with equal gender distribution, and replicated this with similar research methods but an older sample of 128 respondents with an average age of 68 years. The subjects' height and weight were calculated using the DuBios equation (1916), and *CLO* values were controlled at 0.6. The climate chamber of the study was located in the Technical University of Denmark, with chamber dimensions of 2.8 m width, 5.6 m length, and 2.8 m height. Room air was supplied by an AC system, so that T_r, T_a, v, and humidity were controllable, while illumination and acoustic systems were fixed by 150 lux and 45 bB, respectively (Fabbri 2015).

Regarding participants, there were four categories of the subjects, namely female and male college students and elderly people, as described previously. All the respondents were divided into four groups according to gender and age. Before entering the experimented chamber, all the participants were required to stay in the pre-chamber for 30 minutes, where purposes of the experiment and the questionnaire-answering method were explained. They were required to fill out a pre-survey questionnaire enquiring about their quality of sleep and appetite, to assure that information collected from the subjects were comparable and could be used in the analysis.

Regarding the environmental settings of the laboratory, eight different environmental set-points of climate chamber were set, where the T_a values were 21.1°C, 23.3°C, 25.6°C and 27.8°C with 30% and 70% for *RH*, and approximately 0.1 m/s for *v*. Each experiment lasted three hours, either from 2.00 pm to 5.00 pm or 7.00 pm to 10.00 pm. The room was left unattended for three hours to allow the thermal environment of the climate chamber reached the equilibrium state, to avoid a variation in the indoor condition. Each experiment lasted for three hours, taking place during day and night times.

After entering the climate chamber, the subjects were asked to be seated and were not allowed to speak, but they could read, study or communicate without talking, and they were not allowed to communicate concerning their current sensations. The activities inside laboratory were controlled to limit *MET.* They were allowed to consume beverages, but such consumption was monitored and recorded. The respondents were weighed before the first experiment started and after the last experiment in order to calculate weight lost due to the evaporative effect on the subjects' thermal sensations.

After 30 minutes in the chamber, the respondents were required to respond to the questionnaire by allocating a score to the current indoor conditions based on seven answering options: *Cold*, *Cool*, *Slightly cool*, *Neutral*, *Slightly warm*, *Warm*, and *Hot*. This process was repeated every 30 minutes until the experiment ended. At the end of the questionnaire, a set of questions for investigating personal information such as are menstrual cycle, eating habits, and sleep was administered.

Although Fanger's (1970) study elicited people's sensations concerning the current environment, it could not explore the acceptable condition of the majority of people. Thus, he purposed *PPD*, expressing the percentage negative vote of a group of subjects. It should be noted that since it is impossible to satisfy all the users in spaces or the entire population, the minimum percentage derived from the *PPD* prediction is limited only by five percent, although most of the subjects expressed '*Neutral*' (Aulieciems and DeDear 1978; INNOVA 2002; Humphreys and Nicol 2006; Parsons 2014).

2.4.2.3 *Heat balance equation of Fanger*

Gagge's (1936) two-node model, based on heat balance between the body and environment, contributed a heat-balance model expressing an energy transfer between human body and environment. Based on this, Fanger (1970) presented a thermal comfort equation in which the heat storage of the body (ΔS) is assumed to be zero, to represent a thermal comfort state. The equation combines all the six thermal-related aspects covering physiological and

environmental variables. That study led to exploration of the well-known *PMV* and *PPD* solution (Parsons 2003). Fanger's (1970) comfort condition comprises three indicators (Fabbri 2015):

- The body must maintain heat balance
- Skin sweat rate must be limited within the comfort degree
- Average skin temperature *(T_s)* must be in the comfort limit

In this case, the steady state is a condition where no notable shift in environmental and personal variables occurs. The main factors which Fanger (1970) highlighted to define the comfort condition are limit ranges of T_s (skin temperature for comfort conditions) and sweat secretion (E_{sw}) of occupants, as Eqn 19 shows, however he expressed the equations of T_s and E_{sw} in the obsolete metric unit as shown in Eqn 20 and Eqn 21 (Auliciems and Szokolay 2007):

$$a < T_s < b \; and \; c < E_{sw} < d \qquad \textit{Eqn 19}$$

$$T_s(old\ unit) = 35.7 - 0.032\left(\frac{H}{A_{du}}\right)\ (°C) \qquad \textit{Eqn 20}$$

$$E_{sw}(old\ unit) = 0.42\ A_{du}\ \left(\frac{H}{A_{du}} - 50\right)\ (\frac{Kcal}{hr}) \qquad \textit{Eqn 21}$$

According to those equations, it can be seen that T_s will increase when activity is more intense, as the function presented as $\frac{H}{Adu}$, where *H* is human heat production by metabolism, expressed as *M*(*η-1*) or *M - W*. The Fanger's equation was later converted to *SI* units and presented in the standards of ISO 7730 in 1994 and ASHRAE in 1993.

Similar to the two-node model, this equation ignores heat exchange by conduction (C_d); thus, the equation can be written as shown in Eqn 22.

$$H - E - Cv - R_a = 0 \qquad \textit{Eqn 22}$$

Moreover, in Fanger's '*double equation*' that relation is refined, whereby *L* is dry respiration loss and *K* is heat transfer from human skin to clothing surface (Eqn 23) (Aulieciems and DeDear 1978).

$$H - Ediff - Ersw - Eresp - L = K = R_a + Cv \qquad \textit{Eqn 23}$$

- ***Skin diffusion (Ediff) and regulatory sweat (Ersw) heat loss***

Fabbri (2015) expounded upon Fanger's equation in terms of heat loss calculations. The equation of heat loss by skin diffusion (E_{diff}) is based on the effect of different pressure between skin at saturation stage (P_{sa}) and that of the ambient air (P_a) multiplied with body area of DuBois's calculation (A_{du}), and constants of the latent heat of vapour evaporation at 35°C (λ) and the permeability of skin (m) (Eqn 24). λ of water is calculated by Eqn 25, where water temperature is T_w, the status at which 1 g of water evaporates into vapour at 34°C, requiring energy of 4211.3 J. For P_{sa} calculation, temperature of skin is required as presented in Eqn 26. T_s (skin temperature at the comfort state) is converted to *IS* units, as Eqn 27 expresses. Thus, E_{diff} can be expressed as shown in Eqn 28.

$$E_{diff} = \lambda \times m \times A_{du}(P_s - P_a)\ (W) \qquad \textit{Eqn 24}$$

$$\lambda = 2490.9 - 2.34T\ (J) \qquad \textit{Eqn 25}$$

$$P_s = 256.T_s - 3373\ (P_a) \qquad \textit{Eqn 26}$$

$$T_s = 35.7 - 0.0275\ H\ (C°) \qquad \textit{Eqn 27}$$

$$E_{diff} = 3.05 \times 10^{-3}\ (256T_s - 3373 - P_a)\ \left(\frac{W}{m^2}\right) \qquad \textit{Eqn 28}$$

Furthermore, heat also dissipates by regulatory sweat from the skin, which can be expressed as shown in Eqn 29.

$$E_{rsw} = 0.42 \times \left((M - W) - 58.15\right) \left(\frac{W}{m^2}\right) \qquad \textit{Eqn 29}$$

❖ ***Latent (E_{resp}) and sensible heat loss (L) by respiration***

In terms of latent heat loss by evaporation (E_{resp}), the calculation considers latent heat of water at 35°C (λ), different humidity ratios of exhaled and inhaled airs (W_{ex} and W_{in}) and pulmonary ventilation in a unit of $\frac{kg}{h}$. However, when the equation is substituted in the *PMV* formula, the E_{resp} equation is finally transformed into a relationship between *M* and P_a (Eqn 30).

$$E_{resp} = 1.72 \times 10^{-5} \times M \times (5867 - P_a) \left(\frac{W}{m^2}\right) \quad \text{Eqn 30}$$

Calculation of sensible heat loss by respiration (*L*) initially considers pulmonary ventilation (*P*), specific heat (C_p), and the difference between inhaled air temperature (T_{in}) and exhaled air temperature (T_{ex}). The derived equation from substitution can be written as a simple function of inhaled T_a and *M* (Eqn 31).

$$L = 0.0014 \times M \times (34 - T_a) \left(\frac{W}{m^2}\right) \quad \text{Eqn 31}$$

At skin areas covered by clothing, heat loss occurs as a form of conduction, thus this heat exchange is presented as the other part of the balance equation. Heat is transferred from the body skin through the clothing before being dispersed to the atmosphere. The calculation of this mean considers difference between human skin temperature (T_s) and outside surface temperature of clothing (T_{cl}) and total thermal resistance of the whole clothing applied (I_{cl}) (Eqn 32). To calculate I_{cl}, Eqn 33 considers R_{cl} ($\frac{m^{2\circ}c}{w}$), the heat transfer resistance of clothing from skin to the outer surface of clothing.

$$K = \frac{(T_s - T_{cl})}{(0.155\ I_{cl})} \left(\frac{W}{m^2}\right) \quad \text{Eqn 32}$$

$$I_{cl} = \frac{R_{cl}}{0.18}\ (clo) \quad \text{Eqn 33}$$

❖ *Heat loss by radiation (R_a)*

Heat loss by clothing radiation (R_a) is the means by which energy is exchanged from the human skin to the outer surface of clothing. An effective surface of clothed body (A_{eff}) can be calculated using Eqn 34, where f_{cl} is a ratio of the clothed to exposed body surface area, and f_{eff} is a ratio of effective radiation area of the clothed body to the surface area of the clothed body. In this case, f_{eff} can be derived from tables in which the f_{eff} values vary according to activities, such as 0.696 and 0.725 for sedentary and standing body postures, respectively (Fabbri 2015).

$$A_{eff} = A_{du} \times f_{cl} \times f_{eff} \ (m^2) \qquad \textit{Eqn 34}$$

The R_a relation is a function as shown in Eqn 35, where T_{cl} is the outer clothing surface, ε is average emittance of clothing, which in this case is 1.0, and σ is the constant of the Stefan-Boltz-man, which is 5.67×10^{-8} ($\frac{W}{m^2 k^4}$).

$$R_a = A_{eff} \times \varepsilon \times \sigma \times ((T_{cl} + 273)^4 - (MRT) + 273)^4) \ (W) \qquad \textit{Eqn 35}$$

That is the initial equation of radiation via clothing. However, the finalized version used in the heat balance equation is as presented in Eqn 36.

$$R_a = 3.96 \times 10^{-8} \times f_{cl} \times A_{du} \times ((T_{cl} + 273)^4 - (MRT + 273)^4) \ (W) \qquad \textit{Eqn 36}$$

❖ *Convective heat loss (C_v)*

Heat loss by convection (C_v) is the last mean presented in Fanger's (1970) equation. This factor considers the convective heat exchange of the clothed body. The variables used in the calculation are f_{cl}, a difference between T_{cl} and T_a, and convective heat transfer coefficient (h_{cl}) between clothing, skin surface, and ambient air, as Eqn 39 presents. It should be mentioned that h_{cl} varies depending on *v.* For low *v* it is called natural convection, where h_{cl} can be calculated by Eqn 37. In the case of high v, such forced convection is calculated by Eqn 38.

$$h_{cl} = 2.38 \times (T_{cl} - T_a)^{0.25} \left(\frac{W}{m^2 k}\right) \quad \text{Eqn 37}$$

$$h_{cl} = 12.1 \sqrt{v} \left(\frac{W}{m^2 k}\right) \quad \text{Eqn 38}$$

$$Cv = A_{du} \times f_{cl} \times h_{cl} \times (T_{cl} - T_a) \left(\frac{W}{m^2 k}\right) \quad \text{Eqn 39}$$

- ***Thermal comfort equation by Fanger (1970)***

The aforementioned equations elaborate on heat exchanges by different means, they can be substituted in the heat balance equation by Fanger (1970) based upon the comfort condition (Eqn 23). All heat exchange relations substituted in the equation are divided by A_{du} to yield a full heat balance equation, expressed as Eqn 40 (Fabbri 2015):

$$\left(\frac{M}{A_{du}}\right) \times (1 - \eta) - (3.05 \times 10^{-3} \times \left(5733 - 6.99 \times \left(\frac{M}{A_{du}}\right) \times (1 - \eta) - p_a\right)) - 0.42 \left(\left(\frac{M}{A_{du}}\right) \times (1 - \eta) - 58.15\right) - 1.7 \times 10^{-5} \left(\frac{M}{A_{du}}\right) \times (5867 - p_a) - 0.0014 \times \left(\frac{M}{A_{du}}\right) \times (34 - T_a) = 3.96\, x10^{-8} \times f_{cl} \times ((T_{cl} + 273)^4 - (MRT + 273)^4) + (f_{cl} \times h_c \times (T_{cl} - T_a) = \frac{(T_{sl} - T_{cl})}{(0.155.I_{cl})} \quad \text{Eqn 40}$$

Where T_{cl} can be derived by an iteration as shown below (Eqn 41).

$$T_{cl} = 35.7 - 0.028(M - W) - 0.155 I_{cl} [3.96 \times 10^{-8} f_{cl} \{(T_{cl} + 273)^4 - (T_r + 273)^4\} + f_{cl} \times h_c (T_{cl} - T_a)] \quad \text{Eqn 41}$$

This is the heat balance equation of Fanger (1970); however, in the *PMV* estimation, K is not considered, but H, E_{diff}, E_{rsw}, E_{resp}, R_a, and C_v are, as explained in the next section.

2.5 Predicted mean vote *(PMV)* and predicted percentage of dissatisfaction *(PPD)*

The previous section describes the comfort condition of Fanger (1970), consisting three main indicators: range of skin temperature, sweat rate, and body heat balance. This paradigm underpins the *PMV* and *PPD* methods, as discussed in this section. The comfort condition requires thermal load (*TL*) to be equal to zero. Shifting from the balance, it is a cause of thermal discomfort. The predicting results of predicted mean vote (*PMV*) is expressed as numbers based on the ASHRAE seven-point thermal sensation scale ranging from 3 ('*Hot*') to -3 ('*Cold*'). One part of the *PMV* calculation refers to Fanger's double equation expressed in the *SI* unit, as Eqn 42 presents:

$$PMV = (0.303e^{-0.036m} + 0.028) \times (H - E_{diff} - E_{rsw} - E_{resp} - L - R_a - C_v)) \quad \textit{Eqn 42}$$

With substitution of the sub-heat exchanging equations expressed in *SI* unit, the double equation can be expressed as shown in Eqn 43.

$$\begin{aligned} PMV = (0.303e^{-0.036m} + 0.028) \times ((M - W) \\ - 3.05 \times 10^{-3}(5733 - 6.99(M - W) - p_a) \\ - 0.42\big((M - W) - 58.15\big) \\ - 1.7 \times 10^{-5} M(5867 - p_a) - 0.0014M(34 - T_a) \\ - 3.96 \times 10^{-8} f_{cl} ((T_{cl} + 273)^4 - (MRT + 273)^4) \\ - (f_{cl} \times h_c \times (T_{cl} - T_a))) \end{aligned} \quad \textit{Eqn 43}$$

This steady-state model gained a wide acceptance and was included in the European and American standards. *PMV* was converted and illustrated as a nomogram, presenting a relation to *PPD* which is a percentage of people who vote dissatisfaction toward the current space. Figure 2.1 presents an exponential relationship between *PPD* and *PMV*, as presented in Eqn 44. The minimum percentage of user's dissatisfaction presented in this relationship is five percent, since it is impossible for the current thermal environment to satisfy the entire population (ASHRAE Standard-55:2004 2004).

$$PPD = 100 - 95 \times exp(-0.03353 \times PMV^4 - 0.2179\, PMV^2) \quad \text{Eqn 44}$$

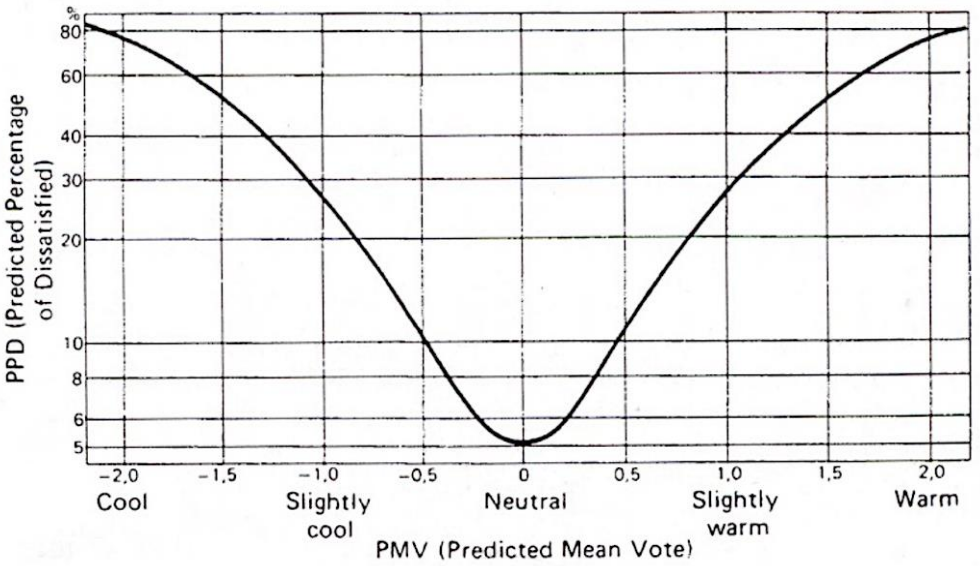


Figure 2.1: PMV and PPD indices

Source: (ASHRAE Standard 55, 2004)

2.6 Subjective thermal measurement in thermal comfort study

The two-node model (Gagge 1936) and the heat balance equation (Fanger 1970) demonstrated objective solutions to elaborate the heat-exchanging phenomenon between human and environmental variables. However, unquantifiable factors are excluded from these equations, such as emotion, experience, or culture, which all have significant roles in human thermal perception. A definition of thermal comfort in terms of subjective expression should consider individual perspectives; for example, ASHRAE Standard 55 (2004, 2010) describes thermal comfort as;

> 'Comfort, Thermal: That 'condition of mind' which expresses satisfaction with the thermal environment and is assessed by subjective evaluation' (ASHRAE Standard 55, 2004, p. 2, 2010, p. 3)

Fabbri (2015) also described the meaning of comfort in *Indoor Thermal Comfort Perception*, a book focused on children's thermal comfort, thus:

> 'Comfort is the result of the interaction of physical exchanges, physiological, psychological, social and culture rights, it depends on architecture, the clothing, the eating habits and the climate' (Fabbri 2015, p. 8)

According to those, it can be seen that this aspect is not related only objective factors, but also subjective aspects, one of which is 'mind' or 'psychological aspect'. Parsons (2014) agreed with the psychologically related evaluation of human thermal comfort, and mentioned that the perspective of thermal judgement might be based on past experiences, language, personal aspects, and culture. Thus, the psychological dimensions in human thermal comfort are significant to understand subjects' perceptions toward the world when investigating their physical and physiological variables.

Human thermal comfort is affected by so many subjective and personal factors that it seems impossible to fully quantify by scientific instruments. Parsons (2014) mentioned that asking subjects directly about their perceptions may be the best way to elicit relevant data, with qualitative evaluation. However, the derived results from this subjective assessment may be individually variable. Besides, the study of human thermal response by questionnaire surveys must be relevant in inquiring about subjects' experiences of the environment, including with regard to contextual situations as well as current personal sensations in the inhabited space, to avoid confusion. The questions must directly ask each individual to immediately report their current thermal sensation, not the condition in general, or a view influenced by other people's opinions (Parsons 2014).

It should be mentioned that the ASHRAE (ASHRAE Standard-55:1992 1992) and Bedford's (Bedford 1936) thermal sensation scales are widely applied in human thermal comfort research, as discussed further in the next section (Parsons 2003).

2.7 Psychometric scales of thermal sensation assessment

There are different types of subjective thermal scales employed in the research field, including the thermal preference scale and thermal pleasure scale, in addition to Bedford's thermal comfort scale and the ASHRAE thermal sensation scale. Each scale was invented to address a particular research question; therefore, when designing or applying a subjective thermal scale in survey, terms should be clarified to avoid confusion among respondents. Parsons (2003) noted that the two most common scales applied in thermal comfort studies are the ASHRAE and Bedford's thermal sensation scales.

The classic study of Dr. Thomas Bedford (1936), known as *The Warmth Factor in Comfort at Work*, was a thermal comfort field study of users in 12 English factories during the winter. Bedford was considered the pioneer of thermal comfort field survey who first introduced a field-based method that included environmental measurement, interviews, and statistical analysis. His research collected data from 3,085 respondents, most of which responded to the questions once (Humphreys *et al.* 2016). Bedford's set of subjective thermal questions focused on sensations of warmth, inquiring if the subjects felt comfortably warm, followed by a question regarding temperature preference. Subjects were asked if they wanted to improve the current thermal environment toward slightly warmer or cooler spaces. After that, they were asked about the degree of sensation which they could sense, such as '*Too warm*' or '*Too cool*'. From these options, the subjects were asked if they felt '*Too much cool*' or '*Too much warm*'. He later arranged these answers into a seven-point psychometric scale, known as 'Bedford's Scale', which has been widely used to the present. The scale ranges from -3 (*Much too cold*) to 3 (*Much too warm*), with a mid-point (0) of '*Comfortable*', as presented in Table 2.3. The other scale which must be mentioned here is ASHRAE thermal sensation scale, employed in Fanger's (1970) study, and which is also commonly used currently. It also has a seven-point Likert-type scale, ranging from -3 (*Cold*) to +3 (*Hot*), with a mid-point of 0 ('*Neutral*').

Table 2.3: Comparison of different psychological scales

Title of Scale	Psychometric Scale									
	-4	-3	-2	-1	0	1	2	3	4	5
Fanger Scale	-	*Cold*	*Cool*	*Slightly Cool*	*Neutral*	*Slightly Warm*	*Warm*	*Hot*	-	-
Rohles and Nevins	*Very Cold*	*Cold*	*Cool*	*Slightly Cool*	*Neutral*	*Slightly Warm*	*Warm*	*Hot*	*Very Hot*	*Painful*
Khedari	-	-	*Cool*	*Slightly Cool*	*Neutral*	*Slightly Warm*	*Warm*	*Hot*	*Very Hot*	-
McIntyre	-	*Cooler*		*No Change*			*Warmer*		-	-
Bedford	-	*Much Too Cool*	*Too Cold*	*Comfortably Cool*	*Comfortable*	*Comfortably Warm*	*Too Warm*	*Too Much Warm*	-	-
RP-884 Thermal Acceptability	-	*Unacceptable*		*Acceptable*			*Unacceptable*			-
Parkinson and Colleagues	-	*Very Unpleasant*	*Unpleasant*	*Slightly Unpleasant*	*Neutral*	*Slightly Pleasant*	*Pleasant*	*Very Pleasant*	-	-

Although these two scales were mentioned in many studies, they can also be modified or adapted to suit particular research questions and designs. Khedari *et al.* (2000) applied the ASHRAE thermal sensation scale alongside the imbalance psychometric scale of Rohles and Nevins (1996), ranging from -4 to 5, varying from '*Very cold*' to '*Painful*', which is commonly utilized in outdoor thermal comfort studies. They also devised a scale to suit the warm environment of sites where -3 ('*Cold*') was scarcely noted, while respondents might require more vote points on the warmer side of the sensation scale. Thus, a seven-point scale vote was developed ranging from -2 ('*Cool*') to +4 ('*Very hot*'), as shown in the comparison in Table 2.3. In this case, it can be seen that the psychometric scale can be modified or designed to reflect the research question. Parkinson *et al.* (2015) created a thermal pleasure scale to investigate subjects' thermal pleasance, ranging from -3 to +3, representing '*Very unpleasant*' to '*Very pleasant*', while the middle of the scale (0) is '*Neutral*'. Apart from these seven- and ten-point scales, a narrower range can be applied. McIntyre's scale of thermal preference was utilised in many studies, including those by DeDear, Brager and Cooper (1997), Feriadi and Wong (2004) and Zhai *et al.* (2013). This thermal preference scale is a three-point Likert scale answered by '*Preferred cooler*' (-1), '*No change*' (0) and '*Preferred warmer*' (+1).

It should be noted that each scale may be suitable in different purposes and may result in different results. The ASHRAE and Bedford scales were employed in parallel by Feriadi and Wong (2004), whose results revealed that although the scales look relatively similar, the subjects responded to each scale differently. Their study compared thermal sensation votes (*TSV*) derived from the ASHRAE scale to thermal comfort votes (*TCV*) according to the Bedford's scale and the predictive results of *PMV*. The comparative results indicate that the most common percentage of *TCV* was at the neutral point (0), accounting for approximately 40% of the votes, while that derived from the *TSV* database presents rather equal votes for the range of -2 to 1 ('*Cool*' *to* '*Slightly warm*'). In contrast, the highest percentage of *PMV* is at 2 ('*Warm*'), as presented in Figure 2.2.

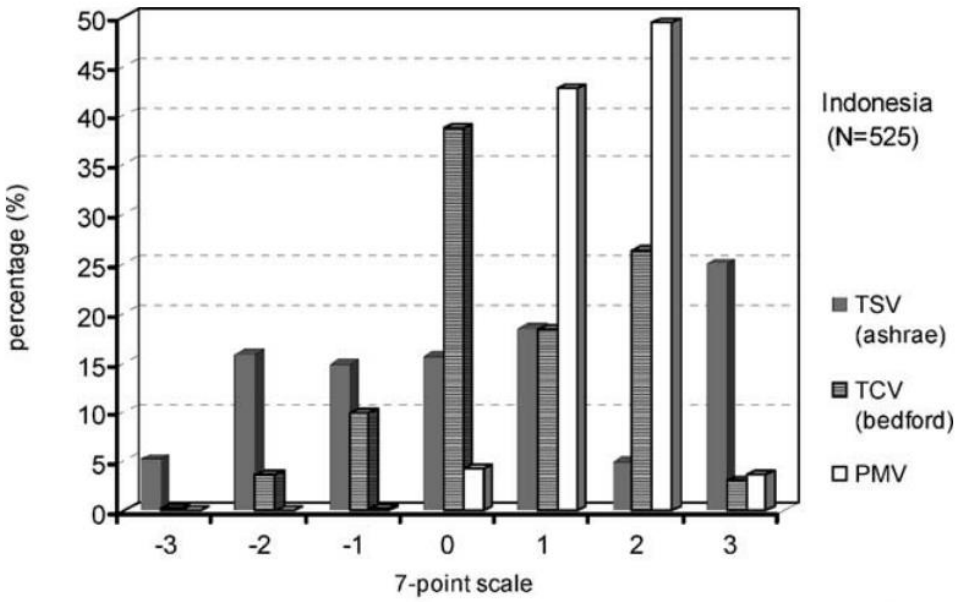


Figure 2.2: Comparison of field study results using different psychometric scales
Source: (Feriadi and Wong 2004)

2.8 Chapter conclusion

This chapter discussed the steady-state model of thermal comfort based on human body thermoregulatory activity and energy-changing phenomena between the human body and the environment. A normal body core temperature is maintained at 37.2°C, while the skin temperature may vary

between 31°C to 34°C in the thermally comfortable state. When the core temperature is too high or too low, physiological responses will trigger vasodilation or vasoconstriction in response in order to restore an appropriate temperature for metabolic activity, in order to avoid hyperpyrexia and hypothermia, respectively.

Human body heat-exchanging phenomena relate to processes of energy transfer from the core and skin of the body to the atmosphere. Gagge (1936) contributed the '*two-node model*', which explains how heat exchanges from body to the environment via the skin. The relationship is expressed as a heat-balance equation of human body, in which body heat storage is dispersed by convection, radiation, and evaporation. However, conduction, which is considered as a minor effect, is excluded in the calculation due to its insignificant impact on the human body.

This body heat balance model was later developed by Fanger (1970) for a thermal comfort equation. This function was established upon three indicators of the thermal comfort state: neutral thermal load, skin temperature, and sweat rate. This model contributed to an establishment of the *PMV* and *PPD* methods, and these solutions garnered wide acceptance from researchers and building designers, becoming influential methods for evaluating indoor thermal conditions for users in *AC* spaces.

Thermal comfort study relies on quantifiable, physical factors and psychological, qualitative, subjective human perceptions and experiences (the latter of which are the ultimate determinant of thermal comfort). Research on thermal comfort involves human-related experiments examining subjects' state of mind and degree of satisfaction with thermal environments, which are highly subjective even on the individual level. Therefore, subjective thermal votes are important information for exploring subjects' attitudes toward thermal environments.

One of the most effective ways to investigate thermal perceptions is simply to ask subjects directly via questionnaire survey methods, utilising Likert-type

numerical scales to quantify subjective perceptions. The questions normally ask the subjects to rate their thermal qualities according to answer options based on different points of psychometric scales. Thus, various subjective thermal scales were invented and modified to address the research questions. The ASHRAE thermal sensation and Bedford scales are the most commonly applied in this field. Albeit there are some similarities between these scales, they can lead to different results, thus employing each subjective scale can yield the most comprehensive data.

Chapter 3

Adaptive Thermal Comfort

Chapter 3: Adaptive Thermal Comfort

As mentioned in the previous chapter, the steady-state model is widely applied to predict indoor thermal environments for building users in *AC* spaces. However, this method seems unsuitable when predicting thermal neutrality in *FR* and *NV* buildings, as thermal environments shift dynamically and unpredictably, and building users are capable of thermal adaptation. Thus, adaptive model has been developed to reflect particular thermal comfort characteristics of users in non-*AC* spaces. This section describes a brief history of such approaches, and explains the subjective states considered thermally acceptable and comfortable, especially with regard to the subjective thermal conditions mentioned in the RP-884 report. The database of this report was later included in the ASHRAE Standard 55:2004, which is considered the predominant standard of adaptive thermal comfort. This chapter also explores the basic psychological parameters involved, such as sensation, perception, long-term and short-term memories, schemata, and past experience, all of which are pertinent to psychological thermal adaptation. Furthermore, other non-thermal factors such as socioeconomic or demographic factors mentioned in past studies are discussed. At the end of the chapter, a summary of thermal comfort study in Thailand and the current standard adaptive thermal comfort in Thai's Rating of Energy and Environmental Sustainability (*TREES*) is reviewed and discussed.

3.1 Brief background of adaptive thermal comfort study

The steady-state model of thermal comfort has been included in international standards such as ASHRAE Standard 55 and EN15251 for evaluating the human thermal environment in *AC* spaces. Human thermal comfort is a consequence of heat exchange between the environmental and physiological dimensions. The theory was derived from lab-based studies wherein respondents behaved as passive recipients under given conditions. However, although the model has garnered wide acceptance, a number of studies report

that the evaluation method may not precisely predict thermal conditions for *NV*-building users, and it seems difficult to apply in building design processes where the *CLO* and *MET* of the users are unclear. For example, a thorough literature review by Brager and DeDear (1998) claimed that the lab-based model may not fully explain human thermal perception and precisely predict thermal conditions for building users in *FR* and *NV* spaces.

Nicol (2004) discussed the unsuitability of the predictive method of the steady-state approach as included in ISO 7730. The study demonstrated that the lab-based model seems not to precisely predict thermal comfort for building users in dynamic conditions in hot and humid climates, since subjects stayed thermally comfortable despite temperatures reaching 30°C or even higher. Humphreys (1978) conducted a meta-analysis of the subjective thermal vote data collected from the subjects living in *AC* and *FR* buildings worldwide. The analysis revealed that T_n for the subjects residing in non-centralized-*AC* buildings varies according to outdoor temperature. A field study by Nicol *et al.* (1999) on human thermal comfort in *FR* buildings in Pakistan reaffirmed the existence of a strong relationship between indoor T_n and outdoor temperature, and found that their subjects could stay in a wide range of indoor T_g (between 20°C to 30°C) with negligible complaints about thermal discomfort. It is supposed that the relatively high thermal comfort threshold in this case is attributable to thermally adaptive activities.

Moreover, predictive results of the physiological model are questionable when applied in *FR* and *NV* buildings, since lab-based models ignore non-quantifiable variables such as the human capacity for adaptation and the dynamic nature of real-life thermal environments. Furthermore, the non-uniformity of the actual thermal environment results in various thermal sensations and different users' thermal adaptations. In contrast, the adaptive model includes all possible scenarios and relevant non-thermal variables occurring in real-life situations, such as demographics, human behaviour, thermal stimuli, and human cognition (Brager and DeDear 1998). Moreover, this more flexible model considers building users as active recipients whose relation with the environment can be

identified as dynamic and responsive. In other words, users are capable of detecting and perceiving the thermal variations and responding to thermally dissatisfying stimuli to maintain or regain their comfort by adaptation (Brager and DeDear 1998).

There are three modes of thermal adaptation, namely physiological, behavioural, and psychological adjustments. It should be noted that acclimatisation, as mentioned in physiological adaption, might not play a significant role in adaptive thermal comfort field study, since this process may require several years or generations for revealing a noticeable change. In contrast, Brager and DeDear (1998) indicated that users' behavioural and psychological adjustments might exert a considerable impact on thermal comfort. They reported different expectations of respondents who stay in *AC* and *NV* buildings. The subjects living in environmentally controlled spaces might strictly expect constant thermal conditions and are sensitive to temperature variations. In contrast, *NV* building users might have more flexible thermal expectations and better thermal flexibility than their counterparts. This psychological set point difference is believed to lead to wide thermal acceptance.

Humphreys (1975) presented that thermal comfort has a strong relationship with non-thermal factors such as the personal experience of outdoor mean temperature. Moreover, human behaviour has an impact on thermal comfort, since it shows solutions of how to deal with such as habitually encountered climate conditions. Thermal adaptation is widely mentioned and discussed in the literature and is not limited to heat-exchanging phenomena, rather it is an important variable in its own right with regard to influences on human thermal perception.

To determine a suitable indoor thermal environment for users in this approach, T_n is widely used and mentioned by various researchers globally. Humphreys (1978) conducted a meta-analysis based on global data. The results presented differences between comfort temperatures of users in *AC* and *FR* buildings. The

T_n of the *FR*-building users clearly demonstrates a linear relation with monthly mean outdoor temperatures ($T_{monthly\text{-}av\text{-}out}$).

A similar meta-analysis based on global data, the RP-884 report (DeDear *et al.* 1997), presented results consistent with those of Humphreys (1978), and confirmed a relationship between indoor T_n and the $T_{monthly\text{-}av\text{-}out}$ of the users in *FR* and *NV* spaces. This report is considered one of the most crucial databases that was later included in the ASHRAE Standard-55:2004 (2004), becoming a foundation of adaptive thermal comfort standards.

In the report, subjective thermal terms such as T_n, T_p, semantic discrepancy (*SD*) and acceptable thermal ranges were mentioned for defining different thermal experiences. These terms are also commonly referred in successive researches in the field. However, the definition of each term should be clarified to avoid confusion caused by different perspectives on thermal preference. In hot contexts, people may prefer relatively cooler operative temperatures than the neutral temperature, while a higher temperature is generally preferred in colder climates. In the adaptive model, human thermal comfort is not solely laid upon the thermal neutrality, but describes a degree of discomfort that can also be expressed as a difference between desirable and neutral temperatures. The smaller the discrepancy between these, the more possible it is that thermal comfort by adaptation can be achieved (Fabbri 2015).

3.2 Thermal neutrality investigation under the adaptive model

As mentioned in the previous section about subjective thermal terms, thermal neutrality is a condition where subjects sense neither hot nor cold, described as T_n in the adaptive model. Various studies affirm that the indoor T_n of building users in *NV* and *FR* buildings varies linearly according to $T_{monthly\text{-}av\text{-}out}$ (Humphreys 1978; DeDear *et al.* 1997; DeDear and Brager 2002; ASHRAE Standard-55:2004 2004). This relationship is one of the fundamental principles of the adaptive thermal comfort school of thought. This type of investigation was initiated by Humphreys (1975), who conducted a meta-analysis by gathering global thermal comfort data collected by *Class-III* measuring instruments. The

analytical result revealed a correlation between T_n and monthly average indoor globe or air temperature (T_i) with r of 0.96, as expressed in Eqn 45.

$$T_n = 2.56 + 0.83\,T_i\ (°C) \qquad \textit{Eqn 45}$$

Humphreys (1978) later conducted a meta-analysis of the global data in *AC* and *FR* buildings, the results of which showed that T_n for the subjects residing in the former space are limited within a narrow range of indoor temperature set by mechanical cooling systems. The T_n of the users slightly increases according to a shift in $T_{monthly\text{-}av\text{-}out}$ as an exponential function (R = 0.72), as shown in Eqn 46 and Figure 3.1. In contrast, the users in *FR* buildings are more thermally flexible, and their T_n seems to be linearly correlated with $T_{monthly\text{-}av\text{-}out}$ in a positive trend (R = 0.97), as the Eqn 47 presents. In Figure 3.1, the regression lines of T_n between both ventilation types are noticeably different. Besides, this linear equation is widely referred and developed to be an '*adaptive equation*' in the adaptive model.

$$T_n = 23.9 + 0.295\,(T_{monthly-av-out} - 22)exp\left(-\left(\frac{(T_{monthly-av-out}-22)}{24\sqrt{2}}\right)^2\right)\ (°C) \qquad \textit{Eqn 46}$$

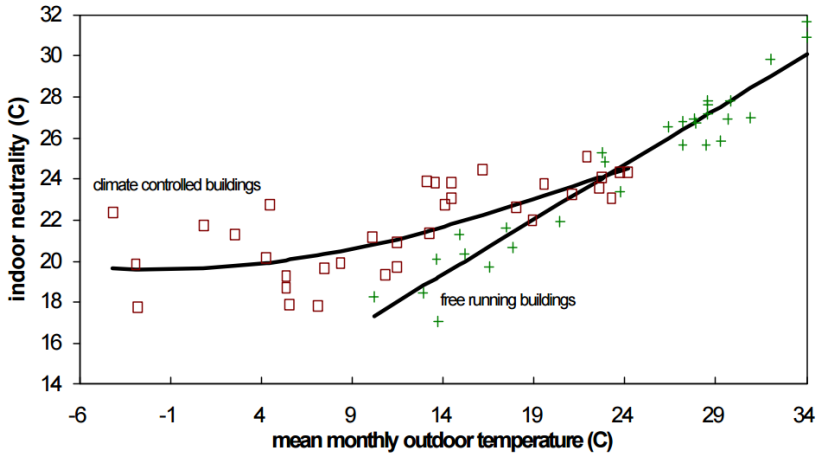


Figure 3.1: T_n lines of the subjects in FR and AC buildings

Source: (Humphreys 1978)

$$T_n = 11.9 + 0.534\,T_{monthly-av-out}\ (°C) \qquad \textit{Eqn 47}$$

Aulieciems (1981) conducted an analysis based on the *Class III* data of Humphreys (1978) with the inclusion of more recent studies. The subjective votes derived from asymmetric subjective thermal scales and children subjects were eliminated from the database. Consequently, the analytical results derived from the database contributed by both groups of the users in both *AC* and *FR* buildings in Australia, Asia, the United States, and Europe reveal a linear regression of T_n with R of 0.95, as expressed in Eqn 48 where T_i is mean indoor temperature.

$$T_n = 0.48T_i + 0.14T_{monthly-av-out} + 9.22\ (°C) \qquad \text{Eqn 48}$$

Humphreys and Nicol (1995) later presented a method to predict a target temperature (T_{it}) by using outdoor temperature index (T_{oi}), which is derived from a combination of current outdoor temperature and an exponentially-weighted running mean of the daily mean outdoor air temperature of the preceding week, as Eqn 49 presents.

$$T_{it} = 12.9 + 0.534\,T_{oi}\ (°C) \qquad \text{Eqn 49}$$

Furthermore, Nicol and Roaf (1996) conducted a field survey of thermal comfort in Pakistan to explore the comfort temperature in summer and winter for the local people. The simple outdoor variable $T_{monthly\text{-}av\text{-}out}$ correlates with T_n (Eqn 50). This algorithm is similar to that mentioned by Aulieciems and DeDear (1978), as presented in Eqn 51.

$$T_n = 17.0 + 0.38T_{monthly-av-out}\ (°C) \qquad \text{Eqn 50}$$

$$T_n = 17.6 + 0.31T_{monthly-av-out}\ (°C) \qquad \text{Eqn 51}$$

Later, DeDear *et al.* (1997) conducted a meta-analysis based on approximately 21,000 data sets contributed by *FR* and *AC* building users in 160 buildings worldwide. This study, known as the RP-884 report, was later included in the ASHRAE Standard-55:2004 (2004), considered the foundation of thermal

comfort standards for the adaptive model. This standard also included five case studies taking place in Thailand, whose data is more relevant to this thesis than that of the European standard, ISO 7731.

The thermal variables used in the RP-884 analysis were T_n and $T_{monthly\text{-}av\text{-}out}$, as expressed in the *ET* index. A relation between the factors for *FR* buildings can be presented as shown in Eqn 52. Apart from relying on a single value of T_n, the adaptive model is flexible and allows users to stay in different levels of thermal conditions, described as 80% and 90% thermal acceptable ranges, as Figure 3.2 shows. It should be mentioned that this model can be applied in a limited range of $T_{monthly\text{-}av\text{-}out}$, from 10.0°C to 33.5°C.

$$T_n = 18.9 + 0.255T_{monthly-av-out}\ (ET)\ (°C) \qquad \textit{Eqn 52}$$

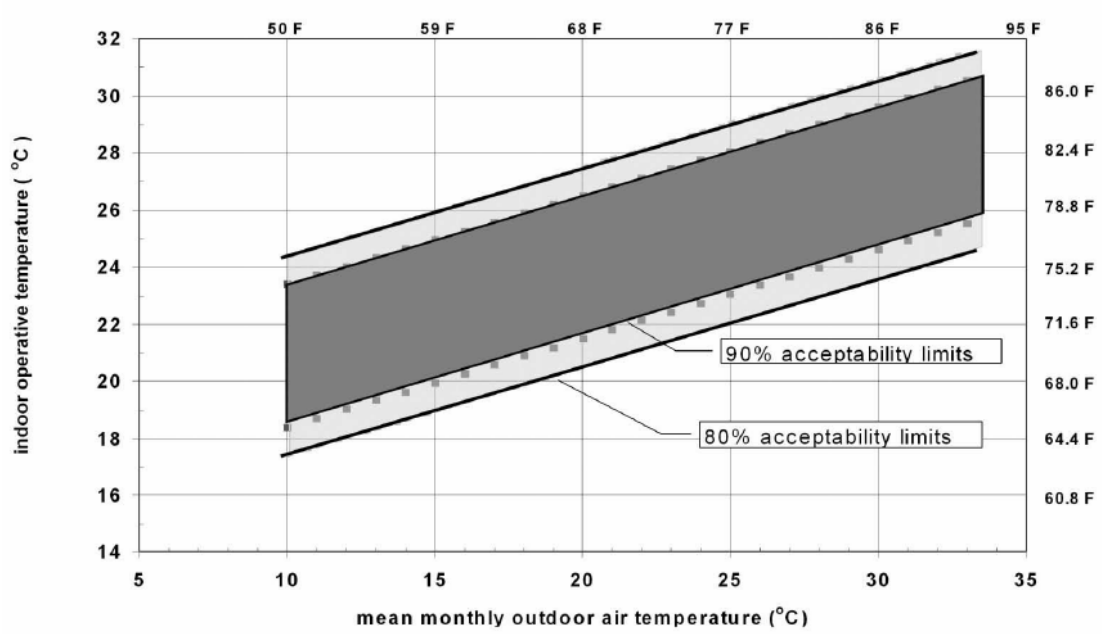


Figure 3.2: Adaptive model with 80% and 90% thermal acceptable ranges
Source: (ASHRAE Standard-55:2004 2004)

As mentioned above, the RP-884 report applied the *ET* index in the algorithm. However, in the ASHRAE Standard, the relation of the factors was converted into operative temperature (T_{op}), as shown in Eqn 53. This equation with the T_{op}

index can be found in previous studies (Nicol and Humphreys 2010; DeDear 2011).

$$T_n = 17.8 + 0.31T_{monthly-av-out}\ (°C) \qquad \textit{Eqn 53}$$

Furthermore, a potential improvement of the adaptive model in the future ASHRAE Standard-55 was discussed by DeDear (2011). It was predicted that the main aim for the future amendment is to harmonise the standard toward the European standard, CEN EN 15251, which is based on the Smart Controls and Thermal Comfort (SCATs) database. The report elaborated that a significant improvement from ASHRAE Standard-55:2010 (2010) was mainly achieved with regard to the *AC* environment, which is beyond the scope of this research.

Besides, the report discussed differences between the two standards, which are the number of subjects in each database, building types of the case studies, calculation methods of T_n and outdoor thermal variables. It can be summarised that there are two key suggested improvements mentioned in the report:

- The prevailing outdoor thermal variable of ASHRAE Standard-55:2010 (2010) in the adaptive chart should be changed from $T_{monthly\text{-}av\text{-}out}$ to weighted running-mean outdoor temperature (T_{rm}). This improvement is advised by Santamouris (2006), as mentioned in *Ventilation Information Paper No.2 of Air Infiltration and Ventilation Centre* (*AIVC*).
- The adaptive thermal comfort standard considers effects of *v* when T_{op} is over 25°C. The upper limit of both 80% and 90% ranges of thermal acceptability should be expanded based on levels of *v* elevations. The elevated *v* would be converted to T_{op} equivalent by referring an index of standard effective temperature *(SET)*. According to the report, a shift in *v* from 0.3 m/s to 1.2 m/s is equal to an increase of T_{op} of approximately 2.2°C.

Although there is a possibility to change the outdoor variable from $T_{monthly\text{-}av\text{-}out}$ to T_{rm} to achieve higher precision in the prediction, this thesis may not be able to follow such a suggested method, since it is still in the on-going development

process during analysing the data of this thesis. Thus, note that this thesis referred to Eqn 53 as a reference for further subjective thermal vote comparisons.

3.2.1 Operative temperature (T_{op})

T_{op} combines effects of *v*, *RH*, *DBT* and *MRT* to represent indoor thermal conditions. ASHRAE 55 and the EN 15251 standards applied this variable for expressing T_n (Nicol, Humphreys and Roaf 2012). In the previous version of CIBSE, the dry resultant temperature was used to describe air condition in a moderate climate. Later, T_{op} was replaced to allow the factor to be applied in different thermal settings worldwide. Such a composited environmental factor considers two effects of heat transfer, from coefficients of surface heat transfer by radiation and convection. The function of the T_{op} can be expressed as shown in Eqn 54 (Humphreys and Nicol 2006).

$$T_{op} = \frac{DBT\sqrt{10.v} + MRT}{1 + \sqrt{10.v}} \qquad \textit{Eqn 54}$$

This equation shows the effect of *v* on *DBT* and *MRT*. However, if *v* is lower than 0.1 m/s, T_{op} is an average effect of *DBT* and *MRT*, as Eqn 55 presents.

$$T_{op} = \frac{DBT + MRT}{2} \qquad \textit{Eqn 55}$$

MRT can be derived by relations of T_g, *DBT*, clothing emissivity (***ε***) and the diameter of globe thermometer sphere (*d*), as presented in Eqn 56 and Eqn 57, when *v* is lower or equal to 0.15 m/s ($v \leq 1.5$ m/s), and over 0.15 m/s ($v > 1.5$ m/s), respectively (ISO 7726:1998 1998).

$$MRT = [\left(T_g + 273\right)^4 + \frac{0.25 \times 10^8}{\varepsilon} \times \left(\frac{[T_g - T_a]^{\frac{1}{4}}}{d}\right) \times \left(T_g - T_a\right)]^{0.25} - 273 \qquad \textit{Eqn 56}$$

$$MRT = [\left(T_g + 273\right)^4 + (\frac{1.1 \times 10^8 \times v^{0.6}}{\varepsilon \times d^{0.4}} \times \left(T_g - T_a\right))]^{0.25} - 273 \qquad \textit{Eqn 57}$$

3.2.2 Classification of field data collection

The RP-884 report (DeDear, Brager and Cooper 1997) collected data worldwide from the UK, USA, Canada, Australia, Pakistan, Greece, Singapore, Thailand, and Indonesia. The raw data of the meta-analysis was directly collected from researchers who conducted the studies instead of referring to data from published papers. The report classifies field studies into three major types, as described below.

Class III: This is the simplest measuring method, requiring only indoor T_a and an optional measurement for humidity. It is not necessary to measure thermal variables contiguously with subjective votes. Basically, ASHRAE Standard-55:2004 (2004) suggests two sets of three different measuring levels ('heights') at 0.1 m, 0.6 m, and 1.1 m, and 0.1 m, 1.1 m, and 1.7 m for samples in sitting and standing postures, respectively. However, measuring at one height over the floor is enough for this class of field study, which was commonly applied in previous studies of adaptive model thermal comfort.

Class II: This class of survey necessitates measurements of T_a, T_r, v, and RH, with the collection of *CLO* and *MET.* Turbulence intensity (*TU*) might also be assessed. Those variables are used in heat index calculation, such as *PMV*, *PDD*, and *SET.* It is unnecessary to complete three heights of environmental measurement, as mentioned in ASHRAE Standard-55. However, it is necessary to collect the environmental factor data at the same time and in the same place where the questionnaire survey is conducted. Anemometer specifications entail measurement by multi-directional hot wire or sphere probes with a minimum threshold of 0.1 m/s.

Class I: This is the highest classification, comparable to a laboratory grade of measuring solution complying 100% with measuring specifications of the ASHRAE Standard-55 (1992) and ISO 7730 (1984). It is necessary to measure three levels of environmental factors. The foibles found in *Class II* are absent in this class. The measuring instruments are laboratory-grade and Omni-directional anemometer with the capability of *TU* evaluation is required. Only

three ASHRAE-funded field surveys (in the San Francisco Bay Area, Townsville, and Montreal) were included in the RP-884 database.

3.2.3 Thermal environmental analysis and standards

As mentioned previously, the steady-state model of thermal comfort might not fully evaluate human perceptions in dynamic thermal environments. Therefore, the RP-884 report (DeDear, Brager and Cooper 1997) presents two separated environment-evaluating solutions for *AC* and *NV* spaces.

3.2.3.1 *For air-conditioned buildings (HVAC system)*

This section considers environmental variables such as T_a, T_r, *RH*, *v*, and the personal factors of *CLO* and *MET*. This section of the report can be only applied to centralized-*HVAC* spaces. In terms of indoor thermal comfort assessment, three evaluating methods (analytic *PMV*, adaptive *PMV*, and prescriptive methods) were suggested to predict indoor acceptable thermal conditions. Such solutions are employed in different conditions depending on information availability. However, since this thesis focuses mainly on building users in *NV* spaces, this section is not of concern to this research. For more information on this issue, it is highly recommended to review the RP-884 report (DeDear, Brager and Cooper 1997).

3.2.3.2 *For naturally ventilated buildings*

Although the evaluation methods suggested for *AC* spaces are considered as a partial adaptation, since environmental and personal factors are modifiable by a consequence of behavioural adaptation, the report proposed a different assessing solution for *NV* spaces. *NV* is defined in RP-884 as an indoor space without centralised cooling and heating systems, while some passive cooling solutions are available, such as operable windows and heating or cooling systems, with the availability of personal environmental controls. Unlike the three evaluation solutions suggested for the *AC* spaces, the adaptive model is specifically recommended for *NV* buildings. In this case, the *PMV/PDD* and prescriptive methods are not recommended to be applied in *NV* buildings, since the outdoor environmental condition, which is a significant variable for *NV*

buildings, is ignored. Besides, the prescriptive method which defines seasonal comfort zones in the universal summer and winter is not universally applicable. DeDear *et al.* (1997) thus proposed the adaptive model for *NV* spaces. This method is similar to the adaptive *PMV*, as mentioned in the *AC* section, but the derived result of the adaptive model was established based on survey data.

The model demonstrates a relationship between indoor neutral new effective temperature (*ET**) in the Y-axis and the mean daily outdoor temperature derived from the meteorological station in X-axis. The nomogram presents a solid linear positive regression line of T_n with equal expansions of 80% and 90% acceptable thermal ranges, as Figure 3.3 presents. It should be noted that an extrapolation of indoor environmental condition will be limited within the range of $T_{monthly\text{-}av\text{-}out}$ between 5.0°C to 33.5°C.

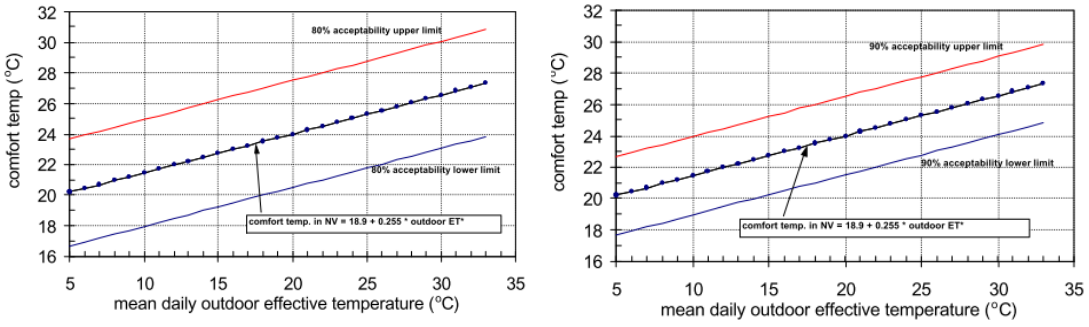


Figure 3.3: 80% (left) and 90% (right) acceptable thermal zones
Source: (DeDear, Brager and Cooper 1997)

3.2.4 Subjective thermal terms mentioned in the RP-884 report

The RP-884 project (DeDear, Brager and Cooper 1997) is a meta-analysis in which the data were gathered worldwide based on various survey methods, and the subjects were assessed by different subjective thermal scales. Thus, the RP-884 report conducted generalisation before pooling and analysing the data. Such data treatment is unnecessary in this research due to its smaller sample size. Therefore, the main interest of this section is mainly focused on how the report defines the subjective thermal terms based on the obtained data.

The RP-884 report discussed and compared the subjective thermal scales applied in the studies. The report mentioned that the research community assumed that thermal comfort was synonymous with thermal neutrality, thermal preference, and thermal acceptability, in a specific range of subjective votes (Figure 3.4). According to the figure, although the ASHRAE thermal sensation scale and Bedford thermal comfort scale look different, both scales may contribute indifferent and comparable results in most cases. Thus, the data samples derived from these scales were directly applied to explore thermal comfort. This section summarises and discusses the relevant subjective thermal terms mentioned in the report.

	ASHRAE scale	Bedford scale	Acceptability	Preference (McIntyre)
3	hot	much too warm		
2	warm	too warm	unacceptable	want cooler
1	slightly warm	comfortably warm		
0	neutral	comfortable	acceptable	no change
-1	slightly cool	comfortably cool		
-2	cool	too cool	unacceptable	want warmer
-3	cold	much too cool		

Figure 3.4: Comparison of the psychometric scales in the RP-884 report
Source: (DeDear et al. 1997)

However, it should be noted that subsequent studies, such as Wong and Khoo (2003), Feriadi and Wong (2004), Parkinson, de Dear, Deb and Ramachandraiah (2010), and Christhina (2015), and Wang *et al.* (2017), demonstrate different distributions of votes on the thermal sensation and comfort scales, when they are concurrently employed. Consequently, it is suggested that each subjective thermal term should be individually investigated, if possible.

- **Neutral temperature (T_n)** is derived from users' thermal sensation vote based on ASHRAE thermal sensation scale. '*Neutral*' vote (*0*) represents thermal neutrality or thermal comfort condition in which indoor thermal condition is perceived neither hot nor cold. Generally, one of the common analytical solutions for deriving the thermal neutrality state is to apply a linear regression analysis. Besides, it is agreed that T_n in adaptive approach varies significantly according to the outdoor temperature, while

that of the steady-state model is limited within a narrower range (DeDear, Brager and Cooper 1997).

- **Thermal acceptability** is an environmental state in which subjects may be acceptable at the time observed. It is assumed that the central three points of the *ASV* (-1.0 < *ASV* < +1.0 in integer-number version) is acceptable. In contrast, it is mentioned that the acceptable range is *-1.5* < *ASV* < *+1.5* in real-number expression. In the RP-884 report (DeDear, Brager and Cooper 1997), two different analytical methods for exploring the subjects' T_p were applied: direct and inferred assessments were applied. The latter method, called '*Proxy TSA*', assumes that an acceptable state is in the band of ±1.5 *ASV*, whereas the other solution is to inquire subjects directly by Thermal Acceptability Question (*TSA*). In this regard, the participants could vote if the thermal environment was either '*Acceptable*' or '*Unacceptable*'. The percentages of *TSA* and *Proxy TSA* were categorised by survey sites for investigating the relationships between the factors, and analysed using a linear regression. The analytical results present a difference between the direct and inferred evaluating methods. For example, the gradient factor of the actual regression of the thermal acceptability is significantly lower than that of the expectation (1.0) in all cases (DeDear, Brager and Cooper 1997).

  Moreover, the percentage of thermal acceptability based on the *TSA* and *Proxy TSA* data samples of all building case studies were correlated with the percentage of indoor thermal comfort conditions according to ASHRAE Standard 55:92 (1992). The result shows low R^2-values for *TSA* and *Proxy TSA* (0.01 and 0.14, respectively) when correlated with the ASHRAE Standard 55:92 (1992). The comfort states appear low relevant to the percentage amount, but replacing the ASHRAE Standard 55:92 (1992) comfort condition using heat indices such as *ET*, *SET*, and T_{op} does not contribute higher R^2-values. Thus, due to the weak correlations, the report employed an alternative solution using *PPD* concept. As a result, it is assumed that 20% and 10% *PPDs* are comparable to the 80% and 90%

acceptable thermal ranges, which correspond with ±0.85 *ASV* and ±0.5 *ASV*, respectively (DeDear, Brager and Cooper 1997).

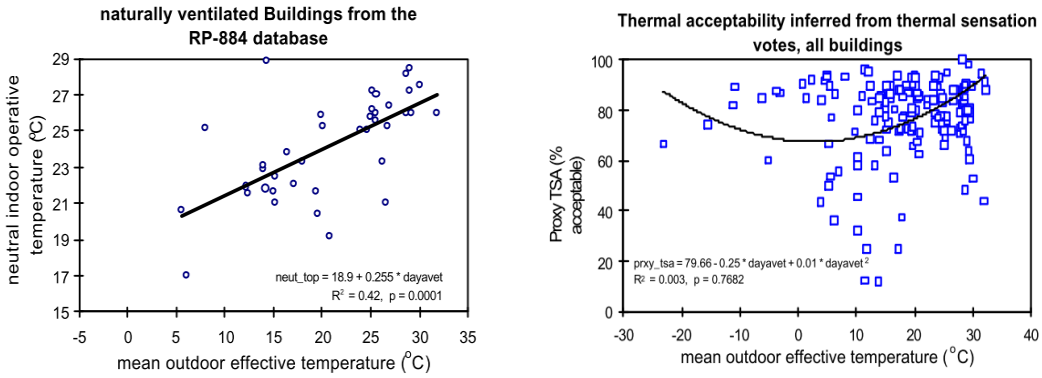
- **Thermal preference (T_p)** is a result derived from the thermal preference question, which asks participants about their preference on current indoor thermal condition. The subjects could vote whether they want '*Cooler*', '*Warmer*' or '*No change*'. The results voted on '*No change*' are split into half; then each of those is pooled with the results votes which are warmer and cooler. These bipolar data samples are converted into proportions of preferences and analysed using the Probit model. The intersection between preference regression lines represents occupants' T_p.

3.3 Analytical method applied in adaptive approach investigation

Adaptive thermal comfort involves a range of field survey data. In this section, the relevant statistically analytical methods employed in the RP-884 report are discussed, including those applied in successive studies.

3.3.1 Statistical analysis applied in the RP-884 report

With regard to the statistical analytical method utilised in the RP-884 report, three main techniques were commonly applied: cross-tabulation, regression model, and Probit analysis. The cross-tabulation technique aims to present data as frequencies, such as ranges, missing values, means, and standard deviations. Such analysis allows readers to understand general information before implementing correlation analyses. Regression analyses such as linear, and quadratic correlations were used for demonstrating a relationship between two factors, such as indoor thermal environmental factors and *ASV*, and neutral indoor T_{op} and average outdoor *ET*. Each figure of correlations also presents a regression model, *p*-value, and R^2, as presented in Figure 3.5. Types of correlation vary according to relations of the data, such as positive and negative linear and exponential regressions. This analytical method is, moreover, used to express an adaptive equation for predicting indoor T_n for *NV* buildings.



(A) Example of linear regression graph

(B) Example of quadratic regression graph

Figure 3.5: Examples of linear and quadratic regressions presented in the RP-884 report

Source: (DeDear et al. 1997)

Moreover, a sigmoid curve derived from Probit analysis was applied in thermal comfort study as an analytical solution by Chester Itter Bliss, an entomologist working for the Connecticut Agricultural Experiment Station in 1934. His study investigated the impacts of different pesticide concentrations on insects. Bliss introduced a solution comparing the chemical dose to insect fatality rate by exploring a best-fit regression model. It is found that the relationship between these factors can be expressed as the sigmoid curve. Later in 1952, David Finney, a statistics professor at the University of Edinburgh, wrote a book named '*Probit Analysis*' based on the principles of Bliss (Vencent 2014).

Probit analysis is also applied in thermal comfort study. Ballantyne *et al.* (1977) pioneered this analytical method as a solution for exploring LC50, which represents T_n at 50% response of the votes. Probit analysis can also been used for exploring T_p, as described in the RP-884 report (DeDear, Brager and Cooper 1997), by investigating an intersection point between two sigmoid curves of '*Preferred cooler*' and '*Preferred warmer*' (Figure 3.6). This method for T_p analysis gained widespread acceptance and has been applied in subsequent studies (Feriadi and Wong 2004; Melikov *et al.* 2005; Hwang and Chen 2010; Wang *et al.* 2017).

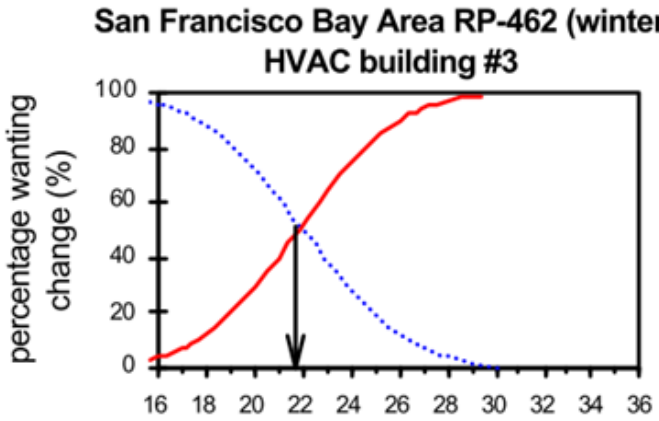
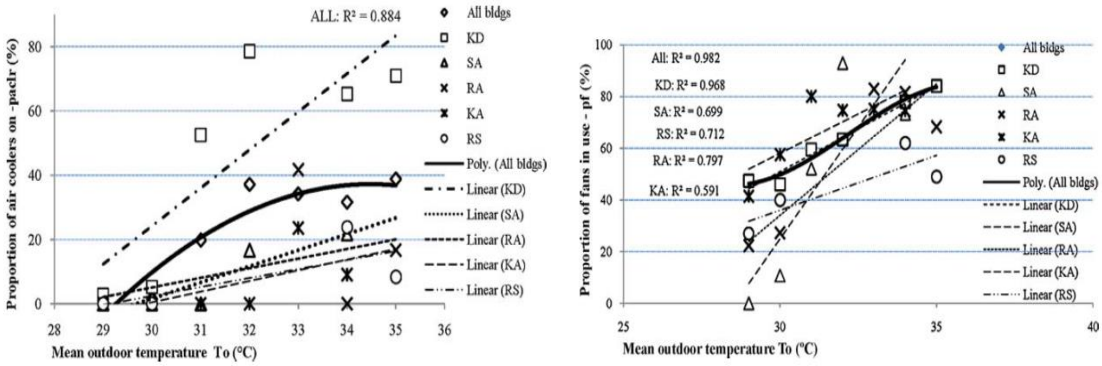


Figure 3.6: Example of Probit model applied in the RP-884 report for T_p analysis
Source: (DeDear et al. 1997)

3.3.2 Statistical analysis method in successive studies

The previous section discussed the cross tabulation, regression analysis, and Probit model analytical solutions employed in the RP-884 report (DeDear, Brager and Cooper 1997), and their application in later studies. Based on the literature review undertaken in this thesis, seven examples of successive studies from 2004 to 2012 were identified that applied such methods: Feriadi and Wong (2004), Khedari *et al.* (2000), Rangsiraksa (2006), Indraganti (2010a, 2010b, 2011) and Nguyen *et al*. 2012) (Table 3.1). The sample sizes used in these investigations ranged from 288 (Khedari et al. 2000) to 3962 (Indraganti 2010b) respondents.

The regression model is applied in T_n exploration and in investigating relationships between users' environmental control modification and T_{op} (Indraganti 2010b). For example, Figure 3.7 presents correlation analyses of the proportion of air cooler and fan functions plotted against mean outdoor temperature. The correlations show different relationships between percentages of the device operations and a shift in environmental factors, which are expressed as linear and quadratic regressions. Such an analytical method is considered one of the solutions capable of expressing human interaction to modifiable environments, since the R^2 values of the models are 0.884 and 0.982 for cases A and B, respectively.



(A) Percentage of air cooler operation (B) Percentage of fan operation

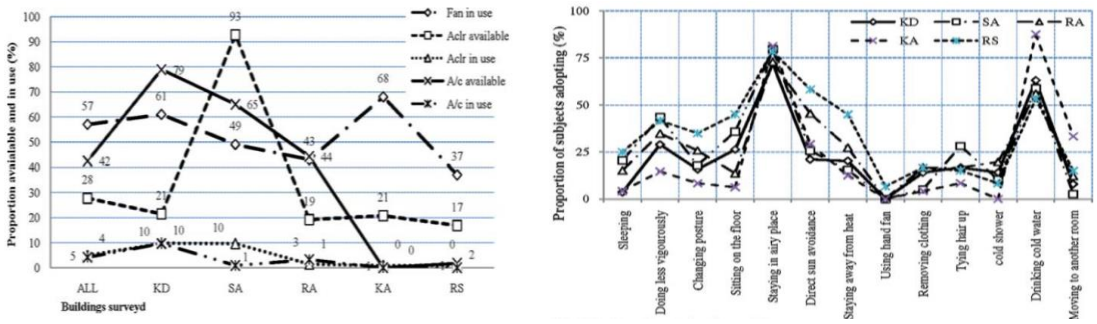
Figure 3.7: Examples of regression analysis applied in behavioural investigations

Source: (Indraganti 2010b)

Table 3.1: Summary of statistical analysis of key studies

	Statistical Analysis	Conclusion	Method	R^2	*p*-value	Result
Khedari et al. (2000) N = 288						
	Investigating Thailand Ventilation Comfort Chart					
1	Comparison of the monthly mean of the outdoor temperature of Bangkok and comfort zone recommended by ASHRAE	Current thermal conditions are out of the ASHRAE comfort zone	Overlay on psychrometric chart	-	-	-
2	Regression analysis of indoor air temperature and thermal sensation vote in three different wind speeds (0.2, 0.5, and 1.5 m/s)	A graph of Thailand ventilation chart was invented	Linear regression	0.7958 (0.2 m/s), 0.7723 (0.5 m/s) and 0.9056 (1 m/s)	-	-
3	Corrected *PMV* by using indoor air temperature to predict *PMV* in different *RH* and *v* conditions	There are 14 scenarios and equations for calculations, including neutral temperatures	Cross tabulation	-	-	-
Feriadi and Wong (2004) N = 525						
	Human thermal comfort in naturally ventilated houses in Indonesia					
1	Comparing of scales used in the study which are Bedford and ASHRAE with PMV	Each scale leads to different votes, although it looks similar. The highest value of *TCV* (Bedford's) reaches 40% at 0, while that of *TSV* (ASHRAE scale) percentage distribution within the range between -2, -1, 0, and 1 varies from 15 to 18% and peaks at 25% at *TSV* = 3	Histogram of PMV, TSN and TCV	-	-	*TSV* and *TCV* scales are different
2	Regression analysis of *PMV* and *TSV*	*TSV* = 1.33, *PMV* - 1.61	Linear regression	0.51	0	-
3	Regression analysis of *TSV* and T_{op}	*TSV* = 1.33, *PMV* - 1.61	Linear regression	0.179	0	-
4	Preferred temperature by probit analysis	Separate warmer and cooler votes and split neutral votes into half. Each binary vote was combined with two warmer and cooler votes, then analysed by Probit analysis to explore the intersection of sigmoid curves. Finally, the preferred temperature is 26.03°C, which is 3.14°C lower than 'neutral' temperature.	Probit analysis	-	warmer = 0.953, cooler = 0.328	T_p is lower than T_n
5	Comparing the percentage of thermal preference in different scale point of ASHRAE with tabulation	People in Indonesia might still need cooler conditions, although they feel neutral or cold.	Histogram and tabulation			
6	Comparison of votes in hot and rainy seasons with observed neutral temperature (*TSV* and *TCV*), predicted comfort temperature, and monthly and indoor temperatures	T_n derived from *TCV* is slightly lower than those from *TSV*. Likewise, predicted comfort temperature by comfort equations purposed by Humphreys are lower than Auliciem's.	Tabulation	R ranges from 0.203-0.427	-	-
7	Behavioural adaptation analysis by presenting the percentage of frequent adaptive actions	Windows are the most likely used, presented as 'always' in the highest percentage of operation	Bar chart	-	-	-
8	Presenting percentage of operation of windows and fans in the morning, noon, evening, and night	The table presents a combination of operation in four periods over 14 days. The results show that 87.4% of the users operated windows in the morning and 78.1% of them use fans at noon	Schedule of operation with percentages	-	-	-
Rangsiraraksa (2006) N = 753						
1	T_n (ASV = 0) in different seasons and ventilation systems analysed by linear regression	T_n varies according to seasons	Linear	R^2 ranges from 0.133-4.58, and 0.347-0.449 for *NV* and *AC*	-	-
2	Comparing T_n with other factors such as gender, age, and building users	Thermal sensation analysed by groups indicates no significant differences, but the age range shows differences of T_n (15-24, 25-59, and 60-90 years are 25.4, 24.6, and 27.3 ºC, respectively)	-	R^2 ranges from 0.49-0.87	-	-
3	Descriptive analysis of ASHRAE thermal sensation votes by cross-tabulation	Different high scores of thermal comfort votes in different ventilation types	Cross tabulation	-	-	-
Indraganti (2010A, 2011)						
1	Proportion of environmental adaptation					
	- Fan operation and Indoor T_g of five sites					
	- Air cooler and indoor T_g of five sites	Various, depending on sites	Various, depending on sites	All cases	-	-
	- *AC* and T_g of five sites					
	- Light and T_g of five sites					
	- The proportion of adaptation performed and types of adaptation					
Indraganti (2010B) N = 3962						
1	Comparing thermal sensation vote (*TSV*) with overall comfort (*OC*) between male and female subjects	Percentage of the neutral vote in men (29%) was less than that of women (38%). On the other hand, 38% of males and 31% of females voted warm. Moreover, 42% of men and 58% of women voted for comfort (*OC* = 4, 5, and 6), justified by the sense of belonging that the women subjects have.	Bar and line chart			
2	Comparing thermal comfort of subjects with different statuses of place ownership and age range	Higher socioeconomic status seems to require lower neutral temperature and a narrower range of that factor	Tabulation	Ranges from 0.258-0.56	-	-
3	Linear regression analysis of air movement sensation *(AMS)* and preference, *AMS* and *TSV*, *AMS* and *OC*, *AMS* and effect of productivity, *AMS* and T_g, and *AMS* and *RH*	*AMS* presents a strong relation to thermal discomfort	Linear regression	Varies between 0.023-0.505	-	-
4	Analysing *AMS* and median square root of air velocity and frequency of vote, humidity sensation *(HS)* and mean relative humidity *(RH)*, lighting level sensation and preference *(LLS* and *LLP)* and indoor air quality *(IAQS)*, and *TSV* and *OC*	-	Linear regression Line and bar chart	Varies	-	-
Nguyen, Singh and Reiter (2012) N = 402						
	A meta-analysis for an adaptive thermal comfort model for South-East Asia					
1	Distribution of Indoor T_{op} and *RH* in *AC* and *NV* buildings	Data is normally distributed	Histogram	-	-	-
2	Correlation between the observed thermal sensation (*TSV*) and *PMV*	Due to the large data, the *p*-value is set at 0.001 a criterion to select the data analysis	Chi-squared (T_{op} and *TSV*) Chi-squared (*PMV* and *TSV*)	0.33 0.021	0.023 0.034	-
3	Used standard residual *(SR)* to examine *TSV* and *PMV* and to filter the *TSV* data samples	*SR* greater than two eliminated (196 data samples were excluded from analysis due to considered bias)	Equation	-	-	-
4	Griffith's constant analysis for comfort temperature. The analysis compares the mean monthly outdoor temperature with observed neutral temperature influenced by G_{cons} (Griffith's constant)	The higher the constant value, the less the inclination of the comfort temperature slope is	Linear regression	-	-	-
5	Comparing *TSA* and *PMV* aiming to explore expectancy factor *'e'* to correct the predicted value	*TSV* = 0.82*PMV* - 0.358 (R^2 = 0.195). Due to low R^2, *'e'* cannot to be derived due to reliability issue.	Linear regression	0.195	-	-
6	Regression analysis of deviation from comfort temperature and mean thermal sensation vote	South-East Asian people tend to be more sensitive to temperature change due to narrower range of comfort temperature compared to the levels posited by ASHRAE-55, and EN1521	Linear regression	0.868	-	-
7	Adaptive comfort equation	$T_n = 0.341\ T_{monthly\text{-}av\text{-}out} + 18.83$	Linear regression	0.52	< 0.001	-

Moreover, apart from the inferentially statistical analysis, a descriptive statistic is utilised in this research field to exhibit the observed and surveyed results. Indraganti (2010a) applied a line graph to present the proportion of environmental control operations of different case studies presented in Figure 3.8 (A). Indraganti (2010b and 2011) used a similar method to describe proportions of behavioural adaptations performed in different months and sites. Feriadi and Wong (2004) employed bar charts to exhibit percentages of various thermally adaptive actions generally performed in residential buildings, and to present percentage of data distribution on each point of the ASHRAE thermal sensation scale. Histograms were used by Nguyen *et al.* (2012) to present data distribution of indoor T_{op} and *RH* in *NV* and *AC* buildings.



(A) Percentages of device operation (B) Percentages of device operations in different sites

Figure 3.8: Examples of behavioural investigations

Source: (Indraganti 2010b, 2011)

Based on this literature review, it can be concluded that descriptively and inferentially statistical analyses were commonly applied in analyses of the adaptive thermal comfort studies, and correlation analysis can be used in exploring relationships between thermal-related and thermal factors.

3.4 Comfort temperature analysis by Griffith's method

Apart from the linear correlation and Probit analysis for T_n, as mentioned in the previous section, Griffith's (1990) method is also widely mentioned in thermal comfort studies (Nicol and Roaf 1996; DeDear 2011; Indraganti, Ooka and Rijal 2015; Mishra and Ramgopal 2015). This method is also applied in the *SCATs*

project, and it is suitable for analysing a small sample size and narrow range of thermal conditions, which may generate a low *R*.

Griffith (1990) proposed a value called '*Griffiths Slope*' (*G*) to describe a linear relationship between differences of thermal sensation vote and comfort temperature (T_c). Griffith's comfort temperature can be calculated based on Eqn 58 and Eqn 59, as shown below where *C* and C_N are comfort and neutral comfort votes, respectively (Nicol, Humphreys and Roaf 2012):

$$(C - C_N) = G\ (T_{op} - T_c) \qquad \textit{Eqn 58}$$

$$T_c = T_{op} - \frac{(C - C_N)}{G} \qquad \textit{Eqn 59}$$

However, Nicol *et al.* (2012) expressed the original equation based on the thermal sensation scale ranging from 1 to 7. In this case, some sources may simplify the equation and express as a discrepancy between *C* and C_N based on the *ASV* thermal sensation scale, in which the minimum and maximum votes are -3 and +3, with a midpoint of 0 (Eqn 60) (Humphreys *et al.* 2013; Mishra and Ramgopal 2015):

$$T_{c-Griffith} = T_{op} - \frac{(ASV)}{G} \qquad \textit{Eqn 60}$$

This method is also used under conditions assuming that respondents undertake no thermal adaptation, and no measurement error occurs. This is impractical for consideration of realistic building environments.

Humphreys *et al.* (2007) conducted an analysis based on an international database of thermal comfort field study and clustered the data by the standard deviation (*std*) of T_{op}. The result shows that the peak regression coefficient reaches approximately 0.4 when the *std* was around 1 K. In contrast, the gradient factors will decrease at higher or lower *std*. A decrease of the gradient factor toward the higher value of *std* can be attributed to human adaptive actions and errors of measurements. Thus, it is acceptable that the coefficient is

assumed to be higher than 0.4. Based on a review of studies including that of Humphreys *et al.* (2010), Nicol *et al.* (2012) concluded that *G*-slope of 0.5 is a probable magnitude for field surveys.

3.5 Human thermal adaptation

As mentioned in Chapter 2 with regard to the heat balance principle, the respondents in the experiment behaved as passive recipients in given thermal conditions. This model considers partial thermal adaptation to thermal sensation, which can be affected by environmental modification to improve indoor thermal conditions (e.g. opening or closing windows), or personal adjustment (such as changing activities or clothing) to improve thermal satisfaction (DeDear *et al.* 1997).

In this regard, such a physiological model seems to limit its evaluating capability within the specified factors as presented in the heat balance equation. Unquantifiable factors such as sociological, socioeconomic, demographic, cultural, and adaptive constraints and opportunities existing in real environments that influence human subjective thermal votes are out of this analytical scope. In contrast, the adaptive thermal comfort point of view believes that building users in *FR* and *NV* spaces are considered as active recipients, who are capable of thermal interaction to thermally dissatisfying stimuli. Such interactive activities, which are believed to be able to extend the users' thermal acceptability, can be categorised into three modes: behavioural, physiological, and psychological adjustments.

3.5.1 Behavioural adjustment

Since thermally environmental variables shift dynamically and uncontrollably in *NV* and *FR* spaces, human skin and core temperatures are continuously exchanging energy with the environment. In this dynamic condition, building users might be faced with an unstable thermal state which may result in discomfort perception. Thermal adaptation essentially comprises human reactions to prevent or resolve unpleasant environmental stimuli. Parsons (2003) considered human behaviour such as adjusting clothing, changing

posture, moving to different locations, and finding shelter to be the most powerful instances of human thermoregulatory adaptation. This relates to the theory of '*psychophysics*', which describes how human behaviour is driven by the desire to avoid thermal discomfort. Cabanac (1971) coined the term '*alliesthesia*' to refer to thermal preference due to a contrast of external thermal stimuli to the internal state of the human body. The external contrast induction allows humans to perceive thermal satisfaction outside the comfort zone. This desire for thermal pleasure is believed to be a trigger of human behavioural motivation to maintain body thermoregulation.

3.5.1.1 *Behavioural adaptation on thermoregulation*

Nicol and Humphreys (1973) discussed thermal comfort in terms of the human self-thermoregulatory system as summarised in Figure 3.9. The diagram describes how the human body processes heat from the body to the environment, how information is transmitted from thermal stimuli to the central nervous system (*CNS*), and how individual responses to such inducement are created. Heat can flow from body tissues via skin, clothing, and the environment, successively. The signal perceived from the body and skin is transmitted to the *CNS*, which is the main information processing hub in thermoregulation within the body, where personal and environmental adjustments are coordinated. Such modification is considered a self-regulating method involving physiological, clothing, and environmental adaptations.

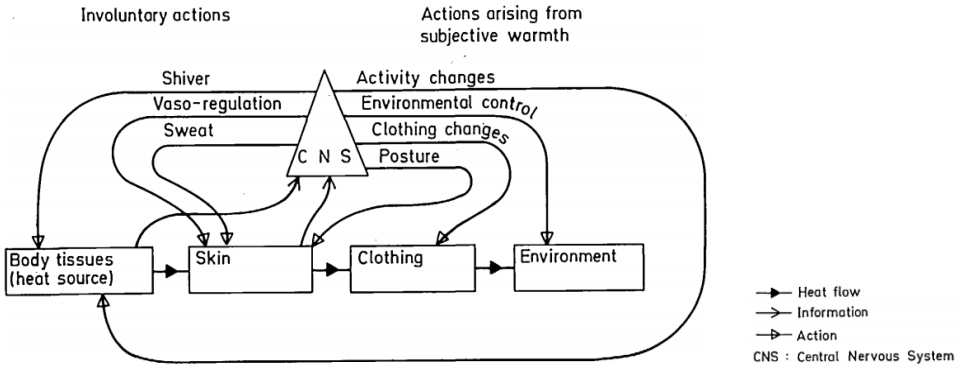


Figure 3.9: Physiological thermoregulatory system and behavioural adaptation
Source: (Nicol and Humphreys 1973)

- ***Adjustment of physiological factors***

This mode of adaptation is a consequence of shifts in *MET* per body surface area. It is relevant to a relationship between activities and postures. Wyon and Holmberg (1972) conducted an experiment to investigate children's behaviour toward a change of room temperature ranging between 20°C and 30°C. The results reveal that the personal factor is employed as a thermoregulatory solution, since the subjects' posture and the indoor environmental variables are statistically correlated. The relation between the posture change and temperature variation was also investigated by Raja and Nicol (1997), who agreed that a change of body surface area by posture alteration is thermally dependent, and it can optimise the heat-exchanging rate between the human body and the environment to improve thermal comfort.

- ***Clothing insulation (CLO)***

Two studies by Humphreys (1972, 1973) conducted with school and office building subjects demonstrated that *CLO* was considered a means of thermal regulation. The subjective thermal vote of Bedford's thermal sensation scale was employed, while *CLO* was recorded alongside measuring indoor temperature. According to both studies, the result of a zero-order correlation shows a significant relationship between the thermal sensation vote and temperature variation. The results also reveal that personal *CLO* shifts inversely with indoor temperature and thermal sensation vote.

Subjects' *CLO* has been studied by investigations of the impact of insulation values on thermal comfort. Fishman (1982) investigated of 26 subjects' *CLO* in the UK and found that the female *CLO* changes seasonally and according to outdoor conditions. For every one degree Celsius increment of outdoor temperature, *CLO* diminishes by 0.02. Nicol *et al.* (1994) studied *NV* buildings in Pakistan with a group of office workers in traditional clothing and found that the flexibility of local clothing styles may be one of the influencing factors in the variation of subjects' comfort temperatures, which are optimally 15.7°C in winter and 26.4°C in summer.

❖ ***Environmental control operation***

Thermal environmental factors are stimuli in building users' interactions with the built environment for indoor thermal condition improvement. In this case, it has been found that outdoor temperatures seem to have more profound influences on users' environmental control modification (Nicol *et al.* 1994). More specifically, standard deviations (*std*) derived from correlation analyses between the number of window operation and indoor and outdoor temperatures show that external factors may exert more influence on environmental adjustment. As a result, *std* of the window operation presents a higher *std* with outdoor temperature (3.7°C) than the indoor temperature (2.4°C).

3.5.1.2 *Categorisation of behavioural adaptation*

Nikolopoulou and Steemers (2003) mentioned that the behavioural adaptation could be categorised into two major aspects, namely '*reactive adaptation*' *and* '*interactive adaptation*'. The former adaptive mode relates to personal adjustments such as *CLO* adjustment, posture change, or relocation, while the latter concerns environmental modifications such as configuring windows, fans, and curtains. Brager and DeDear (1998) mentioned that behavioural adaptation can be performed consciously or unconsciously, and can be divided into three types of adjustments:

- **Personal adaptations** relate to personally modifiable factors, such as clothing, activity, posture, foods or beverage consumption, and user location.
- **Environmental and technological adaptations** describe users' adaptive behaviour when operating environmental controls such as windows, fans, curtains, and cooling or heating systems.
- **Cultural adaptations** include rules or local norms, such as those pertaining to schedule optimisation, flexible outfits, or suitable break periods to suit thermal conditions.

3.5.2 Physiological acclimatisation

Physiological adaptation, which allows humans to develop their thermoregulatory system according to an extended period of thermal exposure, can be divided into two main methods. The first solution relates to a genetic adaptation, which requires a long period from generation to generation to reveal a physiological improvement. Furthermore, acclimatisation can be found by a shift in body thermoregulatory system toward thermal exposure. This aspect can be described by using the heat balance model, where human *MET* is kept constant. In contrast, the adaptive point of view considers that the environmental influence has an impact on a shift of body metabolic set point.

3.5.2.1 *Skin thermo-receptor and thermal acclimatisation*

Schiffman (2001) mentioned that human skin temperature in a normal situation (33°C) is colder than the core temperature (37°C), and the temperature shift away from this threshold of the skin temperature leads to thermal sensation. This phenomenon should be considered with the adaptation of skin temperature. A sensation of hot and warm of human skin can be referred to '*Physiological Zero*', at which temperature humans perceive neither cold nor warm. This neutral condition, known as the '*Neutral Zone*', is a range of 2°C to 4°C around the general standard of 33°C.

However, it should be noted that a phenomenon of cutaneous thermo-receptor function may not always provide a reliable thermal sensation. Schiffman (2001) explained this phenomenon by asking a participant to put his hands into two buckets, one with hot water (40°C) for the right hand, and one with cold water (20°C) for the left. At the initial experience of the sensation, the subject might feel warm and cold according to current water temperatures at the right and left hands, respectively. After a while, the skin of each hand might adapt to the local temperature and reach a new neutral zone, whereby the participant might perceive thermal neutrality (Figure 3.10). After that, the respondent was asked to place hands into a 33°C water bucket, whereupon the subject felt cold at the right hand, and warm at the left hand, despite the identical water temperature.

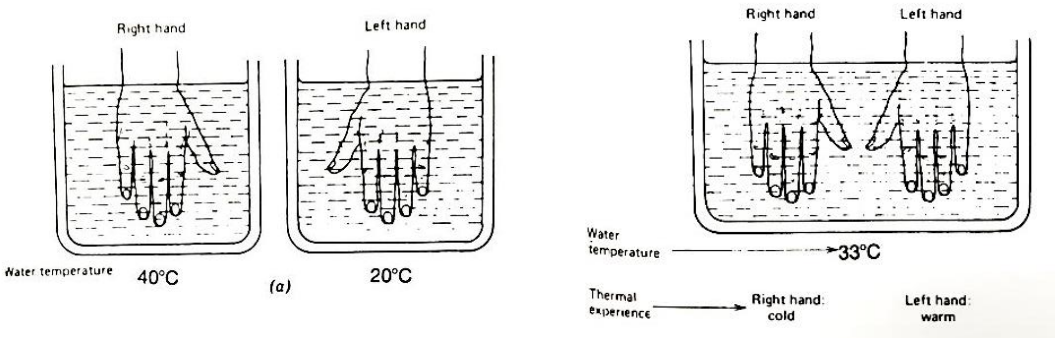


Figure 3.10: Experiment about hands' paradoxical thermal sensation
Source: (Schiffman 2001)

Thermal adaptation abilities normally span the temperature range between 16°C to 42°C for most people, but this band might vary according to different locations on the human body; for example, the thermal adaptability of the forearm typically ranges from 29°C to 37°C (Kenshalo and Scott 1966). Schiffman (2001) mentioned a paradoxical phenomenon of the skins' thermal sensation. Human thermal (warm and cold cutaneous) sensation receptors detect warm or cold temperatures, but cold receptors might present a paradoxical signal of cold sensation when the temperature is as high as around 45°C to 50°C; conversely, the skin might sometimes overestimate warm stimuli because of the operation of the cold receptors, which leads to an intense hot sensation in the human skin. For instance, 40°C of stimuli substance can be perceived approximately 50°C to 60°C. Besides, the human skin might sense warm or cold by external non-thermal stimuli, such as the effect of evaporation of alcohol or irritation of chemical substances, such as methyl salicylate or capsaicin.

3.5.2.2 *Physiological adaptation*

Brager and DeDear (1998) conducted a literature review collecting 135 sources in which a physiological adaptation studies were summarised and discussed. They found that in hot climates, the skin sweat rate is raised to discharge excessive heat from the body core. Human acclimatised to the hot environments lowers the temperature set point to initiate the skin's sweating

system and extend the skin's sweating area. The cardiovascular system raises flow volume to elevate blood circulation, while dropping the heart rate.

It should be highlighted that although the climatically acclimatised people in hot and humid climates may have an advantage of an improvement of the sweating system than the un-acclimatised, such an adaptation may be less effective due to high *RH*, which leads to a low evaporation rate. Therefore, the body compensates for this deficit by encouraging the effect of dry heat loss, such as elevating the blood flow rate at the peripheral of the body and skin temperature. (Brager and DeDear 1998).

Acclimatising to hot conditions while working in high-heat thermal environments or wearing hyperthermic suits may start on the first day of the exposure. To reach the fully acclimatised stage may require approximately three or four days, depending on the severity of thermal stimulus relative to core temperatures. Subjects exposed to heat passively, with sedentary daily activities, or acclimatising to cold, may require a more extended period to adjust their physiological threshold (Bruce 1960).

Studies demonstrating the unreliable nature of thermal sensation were conducted by Parsons and Entwistle (1983), who investigated the effect of thermal context on human acclimatisation. This investigation examined a difference of human acclimatisation in two scenarios where temperature gradually decreased from 30°C to 10°C and increased from 10°C to 30°C over 90 minutes, in which the subjects were asked to rate their thermal sensation while performing a computer-controlling task. The analytical results led to the conclusion that the T_n derived from these two schemes are different, since T_n in the temperature-decreasing scenario is 20.7°C (T_n = 2.23°C), which is lower than that of the counterpart temperature-increasing one (T_n = 23.0°C).

Brierley (1996) investigated the acclimatization program of athletes preparing themselves for the Olympics in 1996. Six male, college-age respondents were examined in a climate chamber set with different thermal environments, as described by Webb and Parsons (1997). In the first two days, the subjects were

required to stay in a room for three hours a day. In the first day, the room temperature was set as 23°C with 70% *RH* for 0 *PMV* for three hours, while the room for the second day was set as 29.0°C with 50% *RH* for 1.5 *PMV*. Later, they took a break for five days before exposing to another four-day experiment where the room was set as 45°C with 40% *RH* for two hours a day. After the program, the participants presented signs of acclimatisation in terms of the increase in sweat rate, a drop in heart rate, a minimal shift in core temperature, and an improvement of heat stress resistance. However, the *PMV* and actual mean vote (*AMV*) results from baseline and after the intervention present a small variation of a thermal sensation among the volunteers. Thus, the study concluded that acclimatisation may have influenced human physiological operation, but did not affect thermal sensation.

Apart from the environmentally controlled studies mentioned above, field research of people's behaviour in the actual site is essential to allow the researchers to explore human responses to different thermal settings. Diverse daily thermal backgrounds of subjects lead to different thermal tolerance levels. Respondents who spend the majority of their time in outdoor areas seem to have better thermal tolerability and prefer staying longer in *NV* spaces (Aljawabra and Nikolopoulou 2010). Moreover, Ellis (1953) investigated thermal response of 34 European and 100 Asian people living in Singapore. He explored that the Europeans who acclimatized to the local Singapore climate perceived the same thermal sensation as the native Singaporeans. Therefore, it can be concluded that country of origin and even genetic predispositions have an insignificant influence on thermal comfort vote over the medium and long term, and acclimatization is much more important.

3.5.3 Psychological adaptation

The psychological aspect is in the interest of researchers in the field, since the physiological model might not fully explain the diversity of subjective thermal votes. Furthermore, psychological adaptability known as '*Perceptual Adaptation*' is mentioned in psychophysics, but ignored by the heat-balance model. Hensel (1981) mentioned that the conditions of warmth and coldness

are subjective, and are qualitatively evaluated by individual sensation, not solely based on a quantitative basis. Thus, human thermal comfort is associated with multidisciplinary aspects.

In the neuroscience research field, Michael and Rolhion (2008) explored the effect of colours on thermal sensation in a nostril. Subjects were asked to take a breath from four bottles (red, green, yellow, and transparent) filled with odourless and thermally equal distilled water. Two experimental scenarios were run, blindfolded and free-viewing tests. In the former condition, the subjects expressed that no thermal difference could be sensed. However, with the second scenario, the subjects perceived different thermal sensations (when they were allowed to see the bottle colours). For instance, they voted a warm sensation for the red bottle, but cool for the green one. The analytical results revealed that the thermal sensation of humans is not solely affected by thermal variables, but a cognitive process.

With regard to the adaptive approach, thermal comfort varies individually according to differences of language, ethnicity, tradition, beliefs, and way of life. In this regard, it is necessary to understand those factors before investigating subjects' thermal sensations in particular contexts, alongside the psychological background of subjects as this may offer insights on their perceptions (Parsons 2003).

Parsons (2003) mentioned that thermal sensation relates to various psychological theories. One of these pertinent to the current research is the model of 'strong' and 'weak' determinists. The former aspect pertains to a model of which the objectives for exploring peoples' suitable indoor temperature are explicitly stated, while the latter considers that conditions should extend further to consider multiple aspects associated with the environment, people, ideas, and subjective factors. This school of thought relates to a behavioural aspect which is intersected with a major section of psychology. In short, the objective of the weaker determinist considers manifold effects of dynamical environmental stimuli, which may cause individual reactions.

According to those two different aspects, it can be seen that the designed room temperature is mainly determined by a thermal environment for occupants derived from the strong determinist model (Parsons 2003), while weaker determinists trying to explore the nature of thermal comfort are better understood in terms of human behavioural adaptation. Parsons (2003) concluded that to adopt models to evaluate suitable thermal conditions necessitates clearly defining the purposes of the investigations for each project.

Aulieciems (1981) presented a diagram of thermoregulation in the adaptive approach, the 'Psycho-*Physiological Model*' (Figure 3.11), which demonstrates a process of thermal adaptation relating to physiological, behavioural, and psychological aspects. The figure shows that behavioural and technological modifications are affected by psychological influences such as thermal preference, satisfaction, and sensation. These non-thermal factors are a consequence of thermal expectation, which is affected by personal and contextual factors, such as pass thermal environments and climato-cultural practices and norms. Thus, it can be seen that a picture of behavioural adaptation is not only based upon the consequence of physiological activities toward thermal stimuli, but also unquantifiable influences.

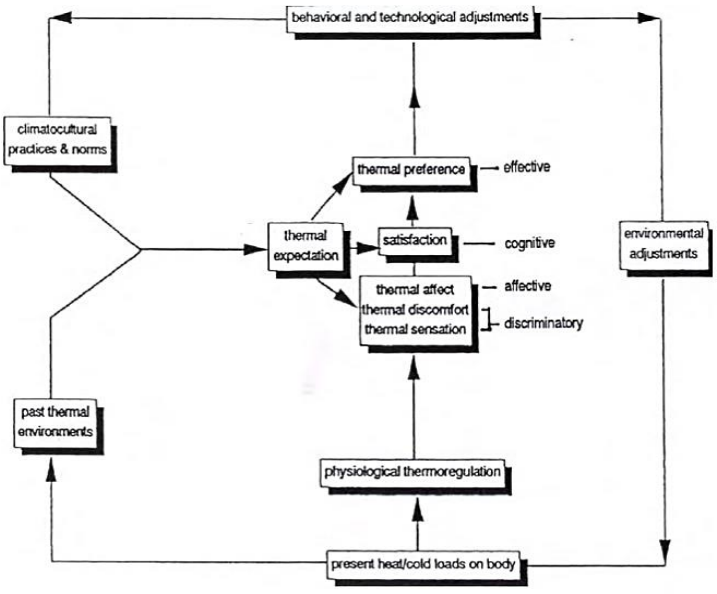


Figure 3.11: Relation between physiological, psychological and behavioural factors
Source: (Szokolay 2014)

A diagram of adaptive behaviour and thermal perception by Feriadi and Wong (2004) is presented in Figure 3.12. The figure elaborates a process of human thermally comfortable perception due to consequences of thermal adaptation. Thermal satisfaction is found when the current thermal environment, expectation, and preference are met. In contrast, dissatisfaction arises with an absence of adaptive opportunity, which may lead directly to adverse feedback in terms of thermal sensation votes. Human adaptive activities are triggered when perceiving thermal dissatisfaction. If the occupants have adaptive capabilities to adjust environmental and personal factors, such a situation is considered '*Positive Adaptation*'. In this case, outcomes of the adaptations can be categorised based on the successfulness of the actions. Both effective and ineffective adaptions leading to positive and negative inputs affect thermal expectations and preferences, which finally influence thermal comfort evaluation.

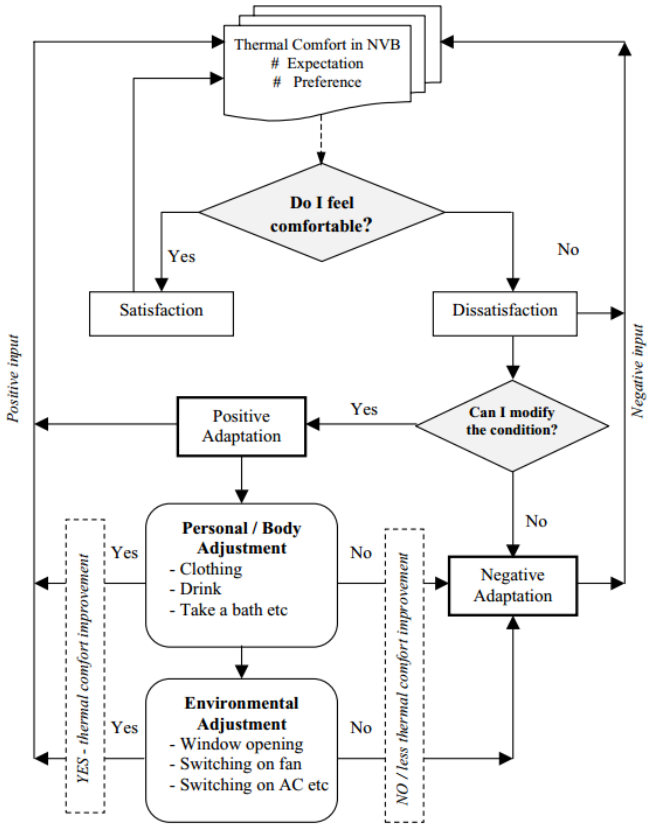


Figure 3.12: Adaptive behaviour and thermal perception

Source: (Feriadi and Wong 2004)

3.5.3.1 *Psychological parameters*

Nikolopoulou and Steemers (2003) discussed psychological impacts on human thermal assessment in outdoor urban spaces. Figure 3.13 describes an interrelation of six psychologically influential factors on human thermal sensation assessment: naturalness, expectation, experience, time of exposure, perceived control, and environmental stimulation. According to the diagram, naturalness is considered independent, while the personal factors (time of exposure, environmental stimulation, and expectation) are clustered and are influenced by the other factors. Each factor is described below.

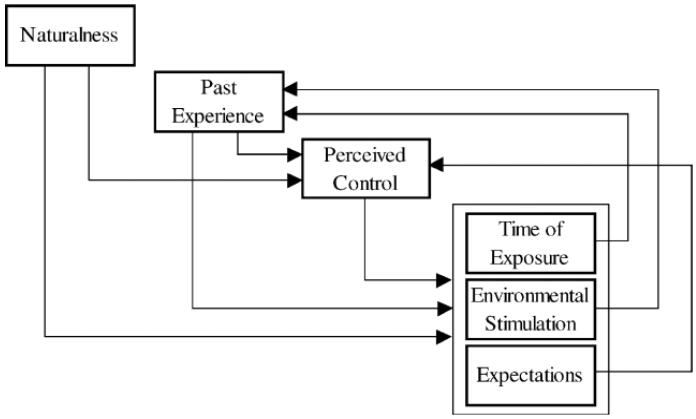


Figure 3.13: Relationship between six psychological parameters
Source: (Nikolopoulou and Steemers 2003)

- ***Naturalness***

As mentioned in the earlier regarding the increased thermal tolerance of occupants in *NV* spaces compared to those in *AC* spaces. Nikolopoulou and Steemers (2003) presented results comparing between the subjects' actual and predicted (*APD* and *PPD*) percentage of outdoor thermal dissatisfaction collected in the UK. The study demonstrated that the isolation of humans from natural conditions leads to a reduction in thermal tolerance, with a noticeable difference between the actual and predicted votes. According to Figure 3.14, the percentage of thermal dissatisfaction calculated by the predictive model representing human thermal sensation in the steady-state condition is as high as 56% and 91%, while actual *APD* votes present a significantly lower percentage at only 9% and 13% in spring and winter, respectively.

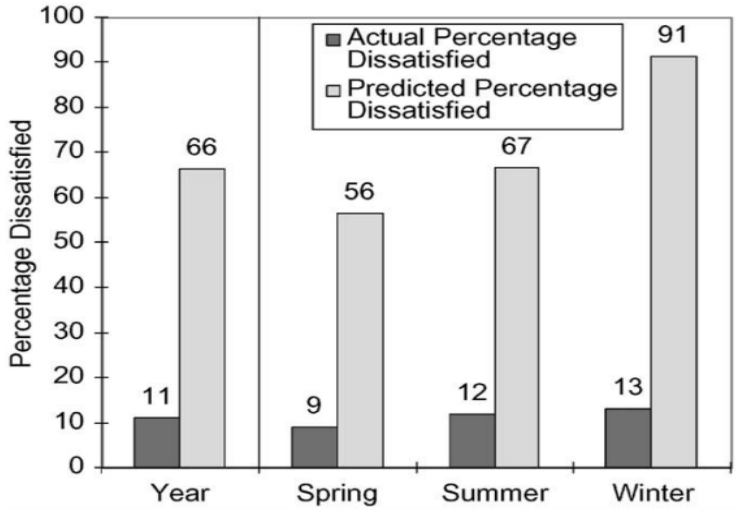


Figure 3.14: Comparison of result of APD and PPD

Source: (Nikolopoulou and Steemers 2003)

- ***Expectations***

Human expectation has a significant impact on thermal sensation judgments. People attach experiences to times and places, which shape their thermal expectations. For example, there are different expectations of variations in indoor temperature in *NV* and *AC* buildings. Users in the former type of buildings might have higher thermal tolerance than those living in *AC* spaces. Seasonal thermal variation might result in undesirable feedbacks, since the occupants might expect and compare experienced temperatures to the threshold of their past experience.

Thermal expectation is also linked to the sense of place. Brager and DeDear (1998) reviewed empirical studies demonstrating differences in thermal expectations in places by comparing occupants' subjective thermal votes in the UK residential and office buildings. The results revealed that the T_n and T_p of the users in residential buildings are lower than those of office users. Besides, two studies focusing on four factors of indoor environment quality (*IEQ*) (air cleanliness, thermal comfort, odour, and noise) conducted in commercial and residential buildings in Hong Kong in 2007 and 2009 found that odour was the most critical factor among a sample of 548 commercial building users in 2007 (Lai and Yik 2007, 2009). Residential building users were mainly concerned

with thermal comfort, indicating the shift in psychological requirements for subjects residing in different spaces.

Expectation also relates to a period of thermal exposure, explained in detail below. Parsons (2003) affirmed the role of expectation and discussed negative impacts of long-term thermal exposure and the influence of expectation on human thermal comfort. He mentioned that when people expect to stay in a room for one or two hours with unpleasant thermal conditions, without environmental controls, they might find that the stimuli are perceived as a threat after five minutes of exposure. Psychological aspects clearly affect thermal comfort votes, and could introduce an element of bias in empirical studies of thermal perceptions. In some situations, an expression of an attitude toward thermal environment might be challenging and complicated to elicit from the respondents, who might not prefer to truly express their sensation, since a better condition than what it is now cannot be expected. Furthermore, a negative attitude toward the current thermal condition might be presented when a better thermal condition is expected. This phenomenon should be carefully investigated if the thermal condition is actually described as comfortable and voted as satisfactory. Expectation also links to *'schemata'* which is later discussed in this section.

- ***Experience***

The physiological model cannot universally explain human thermal perception in all contexts. Non-thermal variables such as climatic, social, economic, contextual aspects influence human thermal perception in non-physiological ways (Brager and DeDear 1998; Knez *et al.* 2009). The adaptive model considers a number of factors existing outside of laboratory, quantifiable conditions. Thermal behavioural adaptation for regaining and maintaining thermal comfort is one of the major focuses of this approach. Consequently, field studies on the suitable thermal environment and human subjective thermal votes and behavioural observation relate to physiological, environmental, and behavioural investigations pertinent to phenomenological epistemology:

> ‘Environment and behaviour research teaches that one’s experience of a place is a multi-variate phenomenon, and a reflection of the degree to which the place contributes to a person’s objectives and expectations’ (Brager and DeDear 1998)

Psychological adaptation is a shift of thermal perception and response caused by personal experiences and expectations (Brager and DeDear 1998). Nikolopoulou and Steemers (2003) mentioned that short-term and long-term experiences can directly affect expectation. Temperature memory in people’s experience affects their expectations and thermal assessment, alongside instantaneous or momentary reactions when facing experienced thermal conditions. For example, drinking a cool beverage or changing clothing is an action associated with fast metabolic rates and overheating, while finding shade is an innate response to high solar radiation.

While psychological adaptations may appear obvious, there are many pitfalls and misunderstandings in this area of research. A review of Nikolopoulou and Steemers (2003) by Knez *et al.* (2009) agreed that memory in cognitive psychology is linked to human experience, which relates to schemata and memory, but they cautioned the misleading conflation of psychological terms in referring to short-term and long-term experiences. They noted that in contemporary cognitive psychology there is a process of information interaction between humans and their environments as a process of *a* ‘*chain of information*’. This concept relates to the detection of environmental stimuli from the environment by the human sensory system and conscious experience. The sensory system receives stimulating information from the environment, and converts this into chemical energy for transfer to the central nervous system. The received data is processed and interpreted in the brain and mind. The details of memory types are further discussed and clarified later in this chapter.

- ***Time of exposure***

Period of thermal exposure also mediates human thermal comfort. In undesirable thermal conditions, people may decide an acceptable period of

stay, and some thermal discomfort situations might not contribute to negative feedback if the length of exposure is acceptable. For example, in a short exposure when moving from a warm car to a building in winter, outdoor cold weather may have caused thermally uncomfortable, but this situation may be thermally acceptable (Nikolopoulou and Steemers 2003).

- ***Perceived control***

Perceived control, which is occupants' perception of personal or environmental controllability, can affect thermal comfort judgment. Nikolopoulou and Steemers (2003) observed people's behaviour and *APD* in outdoor urban spaces. The ones who have free choices of activity might feel more comfortable than those waiting for someone. In this regard, it can be justified that when people have to maintain their location, they might feel they lose their perceived control, whereas those who decide to stay (of their own volition), they might have a greater ability of relocation and a variety of activity options.

Paciuk (1990) discussed a distinction between available, exercised, and perceived controls which are the adaptive opportunity, behavioural adjustment, and expectation, respectively. In this case, users' perceived control is also considered a kind of expectation which can alter the thermal environmental assessment of subjects. Those who have a higher level of personal and environmental controls may tend to have a more positive attitude toward the thermal environment than those with lower or absent controllability.

For example, users in *HVAC*-centralising spaces may have lower thermal tolerability than those living in *NV* or *FR* spaces with the availability of environmental controls. Besides, the *AC* space users may be highly sensitive to slight thermal fluctuations. The users in *HVAC*-centralised spaces with a limited level of personal control may expect a stable and uniform thermal comfort state from the system. If *HVAC* systems fail to meet their expectations, there is a high possibility of receiving users' negative feedback on thermal conditions.

Furthermore, Leaman and Bordass (1999) found that sense of perceived control decreased according to the number of occupants in shared spaces. Luo *et al.* (2016) mentioned that comfort perception is influenced by the level of perceived control, which can lead to a positive or negative thermal sensation vote, and suggested that the adequate provision of environmental controls should be promoted to provide users with more adaptive opportunities to reduce thermal complaints from occupants. Moreover, Indraganti and Rao (2010) investigated the benefit of space ownership on thermal comfort and found that the owners may have a superior sense of perceived control in terms of modifying their paces freely.

- ***Environmental stimulation***

As mentioned previously, building users in *AC* spaces may expect uniform and stable indoor thermal conditions, but a variation in thermal conditions may not always contribute to a detrimental impact on building users' thermal sensations. Although the constant thermal state may provide users with constant thermal comfort indoors, such a monotonous thermal environment may lead to boredom in thermal sensation. Nikolopoulou and Steemers (2003) elaborated different thermal preferences that motivate users to relocate to spaces to experience different thermal stimuli. In this regard, outdoor environmental stimulation encourages users to stay outside buildings for fresh air, different thermal stimuli, and sunshine. Besides, conditions that are either relatively cooler (-1 *ASV*) or warmer (+1 *ASV*) than indoor spaces are required to create contrasting thermal sensation outdoors. Such different thermal requirements encourage building users to change the atmosphere to escape from the monotonous thermal environment of indoor spaces.

3.5.3.2 *Psychological aspects of adaptive thermal comfort*

Brager and DeDear (1998) mentioned experience, expectation, and perceived control as relevant psychological, mediating factors in human thermal perception. Nikolopoulou and Steemers (2003) described psychological adaptation in terms of the six contributing mental factors adumbrated in the previous section. The article also discussed the concept of a '*schemata*', a plan

determining an alternative solution to problems learnt from experiences. Both long-term and short-term experience are influenced by human memory and perceptions, and these psychological aspects are considered influential factors on users' future expectations in thermal situations. The role of memory and the schematic model of Nikolopoulou *et al.* (2001) and Nikolopoulou and Steemers (2003) were corroborated by Knez *et al.* (2009). However, Knez *et al.* (2009) detected some erroneous discussion in the report of Nikolopoulou *et al.* (2001) when linking the report of correlation of the neutral temperature and the past week air temperature to the short-term memory. Thus, there is a misunderstanding issue about psychological adaptation in the adaptive research field which should be reconsidered and discussed.

This section highlights mental factors which are commonly discussed in basic psychology to clarify the terms relating psychologically adaptive process. Sensation and perception are differentiated, since these two words are similar and are sometimes used synonymously in thermal comfort practice, despite the important differences between them. Besides, short-term memory (*STM*), long-term memory (*LTM*), schemata, and past experience are operationally defined, since these words were commonly mentioned in adaptive thermal comfort research (DeDear *et al.* 1997; Brager and DeDear 1998; Nikolopoulou and Steemers 2003; Knez *et al.* 2009).

- ***Definition of sensation and perception***

Sensation and perception seem similar, but in fact their meanings are rather different. Parsons (2003) demonstrated a difference between two thermal subjective terms referring to '*thermal sensation*' and '*comfort pleasure*'; the former is objective, while the latter is subjective.

Schiffman (2001) differentiates those terms in the book '*Sensation and Perception*'. Sensation can be explained as contacts of human organisms and surroundings. Human eyes, for example, receive light from the environment, transforming light energy into bioelectric signals as a code transmitted to the brain. Thus, it can be seen that sensation relates to physiological activities and

environmental stimuli. In contrast, perception is further defined as a psychological process integrating various aspects as one phenomenon. Meaning, context, judgement, past experience, and memory are considered contributing effects.

For instance, an auditory system of a sample is stimulated when the eardrum is vibrated from the external sound. Such a physiological process instantly leads to a sensation of loudness and recognition of the tone quality. Concurrently, perception of the melody of that sound which has integrated the meaning of sensation and object awareness is presented. In reality, sensation and perception are unified, as they always immediately coincide. To separate these experiences, laboratory study is required to control various variables of those inherited by perception (Schiffman 2001). Thus, it is crucial to set clear definitions when mentioning these two terms.

- ***Short-term memory (STM) and long-term memory (LTM)***

Based on the multi-store model of memory purposed by Atkinson and Shiffrin (1968), human memory comprises three types: sensory memory, *STM*, and *LTM*. This model, which is mentioned in the adaptive model of thermal comfort, clearly differentiates *STM* and *LTM*, while sensory memory state works as a buffer for received stimuli from the five sensory receptors, by consciously or unconsciously seeing, hearing, smelling, tasting, and touching. It is the ultra-short-period of precise memory with brief information that can be selectively either ignored or perceived. Useful information can be selected by the brain and processed to a second stage, *STM* (McLeod 2007a).

In the *STM* stage, information of environmental stimuli is sent to particular '*modality-specific stores*'. This type of memory has a limited capacity and period to hold information (approximately 12 seconds), similar to a small container for memorising information, but it is fragile and prone to forgetting when encountering distraction. When this memory is full, a displacement of information occurs, while rehearsing or repeating information can maintain information in this storage. Besides, the rehearsal is the most significant

process to transfer the short-hold information into the *LTM* (Eysenck 1994). Baddeley and Hitch (1974) developed the theory of '*working memory*' to replace *STM*, which they considered too cursory. McLeod (2012) noted that the *STM* working model seems to organise received information according to different processing systems rather than channelling all data into a single processing platform, as described by *LTM*.

The working memory comprises three main aspects: a central executive, inner voice and ear (phonological loop), and inner eye (visuospatial sketchpad). The central executive monitors and coordinates two sub-ordinary functions, phonological loop and visuospatial sketchpad (Figure 3.15). The received information is allocated to the proper processing platform and linked to *LTM*. In case of a conflict caused by the inner ear and voices, the central executive leads attention and prioritises only one specific event for a human to focus on. It can be seen that the working memory does not store information while reacting as an information organiser, unlike the phonological and visuospatial sketchpad, which are capable of storing data.

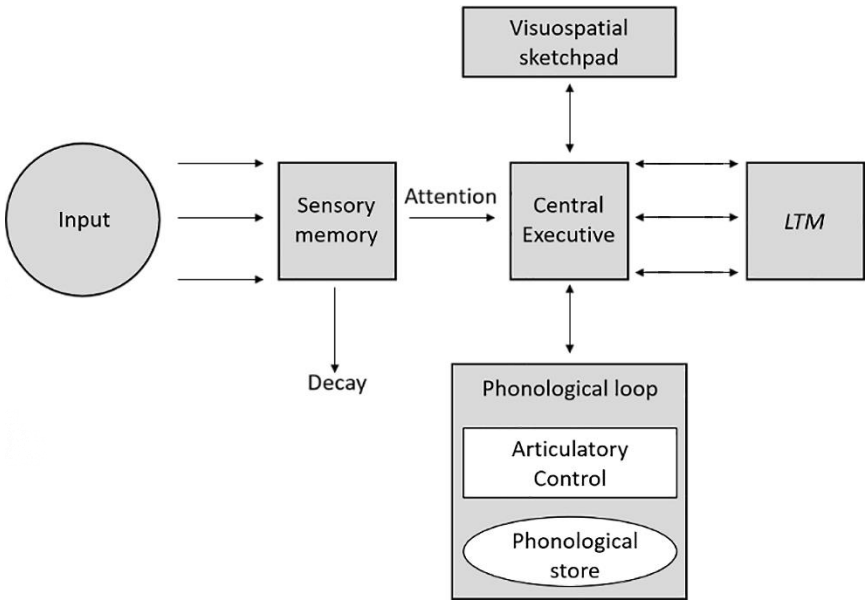


Figure 3.15: Diagram of working memory process of data store

Source: (McLeod 2012)

Visual and spatial data are considered as the visuospatial sketchpad, which allows human to realise their own position and objects in the environment, such

as the position of chairs or desks, enabling the fundamental perception necessary for survival. This visual information is transferred to *LTM*. For example, if a subject is asked to imagine and count the number of windows at the front façade, this task is achievable, thus it can prove a link between the working memory and *LTM*. On the other hand, the phonological loop deals with sounds, languages, and written materials. This loop comprises two sections, the phonological store and an articulatory control process. The former remains information in the mind, as an inner ear to retain information as a form of spoken language. Written materials, on the other hand, are transliterated into articulatory code and transferred to the phonological store. Furthermore, the articulatory control processes an inner voice that performs as a tool to help humans to maintain memory. The information received by an inner voice/ inner ear is rehearsed as a tape loop. As long as the information keeps repeating, it can be maintained in memory, such as repeating a set of digits comprising a phone number.

As mentioned earlier, this working memory model indicates two processing platforms to store the information, by visual and verbal materials, which operate separately and independently. It should be noted that processing both systems may not be easily achievable and may result in a reduction of storing ability. The information held in the working memory is also linked reciprocally to *LTM* to store permanently the information or to obtain solutions to current tasks.

LTM is closely related to the psychological phenomena associated with past experiences, including backup information providing human perspective on phenomena in the external world. *LTM* is an unlimited storage media which can maintain data for an extended period. Information interpretation is an individual perspective based on knowledge and past experience, which is the crux of *LTM*. This kind of memory can also be divided into two sub-categories, '*declarative*' and '*procedural*' knowledge, which were considered in the thermal comfort study of Knez *et al.* (2009).

The former type, which can be simply expressed as knowledge of '*know that*', is related to memories of facts. For example, when we know that the capital city

of France is Paris, we are consciously recollecting in a process of *LTM* information retrieval. On the other hand, procedural knowledge pertains to '*know how*', which involves skill-required performances such as sport and typing skills (Eysenck 1994). Eysenck (1994) mentioned that while practising a new skill, humans might rely on declarative knowledge as information learning; after that, it will be replaced by procedural knowledge.

Tulving (1972) categorised *LTM* into '*episodic*' and '*semantic*' memories. The former type is responsible for recording personal data such as the past involved events or personal biography, which also link to time sequences. Semantic memory registers knowledge such as language or words. However, this memory type cannot record time-related longitudinal information. Both memory types are interdependent, and information is linked rather than working individually.

- ***Schemata***

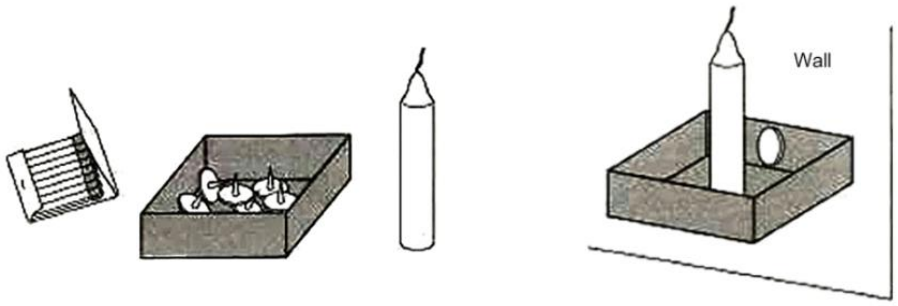
With regard to *LTM*, information is organised in different forms. One form known as '*schemata*' was mentioned in thermal comfort studies by Knez *et al.* (2009) and Nikolopoulou and Steemers (2003). It is a data package informing humans how to behave when engaging in different situations. Besides that, the schema includes '*expectation*' connecting to different occasions. Knez *et al.* (2009) raised an example describing that '*schemata*' processes how we will behave when entering into a restaurant, while '*expectation*' allows us to expect how we should be treated. Thus, schemata are an action guidance and event interpretation in the world, based on past accumulating information. It may, moreover, influence human understanding and perception. This psychological factor is also considered one kind of attitude linked to human environmental evaluation (Eagly and Chaiken 1993).

- ***Past experience***

The term of past experience was widely mentioned in adaptive thermal comfort studies as an influential factor in psychological adaptation (DeDear *et al.* 1997; Brager and DeDear 1998; Nikolopoulou and Steemers 2003; Knez and

Thorsson 2008; Knez *et al.* 2009). In basic psychology, experience is memorised data of a problem-solving process that humans have accumulated, known as a '*positive transfer effect*'.

Although experience generally helps people solve problems, it can also reduce their problem-solving abilities, known as '*negative transfer effect*'. Eysenck (1994) mentioned a study of Duncker (1945) whose experiment asked participants to complete the task of mounting a candle on a wall by using the instruments provided, comprising a box with tacks and a set of matches, as shown in Figure 3.16 (A). The solution to this problem is to use the box as a platform to fix on the wall and then mouth the candle on it, as presented in Figure 3.16 (B). This seems easy; however, according to the results, the participants reported that the task was rather difficult. Duncker justified this phenomenon with the theory of '*functional fixedness*', which is attributed to participants' past experience regarding the functions of the given object. In this case, they might think that objects have their narrow functional applications.



(A) Eysenck's task (B) Expected completed task

Figure 3.16: Provided materials in Eysenck and expected completed tasks

Source: (Duncker 1945)

Eysenck (1994) mentioned that past experience could also interrupt the processes of thinking while solving problems, a phenomenon known as the '*Einstellung Effect*'. He referred to Duncker's (1945) '*water-jar problem*' experiment, which concluded that 95% of inexperienced subjects might solve a problem more easily and rapidly than those who have passed a series of more complex problems, while only 36% of experienced subjects could pass the test. This suggests that past experience creates a mechanised state of mind that

can confound analytical and critical reasoning skills, as participants resort to accustomed behaviours and cognitive patterns rather than solving the problem at hand *per se*. However, it should be noted that experience is generally helpful for solving problems, and it is usually advised that solving a new problem is best attempted by drawing on previous relevant experience of similar problems (Eysenck 1994).

According to Knez *et al.* (2009), psychological adaptation is not a bottom-up psychological process, driven by experiential data of the outcomes of perceptions constructing cognition or stimuli directly, subsequently causing actions. In contrast, they posited that it is a top-down, holistic process of human thermal perception relating to *LTM*, where experience and expectation are included. Such a perception is driven by cognition, experience, expectation, knowledge and entire available information, rather than a single separated or partial data. For instance, reading whole sentences of handwriting create more understanding than reading a single word due to contextual factors that assist the reader in understanding (McLeod 2007b), or humans can walk in a dark room without accident due to their memory of the room layout.

Knez and Thorsson (2006; 2008) mentioned an effect of perspective on human environmental assessment by providing examples of '*collectivistic*' and '*individualistic*' points of view. The former attitude was posited based on their studies of the impacts of cultural differences between Japanese and Swedish cultures, which were reflected in the thermal perceptions of subjects. On the other hand, the individualistic aspect discusses the impact of personal environmental perspective. The analytical results presented that emotions and perceptions differ between urban-type people satisfied with human-made environments and a nature-type people who prefer open-air spaces, sea, forests, and non-manmade surroundings. This difference, consequently, leads to a variation in thermal comfort evaluation.

It can be seen that thermal perception is not a consequence of thermal or physiological factors, as discussed in the steady-state model, rather it is more complex and relevant to human cognition and contextual factors. Thus, based

on this perspective, Knez *et al.* (2009) proposed a conceptual model as depicted in Figure 3.17, which shows a process of human assessment of outdoor weather. The model presents direct and indirect effects which influence the thermal assessment of humans. According to the figure, indirect moderator or mediator effects include personal, cultural, and situation factors located in-between variables of place and human response. However, the researchers mentioned that this conceptual diagram is in an early stage should be further refinement is required. Besides, the degree of psychological influences of outdoor place on human thermal basements are still obscure, and need further development.

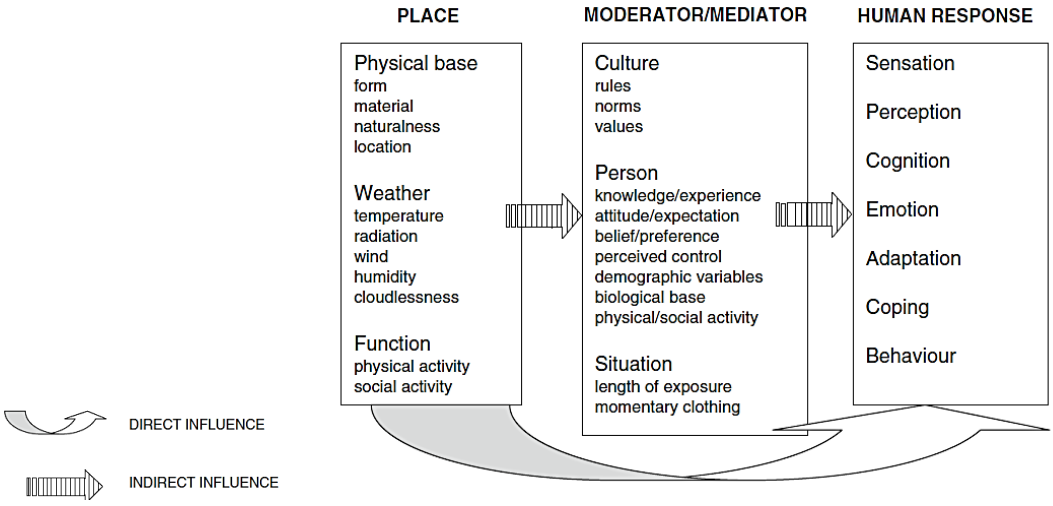


Figure 3.17: Conceptual model of thermal comfort outdoors

Source: (Knez et al. 2009)

3.6 Thermally adaptive opportunity and constraint

Human thermal adaptation can perform under '*adaptive opportunity*' and '*adaptive constraint*', which can encourage or limit adaptive activities (Brager and DeDear 1998). For example, Parsons (2002) discussed that when subjects consider adding more body insulation value, their *CLO* adjustment is based on clothing design and acceptability. On the other hand, a deduction of *CLO* is limited under modesty and acceptability, which may vary according to cultural and organizational conditions. This demonstrates that the capability of thermal adaption may be limited and may not reach its expected potential due to these

non-thermal factors. Thus, the adaptive opportunities and constraints should be carefully observed and considered.

Brager and DeDear (1998) discussed four main aspects which can encourage and limit thermal adaption, which are climate, economics, building design, and organisational aspects. A climatic difference seems to lead to a variety of manifestations of human thermal adaptability. In mild outdoor temperatures, buildings may possess a greater adaptive opportunity to allow their users to stay in thermal comfort indoors, rather than those in the extreme climates where buildings are designed with tight controls to ensure the climate protection from the harsh environment.

The suitability of architectural design is a major factor in human thermal adaptability. Buildings without operable windows and doors, poor layout, and the absence of solar controls might limit occupants' adaptive opportunities. In addition, organisational and social norms such as social agreement, etiquette, or rules and regulations can impact upon users' way of life and behaviour. For example, inflexible uniform or long-period activity without a break may limit thermal adaptability and lead to negative thermal perceptions (Brager and DeDear 1998). Nicol and Humphreys (1973) underscored the cultural and organizational constraints on thermal adaptation by raising the example of the extreme constraints of soldiers on parade; in this situation, adjustments of personal or environmental factors to maintain or regain thermal comfort are out of their control because of self-discipline. Thus, they might tend to suffer from uncomfortable circumstances due to loss of self-control. Aljawabra and Nikolopoulou (2010) agreed, and mentioned that cultural influence might lead to limitations on human behavioural adaptation, which consequently affect their thermal perceptions directly.

3.7 Other non-thermal factors in adaptive model research

Apart from investigating T_n for subjects in actual environments, non-thermal factors excluded from laboratory models were observed and investigated in adaptive thermal comfort research that performed as mediators or moderators,

playing a crucial role in varying human subjective thermal votes (Knez *et al.* 2009). Thus, field studies allow researchers to explore the complexity of real environments and the diversity of subjects to investigate unexplored non-quantifiable factors ignored by laboratory studies, such as socioeconomic and demographic aspects of subjects.

Regarding socioeconomic factors, Shooshtarian (2015) conducted a literature review on the influence of socioeconomic factors on thermal comfort, including aspects of culture, lifestyle, climate, geographical zones, and educational background, and economic aspects including socio-economic status, job condition, level of technology availability, economic status, state of health, and the construction specification of their accommodation. However, he noted that although the studies revealed some pieces of evidence of interrelations between the socioeconomic variables and human subjective thermal assessment, the actual impact of the factors on thermal comfort is not well understood.

For economic issues, Indraganti (2010) reported that the more affluent group of subjects in residential buildings in India might complain that their space is slightly warm compared to people in the same condition from lower income groups. Moreover, Indraganti and Rao (2010) also highlighted that low-income people might have 2 K higher thermal acceptability than those in higher economic classes.

Besides, initial and operational costs for cooling or heating techniques might influence occupants' thermal adaptability and acceptability, especially for low-income people who are the largest population in developing countries. Indraganti (2010) reported that economic resources determine human's thermal flexibility. Higher income occupants might present a narrower range of thermal acceptability due to their affordability of highly-consuming-energy technologies to avoid experiencing thermal dissatisfaction. In this case, this habit may cause '*thermal indulgence*', which may result in highly-energy dependence among *AC*-accustomed occupants. The study also discussed the majority of people's thermal comfort in developing countries where the *AC* system is domestically

unaffordable. This financial issue seems to be an ignorable issue, which may decrease users' thermal comfort.

However, the unaffordability of such an active-cooling technology may not actually limit satisfied perceptions toward the current thermal environment. Indraganti (2010) found that low-income users might have an excellent capacity to withstand uncomfortable environmental conditions without thermal satisfaction. In this case, they may have wider thermal acceptability due to their economic constraints. This finding highlights a different tolerance factor affected by sociological aspects.

Educational level is also mentioned in the adaptive approach. Yamtraipat *et al.* (2005) conducted field research in Thailand in which 1520 data samples were collected. The obtained data were clustered into three groups based on their levels of education as scholar, bachelor, and postgraduate levels, sub-categorised by ventilation backgrounds of *AC* and non-*AC* groups. The *AC*-acclimatised subjects had lower T_n than those acclimatised to non-*AC* spaces. In this case, highly-educated respondents (post-graduate level) whose background was in non-*AC* spaces had lower T_n than others, although they are supposed to be more responsible for energy consumption and concerned about sustainability issues in global climate strategy and economic theory on sustainable development.

Haghighat and Donnini (1999) reported that job satisfaction could also affect thermal acceptability. Similarly, Melikov *et al.* (2005) agreed with this, based on the data samples collected from 227 subjects in 10 office buildings. The analytical results revealed relationships between indoor thermal acceptability, job satisfaction, and relationships between the subjects and supervisors and colleagues. Subjects who were satisfied with their jobs might have better thermal acceptance and less complaints about their office environments, compared to those with higher working pressure.

Concerning gender and age factors, Indraganti and Rao (2010) presented a statistical analysis showing a low correlation (R = -0.08) between thermal

sensation and gender. However, they noted that women might prefer a slightly warmer environment and require a higher thermal set point. Parsons (2003) also mentioned an insignificant impact of the menstrual cycle on thermal comfort, despite an internal process of the female body. Moreover, a literature review on '*Thermal Comfort and Gender*' by Karjalainen (2012) concluded that gender exerts a minor effect on human thermal comfort, but based on the analytical results of the review, 50% of the female subjects reported more thermal dissatisfaction compared to males in identical thermal conditions.

Furthermore, age and thermal comfort present a low correlation, and it seems that the age factor may not be a thermally influential factor. Fanger (1970) found a small difference of T_n between Danish college students and the Danish elderly, and he reported that the latter might require warmer temperatures due to lower *MET*. Langkilde (1977) presented a literature review investigating T_p among 80-year-old respondents. The report presents an agreement with the previous study confirming that age has an insignificant effect on thermal comfort.

Besides, the age factor is included in CIBSE Guide A (Humphreys and Nicol 2006) mentioning an unnoticeable difference between the young and elderly in thermal comfort judgment. Thus, it can be seen that the age factor seems not to be a direct factor influencing human thermal comfort, while ageing may limit human adaptive opportunities, which as a result may decrease the degree of thermal comfort.

3.8 Thermal comfort studies in Thailand

The results of investigations of thermal comfort in Thailand have been published and disseminated online and in hard copy, focused on different building types and groups of people to explore suitable thermal comfort for local conditions. This section discusses Thai adaptive thermal comfort studies published from 1990 to 2015.

Busch (1990) conducted thermal comfort research in four Thai office buildings with 1,100 office workers in both *AC* and *NV* buildings. The results indicate that T_n for the users was 25°C, with an acceptable temperature range from 22°C to 30.5°C on the *ET* index. Such a wide range of thermal acceptability of the subjects shows an opportunity for energy conservation in this type of building. A thermal comfort field study in Bangkok by Jitkhajornwanich (1997) explored architectural elements rather than building types, particularly transitional spaces such as canopy, life lobby, and building circulation in winter during December to January 1996-1997. A total of 593 respondents were categorised into four groups, of which the first two were those currently living in indoor spaces treated by either *AC* or *NV* systems. The last two groups were the subjects who were now outside, and who had just left either *AC* or *NV* spaces.

The results revealed that the expectation of T_n of the subjects was 26.7°C, while the actual T_n was found to be 27.1°C. Such a difference between these variables could be interpreted in terms of the subjects in this study preferring a cooler temperature for their current condition. Thermal acceptability found in this group of the subjects was 25.5°C to 31.5°C. Concerning thermal adaptation from the thermal comfort regain, both groups of subjects in the *NV* and *AC* spaces mentioned that they would increase *CLO* only when they feel cool. In contrast, they might have operated *AC* systems when perceiving warmth, if it was available. However, it is reported that if the *AC* rooms were too cold, the users may have regained their thermal comfort by increasing *CLO*, rather than adjusting the temperature set point.

Also for Bangkok, Khedari *et al.* (2000) plotted the *DBT* of 15 years of climatic data for the city and compared the results with the recommended ASHRAE comfort zone in a psychrometric chart as Figure 3.18 presents. According to the analysis, three issues which relate to human thermal comfort in Thailand are discussed; (i) the overlaid climatic data on the chart presents that the local climate was consistently out of the comfort zone. (ii) Furthermore, they mentioned that an evaporative cooling method might not be suitable for this region due to high *RH*. (iii) Besides, the majority of monthly average daily

temperature is lower than the human core temperature (37°C). This demonstrates that natural ventilation when air temperature is lower than 34°C is considered as a useful cooling technique in this country.

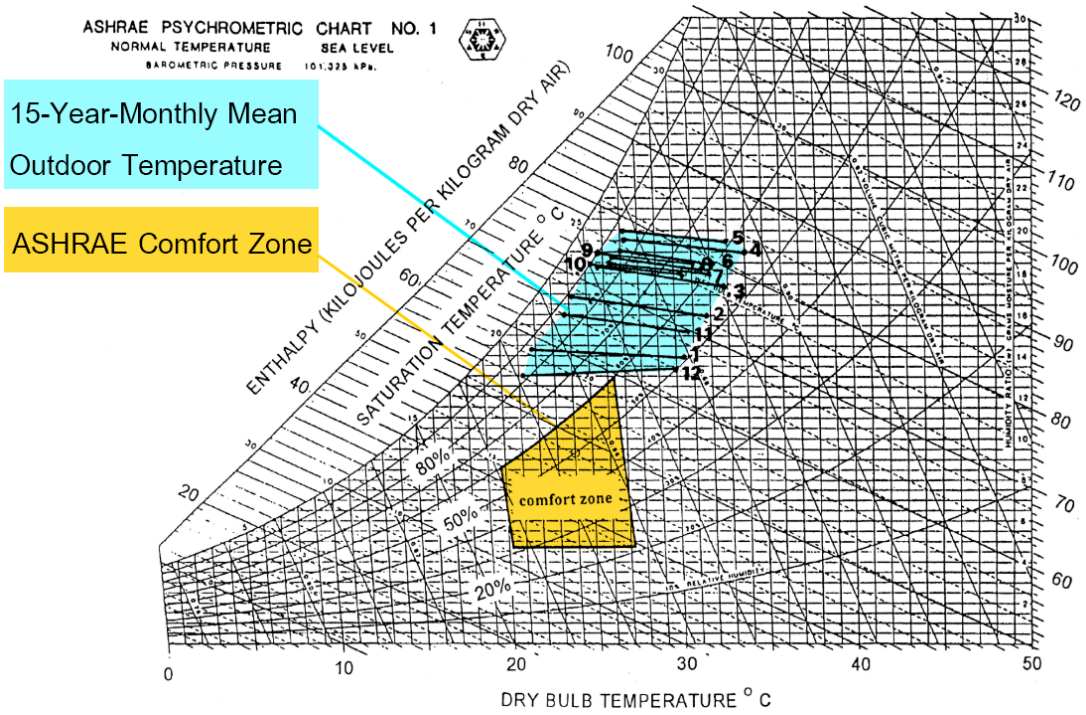


Figure 3.18: ASHRAE thermal comfort zone with 15-year outdoor T_a of Thailand
Source: (Khedari et al. 2000)

Thus, Khedari *et al.* (2000) investigated the impact of air movement on human thermal comfort to establish a '*Thailand ventilation chart*' for working spaces and classrooms. A total of 288 respondents participated in the study, which took place in a *NV* classroom with six electrical desk fans located at the rear of the subjects as Figure 3.19 presents. The electric fans were set to generate 0.2 m/s, 0.5 m/s, 1.0 m/s, 1.5 m/s, 2.0 m/s, and 3.0 m/s of *v*, which is the maximum *v* that does not cause a disturbing noise. The location of the fans was claimed the most suitable point and least disturbing to the respondents' activities. The room temperature and *RH* varied from 27.5°C to 35.4°C and 50% to 78%, respectively. Moreover, the scale used in the study was based on the scales applied in earlier research (Fanger 1970; Rohles and Nevins 1996). Furthermore, they created a new asymmetric thermal sensation scale ranging

from -2 ('*Cool*') to 4 ('*Very hot*'), since the local people might hardly feel cool in this local climate (Khedari et al. 2000).



Figure 3.19: Set up of the classroom for the experiment

Source: (Khedari et al. 2000)

Finally, the ventilation comfort chart shown in Figure 3.20 illustrates six lines of *v* in different *RH* and *DBT.* It can be seen that the higher *v* is, the higher the temperature of the environment people can tolerate. In this regard, they claimed that in non-*AC*-equipped spaces, thermal comfort perception could be found when T_a is over 34°C, but if *v* is over 3.0 m/s this might cause disturbing noise due to airflow.

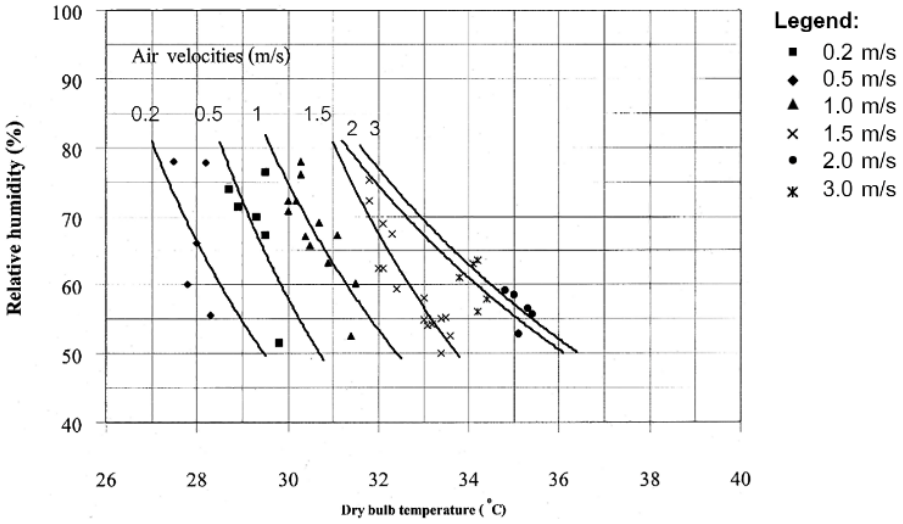


Figure 3.20: Ventilation comfort chart

Source: (Khedari et al. 2000)

A large scale of thermal comfort survey in Thailand was conducted by Yamtraipat *et al.* (2005). A total of 1,520 subjects in *AC* spaces from different climatic characteristic nationwide were examined to explore additionally unquantifiable factors which may influence human thermal comfort, and to create a thermal comfort database and standard set point for building in each part of the country. The researchers categorised the Thai climate into three and four types based on outdoor T_a and *RH* ranges, respectively. Finally, three zones out of the four *RH*-clustered zones were selected as case studies: H1 for Chaingmai, H2 for Bangkok and Mahasarakham, and H3 for Prachuabkirikhan. The results indicate that the maximum acceptable temperatures for zones H1, H2, and H3 were 26.0°C, 27.4°C, and 26.4°C, respectively, while national thermal acceptability is 26°C, with a 50% to 60% *RH* range. Subjects might feel comfortable due to high humidity only when the temperature is at or below 26°C to 27°C. In addition, the highly educated respondents who are acclimatised to *AC* spaces might require approximately 1°C lower temperatures than general users. Although T_p was identified as 26°C, the subjects sometimes set their room temperature lower than their preference.

Rangsiraksa (2006) conducted a thermal comfort study in residential and educational buildings in Bangkok for a sample of 1,377 participants' thermal sensation votes based on ASHRAE and McIntyre scales. The samples were clustered into three groups of age ranges: 18 to 24, 25 to 29, and 60 to 69 years old. The experiment asked the respondents to sit still for 15 minutes for acclimatisation before filling out the questionnaire. The results indicate that users' T_c for *AC* spaces was 25°C with a 90% acceptable thermal range from 22.5°C to 27.5°C. In contrast, T_c of the subjects accustomed to the *NV* spaces was 28°C, with the upper and lower limits of 90% thermal acceptable range of 25.5°C and 30.5°C, respectively. The results showed that the elderly preferred warmer environments than the young. It was also concluded that building type differences might not affect thermal comfort votes, while space-ventilating systems such as *NV* and *AC* seem to play a significant role in subjects' thermal comfort. Additionally, the study found that gender does not affect thermal comfort.

A thermal comfort field survey was also conducted in vernacular architecture by Jitkhajornwanich (2006), who investigated a comfort zone for people living in traditional shophouses. The houses are located in the vernacular context by the river, encompassed by bamboo trees and designed with a private terrace. A total of 1,322 data samples were collected in the summer and monsoon seasons. The environment variables measured comprised T_a, *RH*, and *v*, while *MET* was assumed to be constant at 1.0. The majority of the subjects (65%) were aged in their 40s, and 45% had a mean *CLO* ranging from 0.20 to 0.29.

The questionnaire applies both thermal comfort and sensation scales, including thermal preference and acceptability. Finally, the results show that comfort temperature ranges from a minimum of 25.6°C to a maximum of 31.5°C, with 62.2% to 90.0% *RH*. According to the results, although the majority of the survey participants may have voted on the warm to the hot side of the sensation scale, they inversely voted moderately comfortable and expressed that the current thermal conditions were comfortable and acceptable. On the other hand, when asked about thermal preference, it seems that they preferred to live in cooler environments. Moreover, a new comfort zone based on a classic Olgyay Biometric chart was devised based on their responses, as presented in Figure 3.21.

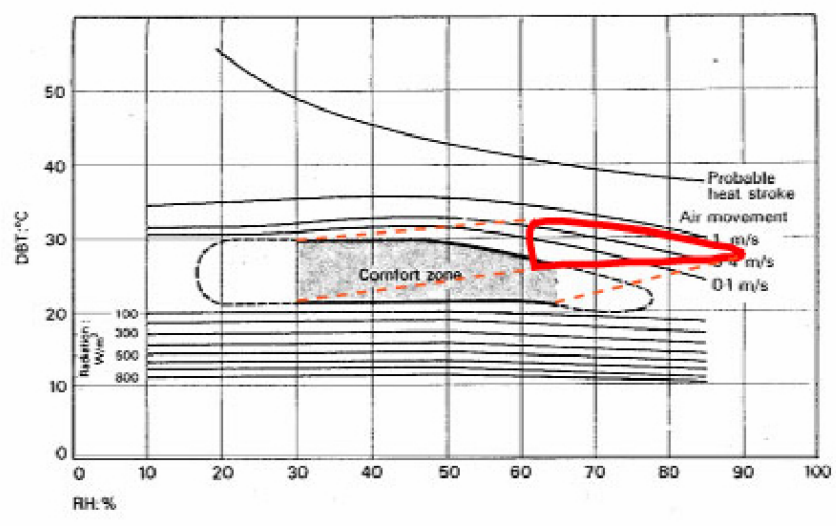


Figure 3.21: New comfort zone based on a classic Olgyay biometric chart

Source: (Jitkhajornwanich 2006)

Atthajariyakul and Lertsatittanakorn (2008) examined the effects of *v* in *AC* spaces on thermal comfort in Thailand. Their results revealed the benefit of small fans in improving personal thermal comfort in *AC* spaces. The experiment was conducted in a test room with dimensions of 2.5 m width, 3.5 m length, and 2.5 m height. The room temperature was supplied by 12000 *BTU* split-type *AC* systems and the temperature was changed hourly from 25°C to 26°C, 27°C, and 28°C. Moreover, the room ventilation was assisted by three small 15 cm-diameter propeller fans located on the desks, producing *v* of 0.2 m/s, 0.5 m/s, 1.0 m/s, 1.5 m/s, and 2.0 m/s. A linear regression analysis was used to analyse the data, and finally, an equation of *PMV* influenced by *v* and indoor temperature was developed (Eqn 61). The result shows that the subjects were accustomed to high *v* (3.0 m/s). Moreover, when *v* was elevated from 0.2 m/s to 0.5 m/s, 1.0 m/s, 1.5 m/s, and 2.0 m/s, T_n for this group of subjects increased from 26.0°C to 26.6°C, 27.4°C, 28.3°C, and 29.2°C, respectively (Figure 3.22).

$$PMV = 0.4444T - 0.7862v - 11.4157 \qquad \textit{Eqn 61}$$

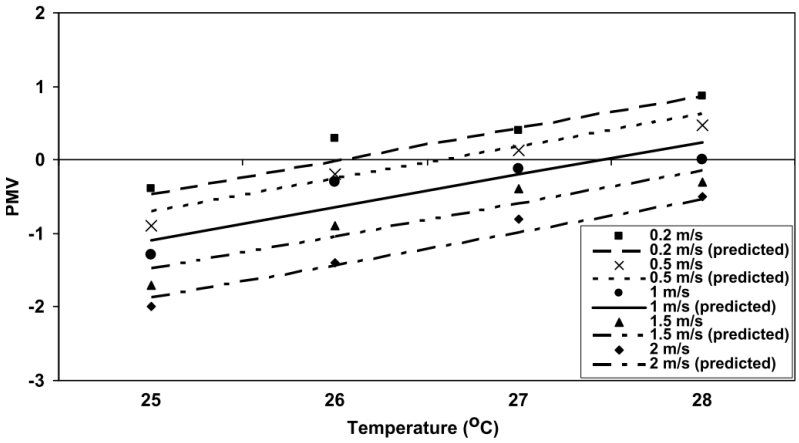


Figure 3.22: Thermal sensation vote in a fan-assisted AC room

Source: (Atthajariyakul and Lertsatittanakorn 2008)

Later, Puangmalee *et al.* (2015) conducted a study of thermal comfort in a climate chamber with 640 Thai university subjects. The dimensions of the experimental room were 8.0 m width, 9.0 m length, and 3.0 m height. The room T_a was conditioned by two split-type units of a 40,000 *BTU-AC* system. Three

mean *v* values were applied (0.5 m/s, 0.7 m/s, and 0.9 m/s) with four different magnitudes of T_a (25°C, 26°C, 27°C, and 29°C). Six measuring instruments were located in the room, as Figure 3.23 illustrates. The results show that T_n varies according to the current *v* of the room. In this case, when average *v* elevated from 0.5 m/s to 0.7 m/s and 0.9 m/s, the subjects' T_n shifted from 27.6°C to 28.0°C and 28.5°C, respectively. Moreover, the study recommended a method for energy conservation by changing the indoor temperature set point from 25°C, which is generally the default point for mechanically controlled systems in Thai buildings, to 28°C, under a *v* range from 0.5 m/s to 0.9 m/s.

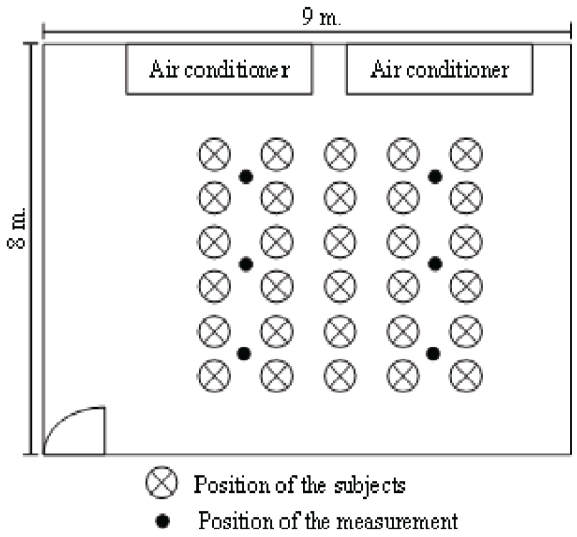


Figure 3.23: Instrument setup and room dimensions
Source: (Puangmalee et al. 2015)

Srivanitand and Auttarat (2015) conducted a thermal comfort research in urban outdoor and semi-outdoor spaces in Chiang Mai province with 296 data samples. The result shows that the subjects in the semi-outdoor areas seemed less accepting of high temperatures than those staying outdoors. When they were in outdoor and semi-outdoor spaces, 28.97% and 26.83% of the respondents voted '*Neutral*' (ASV = 0). Besides, T_n values in physical equivalent temperatures (*PET*) index found in this the study were 27.1°C and 28.5°C for outdoor and semi-outdoor spaces, respectively. Moreover, a range of 80% thermal acceptability of the subjects in semi-outdoor spaces is narrower (22.4°C

to 32.0°C) than that of the counterpart outdoor areas (23.1°C to 31.0°C). These results confirmed the differences in thermal requirements of subjects in these different space types.

As discussed above, previous studies generally concluded that there is no significant link between age and thermal comfort (Fanger 1970; Langkilde 1977; Humphreys and Nicol 2006). However, age-related differences in thermal sensitivity were detected in Thailand by Assavavichai *et al.* (2015), who investigated thermal comfort among 100 elderly Thai subjects in both *AC* and *NV* spaces in urban areas of Samutprakarn and Bangkok provinces. The results demonstrated that elderly people have different thermal sensations compared to their younger counterparts. Under a condition of 1.00 *MET* to 2.30 *MET* and 35 *CLO* to 46 *CLO*, the range of T_c found this research was from 25.64°C to 29.25°C, with 52.68% to 66.83% *RH*, and 0.23 m/s to 1.42 m/s of *v.* It should be noted that thermal sensation to hot temperatures does not differ significantly between the elderly and younger people, rather the difference between age groupings pertains particularly to the greater sensitivity to cold among the former, which is likely due in large part to their physical condition (low *MET*). They mentioned that the majority of the elderly subjects of in this survey were not satisfied with the thermal condition of *AC* spaces where they currently lived since the temperature was set according to general people's requirements. A higher temperature than the usual standard set point is recommended for this group of subjects.

Thermal comfort for low-income people is also investigated in Khon Kaen by Nuntasiri and Rasisuttha (2015). The results revealed that T_c ranges varied from 20.7°C to 28.2°C and 23.5°C to 28.2°C when *CLO* values are 1.0 and 0.5, respectively. Moreover, the range could be expanded to 24.2°C to 32.1°C when *v* was 1.2 m/s, and *RH* varies from 43% to 78%. However, the range of T_c for the subjects found in their study covered a higher temperature zone than recommended by the ASHRAE Standard 55 (2010). In the same *v* (0.55 m/s), the study found that T_c ranges of the subjects were 26.2°C to 31.6°C with *RH*

of 62.9% to 82.4% for the monsoon season, and 27.4°C to 30.7°C with 33.4% to 73.9% *RH* for the winter season.

Furthermore, the subjects' thermal adaptation was surveyed. In this context, men might have advantages on exposing more body surface area to the environment, such as being topless when staying at home. In contrast, this solution might not be suitable for women, who may prefer lightweight, ventilated clothing. It is found that they performed sedentary activities, such as sitting or sleeping, and relocating themselves to more comfortable and less dense areas, such as under shading, with better natural ventilation. Besides, the utilization of hand-held fans and electric fans as an environmental control solution was mentioned (Nuntasiri and Rasisuttha 2015).

The investigations of human thermal comfort in Thailand from 1990 to 2015 as critically reviewed in this section are summarised in chronological arrangement in Table 3.2.

Table 3.2: Summary of thermal comfort studies conducted in Thailand from 1990 to 2015

No	Year	Researcher	Ventilation Type	Samples	Research Type	Building Type	Space	Province	Finding	Notes
1	1990	Busch J.F.	*AC* and *NV*	Office workers	Field study	Office building canopies, lifts	Indoor	Bangkok	25°C (T_n) with 22-30.5°C thermal acceptability range	-
2	1997	Jitkhajornwanich K.	*NV*	Various	Field study	Lobbies and circulation areas	Semi-outdoor	Bangkok	27°C (T_n) with 25.5-31.5°C thermal acceptability range	-
3	2000	Khedari *et al.*	*NV*	University students	Field study	Education buildings	Indoor	Bangkok	28°C (T_n) with 0.2 m/s (v) and 34°C with 3.0 m/s (v)	-
4	2005	Yamtraipat *et al.*	*AC*	Various	Field study	Various: educational, governmental and private buildings	Indoor and outdoor	Chaingmai (H1), Mahasarakham (H2), and Prachabkirikhan (H3)	T_c range is 26-27°C. For H1, H2, and H3, the maximum acceptable temperatures are 26.0, 27.4, and 26.4°C. The national maximum acceptable temperature is 26.0°C.	Highly educated and highly earned people may require a higher standard of thermal comfort (approximately 1°C lower).
5	2006	Rangsiraksa P.	*AC* and *NV*	Various	Field study	Residential buildings	Indoor	Bangkok	For *AC* spaces, T_c is 25.0°C with the range of 22.5 to 27.5°C for 90% thermal acceptability. For *NV* spaces, T_c is 28.0°C with the range of 25.5-27.5°C thermal acceptability.	It is found that gender is not an influential factor in thermal comfort.
6	2006	Jitkhajornwanich K.	*NV*	Various	Field study	Residential buildings	Indoor and outdoor	Not mentioned	T_c range varies between 25.6-31.5°C with *RH* range of 62.2-90%	-
7	2008	Atthajariyakul S. and Lertsatittanakorn C.	Fan-assisted *AC*	University students	Laboratory	Climate chamber (2.5 x 3.5 x 2.5 m)	Indoor	Not mentioned	With *v* generated by small fans, v are 0.2, 0.5, 1.0, 1.5, and 2.0 m/s; then, T_n can be expanded to 26.0, 26.6, 27.4, 28.3, and 29.2°C, respectively.	$PMV = 0.4444T - 0.7862v - 11.4157$
8	2015	Puangmalee *et al.*	*AC*	University students	Laboratory	Climate chamber (8.0 x 9.0 x 3.0 m)	Indoor	Not mentioned	With *v* generated by *AC* system, *v* of 0.5, 0.7, and 0.9 m/s result in T_n of 27.6, 28.0, and 28.5°C, respectively.	-
9	2015	Srivanit S. and Auttrarat C.	*NV*	Various	Field study	Outdoor urban space	Outdoor	Chaingmai	T_n values are 28.5°C and 27.1°C for outdoor and semi-outdoor spaces, respectively. 80 and 90% acceptable temperature ranges are 22.4-32.0°C and 21-23.1°C for outdoor and semi-outdoor spaces, respectively.	The sample staying in semi-outdoor spaces may require a lower temperature than those living outdoors.
10	2015	Assvavichai *et al.*	*AC* and *NV*	The elderly	Field study	Nursing home	Indoor and outdoor	Bangkok	With a *CLO* range of 0.30 to 0.91, and *MET* range of 52.68 to 66.83, the comfort range is between 25.64-29.25°C, 52.68-66.83%, with v of 0.23-1.42 m/s.	The elderly are more sensitive to low temperatures.
11	2015	Nuntasiri P. and Rasisuttha S.	*NV*	Low-income people in an urban area	Field study	Residential buildings	Indoor and outdoor	Khon Kaen	T_c ranges found in a condition of 26.2-31.6°C with 62.9-82.4% *RH* for the raining season, and 27.4-30.7°C with 33.4-73.9% *RH* for the winter. Both conditions are examined under 0.55 m/s of *v*.	-

3.9 Thai thermal comfort standard

This last section of the chapter discusses the Thai Rating of Energy and Environmental Sustainability (*TREES*) building rating system, which has increasingly influenced local building design. This manual was issued by the Thai Green Building Institute (*TGBI*), established in 2009 by the Engineering Institute of Thailand under H.M. the King's Patronage and the Association of Siamese Architects. The objective of this organisation is to develop knowledge and establish a Thai green building rating system for Thailand to serve local requirements, and to cultivate the right awareness of sustainable building designs and constructions to architects, engineers, normal people all concerned organisations (TGBI 2018). TGBI issued *TREES-NC* as a standard for the building rating system to alleviate global warming problems, enhance building energy performance, decrease deterioration of the environment due to construction-related activities, and to enhance the quality of life and well-being of building users. This manual was created for new constructions only (and not for retroactive modifications to existing buildings). It evaluates buildings based on six major aspects, allotting a score out of 85: Platinum (over 61), Gold (46-60), Silver (38-45), and Certified (30-37). The standard consists of eight sections, the sixth of which describes Indoor Environmental Quality. This section is worth only 17 points of the total score, and the score for thermal comfort is 3 (TGBI 2010), which reflects a lamentable lack of awareness of the fundamental importance of building users' comfort, wellbeing, and health.

The standard divides the comfort threshold by *AC* and *NV* types of building ventilation. The former is referred to as the standard set point, mentioning T_a and *RH*, as indicated in ASHRAE 55-2004 and the national standard of the Engineering Institute of Thailand-303. For *NV* spaces, the thermal comfort standard is directly referred to as an evaluating method, as mentioned in title 5.3 of ASHRAE Standard 55-2004. The thermal comfort of the building is rated based on a percentage of the regularly occupied spaces that achieve the thermal comfort thresholds. In this case, if 80%, 90%, and 100% of the occupied area meet the requirements, 1, 2, and 3 points will be awarded, respectively.

3.10 Chapter conclusion

An adaptive model is based on the paradigm that building users are not passive recipients, rather they are capable of responding to thermal stimuli by adapting themselves and their environments to regain or maintain their thermal comfort. A series of studies report that the steady-state model seems to be limited by a temperature set point within a narrow temperature range created by *AC* systems. In contrast, for those in *FR* and *NV* spaces, thermal neutrality varies widely according to outdoor thermal condition. Thermal comfort state in the adaptive model is expressed as T_n, with 80% and 90% ranges of thermal acceptability. A variation of T_n with wide acceptable thermal ranges is attributed to a capability of users' thermal adaption. The thermal neutrality in this approach can be derived from different analytical methods, such as linear regression, Probit analysis, cross tabulation, and Griffith's method. Apart from the exploration of T_n and its acceptable ranges, other subjective thermal terms such as T_p and *SD* are also commonly mentioned.

The adaptive approach, which includes non-quantifiable variables ignored by laboratory study, such as abilities of human thermal adaptation, adaptive opportunities and constraints, and dynamic environments, is considered as one of the energy-conserving solutions which can reduce current energy consumption. Thermal adaptation can be broadly categorised into three modes, namely, behavioural, physiological, and psychological adjustments. The behavioural adaptation can be divided into sub-three aspects, which are personal, technological or environmental, and cultural or organisational adjustments. These techniques can be conducted under adaptive opportunities and constraints which can limit or encourage adaptive actions. For physiological adjustment, two types of adaptation are mentioned, genetic adaptation and thermoregulatory acclimatisation. Psychological adaption involves cognitive processes, and is an emerging area of research addressed in different ways. It is agreed to be one of the most influential factors in the adaptive approach, and is distinct from the physiological model. The basic psychological parameters

such as sensation and perception, *LTM* and *STM*, schemata, and past experience were described in this chapter.

Moreover, other socioeconomic factors were investigated and discussed. Factors such as income, educational level, and job satisfaction seem to influence human thermal response, but the impacts of gender and age are still uncertain, due to ambiguous and contradictory results reported by previous studies (Langkilde 1977; Fanger 1970; Humphreys and Nicol 2006; Karjalainen 2012). Thus, it can be noticed that while thermal comfort in the adaptive point of view relies on physiological or physical factors, it is also shaped by unquantifiable aspects known as mediators or moderators, which vary according to subjective thermal evaluations.

Based on evidence confirming the importance of thermal adaptation, the adaptive approach has garnered widespread acceptance and has been included in international standards such as ASHRAE Standard-55 2004 and 2010 and CEN EN15251, based on RP-884 and the SCATs database, respectively. In Thailand, several studies were conducted based on this school of thought in different building types, such as residential, educational, and commercial buildings, and with various types of subjects, such as office workers, the elderly, students, and low-income people. Regarding its significance, the local standard of Thai building rating system (TREES) includes this issue in its manual. However, it directly refers to the ASHRAE Standard-55 2004, regardless of local particularities. Thus, its suitability for application in the local context is questionable, given the different demographic, cultural, and contextual factors involved.

Chapter 4

Meditation Studies

Chapter 4: Meditation Studies

The fieldwork for this research was conducted in Buddhist meditation buildings in Thailand. This section reviews literature pertaining to meditation, including definitions and applications (including meditations applied in Western psychotherapy), and the impacts of meditations on psychological and physiological aspects and self-evaluation scales of mindfulness employed in research. Based on the literature review, meditation is considered a wellbeing-improving solution which allows human beings to improve their quality of life. This section also discusses ideas included in '*Positive Psychology*' regarding '*Live above Zero*', a recurrent process of thought, *Disidentification*, emotional pain, and a reactive pattern of mind. Apart from these issues, traditional Thai styles of meditation, including suitable places for meditation, conceptual monastic design, and basic techniques of Theravada Buddhist meditation are elaborated upon, before concluding the chapter.

4.1 Broad definitions of meditation

The term 'meditation' is at once universally understood yet ambiguous, referring to numerous meditative practices and different personal experiences. In general, styles and methods of meditation are varied pertaining to disciplines and religious contexts in which the activity is employed. This section explores scholarly definitions of meditation based on previous research.

The definition of meditation may shift according to cultural differences. Keng *et al.* (2011) compared Eastern and Western perspectives on meditation in three major aspects: context, process, and content of practices. Contextually, Eastern people might relate meditation to religious beliefs influenced by religious leaders or gurus, and ultimately the example of the Buddha's pathway to enlightenment, in which meditation is a fundamental solution. During practice, meditators contemplate aspects following the thought of the Buddha, known as '*Satipatthana Sutta*', which is the foundation of Buddhist mindfulness. Contemplation includes aspects such as the truth of nature, impermanence,

and *Disidentification* (i.e. the annihilation of the ego or self and its desires). Regarding contents for contemplation, Buddhist meditation addresses physical, mental, and experiential awareness.

In contrast, Westerners' perspectives on meditation may be diverse, since the definition of meditation is largely disconnected from those religious aspects involving context and process. For the content of meditation, Westerners might also consider both external and internal objects and external sensory systems, such as the experience of smells and sights (Keng *et al.*, 2011).

Ospina *et al.* (2007) investigated meditative activities for health based on a series of studies and described the terms of meditation. They mentioned that a definition of meditation is relatively unclear, and one meaning may lead to misunderstanding of the diverse activities that may comprise meditative experiences. For example, Cardoso *et al.* (2004) described that it covers both traditional rites and psychological medication, and identified four broad aspects that are common to most meditation rites:

- Using a particular and clear technique.
- Relating to the relaxation of muscles of practitioners during the activity.
- Relating to the relaxation of the logical mind.
- Utilising the ability of self-focus to maintain attention.

Furthermore, meditation was also described by Baer (2003), who mentioned that meditation is an observation of the current stream of stimuli induced internally and externally with a non-judgmental perspective. Walsh and Shapiro (2006) conceptualised meditation as training in self-regulation, in which a process of mind is under control by concentrating on both attention and awareness. They also provided behaviour-related descriptions pertaining to relaxing, concentrating, stopping the process of logical thinking, and altering the state of awareness. Besides, Manocha (2000) explained the meaning of meditation as '*thoughtless awareness*' or '*quiet mind*'. This activity is also described as personal-experience and realization practices. Ospina *et al.* (2007) also concluded that meditation involves mind stability and emptiness.

The meditative activity is a psychological training which aims to improve the ability of awareness and acceptance attitude rather than feeling contentment.

4.2 Mindfulness in Western psychological interventions

4.2.1 Introduction of meditation to the West

Although mindfulness meditation has been practiced for over 2,500 years, this activity is rather new in the modern West. Keng *et al.* (2011) conducted a literature review on the title of *Effects of Mindfulness on Psychological Health* and demonstrated a history of meditation application in Western healthcare. The report describes that mindfulness was first introduced to Americans during the 1950s to 1960s by Zen articles contributed by Herrigel (1953), Herrigel *et al.* (1960) and Ross (1960). Such literature attracted psychotherapists' attention and stimulated the growth of meditation research. Until the 1970s, meditation was initially studied as an intervention to improve mental wellness

4.2.2 Research and application of mindfulness in psychotherapeutic interventions

In the early 1970s, Transcendental Meditation (*TM*) by Maharishi Mahesh Yogi became a popular cultural phenomenon in the West. Many researchers (Benson *et al.*, 1974, Wallace 1970; Wallace *et al.*, 1971) investigated the physiological impacts caused by the associated style of meditation. Analytical results revealed that *TM* can decrease the consumption of oxygen and production of carbon dioxide by the human metabolism by reducing the rate of respiration. Keng *et al.* (2011) noted that while meditation became popular in the West from the 1960s, it was not applied in psychological interventions to improve well-being until the 1970s. Kabat-Zinn (1982) first applied mindfulness meditation in treatment with Mindfulness-Based Stress Reduction (*MBSR*), in a randomized controlled trial (*RCT*) delivering the intervention over eight to ten weeks, examining the effect of mindfulness on 30 patients suffering from chronic pain. Patients were required to attend sessions of up to 2.5 hours per week over eight consecutive months, and were encouraged to regularly practise the meditation autonomously, in their own homes. According to the results, the

practitioners who applied *MBSR* were less sensitive and judgmental to their pain stimuli, and stayed more conscious and independent from their recurrent negative thoughts.

Furthermore, *MBSR* and *RCTs* were applied in various studies, as noted in a literature review by Baer (2003) spanning 16 studies published during 1997-2010. The results present that *MBSR* can decrease the level of anxiety, anger, rumination, mental distress, perceived stress, disorganisation of cognition, avoidance of post-traumatic stress, and medical symptom levels. On the other hand, it can improve the senses of empathy, spirituality, cohesion, forgiveness, self-compassion, life satisfaction, and quality. Keng *et al.* (2011) mentioned that successful, integrated intervention leads to successive applications of mindfulness, such as Dialectical Behaviour Therapy by Linehan (1993), Acceptance and Commitment Therapy (*ACT*) by Hayes *et al.* (1999) and Mindfulness-Based Stress Reduction (*MBSR*) by Segal *et al.* (2002).

Meditation fundamentally includes mental activity that affects the human mind; however, one may ask whether and why meditation improves human welfare, including cognitive wellbeing. Walsh and Shapiro (2006) mentioned that refined awareness is shared in common between meditative activity and psychotherapy. They explained that the human mind will create an adaptive process called '*defence mechanisms*', which allow humans to get through difficult situations by creating a highly emotional feeling for a short period. However, if exposed to such difficulties over a protracted period, the defensive system might limit thought and opportunity to solve the problem straightforwardly.

In this regard, skilful psychologists will break through the barrier to allow their patients to express their feelings emotionlessly. When they are facing profound emotions, which might be hurt by the hidden defence mechanism, this is a turning point of the therapy. The therapist might realise this is a true feeling of their patients and it is the right moment to remedy their mind. They will tell the patients to accept and embrace the situation rather than hiding in the defensive mechanisms of their thought (e.g. rationalizations and repressions). In this

stage, the patients are suggested to enter a mindfulness state to allow them to experience real emotion, and realise that they are not debilitated by this. This moment reveals the hidden relief and wholeness in their mind (Baumgardner and Crothers 2009).

Beck (1967) and Beck *et al.* (1979) found that patients with depression suffer from their past interpretations; their mind is captured in a way that leads them to negative thoughts and beliefs they always face in the worst and uncontrollable situations. In this situation, therapists assist their patients in exploring their past experience, influenced by past negative interpretation, before leading them to explore reality, rather than relying on their interpretation. That technique, '*Disidentification*', is a process for preventing one's mind from identifying with one's thought, while encouraging an exploration of and exposure to the reality with understanding and acceptance. This method is also mentioned in the traditional style of meditation discussed later in this chapter.

Baumgardner and Crothers (2009), Wallace and Shapiro (2006) and Shapiro *et al.* (2002) mentioned that the research community interested in meditation are not motivated by exploration of particular aspects such as physiological and psychological benefits for practitioners, rather they fundamentally wish to improve human wellbeing by improving psychological and physical health, such as in terms of the efficiency of handling illness, stress, and pain. While physiological impacts are more easily quantified in positivist investigations, the higher-order outcomes of meditation have more profound implications for wellbeing, although they are generally subjectively experienced, such as self-actualisation, a positive sense of control, emotional stability, heightened vigilance, attention, focus and self-government.

Some studies found that a short period of meditative discipline, for one to six weeks, can develop self-assurance, contentment, optimism, and positive personality traits; systematic training can improve practitioners' emotion, attention, and awareness (Treadaway and Lazar 2009). Moreover, Keng *et al.* (2011) reviewed articles on the effects of mindfulness on mental health and reported benefits in psychological welfare, as it can enhance mindfulness and

reduce reactivity to emotional stimuli by disengagement. Besides, according to the review, mindfulness leads to developed levels of life satisfaction, liveliness, flexibility of emotion, and a decrease in negative impacts of mental disorders.

4.3 Effects of meditation on physiology

Meditation has impacts on the body as well as mental health. This section is a summary of studies discussing the effect of meditative practice on the positive feedback of human physiological factors. Wallace (1970) examined physiological changes of meditators trained in *TM* by monitoring a shift of oxygen consumption, heart rate, skin resistance, and brainwaves, before, during, and after engaging the meditative activity. The result shows that while performing meditation, the meditators presented a drop in the amount of oxygen consumption and heart rate, with an increase of skin resistance. Investigating subjects' brainwaves using electroencephalogram (*EEG*) categorised brain signals into wave types based on ranges of frequency: delta (0-4hz), theta (3.5hz-7.5hz), alpha (7.5hz-13hz), beta (14hz-30hz), and gamma (over 30Hz). The overlapping lower and upper limits of each range is approximately 0.5Hz or above (Kozlowski and Marciak-Kozlowska 2015). Results of *EEG* study illustrate an increase of the alpha waves of yogi subjects, which presents a sign of relaxation (Wallace 1970).

Besides that, Akishege (1968) studied changes in skin conductance of experienced Zen monks using Galvanic Skin Response (*GSR*). It should be noted that the skin resistance is shifted by a variation of a current condition of the sweat gland. The sweat rate is controlled by the Sympathetic Nervous System (*SNS*), which is one of the two divisions of Automatic Nervous System (*ANS*). The rate of perspiration is increased when *ANS* is highly stimulated by psychological or physiological stimuli. Such a coinciding operation leads to a rise in human skin conductance. Thus, based on this principle, a result of skin conductance measurement can reveal the response of *SNS*, which can be used to interpret human emotion and behaviour. The experimental results show an increase in skin resistance and a drop in respiration rate and oxygen consumption. The *EEG* study, moreover, presented subjects' relaxation stage,

since the amplitude of the alpha waves increased gradually, with a decrease in frequency.

Additionally, meditation does not directly affect human physiological function. In contrast, a negative effect on emotion can result in detrimental body impacts, such as elevated blood pressure and heart rate. In this case, it is noted that such physiological effects caused by anger can be alleviated by meditation. Fennell *et al.* (2016) experimented with a group of participants who are inexperienced and expert meditators. The experiment applied Zen meditation and an open monitoring meditation, in which the main concept is to observe thoughts and not to attach to them, just letting them go. The whole experiment, lasting one hour and 30 minutes, included an interview for personal information, and physiological tests including blood pressure, respiratory rate, and *EEG* study. Anger was induced in subjects by recalling negative experiences in the past. After finishing those tasks, they were required to meditate for 20 minutes.

According to the results of the study, the heart rate, blood pressure, and respiratory rates of the inexperienced participants was elevated after the anger induction session. However, during and after finishing the meditation, this group of meditators showed signs of physiological relaxation, with results similar to those of experienced practitioners. Although both groups presented the same anger level during the induction test, the experienced group showed a relatively stable physiological condition, while the anger feedback of the subjects in both groups was reduced after finishing the meditative session.

In terms of anger-induction, two studies (Tang *et al.*, 2007; Zeidan *et al.*, 2010) explored why the anger level of experienced meditators presented a smaller psychological shift during the session. In this regard, these two subjects demonstrated that the positive effects of meditation could last for days or even longer. The expert practitioners are capable of a better emotion-handling ability due to their longer meditative experience compared to their inexperienced counterparts, thus their initial anger response to stimuli is blunted.

Ospina *et al.* (2007) conducted a meta-analysis of meditations for health, of which 813 studies available online from 1956 to 2005 were collected and investigated. 311 studies related to an investigation of the meditative activities on physiological and neuropsychological factors. According to the results, the majority of studies found that meditation can decrease heart rate, blood pressure, and cholesterol. Furthermore, it can improve the creativity of verbal communication, decrease reaction time of visual sensation, and increase breathing holding time. However, they noted that although many studies have been published in this field, their quality is generally relatively poor, due to a lack of explanation of clear methodology, including clarifying withdrawing, randomising, sampling, and blinding processes.

According to those studies, it can be concluded that the meditation practices have an effect on human physiology, such as a reduction of heart rate, blood pressure, cholesterol, and skin resistance. Besides, it can also enhance the ability of verbal communication, induce shorter reaction times to visual sensations, and longer holding time for breathing.

4.4 Evaluation of mindfulness

Effects of meditation can be examined by different methods such as *EEG* and self-evaluation of mindfulness by questionnaire. The former method allows researchers to understand the brain function in different brain regions by observing brain waves. Some examples of the *EEG* application of meditators' brain wave analyses were mentioned in previous sections (Wallace 1970; Fennell *et al.*, 2016). The results derived from this type of study reveal objective insights by which researchers can explore the effects of meditation on the human brain. The study of Davidson *et al.* (2003), who applied *EEG* to investigate brain functions of both meditators and non-meditators, shows greater activation of the left side of the anterior brain of practitioners during meditation. This represents a positive signal of this activity on an anxiety relief. However, Johnson (2007) noted that this method might be expensive, time-consuming, and incapable of exploring individual mindfulness traits while performing meditative activities.

For the self-evaluation method, many sets of questions and subjective scales of mindfulness were devised for different purposes. This section aims to provide only an overview of self-evaluating scales invention and to explore the different purposes of the scale application including *FMI. MAAS*, *CAMS-R*, *SMQ*, *PHLMS*, *TMS*, *KMS* and *FFMQ*. The information derived from this review will be applied in the process of a subjective scale design for this thesis.

4.4.1 Freiburg Mindfulness Inventory (*FMI*)

Freiburg Mindfulness Inventory (*FMI*) by Buchheld *et al.* (2001) was created based on Buddhist meditation. A total of 30 questions were categorised into four major categories: mindful presence, non-judgement acceptance, openness to experience, and insight. This scale should be applied with respondents who have some basic background of meditation to avoid misunderstanding descriptions of the experiences. Examples of *FMI* questions are '*I experience moments of inner peace and ease*, *even when things get hectic and stressful*' and '*I see my mistakes and difficulties without judging them*'*.*

4.4.2 Mindfulness Attention Awareness (*MAAS*)

Mindfulness Attention Awareness (*MAAS*) by Brown and Ryan (2003) comprises a 15-item scale for which the answers range from 1 ('*Almost always*') to 6 ('*Almost never*'). The scale can be used to investigate acceptance and attention observed by present awareness. This scale can be applied among inexperienced subjects. Examples of the *MAAS* questions are '*I find it difficult to stay focused on what*'*s happening in the present*' and '*I do jobs or tasks automatically*, *without being aware of what I*'*m doing*'*.*

4.4.3 Cognitive and Affective Mindfulness Scale (*CAMS-R*)

Cognitive and Affective Mindfulness Scale (*CAMS-R*) by Feldman *et al.* (2007) is a 12-item scale created for assessing impacts of mindfulness impacts on a daily basis. The investigated aspects are attention, current focus, awareness, and accepting or non-judging thoughts and feelings. It should be noted that instead of evaluating respondents' degree of mindfulness, most *CAMS-R* questions focus on ability and intention to be mindful. Besides, this scale is

beneficial to psychotherapy since it is more relevant to negative aspects such as worry and anxiety than those of *MAAS*, *FMI*, *KIMS*, and *SMO* (Baer *et al.* 2006; Bergomi *et al.* 2012). Besides, the results derived from *CAMS-R* allow researchers to explore a level of wiliness to be mindful, and capability of mindfulness, rather than exploring the experience of mindfulness. Examples of *CAMS-R* questions are '*I can accept things I cannot change*' and '*I am able to focus on the present moment*'. The questions can be rated as 1, 2, 3, and 4, which refer to '*Rarely/Not at all*', '*Sometimes*', '*Often*', and '*Almost always*', respectively.

4.4.4 Southampton Mindfulness Questionnaire (*SMQ*)

Southampton Mindfulness Questionnaire (*SMQ*) by Chadwick *et al.* (2008) is a 16-item scale questionnaire focusing on distressing thoughts and images, which are a key problem in psychotherapy. *SQM* focuses particularly on the effect of mindfulness on negative inner experiences, and it is useful for investigating relationships between psychological disorders and awareness of mindfulness. However, this scale may be unsuitable for general application where participants are in neutral psychological states, or mindfulness impact is assessed on a daily basis. All the questions in *SMQ* start with the phrase '*Usually*, *when I have distressing thoughts or images…*', then the next sentence will be a question, for example '*…I am able to just notice them without reacting*' and '*In my mind I try to push them away*'.

There are four answer options to the questions:

- To decentre awareness or to be absent in responding to cognition.
- To pay attention to retaining a connection with difficult cognitions or to avoid experiencing such circumstances.
- To accept difficult thoughts and images or to make a judgment about the related problems.
- To let them go and not to react to them or to ruminate on and worry about them.

4.4.5 Philadelphia Mindfulness (*PHLMS*)

Philadelphia Mindfulness (*PHLMS*) by Cardaciotto *et al.* (2008) is a 20-item questionnaire designed based on past studies of Kabat-Zinn (1994) and Bishop *et al.* (2004). The answers range from '*Never*' (1) to '*Very often*' (5). Those questions can be categorised into two major sets, investigating acceptance and awareness. Sample questions in awareness and acceptance clusters are '*I am aware of thoughts I'm having when my mood changes*' and '*There are aspects of myself I don't want to think about*', respectively.

4.4.6 Toronto Mindfulness Scale (*TMS*)

Toronto Mindfulness Scale (*TMS*) by Feldman *et al.* (2007) was designed for evaluating mindfulness experiences of the non-meditators and meditators after preceding meditative activities. The questionnaire consists of 13 questions, which were categorised into two groups: decentring and curiosity traits. An example for the former question is '*I was more concerned with being open to my experiences than controlling or changing them*', and for the latter '*I was curious to see what my mind was up to from moment to moment*'. The answering options were laid on a five-point Likert scale, varying from '*Not at all*' (0) to '*Very much*' (4).

4.4.7 Kentucky Inventory of Mindfulness Scale (*KIMS*)

Kentucky Inventory of Mindfulness Scale (*KIMS*) is 39-item scale designed to assess four factors of mindfulness on a daily basis: observation, description, awareness of action, and non-judgmental acceptance. The questionnaire asks subjects to answer each question by rating on a five-point Likert scale, ranging from '*Never or rarely true*' (1) to '*Very often or always true*' (5). Example questions are '*I pay attention to whether my muscles are tense or relaxed*' for the category of observation, and '*I tell myself that I shouldn't be thinking the way I'm thinking*' for the category of acceptance.

4.4.8 Five Mindfulness Questionnaire *(FFMQ)*

Five Mindfulness Questionnaire (*FFMQ*) by Baer *et al.* (2006) is a 39-item scale assessing five major aspects of meditation. Four aspects of *KIMS* are included

in *FFMQ*, while exploratory factors are derived from existing scales such as *KIMS*, *FMI*, *MAAS*, *CAMS* and *SMQ*. Finally, five facets analysed included in *FFMQ* are non-reaction, observation, awareness, description and non-judgement. Although this scale is regarded as one of the most comprehensive scales available recently, Bergomi *et al.* (2012) mentioned that some aspects of the five facets might be absent from the *FFMQ*. For example, aspects related to non-identification with own experiences appear in *FMI* and *SQM* but are excluded from the questionnaire. The rating system for the question is the same as applied in *KIMS*, in which the options vary from '*Never or rarely true*' (1) to '*Very often or always true*' (5). Example questions include '*I perceive my feelings and emotions without having to react to them*' and '*I make judgments about whether my thoughts are good or bad*' for the non-reaction facet and non-judgement facets, respectively.

4.4.9 Summary and justification of choosing Meditation Depth Questionnaire (*MEDEQ*)

In sum, the investigation of the effect of mindfulness relies on multiple-item scales. Bergomi *et al.* (2012) noted that each scale provides advantages and disadvantages, and one scale cannot comprehensively assess entire meditative aspects. Besides, some scales may be suitable to be applied with specific subjects or purposes. For example, *CAMS-R* and *FMI* are for clinical subjects and experienced meditators, respectively. The discussed self-evaluating scales investigate the effect of meditation on a daily-life basis, or are to be applied in psychological interventions not focused especially on respondents' meditative experience during meditating itself. Unlike Meditation Depth Questionnaire (*MEDEQ*), the scale is designed for evaluating the subject's meditative stages after fining the practice.

4.5 Meditation Depth Index (*MEDI*) and MEDEQ

The Meditation Depth Index (*MEDI*) invented by Piron (2001) is a scale to evaluate meditation depth investigated by *MEDEQ*. This scale is based on traits of meditation depth from different styles of traditional meditation. Despite a

variety of philosophies and practice methods, they share some traits in common.

The final 30 questions of *MEDEQ* were a result of the process of questionnaire design first developed based on an interview of 27 meditators from different meditation experiences and styles. As a result, 50 meditative experiences were reported and reanalysed. The derived items were organised and analysed by distributing different depths, summarising the repetition of the meaning and eliminating the irrelevance expressions. These meditative experiences were later categorised into different depths of meditation by 45 certified meditation instructors. This process of the questionnaire design was also repeated by another 12 advanced meditation instructors from Zen, Tibetan, and Theravada Buddhism, Qigong, Yoga and Christian traditions. The final 30 items were submitted to 45 authorised gurus possessing more than 12 years of experience. They were asked if each question was agreeable with its depth, and if it should be located to a different level. Each question was rated based on a five-point Likert scale ranging from 0 ('*Very flat*') to 4 ('*Very deep*'), while the centre of the scale is 2 ('*Medium deep*'). The final items can be categorised into five-major depths: *Hindrance*, *Relaxation*, *Personal Self*, *Transpersonal Qualities*, and *Transpersonal Self*, described by Holzel and Ott (2006) as summarised below.

Hindrance is the first stage where meditators still struggle to sustain their focus, characterised by feelings of boredom, impatience, and lack of motivation to achieve concentration. The second depth stage is *Relaxation*, in which the meditators might feel more comfortable due to internal tranquillity. *Concentration* or *Personal Self* is the third depth of meditation, where the practitioners might realise that they can detach themselves from their thought. This step allows them to attain a deeper stage of meditation, which is *Essential Qualities* or *Transpersonal Qualities*, the fourth level of the meditation depth where love, dedication, appreciativeness, and connectedness can be experienced. Finally, *Non-duality* or *Transpersonal Self* is the deepest stage of meditation, where cognitive processes disappear.

The questionnaire mixed the items without the category of meditation depth and asked the respondents to answer the questions such as '*Mainly*, *I was more in a state of dozing or sleeping*' *and* '*There was no differentiation*, *comparison or judgement anymore. Everything could be as it was*' which are in clusters of '*Hindrance*' and '*Transpersonal Self*' states respectively. In this case, the answering options were located on a five-point Likert scale varying from '*Not at all*' (0) to '*Very much*' (4), while the middle of the scale was '*Mediocre*' (2).

One example of *MEDEQ* application is furnished by Holzel and Ott (2006), who investigated relations between absorption, mindfulness, and meditation depth using *Tellegen Absorption Scale* (*TAS*), *FMI*, and *MEDEQ*, respectively. *FMI* was designed for investigating mindfulness on an everyday basis, as explained in the previous section. *TAS* was invented by Tellegen and Atkinson in 1974 to explore a person's hypnotisability or to investigate how easily an individual can be hypnotised (Berkeley University of California 2017). *TAS* questions asking respondents to answer if the statement is either '*Generally true*' or '*Generally false*'*.* Examples of questions include '*Some music reminds me of pictures or changing colour patterns*' and '*Different colours have distinctive and special meanings for me*' (Berkeley University of California 2011). The analytical results reveal that absorption is more influential on the meditation depth of subjects than the amount of meditation training. Moreover, they concluded that the deeper meditative experience the meditators attain, the greater mindfulness is reported.

4.6 Positive psychological study

The initial investigation of the human mind was mainly influenced by the misanthropic perspective of Sigmund Freud's theory, which portrays a negative image of humans being driven by self-serving motivations toward negative attitudes and outcomes for individuals and others, and even positive human actions are sometimes due to negative motivations (Baumgardner and Crothers 2009). Similarly, Reis and Gable (2003) posited that humans are primarily driven by negative ideations, because these exert a significant impact on the

evolution of individuals' behaviour. Crises defined as life threats have a greater impact on the focus and attention of human society.

Thus, Baumgardner and Crothers (2009) mentioned that the negative issues in research also seem to influence the psychological research approach. Actually, we should accept that the researchers are also normal people wishing their works to be a centre of attention; thus, undesirable aspects of human behaviour may enable them to attract more attention (Baumgardner and Crothers 2009). Seligman (2002a; 2002b; 2003) mentioned that studies in this field focus on a '*disease model*', investigating how to treat mental illness and to prevent them accumulating in mind. However, psychotherapy should not be only a repair station of life (Ryff and Singer 1998). Thus, a new principle known as '*Positive Psychology*', which allows humanity to live in a better state of life, should be established, including the concept of 'Life Above Zero'.

4.6.1 Introduction to 'Life Above Zero'

As mentioned above, conventional psychology focuses on negative issues, due to its traditional illness-based orientation, but this approach limits human life and psychological experience to a sub-neutral state of wellbeing. In contrast with this, Martin Seligman (1998), former President of the American Psychological Association and the founder of modern positive psychology, made a significant revolution and contribution to psychological study. He criticised psychological researches for their pessimistic attitudes and preoccupation with the negative qualities of humanity. Instead, he suggested that the attention of the research community should shift from worst to best behaviours by which human beings can achieve positive outcomes (e.g. happiness and bravery). Positive psychology is a combination of various psychological aspects together with a focus on human behaviour affected by positive perspective. This field of investigation emphasises positive emotions without ignoring the empirical evidences of scientific research. Moreover, this novel school of thought was developed to allow researchers to broaden more understanding of positive behaviour, and to create a balance to mainstream conventional psychological research, with its skew towards negativity.

It should be noted that although positive psychology is situated as a counterpoise to conventional mental health studies, it is not created in fundamental opposition to the old school of thought. In contrast, it seeks to fulfil and complement it, by describing the neglected, positive state of the human mind. If a threshold is created to make a separation between a bad and good life, such a boundary represents a neutral life. In this case, the psychological study generally investigates life under the zero line, while the positive psychologists might consider that human life should be more meaningful than the absence of illness and biomedical and basic mental health. These two factors may allow human beings to maintain neutrality, but fail to attain the above-zero life condition (Baumgardner and Crothers 2009).

Seligman (2003) described positive psychology based on its three pillars (Gable and Haidt 2005):

- Experiences of positive emotions such as delight, pleasure, optimism, and hope.
- Positive personality contributing to personal strengths and mental health.
- Communities and positive institutions of social value leading to happiness and a healthy mind for individuals.

These aspects reveal a depth of wellbeing which ranges from internal to external influences. With regard to personal qualities, psychological studies show that characteristic differences of people in terms of positive and negative thoughts play an important role in both welfare and personality. Personality psychologists state that healthiness and happiness are established over positive characteristics and personal strengths (Watson and Tellegen 1985; Watson *et al.*, 1999; Watson 2002). Furthermore, such personal qualities lead to social satisfaction, in addition to wellness. In this case, social psychology explains the importance of human social satisfaction caused by social interactions. Belongingness to a community seems to lead to a significant impact on emotional patterns and human cognition. An absence of this sense may result in detrimental effects on physiological and psychological aspects,

adaptability, and well-being (Baumeister and Leary 1995). They mentioned that life satisfaction is also established based upon good relationships, such as a friendship and marriage.

McCullough et al. (2000) and Emmons and McCollough (2004) confirmed the benefit of human qualities encouraged by religious values, such as forgiveness and gratitude. These virtues allow not only the contributors but also the recipients to experience a more satisfying life. Well-being is partly formed by varying cultural and religious impacts (Ryff and Singer 1998). This concept of life is not a universal model to be applied directly to view or evaluate other different cultural perspectives. In contrast, to understand the discrepancy between cultures, researchers are required to investigate their own background deeply to explore differences and commonalities. Baumgardner and Crothers (2009) discussed a variety of attitudes between different groups of people. Happiness is just a perspective of one particular group of people. Therefore, applying such a conceptualisation as a template to depict or evaluate the other cultural subjective qualities seems to be a 'one-size-fits-all' model which may lead to misinterpretation of those virtues.

Cushman (1990) and Kasser and Kanner (2004) mentioned that happiness is subjectively and individually diverse. For example, from a Buddhist perspective, the avaricious pursuit of affluence and prosperity is a source of personal and societal suffering. The utilitarian pursuit of wealth is the underlying animating principle of modern Western materialism and neoliberal political economy, but it generally has a detrimental effect on wellness for societies and even wealthy individuals, and it is destroying the ecosystem. Individuals who devote themselves to the pursuit of wealth and reputation generally sacrifice happiness and life satisfaction, usually believing this to be a delayed gratification *quid pro quo* (i.e. they believe that if they sacrifice other aspects of life for the pursuit of wealth, they will ultimately be free to develop those other aspects). Diener and Oishi (2005) agreed with the essential failure of materialism to deliver happiness, and confirmed that such a quality is not purchasable. For instance, an immediate burst of happiness may be experienced by lottery winners who

are immediately enriched, but their new-found wealth does not provide sustainable happiness, as they soon begin to experience new problems and challenges. This type of delight is a case that can portray the reality of the illusory nature of happiness pursued through materialism.

In contrast to the prevailing neoliberal paradigm that dominates global economics and politics, Buddhism predicates a good life on contentment (analogous to 'happiness', although ontologically different from the conventional understanding of the latter in Buddhist thought), a balanced 'Middle Way', and mental health, with suggestions on how to achieve these (Walsh and Shapiro 2006). Buddhists believe that true delight is independent of money; indeed, money and avarice are held to be sources of suffering, and Buddhist 'happiness' consists of reducing and freeing oneself from desires to achieve enlightenment, rather than seeking to slake such desires as encouraged by capitalist society. Wallace and Shapiro (2006, p.691) quoted the Dalai Lama mentioning the importance of happiness, noting that '*the purpose of our life is to seek happiness*', but the paths to this goal promised by consumer capitalism are in and of themselves sources of pain and suffering in the Buddhist worldview.

The Buddha declared that opportunities to achieve enlightenment are all around us; paths to more sustainable wellbeing are also tangible and all around us (Baumgardner and Crothers 2009). Buddhadasa (2009) mentioned that happiness in the mind is an extra factor apart from four fundamental needs to fulfil human life and encourage wellbeing. In this case, Buddhism believes that meditation can elicit rapture and happiness of mind from obscurity, and allow human beings to experience sustainable inner happiness.

Consequently, positive psychology was developed based partially on Buddhist principles, but some inherent ideas of the traditional styles were omitted when discussed in the Western context. However, McIntosh (1997), Shapiro *et al.* (2002), and Wallace and Shapiro (2006) discussed that Eastern approaches were considered a rich source of positive psychological research. Wallace and Shapiro (2006) noted the research discrepancy and called for further studies

relevant to these topics to bridge tentative directions in similar disciplines to achieve a greater understanding of Life Above Zero for human beings.

Based on the discussion above, it can be seen that wellbeing in the perspective of positive psychology is not limited only to life below zero, or a neutral state. Life is more meaningful than the interpretation of the old school of psychology, based on the negative drives of humans. Optimistic psychology, established based upon the three pillars of positive emotions, positive personality, and positive institution, believes that human beings are capable of rising above neutrality. Multidimensional factors can contribute to wellbeing, including both personal and social aspects. As a consequence, this type of psychological perspective has gradually attracted the interest of Western psychologists, and it has encouraged new relevant studies to make further contributions to the field. With its radically different conceptualisation of the purpose of human existence and the route to happiness, along with its commitment to sustainability, Buddhism can offer profound and instructive insights in this regard.

4.6.2 Recurrent process of thoughts and disidentification

Meditation can produce different effects among practitioners, depending on individual absorption, and they are measurable by various solutions, as discussed in the previous sections. While positive results of meditation include reduced stress and (in the best cases) blissful feelings of tranquillity, it can potentially result in detrimental effects on emotion and feeling. Wallace and Shapiro (2006) noted that ‘any therapy powerful enough to heal is also powerful enough to harm, and meditation is no exception’. However, over the long term, this activity improves concentration levels in order to allow the meditators to maintain their focus during the practice and in real life, and leads to the dilution of individual identity, which is called ‘*Disidentification*’, a core part of Buddhism ontological aspiration. Goodman (2013) referred to the Buddha’s discussion with monks, as mentioned in *Alagaddūpama-sutta*, noting that nothing really belongs to themselves, and suggested letting things that were not genuinely possessed go, as in the quote below.

> 'Bhikkhus, what never is not yours, abandon it. When you have abandoned it, that will lead to your welfare and happiness for a long time. What is it not yours? Material for is not yours… Feeling is not yours… Formations are not yours… consciousness is not yours. Abandon it when you have abandoned it. That will lead to your welfare and happiness for a long time' (Nanamoli and Bodhi 1995, p. 235, quoted in Goodman 2013, p. 651).

Identification is a psychological process related to people's thoughts generated over a period of time. In Buddhist practice, the unconquered mind does not blindly obey commands to comply, enforcing it to stop disidentifying itself. Indeed, the mind behaves like weather, requiring frequent checking, changing unpredictably and capriciously. Mind comes and leaves, it cannot be intentionally created, and it should not be held on to. In contrast, meditation allows the human to disidentify from the process of recurrent thought. These patterns of habit influence personal characteristics.

Discontinuing the recurrent process of thoughts can break the production process of personal identification that shapes the human mind. Such interruption or a deconstruction of the recurrent patterns reveals the real mind, which results in a different perspective of seeing or interpreting things in the real world. Disidentification can minimise human anger, while encouraging them to be more patient, enduring and equanimous. When the process of mind-recurrent patterns tries to influence one's thoughts, it is unnecessarily to follow the orders, one merely perceives the experience and acknowledges it to be a mental process detached from the essence of one's being.

4.6.3 Emotional pain and reactive pattern of mind

Benefits of meditation were mentioned in various psychological and physiological studies, as mentioned in the earlier sections. In terms of psychological impacts, Goodman (2013) discussed how meditation works, and differentiated the affects and results of meditation. The differences between short-term effects and long-term results of meditation were raised. For short-

term outcomes of each meditation session, practitioners may report various experiences, which can be overwhelmingly positive or negative perceptions, and which may vary personally according to each practising session. Thus, the effect of meditation during the short-term period may be unpredictable.

However, it is proved that the long-term meditation practice benefits practitioners while engaging in meditative activities and on a daily basis, regarding an increase in levels of attention retention with less reactivity. Meditators who have long experience of practice may have a better opportunity to develop their ability of disidentification, which is an important quality in Buddhism. Such a capability allows the meditators to consider what is self, what is not self, and what does not belong to self. Instead of considering emotion and mind as the fundamental manifestation of oneself, it is suggested to see them as weather conditions that sometimes appear or disappear without restriction. In this case, it is not necessary to control and rely on them. When isolating from external stimuli and performing sitting meditation, thoughts and emotions emerge continuously. In this case, meditation allows the practitioners to perceive the reactive pattern arising in the mind and realise that this happens continuously, and it is factually not the real identity.

Consequently, the meditation practice allows practitioners to gradually see things as they are, and disidentify them from the production process of thought and the recurrent emotional patterns. This disidentifying process can dissipate the perception of self and allow practitioners to be less influenced by such influential patterns, seeing things clearly as a result of long-term practice. Chares Goodman (2013) mentioned that disidentification is the fundamental goal of meditation, and mindfulness of the body is one activity to achieve this ability. Body mindfulness involves the capacity of retaining clear awareness of the various body parts, thoughts, and emotions in the present moment. The key importance of breathing meditation, one form of mindfulness body training, is to '*let go*' of thoughts, retentions, and fantasies, while walking meditation is considered the most suitable form of body mindfulness cultivation, allowing meditators to build a present awareness of inside and outside factors, namely

the mind and actual surroundings. This type of training requires an observation of feet sensations when standing and walking, while perceiving actual environments with open eyes. This activity effectively creates the capability of mindfulness to engage in present activity with actual details.

It is believed that psychology and physiology are linked with subtle relations. For example, mental stress can result in the tension of muscles, while a smile can physiologically trigger better feelings. Painful feedbacks due to physical reactions of muscular tensions directly lead to psychological interruption, causing emotional impacts that deviate the meditators' mind from stability and clarity of concentration. The emotional pain which is a human preventive reaction is linked to the body with an intense sensation to prevent the humans from exposure to situations prone to pain. When a physical stimulus is aroused, the emotion linked to that body part is activated.

In this case, a distraction of physiological disturbances experienced during engaging mindfulness of body can lead to psychological pain and interference with the clear mind. This bodily meditation allows meditators to develop a capacity to tolerate the dissatisfied sensations. When clear and vivid attention is brought into an observation of the reactive pattern and emotions, things are more obvious. This practice is possible to weaken the association between body and mind, and leads to a dissipation of the linked emotion. Such a phenomenon is believed to lessen the distraction of the mind with the body, allowing the meditator to physically relax (Goodman 2013).

4.7 Meditation retreats in Thailand

Buddhism is the national religion of Thailand and it has pervasive impacts on people's way of life, mind, and meditative activity. In general, there are two different sects of Buddhism, known as Theravada and Mahayana. Theravada Buddhism is the predominant sect commonly found in Thailand, where it arrived in the third century CE (Thailand was probably the first region outside South and Central Asia where Buddhism spread). The Thai monarchy has patronised the faith for centuries, and King Lithai (1347-1376 CE) abdicated the throne and

became a monk for a short period. Since then, young Thai men are supposed to get ordained when they are mature (25 years old), which has become a Thai tradition (Chareonla 1981).

Naturally meditation is one of the most important activities of Buddhists, as it was one of the paths to the enlightenment taken by the Buddha. Meditative activity was limited to the circles of Buddhist monks and ascetics, but it gradually came to be more open to the public, and has been widely adopted by the laity since the 1950s. Nowadays, meditation is commonly practised in Theravada Buddhism monasteries in Thailand, Sri Lanka, Nepal, and Myanmar (Cook 2010).

Meditation-practising sessions are held in Buddhist monasteries, especially on Buddhist holy days. Evidence concerning meditation retreat foundations in Thailand is scarce as few disciplines have explored these phenomena, and as Tanissaro (2012) mentioned, there is often no specific place or organised programme for such activities. The Buddha mentioned general criteria in *Tripitaka* for suitable places for Buddhist monks to meditate, suggesting that they keep away from crowds and live alone in peaceful places, particularly forests, mountains, cemeteries, or open areas, isolated from interruptions and the circulation of people, and they should hide themselves for mindfulness cultivation, sitting cross-legged, with a straight spine. This statement emphatically indicates by omission that there is no need for a structure to perform meditation but it is intended for ascetics and mendicants who have devoted their lives to Buddhist practice, not for ordinary people seeking to enrich their spiritual lives. Tanissaro (2012) noted that a wealthy early Buddhist in Rajgir, India, donated buildings for monks to shelter them from harsh environmental conditions, to support the practice of meditation, which affirms the early adoption of constructions for meditative practice.

4.7.1 Conceptual design of Thai monastic architecture and Buddhist cosmology

In Thailand, meditation sessions instructed by monks can be found in Buddhist monastic areas where intensive organisational and cultural factors and infrastructure exist. It is necessary to discuss the symbolic importance of monastic spaces and the intangible influence behind the monastic planning and architectural design which may impact the building users' perception. Naturally it is beyond the scope of this thesis to explain Buddhist philosophy in depth, but it is necessary to have an overview of the implications for religious architecture, particularly monastery planning and designs that affect building users' perspectives on sacred spaces.

Thai Buddhist architecture has a long history of development, and its principle of design and planning are varied due to a period of construction and requirements for each function. The main conceptual planning is influenced by a concept of Buddhism cosmology, as depicted in the classic religious text *Trai Phum Phra Ruang*, composed more than 700 years ago by King Phya Lithai. This is one of the most significant texts in Theravadan Buddhism that influences Buddhists' thought on doing good actions, so that they can reincarnate into higher realms after death. This concept, which is considered Thai-perspective Buddhism, also had an impact on neighbouring Buddhist nations, such as Laos and Cambodia.

In Buddhist cosmology, as extrapolated from *Trai Phum Phra Ruang*, the universe is an infinite space consisting of a million *Cakkavālas.* The centre of each *Cakkavālas* is a place of the *Sineru* mount, where different types of heaven are stacked. The great mount is surrounded by seven layers of mountains known as *Satta Borriphan* Mounts, inhabited by giants and gods. Each mountain ring is separated by the *Si-Thandon* waterbody, and outside those seven layers of maintains, there are four continents. In each *Cakkavālas* there are three realms: the sensual plane (*Kāmāvacara Bhūmi*), the form plane (*Rūpāvacara Bhūmi*), and the formless plane (*Arūpavacara Bhūmi*).

Kāmāvacara Bhūmi, comprising 11 sub-realms, is a world for the rebirths of those possessing sensual desire, caused by vision, sound, smell, taste, and touch. Human beings are one type of dwellers in this realm. *Rūpāvacara Bhūmi* or *Rūpā Bhūmi* consists of four major realms, which contain 16 sub-realms. The ones who reincarnate in each realm are categorised by levels of their *Jhāna*, which is a state of concentration achieved by meditative practice. It is the higher division inhibited by the rebirths who still have body form, with greater qualities of consciousness and mind, and lower sensual desire. Thus, it can be seen that this realm is for those who develop *Jhāna*, which can be only attained by practising meditation. *Arūpavacara Bhūmi* is the highest realm of the three, inhabited by those reincarnating without tangible forms, but the mind is considered a formless state or non-material body (Rajeev 2008). The summary of the realms in Buddhist cosmology can be expressed as presented in Figure 4.1, which illustrates the psychical setting of one cosmology, and Figure 4.2 shows a summary of three major realms with different sub-realms.

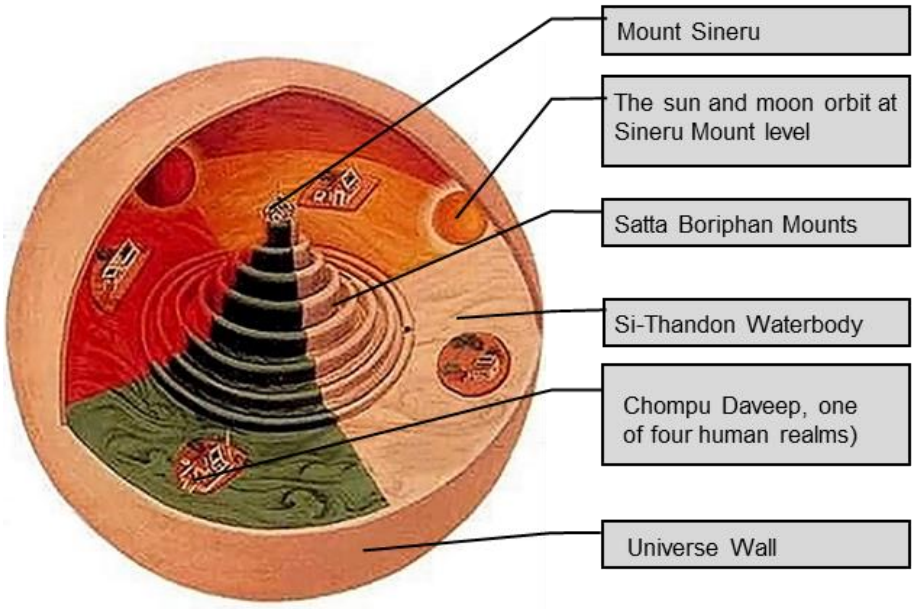


Figure 4.1: Illustration of the Cakkavālas as mentioned *in 'Trai Phum Phra Ruang'*
Source: (Astroeducation 2016)

Arūpavacara Bhūmi				*Rūpāvacara Bhūmi*												*Realm of Gods*							*Realm of Demon*			
4	3	2	1	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	6	5	4	3	2	1	*Human Being*	4	3	2	1
Arūpavacara Bhūmi				*Rūpāvacara Bhūmi*																*Kāmāvacara Bhūmi*										

Figure 4.2: Relation between realms and sub-realms in Buddhist cosmology

The circle of life in the Thai Buddhist perspective believes that people with good karma will reincarnate in a better *Bhūmi* after their death than the sinners who may reborn in the animal realm or hell. It can be seen that there are a range of realms categorised by levels of karma and the quality of Jhāna, and rebirths do not escape from cycle of suffering. However, it should be highlighted that another realm which is totally different to and greater than those mentioned is the supramundane plane (*Lokuttara-bhāmi*) (Payutto 2016), the condition of whose inhabitants is known as Nibbāna or unconditioned state, which is the authentic termination of the suffering cycle, and the ultimate goal of Buddhists. Payutto (2016) defines *Nibbāna* as:

> *'*The extinction of the fires of greed, of hatred and of ignorance; the Unconditioned; the supreme goal of Buddhism; the *Summum Bonum* of Buddhism; the Final Goal; the extinction of all defilements and suffering*'* (Payutto 2016, p. 332).

Based on the beliefs of the Buddhist cosmology and reincarnation, it can be seen that the path of enlightenment in Thai Theravadan Buddhism requires the extraction of the mind from the body, and purification of the former. As mentioned earlier, the higher realms before reaching *Nibbāna* is also determined by *Jhāna* which can be attained by meditation practice. Thus, this reveals the influence of meditative activities on Thai Buddhists.

These primordial beliefs are reflected in architectural designs (Khanjanusthiti 1996). This religious perspective has a strong influence on Thai Buddhists' way of life, and it is reflected in physical planning, architectural design, and decorations in Thai monastic architecture. Thai Buddhist monasteries are generally characterised as complexes broadly divided into three main zones. The first area is a temple ground, which is a public space. It may comprise a public park, cremation area, school, or even rental areas such as markets or row houses.

The other two spaces are '*Sanghavas*' and '*Buddhavas*', the main areas of the monasteries. The latter zone is considered a private area restricted to the

monks and their daily lives (e.g. dormitories etc.). It is not related to sacred rites, and there is no symbolism or metaphor related to Buddhist cosmology in planning in this area. The buildings in this zone are created for monks to be used on a daily basis, such as the *Kuti*, a small residential building approximately 3 x 2 m in area, and the *Sala Kan Parian*, a large open-plan structure functioning as multi-functional space. In the past, this building type was used as a classroom for monks.

The *Buddhavas* zone is considered a sacred area, which is a semi-public space in which religious rituals are performed (Khanjanusthiti 1996). This area is clearly separated from the other zones. One example is the layout of Wat Suthatthepwararam, as shown in Figure 4.3, where green, yellow, and red areas indicate the temple ground, *Shangavas*, and *Buddhavas* zones, respectively.

The *Buddhavas* zone represents the area of the Buddha, where the major religious rituals of the monastery are held. It symbolises the Buddhist cosmos, reflected in planning and architectural design. This area is separated from the other spaces by walls representing the limits of the physical universe. The centre of this sacred area is the most important location, which represents the Sineru Mount. In general, this location is zoned for the most significant symbolical constructions, including the following elements:

- **Stupa** or Chedi, a sacred monument that originally referred to the shape of a tumulus. Nowadays, it is used as a reliquary. In some monasteries, the Chedi is replaced by Pra Prang, which is a kind of stupa in the Khmer architectural style.
- **Ubosot** or Bot is the most significant building in a monastery, where the most sacred objects are placed. This building is encompassed by the Bai Sema, identifying a holy area of the monastery. It is mainly used in sacred rituals, mainly by monks.

- **Vihara** is a duplication of Uposatha. The function of this building is rather different from Uposatha, since it is open to the public. This space is a shared area between lay people and monks.

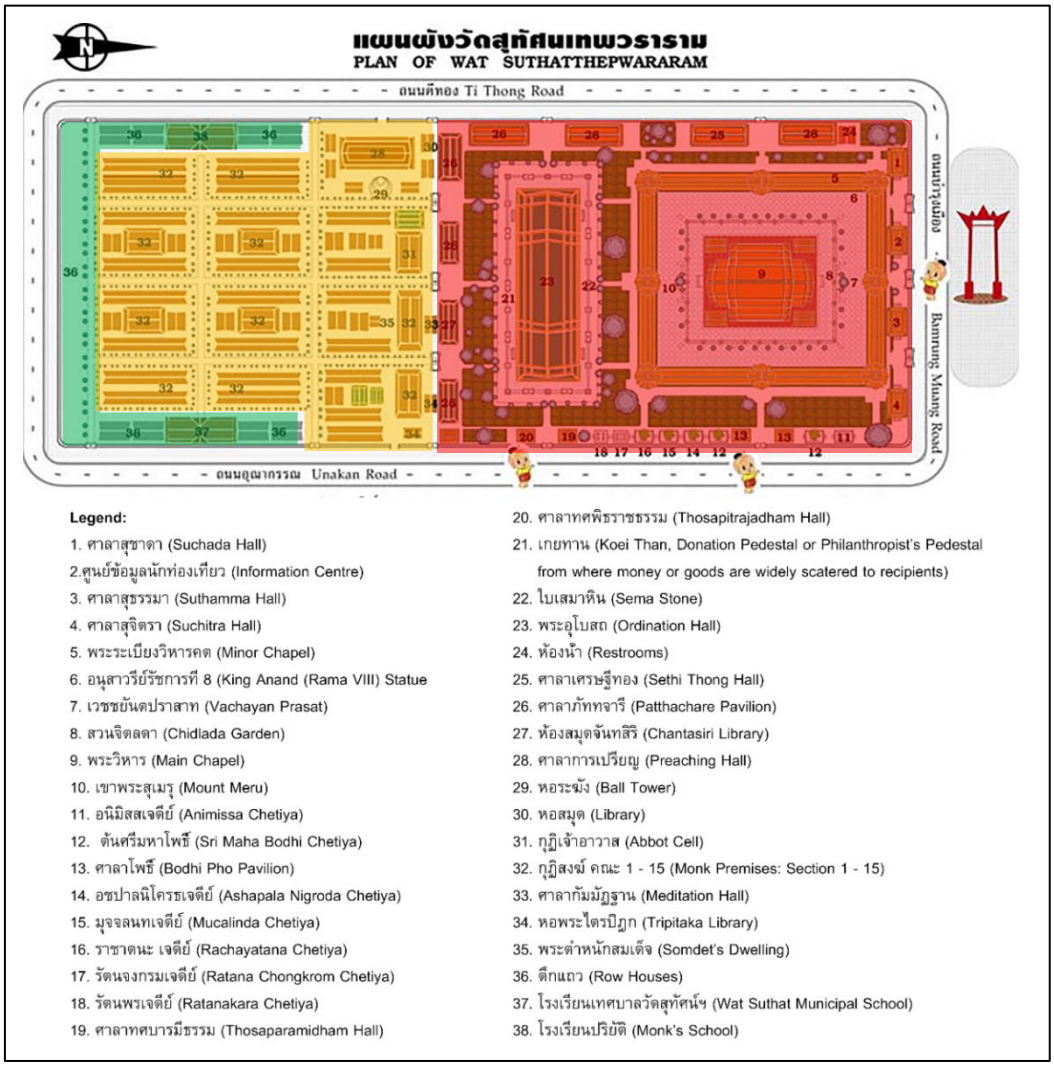


Figure 4.3: Example of monastic zoning of Wat Suthathepwararam

Source: (Katitham n.d.)

The outer layer of the heart of the monastery is encompassed by low wall known as *Kumpang Keow* ('Jewel Walls'), which is a metaphor for the boundar separating the lower (physical) from the higher (spiritual) world. The next layer of the wall surrounding the Jewel Walls is the cloisters symbolised as the seven-

layer mountains or the *Satta Borriphan* Mounts. This area is used as a gallery for walking meditation (Khanjanusthiti 1996).

The architectural and spatial layout of monasteries thus materialises ideals of heaven from the Buddhist perspective in the material world. However, it should be noted that the planning varies according to the period of construction. A clear example of such planning can be found in the Buddhavas zone of Wat Phra Chettuphon Wimon Mangkhalaram Ratchaworamahawihan or Wat Pho, as Figure 4.4 presents.

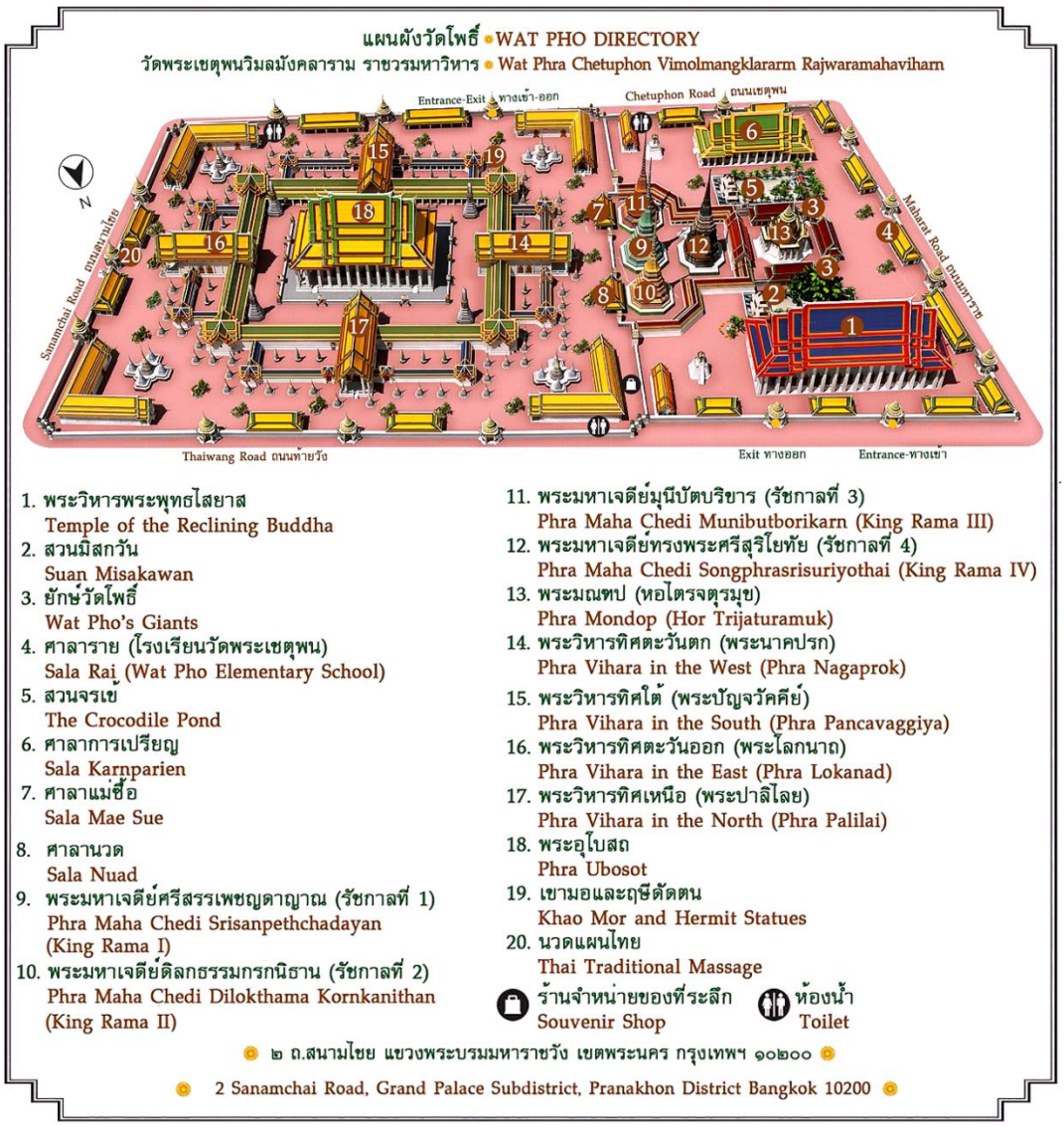


Figure 4.4: Map of Wat Pho at the Buddhavas zone with legends

Source: (Watpho 2018)

4.7.2 Suitable external and internal environments for practising Buddhist meditation

This section explains environments considered suitable for meditation in Buddhist thought. Buddhadasa (2009) mentioned the importance attached by the *Tripitaka* to the environment for meditative activities. Suitable environments can lead to a better experience of the practice, and help meditators develop their mindfulness more efficiently. The suitable environment is not only defined by the physical or external surroundings, such as constructions or weather, but also internal environments, called temperament. The suitable environment for meditation in Buddhism is defined by external factors called the '*Sappaya 7*' (Payutto 2016):

- ***Avāsa Sappāya*:** a safe and peaceful place.
- ***Gocara Sappāya*:** a place located not too far from the community, so that monks can walk their alms round.
- ***Bhassa Sappāya*:** a place where people discuss suitable topics relating to '*Kathāvatthu 10*' (ten topics monks should converse about, such as seclusion, concentration, modesty, and the encouragement of deliberation).
- ***Puggala Sappāya*:** a place with moral and intellectual people.
- ***Bhojana Sappāya*:** a place where suitable foods are available.
- ***Utu Sappāya*:** a place with suitable climatic conditions.
- ***Iriyāpatha Sappāya*:** a place suitable for individual meditation postures, such as a place for walking meditation or sitting meditation.

As mentioned above, *Avāsa Sappāya* and *Utu Sappāya* are psychical and climatic environments, whereby architecture and indoor and outdoor climate factors can influence meditation quality. However, it can be noticed that social and psychological factors, such as quality of surrounding people, encouragement, and topics of discussion are also stated as influential factors on the meditative practice. Naturally this thesis is not concerned with the holistic array of factors affecting the ambience of meditative spaces, and its scope is

restricted to architectural elements and climatic factors, thus it focuses on *Avāsa Sappāya* and *Utu Sappāya*.

Buddhadasa (2009) mentioned that internal and external environments are related. He mentioned that *Avāsa Sappāya*, an external factor, must be matched by personal temperament, which is an internal variable, which may be in one of the following conditions:

A. ***Rāgacarita*:** a lustful temperament.
B. ***Dosacarita*:** a hateful temperament.
C. ***Mohacarita*:** an ignorant temperament.
D. ***Saddhacarita*:** a devout temperament.
E. ***Buddhicarita*:** an intellectual temperament.
F. ***Vitakkacarita*:** a discursive temperament.

According to the suggestion explained by Buddhadasa (2009), the temperament manifests psychological factors representing human identity. It is suggested that a suitable environment for practices should be characterised inversely to personal temperament. Opposite characteristics to the person's temperament are used in meditative practices and supporting facilities to counteract their predispositions in pursuit of equilibrium. For example, in *Rāgacarita* the mind strongly persists in the desire for worldly beauty and greed, and is concerned with tidiness and wellbeing. People with this temperament are advised to wear coarse, old clothes and live in sloppy, inconvenient, and unimpressive environments. Appropriate colours for this temperament should not be vibrant and luxuriant, such as dark green. Such people are advised to perform walking and standing meditations, while avoiding sitting and sleeping postures.

However, it should be noted that the proper locations for meditation also share some aspects in common amongst the six temperaments. For instance, the practising spaces should be suitable in size and not be too new or old, while low maintenance is required. The recommended places are forests, villages, temples, gardens, cottages, houses, caves, and under sentinel trees. They

should be located at accessible areas, but away from walkways, public reservoirs, flowers, areas of conflict, desirable objects, cities, farms and paddy fields, ports, and borders (Buddhadasa 2009). The aspects mentioned above describe physical environments which relate to *Avāsa Sappāya*, *Gocara Sappāya and Iriyāpatha Sappāya* points of view.

In terms of *Utu Sappaya*, it is relevant to the time of practice and climatic factors. It includes the right or suitable time to meditate, which can contribute to more impressive experiences. *Utu Sappaya* entails good scenery, good air quality, and comfortable weather. Periods, times, seasons, and locations of practice should be carefully considered. In this case, a suitable period of start time is highlighted as the most significant factor for beginners. It is also recommended to create a routine training schedule to follow. If the environmental conditions are unsuitable, a relocation method should be considered. However, if such a solution cannot be implemented, improvement of the existing environment is necessary (Buddhadasa 2009).

4.7.3 Theravada Buddhism meditation in Thailand

As discussed in the preceding section about various types of meditation provided by different meditation gurus, some techniques are used for the purpose of mindfulness cultivation to improve awareness and wellbeing in daily life. On the other hand, some of them might relate further meanings regarding the religious point of view. The study sites of this thesis are located in Theravada Buddhist monasteries, where the Buddha's thought has a significant influence on the people' behaviour and perspectives on how they see the world. Meditation is believed to be a path to terminate the suffering cycle, emulating the Buddha's practice toward enlightenment. Thus, meditation is considered a profoundly significant activity for Buddhists. This section discusses styles of meditation found in the sites, in the forms of walking and sitting postures.

4.7.3.1 *Sitting meditation posture*

Sitting meditation, known as '*Anapanasati*', is a breathing mindfulness meditation involving mental activity. A sitting posture requires a straight back in

a comfortable position, not too relaxed or rigid; the body should be relaxed without muscle tension. During meditation, although physical sensations of itching or pain might occur, those should be perceived, but not physically reacted to, in order to alleviate them. Breathing is natural; not too hard or too low, fast or slow, and deep or shallow. There is no enforcement of breathing, but it is carefully observed. By a posture of sitting with crossed legs and closed eyes, meditators experience their mind chatter, revealing arising thoughts, emotions, or sensations. If distractions appear during meditating, causing deviation from concentration, one gently draws the mind back to the focal point of breaths. This process is significant in *Anapanasati*, which improves the clarity and stability of mind. For beginners, if the distraction still gradually emerges, counting the number of inhalations and exhalations from one to ten might be a helpful technique to manipulate the mind back into concentration.

Moreover, agitation and dullness are mind distractions which deviate the meditator's mind from concentration. One recommended solution for this is to retrieve the focus back into the breaths. Furthermore, this distraction may result from a gaze angle of the closed eyes; too low an angle might result in dullness, while too high angle might result in an imbalance of the body. Thus, an adjustment to an optimum angle, not too high or low, is recommended.

Attempting to compel the mind to reach a stable stage is counterproductive, which can be explained by the metaphor of the mind being like mud in a jar. If one wants to turn the mud into clear water, stirring it (equivalent to conscious willing to discipline the mind) will make it muddier. Conversely, waiting until the dirt is settled as sediment reveals the clear water (equivalent to passively experiencing and not engaging with mind chatter). During the meditation, unpleasant images or thoughts might emerge in the mind, which one experiences and lets go naturally, not intellectualising such sensations by attempting to explain or interpret them. Instead, it is important to try to return to observe the breaths as a form of attachment (Goodman 2013).

Clarity of mind emerges when the mud of distractions settles down and the breaths are stable. If a short period of practising time can be achieved, it is

recommended to continue and extend the stable mind for a longer period. However, it should be noted that that extension of practice might lead to further interruptions, which might occur more frequently over a longer period. Sadhu (1967) explains mind during meditation as a line of mind, as presented in Figure 4.5. It presents mind work as ideal lines of X to Y during engaging in the activity (Figure 4.5 A, B, C, and D). Ideally, the trained mind is stable and perfectly straight, as in Figure 4.5 (E). Unexperienced meditators might be unstable and discontinuous, caused by distraction, as presented in Figure 4.5 (A). However, the more the mind is trained, the more stable and even the mind will gradually appear, as shown in Figure 4.5 (B), (C) and (D).

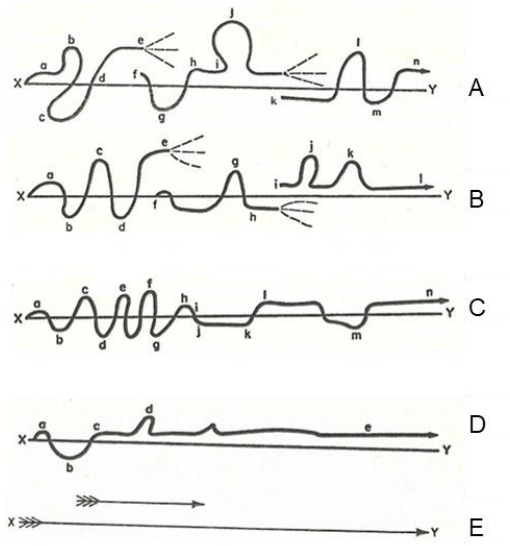


Figure 4.5: Line of meditation

Source: (Sadhu 1967)

- ***Anapanasati meditation***

As mentioned in the previous section, the studied sites are located in Thailand, where Theravada Buddhism has a strong influence on people's way of life, and it is a core part of national culture. Meditation is a slow or static activity allowing practitioners to observe and experience their mind. This section discusses the Theravadan Buddhist meditation known as *Anapanasati*, and its basic methods of practice, since it is a style which the subjects of this research performed.

Anapanasati meditation, a breathing meditation (Payutto 2016) combines both *Samathā* (repose) and *Vipassnā* (insight) meditations (Buddhadasa 2009), the

former of which is more instrumental at lower levels, while the latter becomes more significant among proficient devotees. Goodman (2013) mentioned that the Buddha highlighted the main difference between *Samathā* and *Vipassnā* meditations are the development of tranquillity and insight, respectively.

First, meditation was not invented by the Buddha; it is believed that he learnt methods of meditation from two masters, one based on the principle of nothingness, and the other one on non-perception, when he was a bodhisatta. He achieved those techniques, but felt dissatisfied with the momentary contentment and peace. Besides, it could not be a solution to terminate the true suffering cycle. In this regard, it can be described that everything will return to reality after finishing the meditation; repetitively, people, including his teachers, still suffered from real-world bondage. It can be seen that, according to his perspective, the results of *Samathā* meditation benefit their present and the next life. However, this is not the way of liberation out of the real world. In contrast, the aim of *Vipassnā* is to escape from the cycle, to enlighten and reach the *Nibbāna*, which is ultimate liberation (Goodman 2013).

Anapanasati analyses tangible and intangible factors to allow meditators to consider things based on four major categories, known as *Sattipathāna 4*, considered to be the four major mindfulness foundations. Each of them has another four bases, called *16-based Anapanasati.* The four main bases are *Kāyānupassanā*, *Vedanānupassanā*, *Cittānupassanā*, and *Dhammānupassanā*, which are contemplations of body and breath, feelings, mind, and mind-objects or ideas, respectively. In this regard, Payutto (2016) noted that in the first three of the four bases of contemplation, a mixture of *Samathā* and *Vipassnā* can be found, but in the last base, *Dhammānupassanā*, only the *Vipassnā* remains.

Regarding *Kāyānupassanā* or body contemplation, Buddhism considered that the body is not just only the human body, but also breath, which are interrelated and affect each other reciprocally. This type of contemplation requires meditators to realise that body is not theirs (Payutto 2016) and requires investigating the characteristics of short and long, strong and delicate breaths,

to explore the effects of different breaths to the body. For that aspect, Buddhadasa (2009) explains that the main activity of *Kāyānupassanā* is to catch, monitor and create a mark of focus in mind '*Uggahanimitta*', to allow the body to stay serene. The mark can be modified by changing colour or moving, as determined by practitioners. If this phenomenon is achieved, the mind will reach a more stable stage, and *Uggahanimitta* will become *Patibhāganimitta*. That is a sign of *Upacara-Samādhi*, the first stage of *Jhāna* or the first absorption, discussed later in this chapter (Buddhadasa 2009; Payutto 2016).

The second stage is *Vedanānupassana*, which is a contemplation of feeling. This stage aims to allow meditators to realise that feeling does not belong to them (Payutto 2016). Buddhadasa (2009) mentioned that the four fundamental requirements of humans are not enough, while psychological factors play a significant role to allow humans to live in the world with happiness. However, humans are seeking careless solutions to indulge them for unsustainable pleasure.

The authentic delight is valuable, and it can be discovered in mind. A negative mind is considered an engine of the human body that contributes toward bad outcomes, while a good mind leads to positive productions. In this stage, the practitioners might appreciate the power of tranquillity when they attain the first *Jhāna* since mind qualities *Pīti* (rapture) and *Sukha* (happiness or bliss) appear more obvious and profound. As there are two sides of coins, their pleasured mind allures the practitioners to trap and limit the mind development to the further stages. Thus, to reach a higher level of mind, it is suggested to repress feelings and consider them as an impermanent condition unworthy of attachment. When these feelings are considered to be unsustainable and momentary, *Piti* and *Sukha* are abandoned.

Cittānupassana is the third stage, in which the mind is more stable, and it is suitable to be employed to analyse mind. The main purpose of this stage is to analyse eight objects: *Rāga* (lust), *Lobha* (greed), *Dosa* (hatred), *Khodha* (anger), *Moha* (delusion), great goodness of mind, a greater mind of mind, and focus and mind of liberation. Those are objectives applied to suppress bad

qualities of mind to reveal a greater mind and to realise that the mind is not the self. The mind with this understanding is overwhelmed with elation, called *Pāmojja*, followed by an emergence of *Pīti*, which is a significant factor in enlightenment, known as *Bojjhanga 7*. Payutto (2016) briefly explained this stage as the mind clearly understanding its own mind in a current occasion, with and without the influence of *Raga*, *Lobha*, *Dosa*, *Khodha*, *Moha*, sombre or bright mind, and distracted or focused of mind.

The last stage of *Anapanasati* is *Dhammānupassanā*, which is a contemplation of ideas or mind objects. This stage of meditation allows the practitioners to realise that things are Dhamma and they are not ours. The mind is insight in Dhamma, which is *Nivarana 5*, *Panca-Khanda*, *Ajjhatiikayatana 12*, *Bojjhanga 7*, *Ariyasacca 4* or the Four Noble Truths, concepts explained in detail by Payutto (2016). Those are contemplated to reveal their cyclical nature and to perceive things as they are, such as start and finish, existence and inexistence, and appearance and disappearance (Payutto 2016). Buddhadasa (2009) mentioned that this contemplation allows meditators to reveal that things are impermanent, non-self, non-soul, and a cause of suffering. Those are the truth of nature, whereupon meditators should surrender and accept what they are.

Thus, when those are realised as they are unstable and everything has causal factors as a truth of nature, in which things are characterless and nameless, the mind realises that things are unreliable and should not be adhered to. In this case, the attachment with things should be terminated, as they are artificial and everything is just emptiness. This thought separates the mind between the real world and the supermundane plane (*lōkuttara*). Finally, when all internal and external factors are contemplated and completely understood, the practitioners perceive dilutions of their attachment and get bored this suffering circle. Such boredom is a path to enlightenment, by which the mind is completely liberated. The consequence of the contemplation depends on levels of detachment or dispassionate *Virāga*. Practitioners with high *Virāga* are considered *Arahant*, who have attained *Nibbāna*, enlightenment or the holy life, and who are completely liberated from the cycle of suffering (Buddhadasa 2009).

❖ *Objects of abandoning in Upacara-Samādhi*

Meditation can be broadly categorised into three main stages: *Khanika-samādhi*, *Upacara-Samādhi*, and *Appanā-samādhi* meditation. *Khanika-samādhi* means short-period concentration. The mind in this depth can be easily interrupted by internal and external stimuli. The higher stage is *Upacara-Samādhi*, in which the mind starts to rest deeply and is developed to attain a deeper state, and *Jhāna* is gradually revealed. The *Pali* canon categorised *Jhāna* in this level of concentration into four-sub levels known as '*the Four Jhanas*', namely, *Pathama-Jhāna*, *Dutiya-Jhāna*, *Tatiya-Jhāna*, and *Catuttha-Jhāna* (Goodman 2013).

There are objectives with which the mind can be attached. When the mind reaches each state, it abandons each objective. Those objectives or attainments of mind are *Vitakka*, *Vicāra*, *Pīti*, *Sukha*, and *Ekaggatā.* Elements of each *Jhāna* are established based on a deduction of feelings to attain higher absorptions, as Table 4.1 presents.

Table 4.1: Summary of the Four Jhāna in Upacara-Samādhi

Khanika-samādhi	**The first stage of meditation (short-period concentration)**							
	Absorption	**Jhāna**	**Elements**					
Upacara-Samādhi	1st	Pathama-Jhāna	Vitakka	Vicara	Piti	Sukha	Ekagata	-
	2nd	Dutiya-Jhāna	-	-	Piti	Sukha	Ekagata	-
	3rd	Tatiya-Jhāna	-	-	-	Sukha	Ekagata	-
	4th	Catuttha-Jhāna	-	-	-	-	Ekagata	Upekkhā,
Appanā-samādhi	Higher state of Jhāna							

Vitakka, '*applied thought*', is an objective in which the mind can focus on the beginning stage of meditation for the stabilising and clarifying of the mind. This process of meditation creates a strong foundation before entering the stage of *Jhāna* (Gunaratana 1988).

Vicāra is a sustainable recognition of the existence of body parts and breaths, with a consideration of those characteristics. For example, it is an observation of inhalation and exhalation in terms of breath length and pace and a recognition of air flowing from the nose tip to chest and to the abdomen, before releasing via the same route (Goodman 2013). *Vicāra* is an initial application of mental preparation, while *Vitakka* is a solution to sustain the concentration (Gunaratana 1988).

Pīti is rapture and pleasure happening during the meditation. It can emerge from *Pamojja*, which is happiness and joy. It is a result of abandoning the five hindrances, known as '*Nīvarana 5*', comprising:

- *Kāmachanda*, sensual desires. This hindrance ranges from subtle to aggressive desires.
- *Byāpāda* is malevolence, in which the mind is attached to anger and want to revenge.
- *Thīna-middha* is laziness and drowsiness, which result in inactive and unproductive performances.
- *Uddhacca-kukkucca* is daydreaming, confusion, hallucination, or anxiety.
- *Vicikicchā* is hesitation and unbelief in the results of the practice.

The abandonment of those hindrances allows the mind to experience happiness, joyfulness, merriment, and the exhilaration of tranquillity (Gunaratana 1988).

Sukha is happiness and pleasure which appears in the body resulting in a mind reaction. This happiness might sometimes be confused with *Pīti*, since it co-exists in the early stage of absorption. However, *Pīti* presents a succinctly-profound effect before *Sukha* emerges in the early stage of meditation. When the meditators attain to the third *Jhāna*, where *Pīti* is abandoned, *Sukkah* is revealed more clearly and exerts an intensive impact to the mind, and this effect suffuses throughout the whole body.

Ekaggatā is a combination of the preceding four objectives (*Vitakka*, *Vicāra*, *Pīti*, and *Sukha*) to become one-pointed of centred. This object prevents meditators from unwholesome thoughts caused by *Nīvarana* 5, especially sensual desire, to allow experiencing wholesome thoughts.

Upekkhā is equanimity or neutrality of mind, which allows meditators to consider things with wisdom, without bias or emotions, and the outcomes at the present moment have causal factors resulting from a consequence of good or bad actions, as cause and effect. In this case, people with *Upekkhā* will see things as they are with tranquillity and neutrality, and realise that things should be responsible for themselves and deserve what they have done.

- ***Abandonment of the five objectives in Upacara-Samādhi***

In the first *Jhāna* of in *Upacara-Samādhi*, meditators experience all five objectives, but the main focus is on *Vicāra* and *Vitakka*. The concentration must be sustained until the mind can attain to a deeper stage of meditative experience. However, the '*Nīvarana 5*' hindrances faced during meditation prevent the mind from stability. Humans experience both *Jhāna* and *Nīvarana*, but the default condition is the latter, causing suffering in the world, while the former can only be obtained through spiritual discipline. Thus, it is believed that practising meditation allows meditators to explore their hidden parts of their mind and to rise above their hindrances of normal human experience.

Table 4.1 presents steps of attainments of four-*Jhāna* stages by the deductions of four of the five objectives. The first two *Jhāna* or the first absorption is to focus on *Vitakka* and *Vicāra*. However, it is unclear which one should be abandoned first during the initial steps, due to their significance in mind manipulation and concentration. Goodman (2013) and Gunaratana (1988) confirmed that those two objects are interrelated, and deductions of these two objects are unclear (Goodman 2013). In contrast, to reach the second level of *Jhāna*, *Vitakka* should first fade, followed by *Vicāra*, when knowing the flows and path of breaths will be abandoned. When those are absent, the mind will

experience more profound effects of *Pīti*, *Sukha*, and *Ekaggatā*. At this moment, the feeling of *Pīti* and *Sukkah* create a pleasant moment.

In the third stage of *Jhāna*, the mind leaves *Pīti* to allow meditators to appreciate the purer *Sukha*, before reaching the fourth stage where those objectives of mind and body disappear, while *Ekaggatā* appears. Mind with *Ekaggatā* in this fourth stage of *Jhāna* is in conjunction with *Upekkhā*, which is equanimity or neutrality, which emerges simultaneously. The mind reaching this level becomes strongly stable and ready to attain a deeper absorption.

The next stage of meditation, called *Appanā-samādhi*, allows retaining the mind in a higher spiritual state. This level is beyond the scope of this thesis and of normal practitioners. This stage of mind can provide extreme happiness, which can deceive meditators into the experience that they are staying in *Nirvana*. However, this stage of meditation might not allow practitioners to escape from the suffering cycle in real life. Thus, when they realise that they have reached this stage, it is recommended to decline the mind back into the *Upacara-Samādhi*, which is a more suitable depth for analysing *Dhamma*.

4.7.3.2 *Walking meditation*

Apart from the sitting meditation, walking meditation is one of the practising postures found in the meditation centres that can be practiced on a daily basis. The walking meditation is a slow activity involving synchronisation of rhythms of body movement and cycles of breathing with the eyes open. However, every walking step requires attention to the legs and feet, whereby one foot should always be in contact with the floor. Feet sensation and ground touching must be experienced knowing the exhalation and inhalation of the breath (Goodman 2013).

Although the visual information received during meditation may prevent practitioners from a psychical accident while practising, it may deviate the practitioner's focus and distract the mind. The solution to this problem is to perceive but let it go, and retrieve the mind back into focus on the synchronisation. The style of practice allows the practitioners to grow

mindfulness while appreciating the real environment. This process can be applied to other general activities in daily life (Goodman 2013).

4.8 Chapter conclusion

This chapter has explained meditations in traditional and applied styles. According to the literature, meditative practice is a form of mind training which allows the practitioners to see everything as it is, which from the Buddhist perspective is nameless, characterless, and impermanent. Mindfulness meditation, which was developed based on the eastern meditative method, was introduced into Western cultures in the 1960s, and it has since attracted widespread acceptance in Western psychotherapy, often being applied as an integrative intervention to manage stress and negative feelings.

Furthermore, the effects of meditation on the body and mind have been investigated by neuroscientific instruments and self-evaluating questions. Reviewed studies confirm the benefits of practices based on improvements in participants' physiological and psychological factors. For former aspect, practising meditation can reduce heart rate, blood pressure, and skin resistance, while increasing the holding time of breath. Besides, in terms of psychological effects, it can reduce stress, pain, and negative effects of mental illness, while improving emotional control and flexibility, attention, liveliness, self-assurance, contentment, optimistic personality and levels of life satisfaction. Such concepts led to the establishment of '*Positive Psychology*', which fulfils the other side of the conventional psychology. This novel school of thought introduces the idea of '*Life Above Zero*' that highlights solutions to improve wellbeing rather than focusing on the '*disease model*' of traditional psychology, and in which meditation can (and does) play a major role.

Meditative practice was traditionally the preserve of a spiritual elect, but in recent years it has become a widespread and popular activity. In Thailand people can and do practice meditation on their own or in social contexts, in private or religious sectors, and meditation activities are commonly arranged by groups of meditation instructors in Theravada Buddhist monasteries, where

strong cultural influences enhance the experience for many. Thai monasteries comprise three zones, one of which, the *Buddhavas*, is designed as a sacred space representing the Buddha's area, which normal people can access to perform religious activities. This zone is created based on a metaphor of Buddhist cosmology, which is strongly relevant to religious belief.

Regarding the traditional meditation styles, two common forms of meditative practice, walking and sitting postures, are found in Thai meditation centres. The former type is the mindfulness cultivation of body, which is a slowing-moving activity with eyes open, while the latter form is static activity, allowing meditators to attain a deeper meditative stage with eyes closed. In Theravada Buddhism, such activity, known as '*Anapanasati*', is an observation of internal and external factors, without judgement. The objective to be analysed is the truth of nature comprising four major aspects of experience: body, feeling, mind, and Dhamma. These contemplations allow practitioners to realise the sense of non-self or *Disidentification*, in which everything is not themselves, unstable and impermanent. This practice is believed to result in authentic and sustainable happiness.

Chapter 5

Research Methodology

Chapter 5: Research Methodology

This field study of human thermal comfort involves collecting data including participants' subjective votes, thermally adaptive behaviour, and thermally environmental parameters. This chapter describes the research method employed in the pilot study and main survey, such as data sampling, collection, and analyses. It elaborates on the physical information of the built environment of the meditation centres and the halls, and the routine meditation activities conducted within such facilities. Moreover, a method of measuring instrument selection, a summary of the instrument accuracies, and an environmental measuring method are discussed. For the data collection, this chapter describes the questionnaire design and development in detail, from the pre-test to the final versions. Methods of environmental variable calculation, physiological model evaluation, and statistical analysis are explained.

5.1 Research philosophy

According to Saunders *et al.* (2007), the process of research design can be described as layers of an onion, as Figure 5.1 presents. The steady-state model of human thermal comfort study involves objective explorations of the heat-exchanging phenomena between the human body and physical environment using laboratory experiments, as mentioned in Chapter 2. In contrast, this human adaptive thermal comfort study, which was conducted in a real-life contextual environment under the intensive cultural conditions of Buddhism, was associated with objective and subjective explorations. Its investigation extends over different aspects, such as subjects' suitable thermal states, thermal adaptations, thermal attitudes, and variation of meditative qualities. Traced from the outer to inner layers of the research onion, this research is therefore based upon the interpretivist ontology, using deductive epistemology based on the adaptive model of thermal comfort, considering physiological, psychological, and physical factors. This cross-sectional, mixed-method research includes physical measurements, a structured questionnaire, in-depth

interview, and observation of the behavioural and environment interactions of subjects.

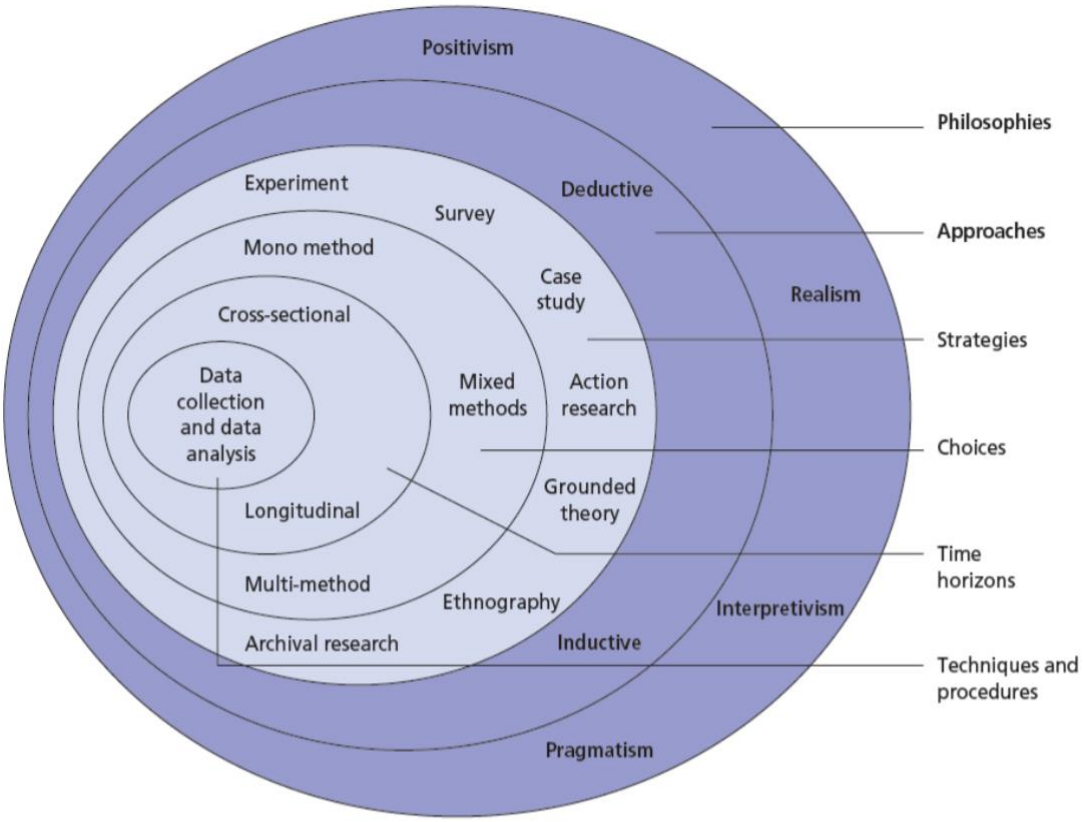


Figure 5.1: Onion model of research methodology.
Source: (Al Zefeiti and Mohamad 2015)

5.2 Research workflow

This section describes the research workflow from the initial stage to completion as summarised as presented in Figure 5.2. The first stage of the research was defining the research discrepancy and problems based on literature reviews. The literature review of past published studies in this field revealed many thermal comfort studies conducted in different building types, such as educational, residential, and commercial buildings. However, no evidence of adaptive thermal comfort study was found that was conducted in Buddhist monasteries, especially in *NV* meditation buildings. Thus, this building type and its users are the main focal point of this research.



Figure 5.2: Research workflow

Before implementing site selection as mentioned in Chapter 5, 15 different potential meditation centres, located within a 40-km radius from Khon Kaen city centre, were visited to observe their annual and routine practising schedules, the number of participants, and indoor and outdoor environments of their meditation hall. Apart from this pre-observation, the author engaged a 5-day meditation course as a normal meditator to experience the actual practicing sessions and living.

After finishing site selection, the initial version of the research established the aims and objectives, and designed the research methods (questionnaires, observation forms, consent form, and information sheet), and measuring instruments accordingly. The pilot study took place in April 2016, which aimed to test the research method and instruments and practice the research assistants' operations. The collected data and research method and tools were

analysed and evaluated for the further development of the main survey. Before the main survey started, the final version of the research method, research aims and objectives, and relevant documents such as the information sheet, questionnaire, observation form, consent form, participant-recruiting poster, and gatekeeper letter were reviewed and approved by the Research Ethics Committee of the School of Engineering, at the University of Nottingham (UK).

There were two rounds of the main survey conducted in three meditation centres during the winter (November 2016 to January 2017) and monsoon (June to July 2017) seasons. The consenting users in each meditation hall of each centre were surveyed, while the indoor and outdoor thermal environments of the halls were measured and observed. The results reported in this thesis were transcribed and analysed in Microsoft Excel (2010) and SPSS (version 24).

5.3 Site selection

This section will focus on a process of site selection concerning which of the selected sites will be employed in both the pilot and major studies. Buddhism is the official religion of Thailand and the vast majority of its inhabitants. There are 40,736 monasteries nationwide, 33,000 of which regularly hold meditation sessions open to the public (Cook 2010). According to the National Office of Buddhism (ONAB 2011), 1,200 Buddhist monasteries were registered as provincial meditation centres in various administrative regions (450 in the north-east, 276 in the middle, 149 in the east, 123 in the north, 111 in the west, and 91 in the south) (Boontang 2015). As shown in Figure 5.3, the north-eastern region accounts for the largest proportion of registered monasteries comprising 37.5% of the national total (National Office of Buddhism 2011), thus it was selected as an area of study, particularly Khon Kaen province (16°27’N, 102°50’E) (Figure 5.4 (A)), since it is one of the main provinces in this region and holds the fourth place of the number of provincial meditation centres according to ONAB (2017).

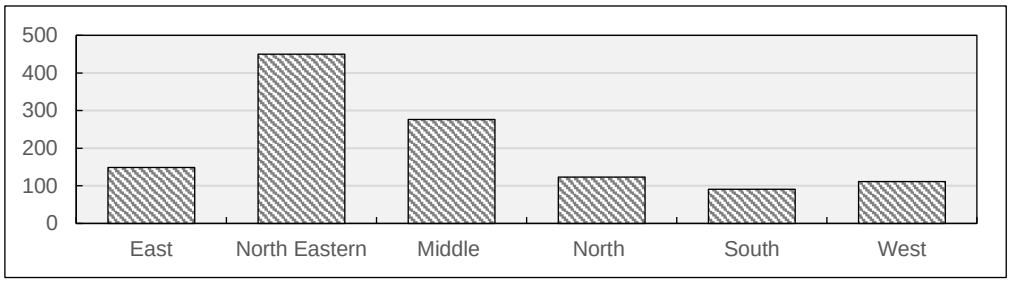
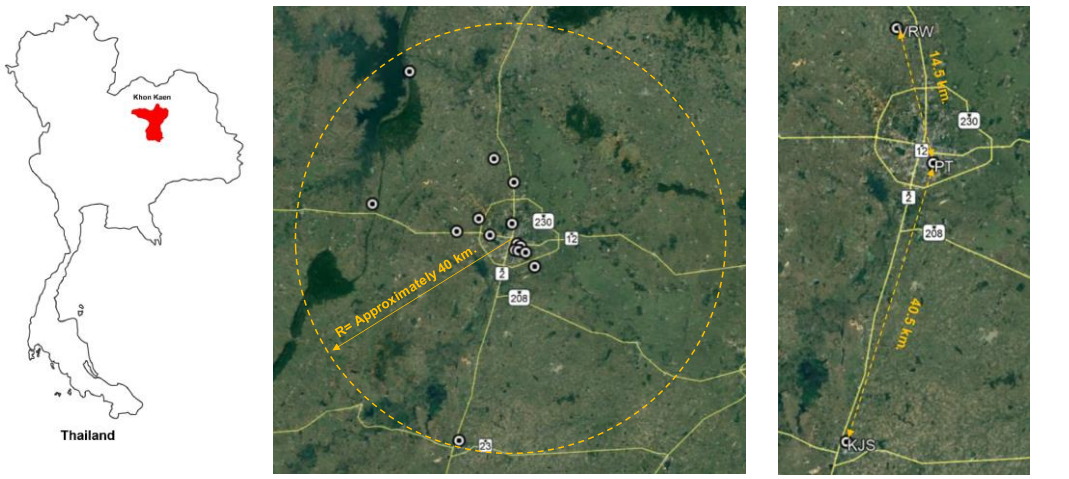


Figure 5.3: Number of provincial meditation centres registered with ONAB

Source: (National Office of Buddhism 2011)

ONAB (*2017*) also reported that 35 monasteries in Khon Kaen organise public meditation sessions. The large number of potential case studies facilitates conducting the study in this area, and it was intended to visit all sites to request consent and research collaboration. However, personal visits at some sites could not be implemented due to logistical difficulties (i.e. inaccessibility). Therefore, this research narrowed the geographical scope to an area of 40 km radius from Khon Kaen city centre, as Figure 5.4 (B) presents.



(A)Map of Thailand *(B) Khon Kaen with 40-km radious* *(C) Distances between the sites*

Figure 5.4: Map of Thailand showing location of Khon Kaen and the study sites

Source: (Google Maps n.d.)

According to the observation, responsible people from 16 meditation centres were contacted by phone or in person to discuss the research activity and request their consent to research in their monastery areas. Finally, three places (*VRW*, *PT*, and *KJS*) were chosen as the study locations (Figure 5.4 (C)), based on the following criteria:

- The centre must consent to allow the research team to conduct the research.
- The centre must have a routine practice schedule, and organise regular activities to allow the research team to be able to plan the survey.
- The places should have at least 15 meditators in each session.
- The meditation activities must be conducted inside *NV* halls under the supervision of meditation instructors.
- The centres must require participants to register to the practising session (in order to screen the outsiders/ non-regular attendees/ building users).

5.4 Outdoor environmental conditions of Khon Kaen

Since the three sites are located in Khon Kaen, the outdoor thermal environment should be briefly described. According to secondary data measured over 2016 by Thailand Meteorological Department (2017), an average outdoor *DBT* ranges from 23.96°C to 32.71°C, with minimum and maximum temperatures of 10.00°C and 41.60°C in January and April, respectively (Figure 5.5 (A)). A mean *RH* varies from 54.77% to 83.06% in April and September, while the lower and upper limits of the factor are 22.00% and 99.00% in April, as Figure 5.5 (B) shows.

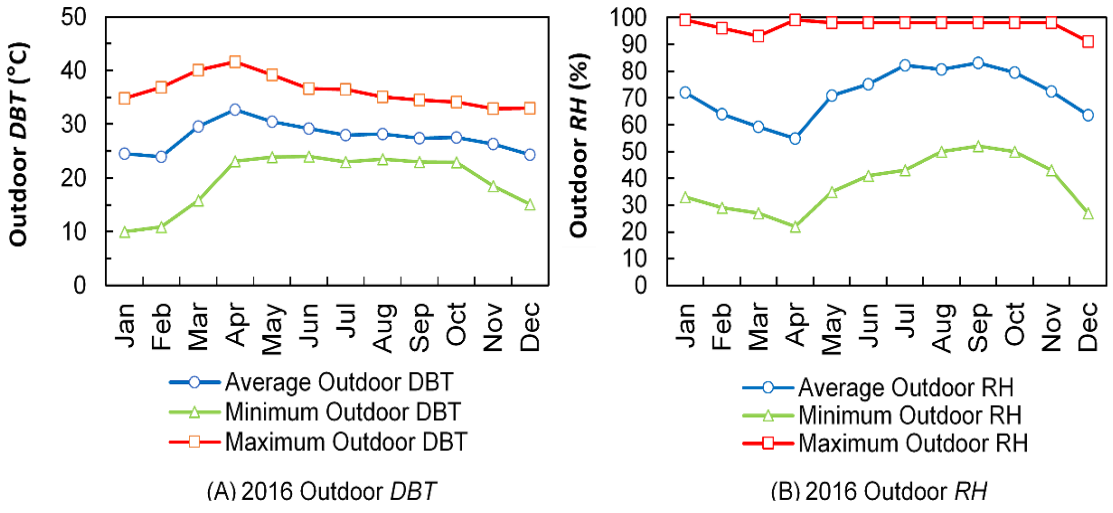


Figure 5.5: Outdoor DBT (A) and RH (B) of Khon Kaen in 2016

Source: (Thailand Meteorological Department 2017)

5.5 Activities and physical properties of the meditation halls

This section focuses on the external environments and construction details of the *VRW*, *PT*, and *KJS* halls and their activities and practising schedules of each centre. Before discussing the meditation sessions in detail in terms of their contexts and built environment, this section summarises the general activity sequences found in each meditation centre.

The session lengths vary from 90 to 180 minutes, depending on places of practice and practising times. For example, the most extended meditation was found in the afternoon session (180 minutes) in *VRW*, while the shortest session (90 minutes) was found in the morning and afternoon sessions provided by the *KJS* centre. Based on a pre-observation, each meditation session started from a brief instruction provided by a meditation instructor. After that, the participants performed 30-minute-walking meditation following by a 30-minute sitting meditation, before finishing the session with a 15-minute activity of prayer and sharing loving-kindness.

Similarly, most extended training sessions may last for 180 minutes, with practice starting and finishing with the same activities as shorter sessions. However, the sequence of the beginners' meditation activity was different from that of more experienced meditators. The posture of the un-experienced meditators was changed on a loop every 30 minutes, from walking to sitting until finishing the practice. In contrast, the experienced practitioners might maintain the sitting meditation throughout the training session, for 150 minutes, as summarised in Figure 5.6.

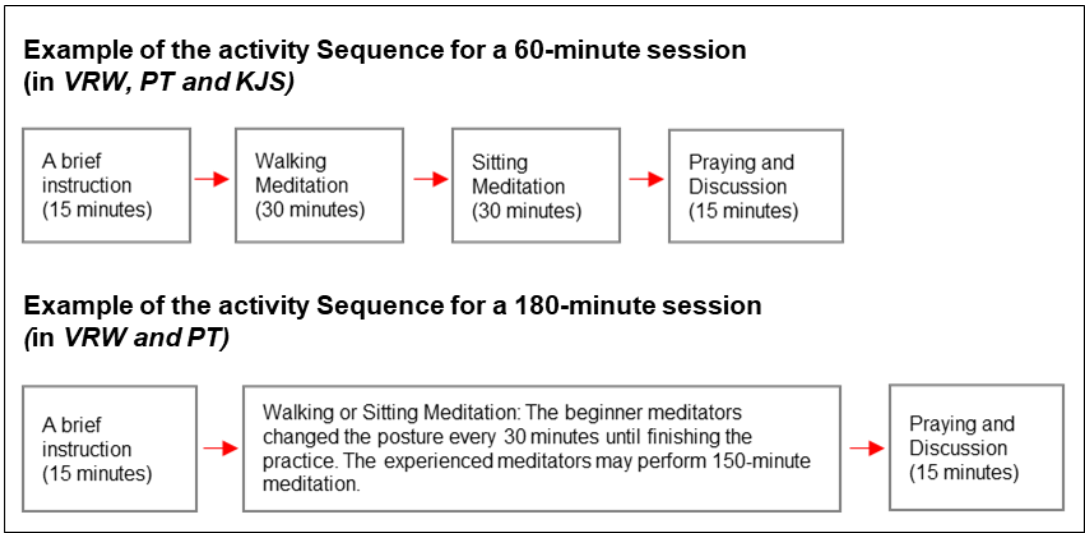


Figure 5.6: Summary of the sequences of meditation sessions in this research

5.5.1.1 *VRW meditation centre*

- ***Meditation sessions of VRW***

VRW centre is a branch of a successful meditation centre in Sing-Buri province located in the middle region of Thailand. The practising solutions, styles, and schedules are adopted from the headquarters. The *VRW* organises daily activities, each session of which may last two to three hours, and the centre is open to the public.

The earliest session (4.00 am to 6.00 am) focuses on morning prayer lasted approximately one hour, followed by a one-hour meditation session. The second session lasts for two hours (8.00 am to 10.00 am), of which one and a half hours are devoted to the meditative practice. The activity of this session starts with a 30-minute sitting meditation. The meditators have freedom to choose practising postures and the length that they prefer to perform after the first 30 minutes of the practice. For beginners, the activity was changed from sitting meditation to walking posture every 30 minutes, according to the instruction of the meditation instructor. In contrast, the experienced meditators remained in the sitting meditation throughout the session. When the activities finished, the instructors led all the meditators to pray and share loving-kindness before taking a lunch break. The third session lasted for three hours starting at

1.00 pm and finishing at 4.00 pm. An activity sequence of this most extended session was similar to that of the second session.

The evening session mainly focused on religious rites (praying), which began again at 5.00 pm, before leaving the halls to take a break at 6.00 pm. It should be noted that the participants of this centre are required to embrace the eight precepts, thus in this case eating in the afternoon was prohibited. Thus, during this break, the meditators could drink only juices or soya milk. The last meditation session started again at 7.00 pm and ended at 9.00 pm. The sequence of the practice was similar to that of the second session. The questionnaire survey in this research aims to examine the participants' subjective votes twice a day, in the second and third meditation sessions.

- ***Monastery environment and meditation halls of VRW***

The *VRW* mediation centre comprises of a group of buildings including a registration office, housing for monks and staff members, public toilets, canteen, Ubosot (see Chapter 4), and meditation buildings. According to observation during the site visit and interviews with representatives, the four meditation buildings are built in the monastic area, as shown in Figure 5.7. This centre is open to the public, so that participants can register for the sessions every day after 3.00 pm. There was a two-hour orientation session taking place at 7.00 am every day at Building 4 for beginner meditators, who require learning the fundamental techniques and methods of meditation.

Building 1 is the largest hall which can accommodate more than 500 meditators. This building is only employed when a large private group of meditators such as school students and government officers arrange a meditation camp. The usage schedule of Buildings 1, 3 and 4 is unpredictable, and may be unsuitable to select as samples; sometimes they were closed. Thus, the centre recommended conducting the survey in Building 2, which is located in the north area of the monastery, where activities are consistently held daily.



Figure 5.7: Layout of VRW meditation centre showing four meditation buildings on site

The façade design of Building 2 represents the simplicity of its interior functions (Figure 5.8 (A)). The north and east façades of the building are exposed to a large open area. The south and west sides, in contrast, are surrounded by a green space functioning as a buffer to screen direct solar radiation before reaching the building, as presented in Figure 5.8 (B) and (C).



(A) East façade



(B) South façade



(C) West façade

Figure 5.8: East, south, and west façades of VRW meditation building

The building was designed in an L-shape layout, including rooms with different functions such as accommodation, office space, a multi-purpose hall, and a training hall. The west wing of the building was a three-storey structure of which the first and second floors were used for meditators' accommodation, while the ground level is a common area. Its north wing is a two-floor structure, with the main meditation hall and a multi-purpose space are located on the first and ground floor, respectively. The latter space is also used when the meditation

hall cannot accommodate the excessive number of meditators. Thus, the upper space was selected as a study location for the *VRW* site.

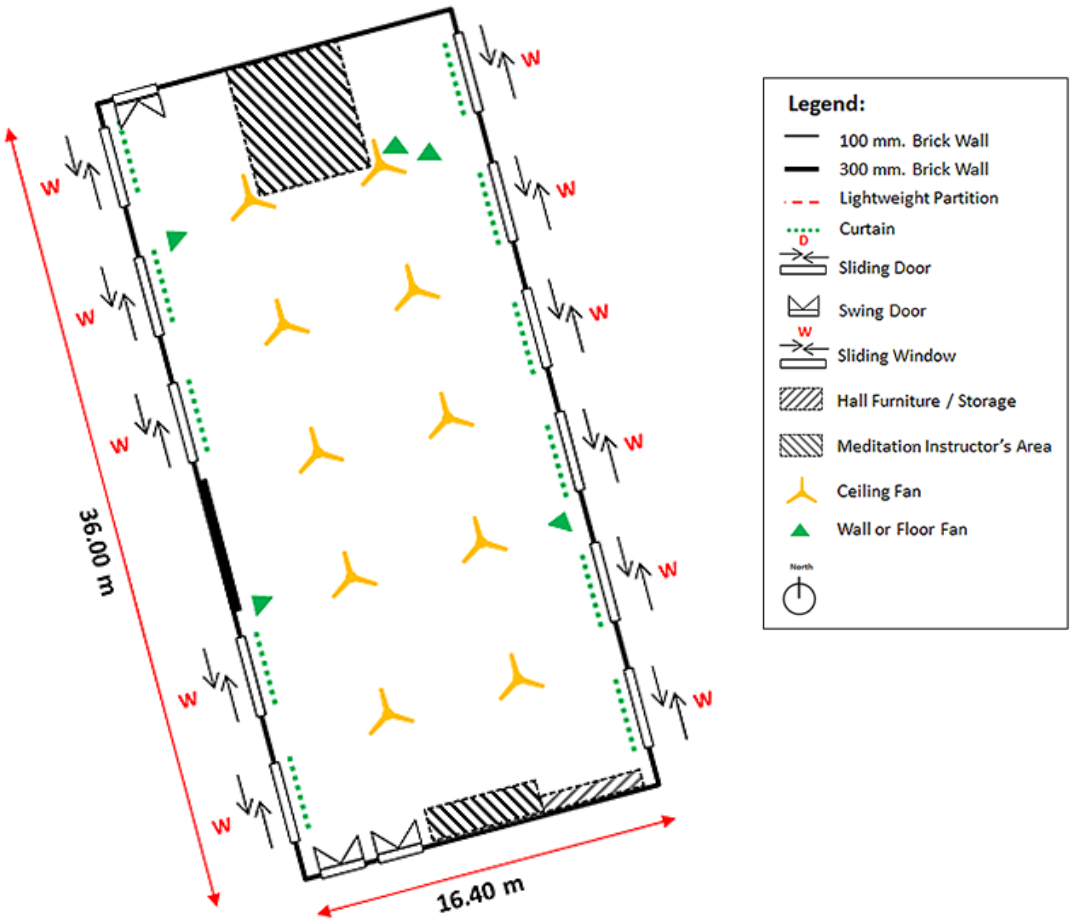


Figure 5.9: Floor plan of the VRW hall

For an indoor physical environment, the *VRW* hall is the largest training space amongst the case studies, with a floor area of 578.66 m^2, while *PT* and *KJS* have areas of 390.51 m^2 and 200.05 m^2, respectively. There are two functions of the open-plan hall used by the meditators and instructors. The meditation instructors' area, separated by a 0.20 m-high wooden step, is preserved and not accessible to meditators without permission. The north and the south walls of the hall are connected to an instructor's room and circulation hall, while the east and west sides of the room are exposed to outdoor space. The hall is equipped with environmental controls, including curtains, doors, windows, and

electrical fans (Figure 5.9). The atmosphere of the hall when accommodating meditators is presented in a panoramic photo in Figure 5.10.



Figure 5.10: Panoramic view of the VRW meditation hall

❖ *Construction details of VRW hall*

The *VRW* hall is built with 10 cm-thick brick walls with plaster render, painted in white, with a concrete floor finished with white cement. The ceiling material is gypsum board built underneath the roof structure according to the shape of the gable hip roof; Figure 5.11 and Figure 5.12 illustrate cross sections of the meditation hall.

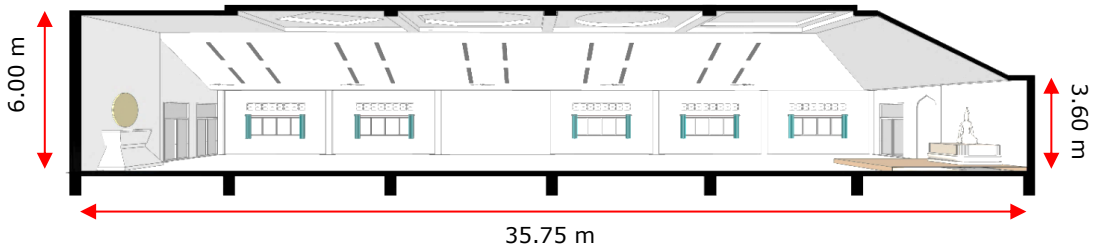


Figure 5.11: North to south cross section of the hall

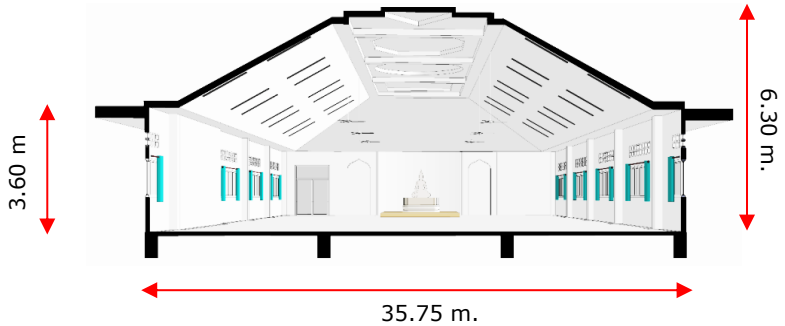


Figure 5.12: East to west cross section of the hall

The highest points of the north, east, and west walls are 3.60 m, while the height of the south wall is 6.00 m. The highest point of the ceiling is 6.30 m from the floor. For window and door details, 11 external and one internal sliding windows and three pivot doors were built with aluminium frames filled with large glass panes. A 1.10 m high x 3.20 m wide window is installed 1.00 m over the floor with a set of curtains, which is a typical design of the hall windows. A set of ventilation blocks of 0.40 m height x 3.20 m length with sets of mosquito mesh are placed over 0.35 m over each window set, as Figure 5.13 and Figure 5.14 present.

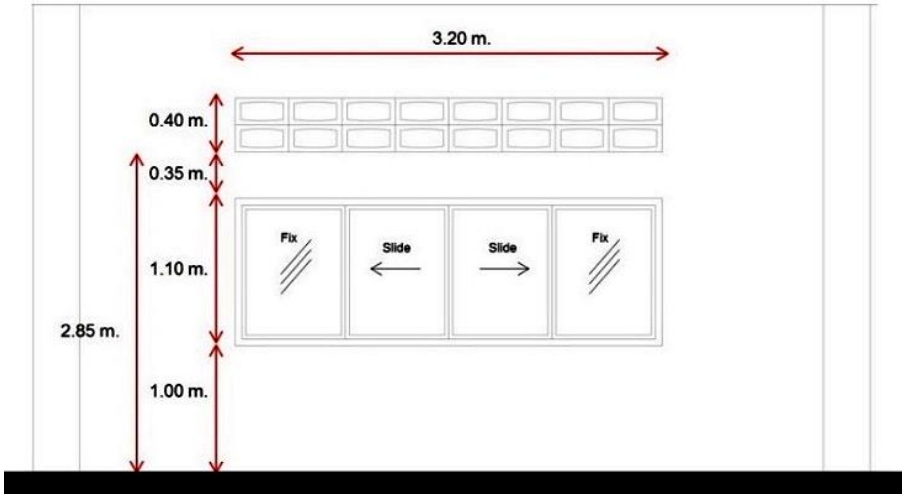


Figure 5.13: Typical window design and ventilation blocks with dimensions of the VRW hall



Figure 5.14: Installation of mosquito mesh of VRW hall

Apart from the windows and curtains, 15 electric fans circulate air in the hall, comprising five standing fans and ten ceiling ones. The control panels of each ceiling-type device were installed in an accessible area.

5.5.1.2 *PT meditation centre*

- ***Meditation sessions of PT***

The *PT* meditation centre is located in a Buddhist monastery in Khon Kaen city centre. The monastery separates the sacred space from the external environment by high and thick fences and vegetation, to preserve peacefulness and tranquillity for the monks inside the temple. The *PT* centre does not organise the meditation activities daily, rather they are held almost every month on Buddhist holy days and public holiday days. Thus, the training timetable is rescheduled annually, and a new schedule is issued before the new year. The training period might last from three to six days. Typically, there is no training session in the first and the last days of the program, since these days are dedicated to registration, orientation, and personal training. Training sessions are supervised by the experienced monk instructors, similar to these of the *VRW*. According to the observation, the responsible instructor of each session might be changed without advanced notice, due to internal and external monastery events.

The training sequence of the *PT* centre found in this site is similar to that of *VRW* but less flexible. Both beginners and experienced meditators are required to follow the supervisor' practicing instruction in which the session starts with the sitting posture, with a switch to walking meditation every 30 minutes, followed by finished with the sitting meditation. At the end of the session, the instructor leads the meditators to share loving-kindness and pray for 30 minutes before leaving the hall for a break.

In the first day of training, all participants were asked to embrace eight precepts. The first training session, taking place from 5.00 am to 7.00 am, consisted of two major activities which were a morning prayer and a one-hour meditation. The second and third sessions took place from 9.30 am to 11.00 am, and 12.00

am to 4.00 pm, respectively, mainly focused on meditations. The last training session, lasting from 6.00 pm to 9.00 pm, consisted of 90 minutes of evening prayer, one-hour meditation, and half an hour of sharing loving-kindness.

For the questionnaire survey, it was planned to collect the meditators' subjective votes twice a day in the second and third sessions, which are similar to those of the *VRW* site. However, the second session of *PT* was unsuitable for the questionnaire session, since the practice finished at 11.00 am, whereby the subjects had only one hour for lunch (before noon, due to the requirements of the eight precepts). Thus, time constraints led to a change of survey times from the second and third sessions to the third and fourth sessions, to avoid compromising and to preserve the actual activities of building users that are the ultimate concern of this research.

- ***Monastery environment and meditation halls of PT***

The *PT* meditation hall is located inside the monastic area, where two buildings (A and B) are used to hold meditation activities (Figure 5.15). For this research, Building A was selected as the primary study site, since it is the main building used for practising meditation. Building B was used when Building A was overcrowded or employed by a group of meditators for private training sessions.



Figure 5.15: Layout of the PT monastery with locations of the meditation buildings

Building A is located at the west side of the monastery, surrounded by small buildings in the East, South, and West. The north side of the structure is

exposed into an open, concrete parking area. The building was designed in an L-shape layout, with a three-storey structure, in which the meditation hall is located on the ground level (Figure 5.15). The longest space of the *PT* hall is 23.70 m from the inside east wall to the inside west wall, while the distance between the inside north wall to the inside south wall is 21.80 m (Figure 5.16).

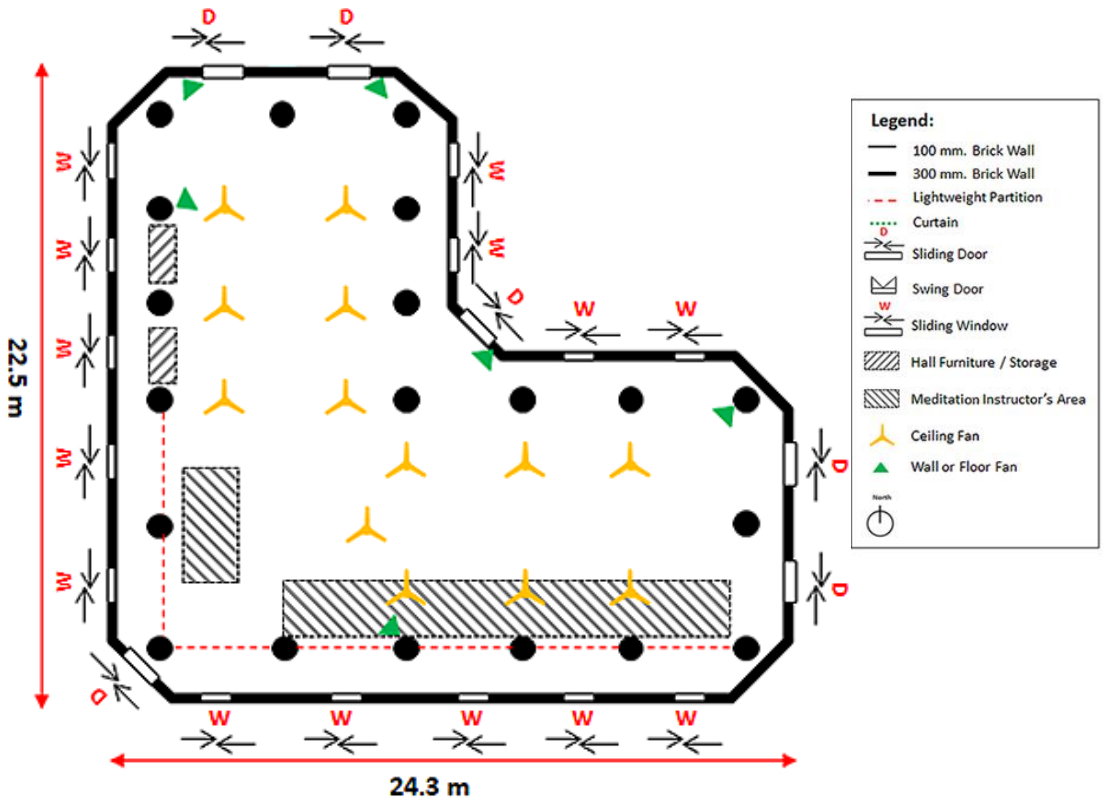


Figure 5.16: Floor plan of PT hall

Each side of building façade is similar. The ground level of the façade is decorated with cement stucco depicting the local people's way of life and proverbs (Figure 5.17). The first floor of the building is treated by the second layer of 10 cm-thick brick façade with circular fenestrations, while the second floor presents a simple design with rectangular windows and doors, as shown in Figure 5.18 (A - C).



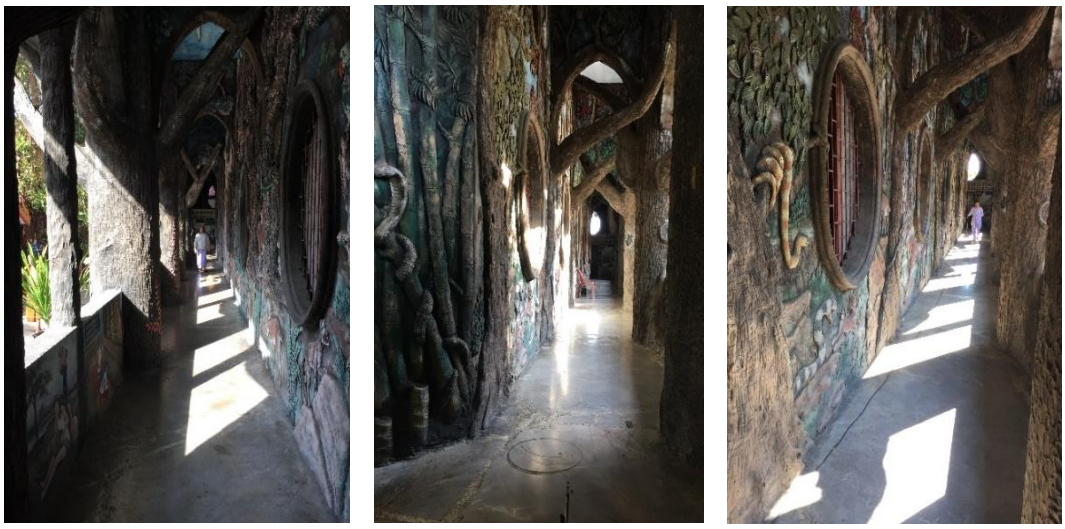
Figure 5.17: Ground floor façade decoration by cement stucco



(A) North façade (B) South façade (C) West and South façades

Figure 5.18: North, south, and west and south façades of the PT meditation building

The majority of the ground floor is dedicated to the practising space with small areas of storage, circulation, the control room, toilets, and the staircase. The practising hall is protected from direct solar exposure by a 1.70 m-wide corridor. Figure 5.19 (A), (B) and (C) presents the exterior corridors at the ground level of the East, North, and West sides of the building, respectively. The entire area of the first and second floors function as male and female accommodation, respectively.



(A) East corrid (B) North corridor (C) West corridor

Figure 5.19: Corridors of the ground level of the PT meditation building

Accessibilities to the hall for lay meditators and monks are separated. For the meditators, the hall can be accessed at the north and east ends and the north-eastern wall of the hall. However, the door at the north-east was noted by the centre as an equipment malfunction. The main entrance the monks is located at the south-west corner of the hall.

For the indoor atmosphere of the hall, the meditation spaces of the monks and the instructors are separated from the meditators by 0.50 m-high timber benches. The hall is decorated with red curtains functioning as partitions installed behind the monk's area, creating a private space for the monks' circulation, as Figure 5.20 shows.



Figure 5.20: Panoramic view of the PT hall interior

❖ ***Construction details of the PT hall***

The *PT* meditation building is constructed with 30 cm-wide brick walls with 70 cm-diameter cylinder columns and curved concrete beams. The floor is constructed with concrete finished by white cement, filled with large white marble floor slabs. Sliding windows and doors are built with metal frames with large panes of white marble, without curtain installation. The hall is ventilated by environmental controls such as windows, doors, ventilation voids, and fans. The opening area of each window is designed in an oval shape (Figure 5.21). The windows are installed 95 cm above the floor, with a 50 cm-circular shape void located at 60 cm over each window. Apart from the windows and doors, Figure 5.16 (A) shows 19 electrical fans, of which six are wall types and 13 are ceiling fans, with accessible control panels equipped in the hall.

Regarding the hall dimensions, the highest point of the hall is at 4.80 m, and the longest space (23.70 m) is found inside east to west sides of the hall (Figure 5.22). The longest span is 8.80 m, found at the north and east wings of the hall. Figure 5.23 presents a south cross-sectional illustration of the hall.

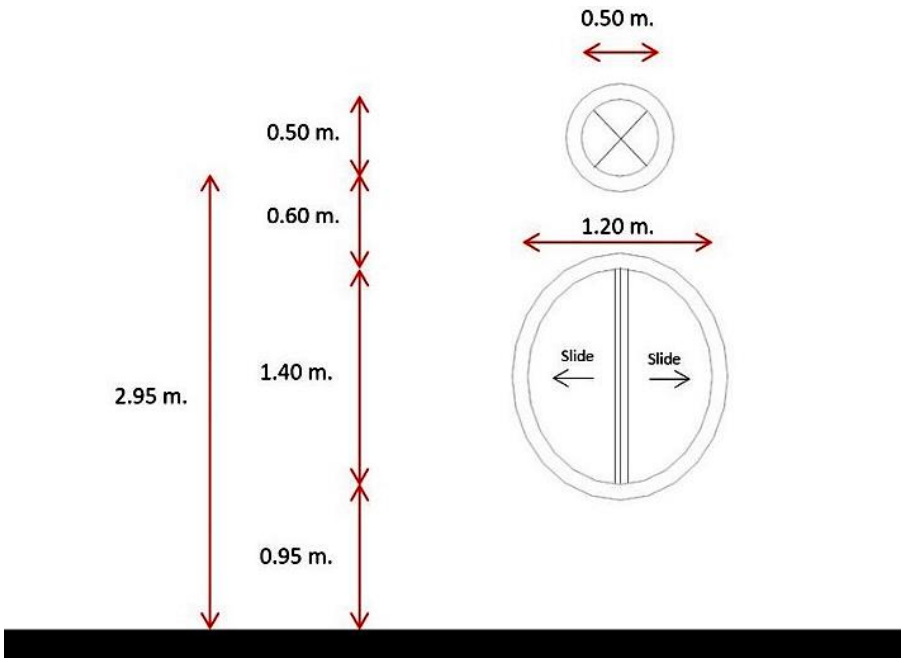


Figure 5.21: A drawing of the typical windows and ventilation voids of the PT hall

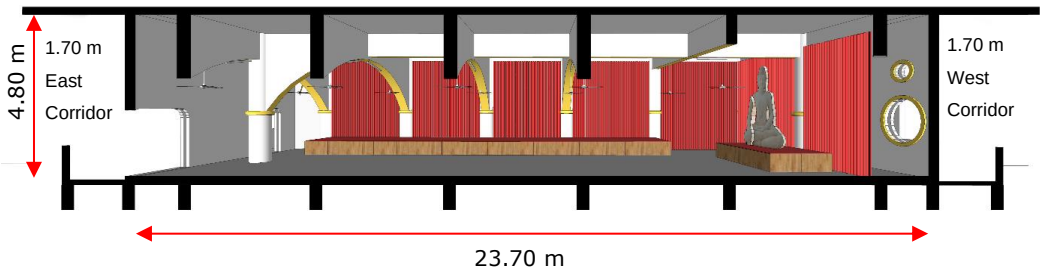


Figure 5.22: East-west cross section at the east wing of the PT hall

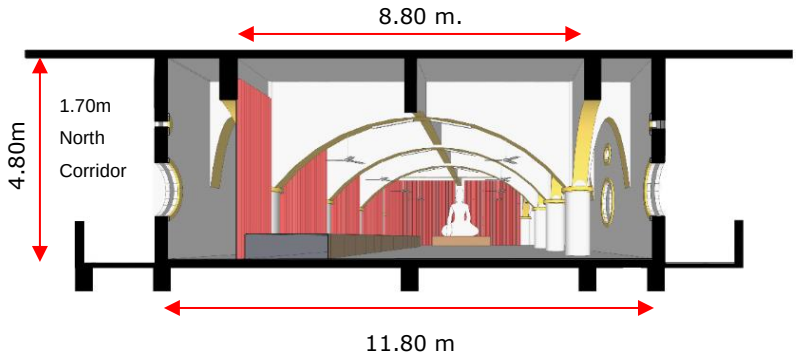


Figure 5.23: North-south cross section at the east wing of the PT hall

5.5.1.3 *KJS meditation centre*

❖ ***Meditation sessions of KJS***

The *KJS* meditation centre is located in the Ban-Phai district, 45.5 km away from Khon Kaen city centre. This centre adopts a training curriculum from the headquarters in Bangkok. A course for beginners was held only at weekends, lasting for six consecutive months from August to January. The registered participants were not required to embrace eight precepts, and meditation uniform was not compulsory. On the other hand, they were expected to attend a class of meditation theory before practising meditation in each session. It should be noted that the meditation sessions and classes were organised more casually than the other sites, since they were instructed by experienced lay meditators nominated by the centre, rather than monks.

Regarding the training schedule of the centre, there were two training sessions per day, in the morning and afternoon. The first session started at 9.00 am

consisted of a one-hour lecture followed by a 90-minute meditation session. The practice started with a 30-minute walking meditation, and finished with a 30-minute sitting meditation, loving-kindness, and prayer before the 11.00 am lunch break. The afternoon activities (12.00 pm to 3.30 pm) lasted slightly longer than those of the morning session due to two lectures before and after the second meditation practice. The afternoon meditation session took place from 1.00 pm to 2.30 pm, and the sequence of this afternoon training session was identical to that of the morning practice.

- ***Monastery environment and the meditation hall of KJS***

There are two meditation centres sharing the same monastic area. The activities held at Buildings 1 and 2 were organised by the owner of the area and a meditation institute, respectively. The former place was excluded in this study, since it was only employed for private group training events, thus its practicing schedule and number of participants was unpredictable. Therefore, the other centre located in Building 1 was selected as a case study, and was named *KJS* in this research.



Figure 5.24: Layout of the KJS monastery showing the location of Building 1 and Building 2

The *KJS* meditation building is a two-storey structure designed in an L-shaped layout, exposed to a large open area in its east and west sides (Figure 5.25 (A, B)). The structure was shaded by the kitchen, which is an extension part located at the north side of the structure, and a small library at the south side of the

building (Figure 5.25 (C, D)). The building façade was built with 10 cm-thick brick walls painted in white with sliding windows at the east and west walls (Figure 5.26 (A, B)). Direct solar radiation from the east and west was screened by vegetation and 1.20 m-wide concrete awnings.



(A) East environment (B) West environment (C) North environment (D) South environment

Figure 5.25: Surroundings of the KJS building



(A) East façade (B) West façade

Figure 5.26: East and west façades of the KJS meditation building

An *AC* classroom is located on the first floor, while an *NV* meditation hall (202.47 m^2) and toilet (16.60 m^2) are on the ground level. Six and two ceiling and floor-type fans with the accessible control panels were fitted in the hall (Figure 5.27). Unlike the *VRW* and *PT* meditation halls, no step separates the areas of instructors and meditators, since the sessions are organised by a group of lay alumni. Figure 5.28 represents the ambience of the hall.

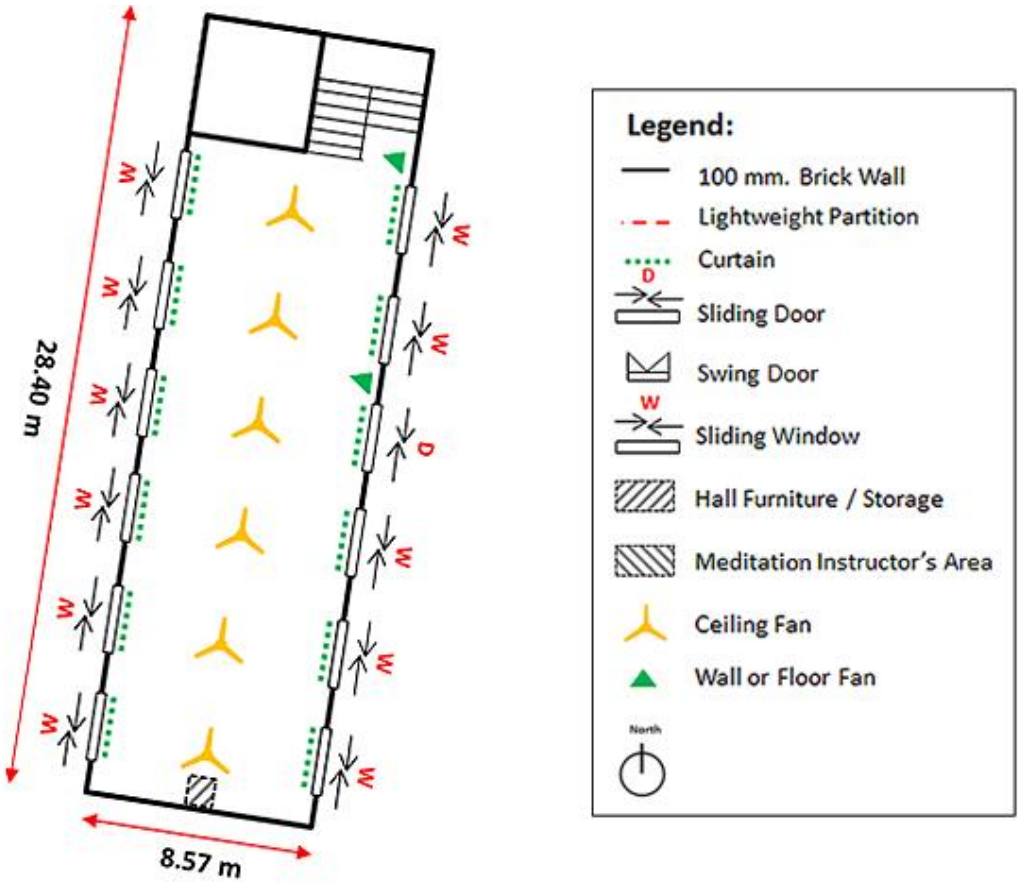


Figure 5.27: Floor plan of the KJS meditation hall



Figure 5.28: Panoramic interior view of the KJS meditation hall

❖ *Construction details of the KJS hall*

The *KJS* hall is designed with a rectangular layout, 8.37 m wide and 24.2 m long. The maximum and minimum ceiling height is 3.85 m and 3.15 m, respectively, as the cross-sectional views shown in Figure 5.29 and Figure 5.30 illustrate. The hall is a concrete structure with 10 cm-thick brick walls rendered by cement, with a concrete floor paved by dark-polished granite. The exterior windows and doors of the hall are made of aluminium frames filled with grey-

tinted glass. A typical set of windows found in the meditation hall is 1.15 m high, with a 3.00 m long sliding window placed 90 cm over the floor. Besides, a 50 cm high and 3.00 m long clerestory divided by a vertical aluminum frame is installed over each window set, as Figure 5.31 presents.

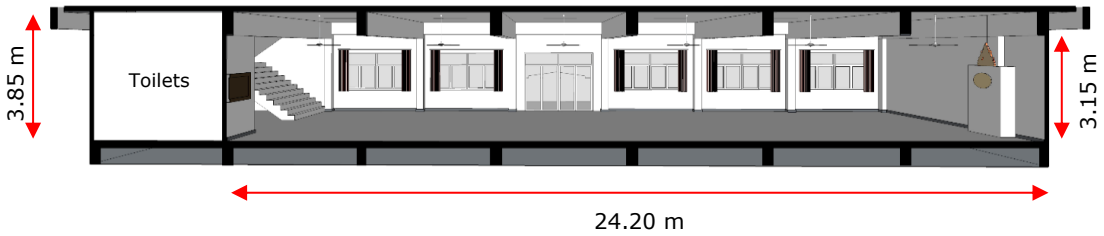


Figure 5.29: North-south cross section of the KJS meditation hall



Figure 5.30: East-west cross section of the KJS meditation hall

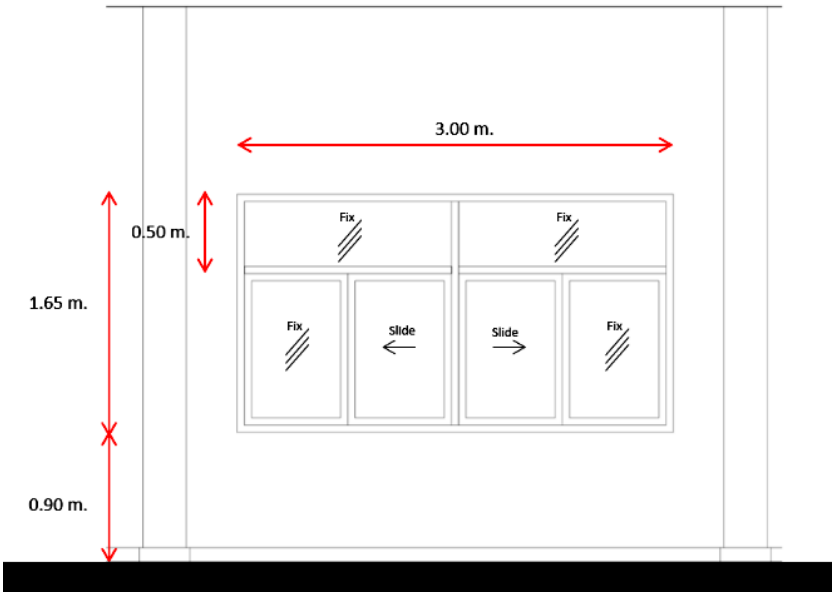


Figure 5.31: Dimensions of the typical window set found in the KJS meditation hall

5.6 Instrument selections and specifications

The measuring instruments employed in this study were selected to measure four of Fanger's six thermal comfort variables: *DBT*, *RH*, *V*, and *MRT. MRT* cannot be directly measured, but it can be calculated by the sum of the surface temperature of each room surface multiplied by angle factor, or by relationships of the T_g, *v*, and *DBT*, as Eqn 56 and Eqn 57 explain (as discussed in Chapter 3).

Before discussing the method of measuring instrument selection, it should be noted that the financial constraints of this research affected the environmental measuring method. Apart from the tuition fees during the PhD course, subsidised by the University of Nottingham Scholarship, all the expenses involving research activities, such as hiring research assistants, travelling costs, and purchasing the measuring instruments, were self-supported and subject to the researcher's responsibility. Therefore, the budget for purchasing the measuring instruments, which is also one of the research constraints, was allocated as approximately £2500, excluding the calibration fee for each instrument.

A comparison to find the most suitable measuring instruments available in the UK and Thailand for this project was undertaken based on functions of measurements, after-sales service, device accuracies, and the research budget. The information of the instruments shown in this section were collected in 2015 before the pilot study started. The selective process, moreover, considered the *Class II* of research protocol of adaptive thermal comfort field study, as mentioned in Chapter 3. Apart from these variables, data of indoor surface radiant temperature (T_r), and thermal imaging of the hall, including environmental adjustments, were monitored.

5.6.1.1 *Measurements of DBT, T_g and RH*

This project measured *DBT*, *RH*, and T_g in outdoor areas and large indoor spaces of *NV* meditation halls. Thus, four measuring locations were used: one outdoors and three indoors and a total £1000 budget was expected to be

allocated for this set of instruments. According to the online observation for the measuring instrument functions, *DBT*, *RH*, and T_g can be individually measured by a single device such as dry bulb thermometer, *RH* meter and globe thermometer, respectively. However, harnessing many instruments at the same time may increase the chance of time-synchronisation errors and require a number of research assistants to operate the devices. Thus, to minimise avoid these challenges, Wet Bulb Globe Thermometers (*WBGT*) for *DBT*, *WBT*, T_g, and *RH* measurements and hygrometers for *DBT* and *RH* measurements were considered as one of the options in the instrument-selecting process.

Table 5.1 presents a summary of eight instruments found during the online observation. A Testo 625 hygrometer is the most accurate *DBT*-measuring measurement among the available options, since it measures the accuracies of *DBT* and *RH* between ±0.5°C and ±2.5%, respectively. However, despite its superior measuring accuracy, this device was unsuitable to be employed in this field project as it is a hand-held device without a tripod mount; it requires manual operation, with no data logger; and it cannot measure T_g.

Besides, based on the online observations and discussions with suppliers, a single device for measuring one particular factor is more accurate, but this is expensive and fragile. Thus, multi-functional instruments such as WBGT meters, which offer a more convenient operation at a cheaper cost are recommended.

Table 5.1: Summary of WBGT thermometer performance, function and price comparison

Hygrometer and WBGT meters															
No.	Photo	Location of Supplier	Model	Origin	Brand	Variable	Measuring Range	Resolution	Operating Temperature	Black Globe Diameter	Accuracy	Response Time	Price (Bath)	Price (£)	Currency (1 GBP to THB)
1		Only in Thailand	AZ 8758	China	N/A	*DBT*	0 to 50 °C	0.1 °C	0 to 50 °C	-	± 0.6 °C	15 s	12500	227	55
						TG	0 to 80 °C	0.1 °C	0 to 50 °C	75 mm.	±2.5 °C	15 s			
						RH	0 to 100 %	0.10%	95 % RH	-	± 3% (10-90 %RH)	15 s			
2		Both UK and Thailand	HT 30	USA	Extect	*DBT*	0 to 50 °C	0.1 °C	0 to 50 °C	-	± 0.6 °C	N/A	7200	131	55
						TG	30 to 550 °C	0.1 °C	0 to 50 °C	40 x 35 mm	± 2.0 °C	N/A			
						RH	0 to 100 %	0.10%	80 % RH	-	±3%	N/A			
3		Both UK and Thailand	TM 188D	Taiwan	Tenmars	*DBT*	0 to 50%	0.1 °C	0 to 50 °C	N/A	± 0.8 °C	1s	7200	131	55
						TG	0 to 56 °C	0.1 °C	0 to 50 °C	N/A	± 0.8 °C	1s			
						RH	0 - 80 %	0.10%	N/A	N/A	±0.6 %	1s			
4		Thailand	800037	USA	Spur Scientific	*DBT*	0 to 50 °C	0.1 °C	N/A	-	±0.8 °C	1s	23800	433	55
						TG	0 to 80 °C	0.1 °C	N/A	75 mm.	± 0.6 °C	1s			
						RH	5 to 95 %	0.10%	N/A	-	± 3 %	1s			
5		Only in the UK	WD 20 SD	USA	PCE	*DBT*	0 to 50%	0.1 °C	0 to 50 °C	-	±0.8 °C	1s	10450	190	55
						TG	0 to 80 °C	0.1 °C	0 to 50 °C	75 mm.	±0.8 °C	1s			
						RH	5 to 95 %	0.10%	N/A	-	±3%	1s			
6		Only in Thailand	WD 10 SD	Taiwan	Digicon	*DBT*	0 to 50 °C	0.1 °C	N/A	-	±0.8 °C	1s	10500	191	55
						TG	0 to 80 °C	0.1 °C	N/A	75 mm.	±0.8 °C	1s			
						RH	5 to 95 %	0.10%	N/A	-	± 3 %	1s			
7		Only in Thailand	WBGT 2010SD	Taiwan	Lutron	*DBT*	0 to 50 °C	0.1 °C	0 to 50 °C	-	±0.8 °C	1s	14600	265	55
						TG	0 to 80 °C	0.1 °C	0 to 50 °C	75 mm.	±0.6 °C	1s			
						RH	5 to 95 %	0.10%	Less Than 70 %	-	± 3 %	1s			
8		Both UK and Thailand	Testo 625	German	Testo	*DBT*	0 to 50 °C	0.1 °C	-20 to 50 °C	-	± 0.5 °C	1s	11984	218	55
						RH	0 to 100 %	0.10%	-20 to 50 °C	-	± 2.5%	1s			

Based on the observations, the accuracies of *DBT* and T_g measurements measured by WBGT meters (items 1 – 7 in Table 5.1) vary between ±0.6°C to ±0.8°C and ±0.6°C to ±2.5°C, respectively. Besides, the precision of the *RH* measurement changes according to the measured conditions. For example, the measuring accuracy of Spur 800037 WBGT, PCE WD 20 SD, and Lutron WBGT 2010 SD varies between ±3.0% of the reading when *RH* is below 70% to ±3.0% of the reading with +1% *RH* extra over or equal to 70% (i.e. the accuracy slightly decreases).

5.6.1.2 *Anemometer*

v can be measured by different types of anemometer, such as hot-wire, propel, and cup anemometers. A total budget allocated for this instrument is approximate £700. Table 5.2 presents a comparison of eight anemometers commonly available in the UK and Thailand. According to the observation of the product in the market, the price of the instrument type varies greatly from £63 to £782, depending on brand, functions, and measuring precision. Some instruments can measure both *v* and *DBT*, while others are designed to monitor only *v*.

Table 5.2: Summary of anemometer accuracies, functions and prices

Anemometer															
No.	Photo	Location of Supplier	Model	Origin	Brand	Variable	Measuring Range	Resolution	Probe	Accuracy	Response Time	No. of Record	Price (Bath)	Price (£)	Currency (1 GBP to THB)
1		Thailand	DT-8880	China	CEM	*v*	0.1 to 25.0 m/s	0.01 m/s	Hotwire	± 0.1 m/s (5%)	N/A	Not mentioned	10900	198	55
						TA	+- 0 to 50 °C	0.1 °C		± 1 °C	N/A				
2		Both UK and Thailand	TM-4001	Taiwan	Tenmars	*v*	0.01 to 40 m/s	0.01 m/s	Hotwire	± 3 %	N/A	99	12000	218	55
						RH	20 to 80	0.10%		±3.5 %	N/A	99			
						TA	-20 to +50 °C	0.1 °C		± 1 °C	N/A	99			
3		Both UK and Thailand	SDL350	USA	Extech	*v*	0.2 to 25 m/s	0.01 m/s	Hotwire	±5%	0.1 s	99	7200	131	55
						TA	+- 0 to +50 °C	0.1 °C		±0.8 °C	0.1 s	99			
4		Thailand	DT - 620	China	CEM	*v*	0.4 to 30.00 m/s	0.01 m/s	Propel	±3 %	N/A	20	5900	107	55
						TA	-10 to 60 °C	N/A		N/A	N/A	20			
5		Thailand	AMF 208	China	Tlead	*v*	0.3 to 45 m/s	0.1 m/s	Propel	±3 %	N/A	Yes, but not mentioned the No. of record	3490	63	55
						TA	N/A	0.1 °C		±2 °C	N/A				
6		Only in the UK	PCE 009	USA	PCE	*v*	0.2 to 20.0 m/s	0.1 m/s	Hotwire	±1 °C	N/A	Yes, but not mentioned the No. of record	19250	350	55
						TA	+- 0 to 50 °C	0.1 °C		±0.8 °C	N/A				
7		Both UK and Thailand	Testo 425	German	Testo	*v*	+-0 to 20 m/s	0.01 m/s	Hotwire	± 5%	N/A	Yes, but not mentioned the No. of record	23000	420	55
						TA	-20 to +70 °C	0.1 °C		± 0.05 °C	N/A				
8		Thailand	TA 411 DA	Japan	Tasco	*v*	+0.02 to 60 m/s	0.01 m/s	Dumbbell	± 5%	N/A	Yes 99 data	43000	782	55

The accuracy of the instruments varies between ±3.0% to ±5.0%. TM-4001 by Tenmar presents the lower limit of the measuring range with 0.01 m/s, followed by TA 411 DA of Tasco with 0.02 m/s. The devices which can provide two-

decimal results are DT-8880 of CEM, TM-4001 of Tenmar, and TA 411 DA of Tasco.

The instruments are connected to different types of sensor with propel, hot-wire, and dumbbell probes. In this case, the propeller and hotwire types must face air flow perpendicularly; otherwise, a wind vane is required for adjusting the sensor of the anemometer to detect directions of the flow. The dumbbell probe of the Tasco model TA 411DA is designed to address this limitation. Its probe can detect wind flowing horizontally from multi-direction (0° to 360°) with 45° altitude from the horizontal line, as Figure 5.32 presents

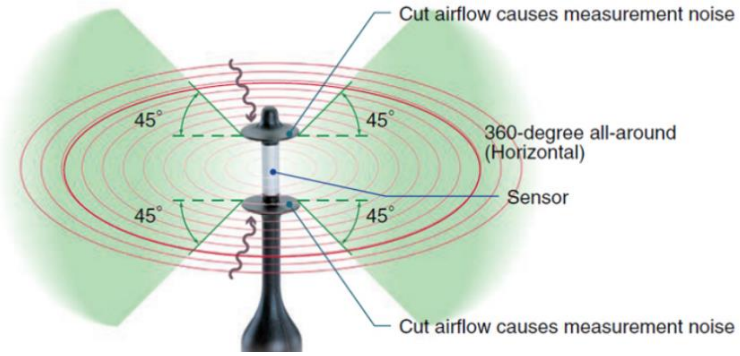


Figure 5.32: A dumbbell probe of TA 411 DA anemometer by Tasco
Source: (LEGATOOL 2016)

5.6.1.3 *Infrared thermometer*

Different types of instruments were employed to collect infrared surface temperature (T_r). Options of infrared (*IR*) thermometer were listed based on the research constraints, including the research budget (approximately £400 was allocated for this) and the physical characteristics of meditation halls (large spaces with high walls and ceilings). Although the data logger type of *IR* thermometers, with a surface-contact probe, provides convenience for data collection and decreases human and time-synchronisation errors, several instruments and sensors would be required to cover the relatively large area of the meditation halls, entailing significant costs. Consequently, this research selected a contactless-type of *IR* thermometer due to portability, and the capability to collect the data in hard-to-reach areas. Consequently, ten infrared *(IR)* thermometers available in the UK and Thai markets were used, as listed in Table 5.3.

The accuracy of the measurement varies according to a factor called a Distance-to-Spot ratio (*D/S* ratio) which is a measuring distance between the target and the instrument. The higher the ratio of the instrument, the more precise the result obtained. According to the table, the range of the *D/S* ratio of the instruments varies between 1:10 to 1:50. PCE, Lutron, and Digicon instruments have the highest *D/S* ratios, but all the instruments provide one decimal place of measuring resolution. The model 42750 by Extect and PCE 779N by PCE presents the highest accuracy (±1%).

Table 5.3: Summary of IR thermometer performance, function and price

Infrared Thermometer																		
No.	Photo	Location of Supplier	Model	Origin	Brand	Variable	Measurement Range	Resolution	Operating Temperature	No. of Laser Points	Accuracy (over 0.1 °C)	Measurement Rate	D/S Ratio	Type-K Probe Extension	Price (Bath)	Price (£)	UK Price	Currency (1 GBP to THB)
1		Both UK and Thailand	Testo 830 -T1	Germany	Testo	*Tr*	-30 to +400 °C	0.1 °C	-20 °C to +50 °C	1	± 1.5 %	0.5 S	01:10	No	5200	95	-	55
2		Both UK and Thailand	Testo 830 -T2	Germany	Testo	*Tr*	-30 to +400 °C	0.1 °C	-20 °C to +50 °C	2	± 1.5 %	0.5 S	01:12	Yes	10000	182	-	55
3		Only in Thailand	CEM 8835	China	CEM	*Tr*	-50 to +1050 °C	0.1 °C	N/A	1	± 1.5 %	0.5 S	01:30	Yes	6900	125	94	55
4		Thailand	CEM DT-8894	China	CEM	Multi-Tools	-50 to +500 °C	0.1 °C	N/A	1	± 2.0%	N/A	01:30	Yes	25600	465	80	55
5		Both UK and Thailand	42570	USA	Extect	*Tr*	-50 to + 2200 °C	0.1 °C	N/A	2	±1.0 %	N/A	01:50	Yes	19400	353	-	55
6		Only in the UK	PCE IR 425	USA	PCE	*Tr*	-60 to 1000 °C	0.1 °C	+- 0 to 50 °C	2	±2 %	Less than 1 s	01:50	No	9900	180	180	55
7		Only in the UK	PCE 779N	USA	PCE	*Tr*	-60 to 760 °C	0.1 °C	N/A	2	±1.0 %	1 s	01:30	Yes	4675	85	85	55
8		Only in the UK	PCE 890 U	USA	PCE	*Tr*	-50 to 1150 °C	0.1 °C	+- 0 to 50 °C	N/A	± 1.5 %	N/A	01:50	No	7425	135	135	55
9		Thailand	TM 969	Taiwan	Lutron	*Tr*	-60 to 1000 °C	0.1 °C	+- 0 to 50 °C	N/A	± 2.0%	N/A	01:50	Yes	10500	191	-	55
10		Thailand	DP-89	Taiwan	Digicon	*Tr*	-60 to 1000 °C	0.1 °C	+- 0 to 50 °C	N/A	± 2.0%	N/A	01:50	Yes	7700	140	-	55

5.6.1.4 *Thermal imaging thermometer*

Similar to the *IR* thermometers, a thermal imaging thermometer is a non-contact measuring tool used to measure infrared energy emitted from objects, with

results exhibited as values of measured points with thermal illustrations. According to the observations, the price of this instrument type is relatively high, whereas the budget allocated for this instrument is limited within £400. An economical product, FLIR TG 165 by FLIR, was relatively cost effective (£364), with a 1:24*D/S* ratio and a single laser point presenting a measuring accuracy of *DBT* at ±1.5% or ±1.5°C under a measuring range from -25ºC to +380ºC. This instrument provides 4800 pixels of thermal images, of which the data can be stored in a micro SD card.

5.6.1.5 *Summary of instrument selection*

As discussed in the previous section about the instrument functions, accuracies, and prices, this section focuses on the instrument-selecting solution for this research. It should be noted that although some of the instruments are rather expensive and less accurate, they were selected for expediency, due to issues of after-sales service and local availability.

Four devices of WBGT 2010SD by Lutron were selected due to their comparable accuracies and after-sales service, although their price was slightly higher than other variants. Besides, this instrument is a data logger, which can be mounted on a tripod so that locations and heights of measurements are controllable. For *IR* thermometer, two instruments of a TM 969 by Lutron were employed due to their measuring function of adjustable emissivity, with 1:50 *D/S* ratio and two laser beams. These qualities allow obtaining more precise measuring results. However, this instrument is not a logger; thus, manual operation and data record are required.

For *v* measurement, TA 411 DA anemometer by Tasco was selected, although it is the most expensive device. This drawback was offset by its dumbbell probe capability, which can detect and measure multi-directional wind flow with two-decimal readings. This function of the probe with high measuring accuracies provides two-decimal-number results, which also comply with *Class II* instrumentation, as mentioned in Chapter 3. However, this hand-held instrument is not a data logger; thus, manual operation is required. Apart from

the measuring instruments mentioned above, thermal imaging camera of Flir TG 165, distance meter for hall dimension measurement, and two wide-angle VDO recorders for observing the users' environmental adaptive actions were employed.

In conclusion, this project used four WBGT meters, two *IR* thermometers, one thermal imaging camera, one anemometer, one distance meter and two wide-angle VDO recorders. Figure 5.33 presents a summary of the devices used, and their accuracies are presented in Table 5.4. All the instruments were calibrated by authorised laboratories and the manufacturers before being applied in the surveys. All the calibration certificates can be found in Appendix A.

Table 5.4: Summary of the environmentally measuring instruments and accuracies

	Parameter	Resolution	Accuracy	No. of Device
Lutron Heat Index WBGT Meter	*DBT*	0.1°C	±0.8°C (15°C to 40°C)	4 (3 indoor and 1 outdoor)
	T_g	0.1°C	±0.6°C (15°C to 40°C)	
	RH	0.10%	≥70% *RH*: ±(3% Reading + 1% *RH*) or <70% *RH*: ±3% *RH*	
Lutron Infrared Thermometer	T_r	0.1°C	±2%	2 (handheld)
Tasco Anemometer	*v*	0.01 m/s	± (5% +0.12) m/s with 3-second response time	1 (indoor)
FLIR Thermal Imaging Camera	Thermal image with *IR* thermometer	0.1°C	±1.5% or ±1.5°C	1 (handheld)

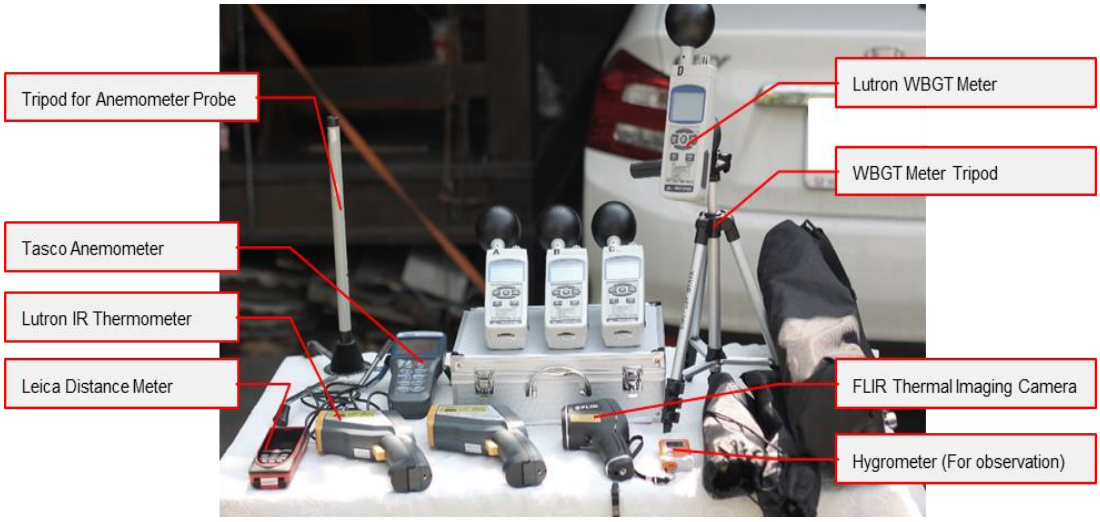


Figure 5.33: Summary of all measuring instruments applied in the research

5.7 Ethical approval

This project was conducted subject to the review and approval of the Research Committee of the School of Engineering at the University of Nottingham, UK. All relevant documents, such as the participant information sheet and questionnaire, were written in Thai language, so that the local subjects could understand them comprehensively. However, the documents as listed in Table 5.5 were professionally translated into English for submission to the Research Ethics Approval authorities.

Table 5.5: Summary of the documents submitted for ethical approval and language availability

No.	Document	English	Thai
1	Ethics application form	✔	✗
2	Document checklist	✔	✗
3	Participant information sheet	✔	✔
4	Consent form for participants	✔	✔
5	Gatekeeper letter	✔	✔
6	Research aims and objectives	✔	✗
7	Brief description of the study	✔	✗
8	The final version of the questionnaire	✔	✔
9	Observation forms	✔	✔
10	Project poster	✔	✔

The bundle of documents (Appendix B) was submitted to the Research Ethical Administrator on the 21st of September 2016, in both hard copy and electronic formats, and was reviewed by Robert Houghton on the 7th of October 2016. The Committee decision was officially announced on the 12th of October 2016 by email, and the project was awarded subject to minor amendments. Further improvements after the revision were reviewed and approved by the main supervisor before the fieldwork commenced.

5.8 Field research method

5.8.1.1 *Research assistants and responsibilities*

This field study involves data collection concerning personal subjective votes, measurement of thermal environments, and observations of the modification of environmental controls over the survey periods. Thus, four research assistants, who were third-year and fourth-year students of the Faculty of Architecture at Khon Kaen University, Khon Kaen, were hired. Apart from the behavioural observation and thermal environment measurement, the assistants were responsible for distributing and collecting the questionnaires and supporting the volunteers to fill out the forms, as shown in Figure 5.34. After finishing each questionnaire session, the staff members were required to record the locations of the forms with serial numbers into key plans.



Figure 5.34: Pictures of the assistants while assisting the participants to complete the form

All the qualified students had a prerequisite two-hour training session before the surveys, to ensure their understanding of the relevant theories, such as thermal comfort and fundamental meditation techniques. Important information was imparted to all assistance, such as methods of questionnaire surveys and observations, as well as explaining the research aims, research ethics, cultural and organisational considerations, their roles, and participants' rights according to the research ethics protocol. Each question as presented in the questionnaires and the answering method were explained. At the end of the training, the measuring instruments and relevant document employed in the project were brought into the training sessions.

5.8.1.2 *Survey dates and times, and a summary of the number of collected subjective votes*

This project aims to examine human thermal perception in *NV* buildings in a wide range of indoor and outdoor local climates to explore the most precise result of the subjects' thermal comfort. The survey dates were initially planned to take place in the hottest and coldest months in April and January (see Figure 5.5), respectively to obtain ranges of environmental variables as wide as possible. However, the research strategy was slightly amended to compromise between the research requirement and the annual training schedule of each case study site.

The annual training schedule of each site is different. For example, the *VRW* centre regularly holds the activities daily and, on some occasions, the centre hosted private meditation camps for which the training schedule was unpredictable. In contrast, the *KJS* centre organised the activities over six consecutive months, from August to January of the next year. The *PT* centre hosted the activities only during public holidays or minor Buddhist holy days (that are not official public holidays). Figure 5.35 presents a summary of the annual training periods of the meditation centres in 2016. It should be noted that the annual plans might be amended by the centres according to circumstances and requests from external organisations. As shown in the figure, the most suitable time for surveying was August to January (the monsoon to winter seasons), when all sites hosted training activities simultaneously.

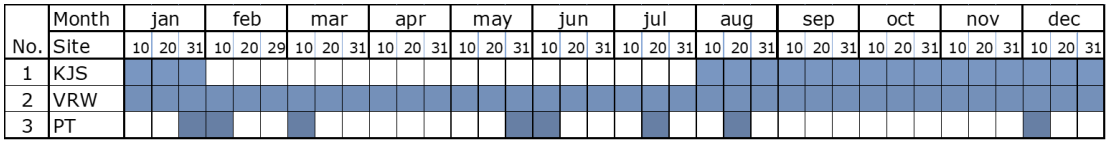


Figure 5.35: Summary of the meditative activities organized by the KJS, VRW and PT centres in 2016

The questionnaire-surveying session was planned to be conducted twice a day after finishing the morning and afternoon practices. Table 5.6 presents a summary of times and dates of the pilot study and main survey. However, the

initial survey plan for *PT* was slightly amended due to the short lunch break of the centre schedule (11.00 am to 12.00 am). In this case, the researcher decided not to interrupt the centre activities, while preserving their timetable. Thus, the morning survey session of *PT* (9.30 am to 11.00 am) was omitted, but the missing session was compensated by the evening session (4th) taking place from 5.00 pm to 9.00 pm.

Table 5.6: Summary of the survey times and dates from 2016 to 2017.

Survey	Place	Date	Total no. of sessions organised	Session observed	Questionnaire survey		n
					Session 1	Session 2	
Pilot Study	*VRW*	5 April 2016	4	2nd and 3rd	10.00 - 10.30	16.00 - 16.30	28
1st Main survey (Winter)	*VRW*	26 November 2016	4	2nd and 3rd	10.00 - 10.30	16.00 – 16.30	97
	PT	3 December 2016	4	4th	21.00 - 21.30	-	39
	PT	10 December 2016	4	3rd and 4th	16.00 - 16.30	21.00 - 21.30	25
	KJS	17 December 2016	2	1st and 2nd	11.30 - 12.00	14.30 - 15.00	45
	KJS	14 January 2017	2	1st and 2nd	11.30 - 12.00	15.00 - 15.30	31
2nd Main survey (Monsoon)	*PT*	8 June 2017	4	3rd	15.30 - 16.00	-	34
	VRW	15 June 2017	4	2nd and 3rd	10.30-11.00	15.30 - 16.00	124
	PT	12 July 2017	4	3rd and 4th	14.30 - 15.00	21.00 - 21.30	71
	KJS	19 July 2017	2	1st and 2nd	5.00 - 5.30	14.00 - 14.30	33
Total (excluding the pilot study)							499

Besides, the number of the daily survey sessions decreased from two to one on the 3rd of March 2015 and 8th of June 2016 due to extra activities of the centre due to Buddhist holy days and extra religious activities. Finally, the pilot study took place in *VRW* on the 5th of April 2016, with 28 pairs of *ASV* and environmental data samples collected from two meditation sessions. The period of the main survey was held from November 2016 to July 2017, in which a total of 499 pairs of the data samples were collected from 16 meditation sessions.

5.8.1.3 *Measuring instrument setups and methods of thermal environment measurements*

As mentioned in the previous section about the employed automatically-operated and manually-operated-measuring devices, this section discusses setups of the measuring instruments for the pilot study and main survey.

- ***Setup of automatically operated instruments***
  - ***Automatically operated instrument setup for the pilot study***

The automatically operated devices applied in the pilot study consisted of a video recorder and four WBGT meters. The WBGT meters (A, B, C, and D) were installed in the site at 6.00 pm on the day before the survey day (4th of April 2016) to record a 24-hour cycle of the inside and outside thermal variables. The devices were set to measure and record the factors every 30 minutes, and were located in areas away from direct solar radiation. WBGTs A and B were placed at 1.0 m away from the west and east wall, while WBGT C was located at the centre of the hall between these devices, as presented in Figure 5.36.

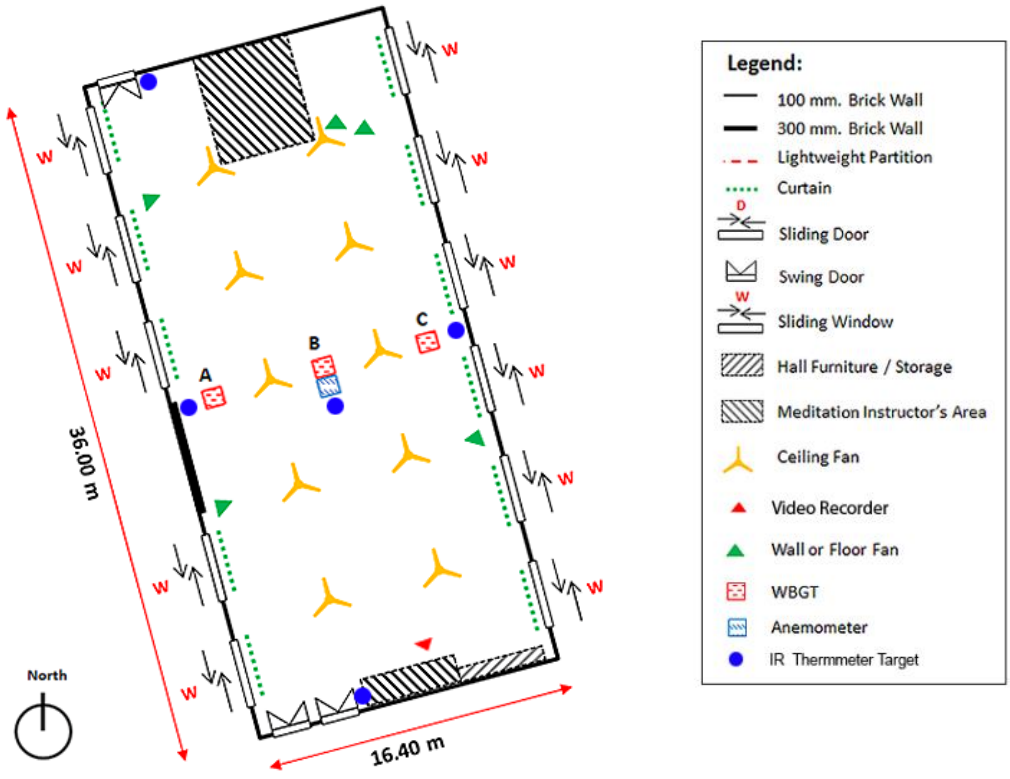
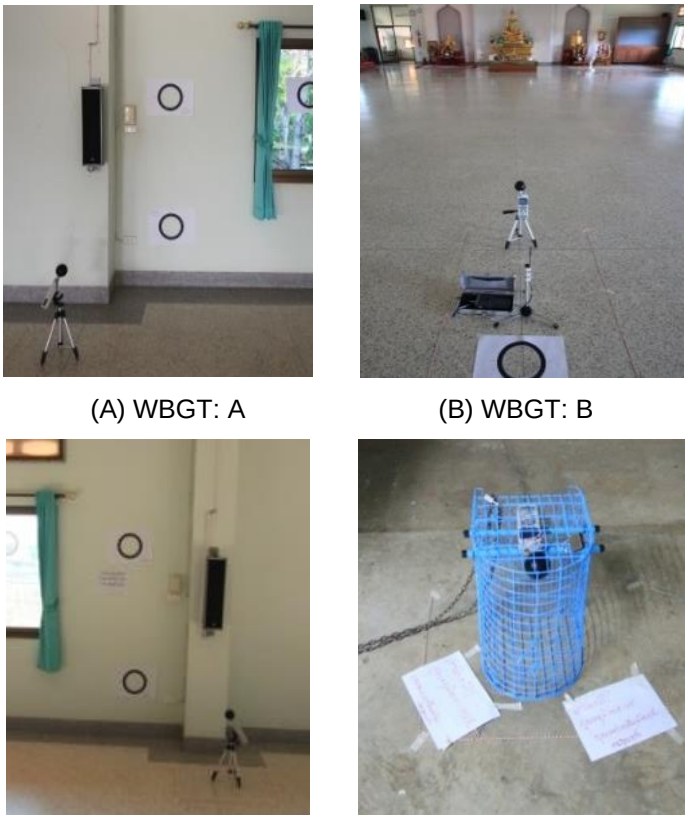


Figure 5.36: Measuring instrument locations in the VRW hall for the pilot study

WBGT D was secured inside a birdcage, was located outside the building at the ground level under the building canopy for measuring outdoor environments, as shown in Figure 5.37 (D). A perimeter protective area was created around each instrument by a rectangular frame of rope, with labels informing '*Please do not touch*, *the instrument is in operation*' (Figure 5.37).



(A) WBGT: A (B) WBGT: B

(C) WBGT: C D) WBGT: D (Outdoor)

Figure 5.37: Setup of the measuring instruments for the pilot study

The heights of the measuring instruments for the environmental factors were initially determined by the ASHRAE Standard-55:2004 (2004). Three different measuring levels for seated and standing subjects are suggested: at 0.1 m, 0.6 m, and 1.1 m; and 0.1 m, 1.1 m, and 1.7 m, respectively. These suggested levels seem unsuitable to be applied in this study, since the subjects sat on the floor while filling out the questionnaires.

In contrast, the *Class II* research protocol (DeDear *et al*. 1997) indicated that one height of measurement might be sufficient for adaptive thermal comfort field

survey. This study, therefore, set the sensors of the WBGT meters, the anemometer probe, and the lowest level of *IR* thermometer targets equally at 0.45 m over the floor. This level was comparable to the height of a human chest while sitting on the floor (Figure 5.38).

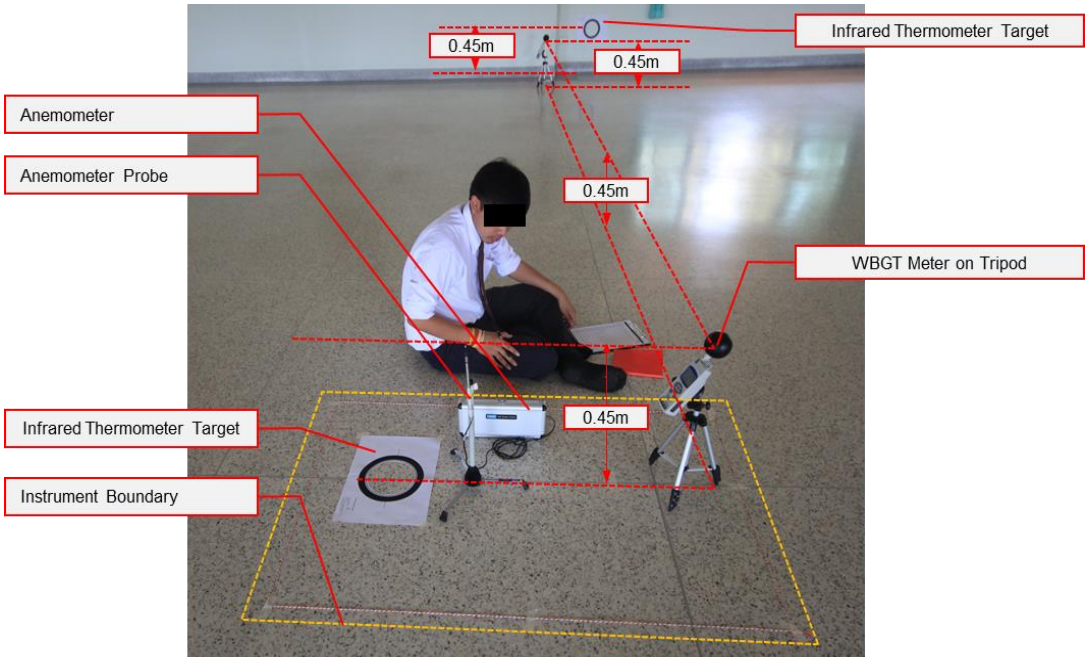


Figure 5.38: Instrument heights at 0.45 m

- ***Automatically operated instrument setup for the main surveys***

The same set of the instruments used in the pilot study were also employed in the major studies. These instruments were installed at least 12 hours before the first survey of the meditation session when each survey day started. Due to long exposure to indoor and outdoor environmental conditions, the devices were supposed to be acclimatized to the local climates.

The locations of the indoor WBGT devices were distributed to cover a more extensive area of the halls (Figure 5.39 and Figure 5.40). The same measuring interval of the instruments remains unchanged from that applied in the pilot study (every 30 minutes). The area around each instrument (equal to one footprint of a meditation mat) was created by a rectangular-shape rope to separate the spaces between meditators and the instruments. Figure 5.41 (A), (B), and (C) present WBGT locations *in KJS*, *VRW*, and *PT*, respectively.

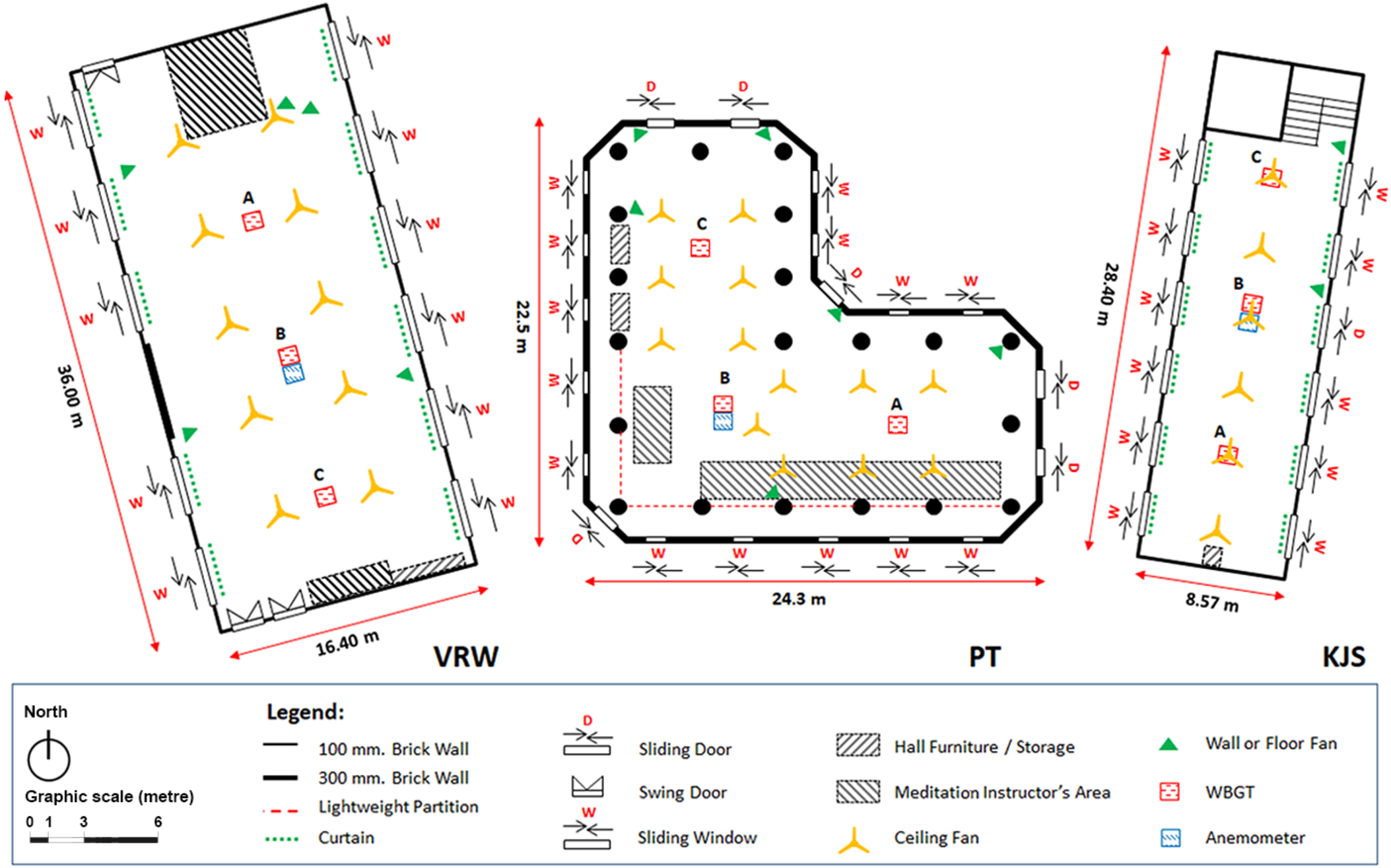
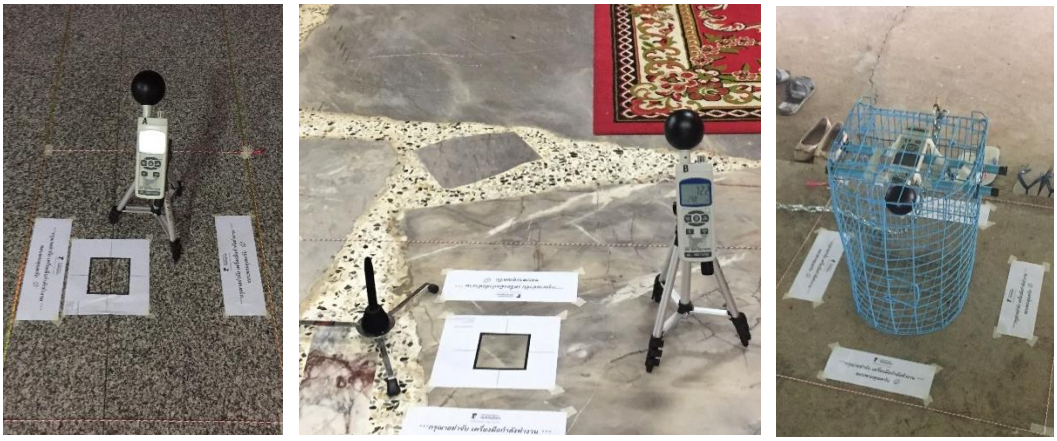


Figure 5.39: Hall layouts with locations of the measuring instruments



Figure 5.40: Examples of indoor instrument setup in the halls



(A) WBGT: A at KJS (B) WBGT: B and anemometer tripod at PT (C) WBGT: D at VRW

Figure 5.41: Measuring instruments with area protections and labels

WBGT D was placed outside the halls under building covers away from direct solar exposure. Figure 5.42 presents the device location at different sites. In the *VRW* centre, the instrument was located at the south of the meditation building under a canopy, while it was placed at the north of the *PT* and *KJS* buildings at the semi-outdoor corridor and the extension roof of the kitchen space, respectively. The locations and measuring levels of the WBGT devices remained unchanged throughout the surveys in the winter and monsoon seasons. Furthermore, modifications of the environmental controls in the halls made by the participants were observed by two VDO recorders.

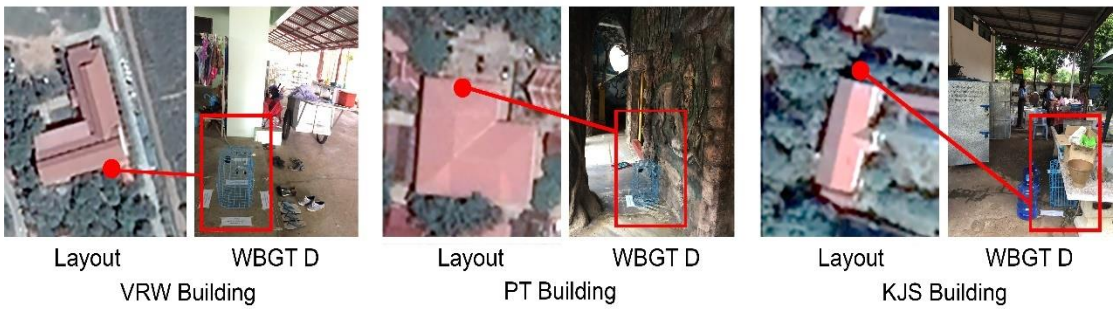


Figure 5.42: Locations of WBGT D in VRW, PT, and KJS

- ***Setup of the manually-operated devices***
  - ***Manually operated instrument setup for the pilot study***

The manually controlled devices (anemometer and *IR* thermometers) were employed to measure indoor v and T_r, respectively. Regarding the T_r measurements, points of internal walls, ceiling, and floor were selected as shown in Figure 5.36. A measuring target for *IR* thermometers (a piece of paper with a hole) was used to define measured spots for surface temperature measurements. The targets were attached into each wall at 0.45 m, 1.60 m, and 2.80 m above the floor level, as Figure 5.43 shows. Two targets were attached at the middle height (1.6 m) of each monitored wall, one of which was at the 0.1 m-thick brick wall, and the other one was at a glazing pane of a sliding window.

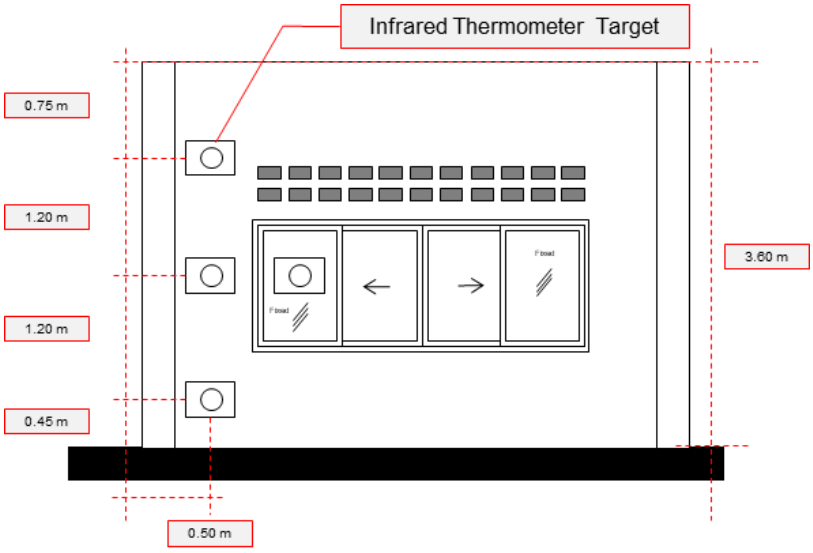


Figure 5.43: Examples of the target locations attached to a wall for IR thermometer

The anemometer probe was set at 0.45 m height at the middle of the hall, at WBGT B. These instruments were manually operated every 30 minutes, and the obtained results were recorded in the observation forms by research assistants. However, due to the dynamic characteristics of *v* in the hall, *v* was measured and recorded as a range over one-minute periods to explore the minimum, maximum, and the average velocity.

- ***Manually-operated instrument setup for the main surveys***

The same 30-minute interval for the T_r and *v* measurements remain unchanged from the pilot study. However, two measuring spots on the floor surface were added at the location of WBGTs A and C. In the major study, the measurement of glassing surface was excluded from the data collection, since curtain operations limited accessibility for measurement, resulting in missing data. Furthermore, the measuring points at *PT* and *KJS* were allocated for the main surveys in both winter and monsoon seasons, as Figure 5.39 presents.

The location of *v* measurement at the *PT* and *KJS* halls were assigned at the centre of the halls at the WBGT B location, as Figure 5.44 presents. However, the measuring method of *v* in the main survey was slightly amended from that of the pilot study. It was a one-minute observation whereby data was collected every five seconds (see Appendix C ii). This measuring method contributed a set of 12 sub data samples of *v* in each measuring interval, which were averaged to represent the data obtained from each period of measurement, which was also applied in *MRT* and T_{op} calculations.

Examples of typical wall T_r measurements are presented in Figure 5.45. The locations and heights of the targets on the walls remained unchanged throughout the surveys.



VRW PT KJS

Figure 5.44: Locations of the anemometer at WBGT B location in the halls

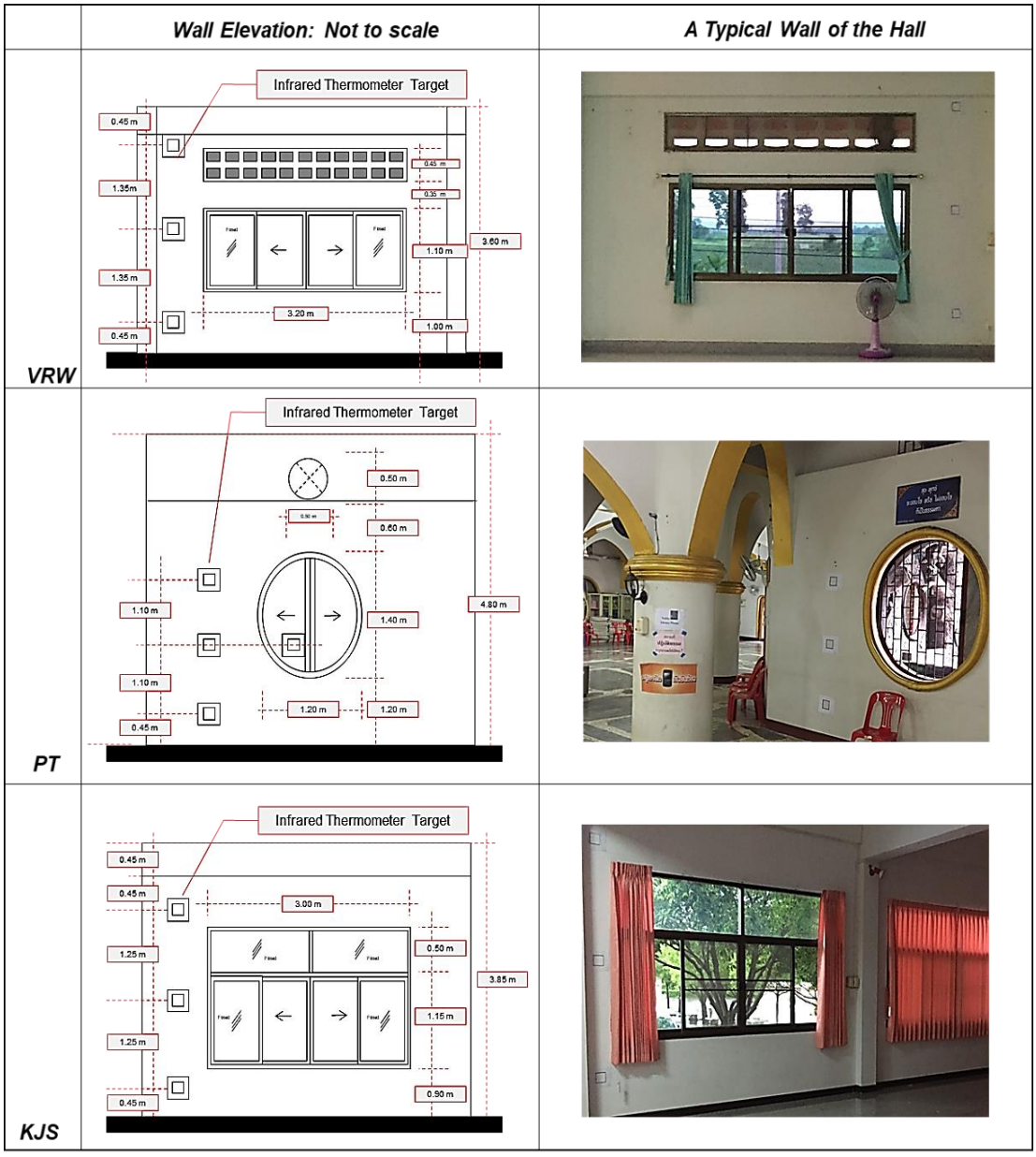


Figure 5.45: Examples of infrared thermometer target set up in the halls

- ***Measuring period of the environmental factors***

The measurements of the manually functioned devices started recording at the 8.00 am in *VRW* and *KJS*, and noon in *PT*, and stopped at 5.00 pm, 4.00 pm and 9.00 pm in *VRW*, *KJS*, and *PT*, respectively. This set of the instruments started recording after finishing the installation, and stopped when the last measurements of the manually operated instruments were taken. The environmental measurements and environmental and behavioural observations were set at 30-minute intervals. This measuring period was set to cover the questionnaire-filling out period (approximately 30 minutes).

In terms of the limitation of thermal environmental measurements, this research considers that individual environmental data should be measured whenever each respondent casts each subjective vote. However, due to the limited number of staff members and measuring instruments and a large number of participants, such a measuring procedure could not be implemented in this study. Besides, although all the participants started filling out the form at the same moment, the finishing time varied due to individuals' reading capacity and ability to understand the questions. Therefore, this study decided to apply a 30-minute average of the environmental data over each questionnaire-filling period in order to represent the thermal environment when the subjects answered the questions.

5.8.1.4 *Observation method*

Field surveys involved observations of building users' modifications of environmental controls in the halls, such as windows, doors, and fans, and variations of sky openness. The research assistants were required to observe and record such changes every 30 minutes at the same environmental measuring intervals. It should be noted that the research members were informed not to adjust the environmental controls during the survey periods, as the modifications of concern had to be made naturally by the building users.

Furthermore, specific terms to describe the number and status of devices were created for further data analysis. The gross number of each device type

available in the halls is called the '*total number of available devices*'. Such a number may not be directly applied in the analysis, since some devices were inaccessible and inoperable in reality. Thus, the term '*the total number of effective devices*' was created, to define accessible and operable devices.

Regarding evaluation of the fan operation, each effective device was scored as '*On*' (1.0) or '*Off*' (0.0). The operation evaluation of the windows was conducted following a similar method. However, rather than collecting such those binary data, the operation of each effective window was scored according to the percentage of an actual opening area of the windows, as Figure 5.46 presents. For example, each window score can range freely from '*Fully Closed*' (0.0) to '*Fully Opened*' (1.0) depending on the actual operation. The total score of each device in each observing interval was converted into a percentage of operation.

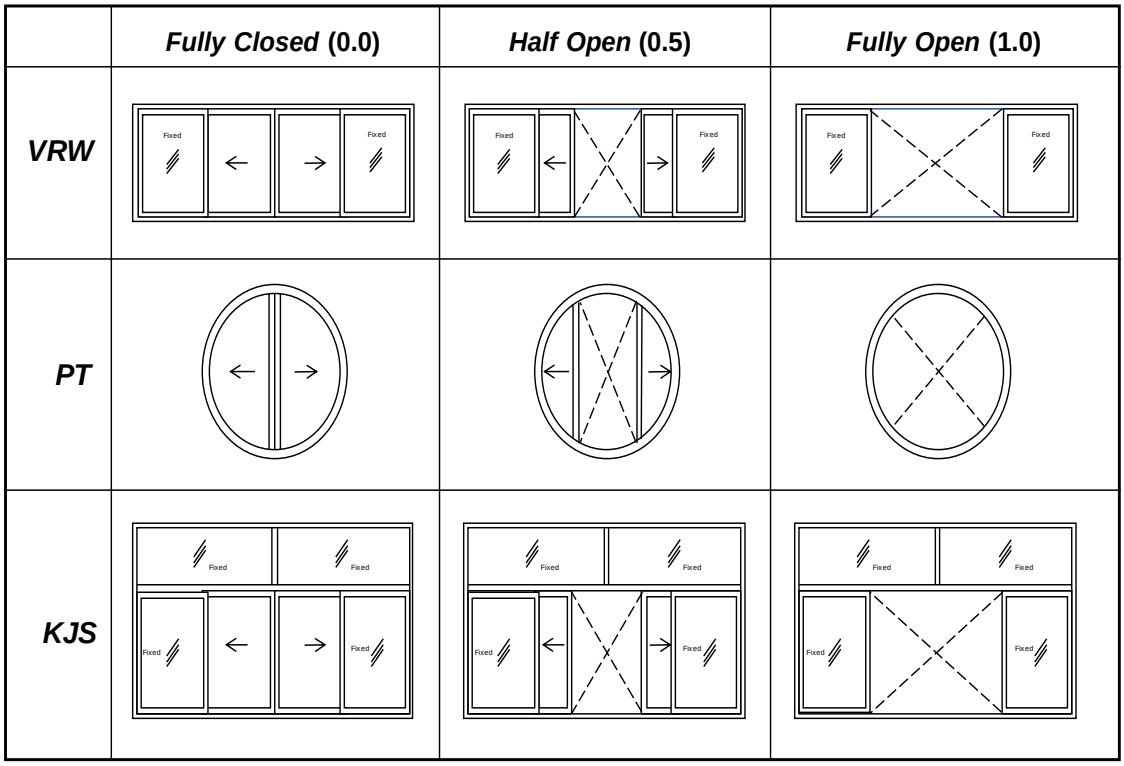


Figure 5.46: Examples of operating-score evaluation of the windows

For assessment of sky condition, a photo of sky condition and a clearness score were collected and observed every 30 minutes at the same measuring interval. The evaluation of the sky openness conducted was based upon a reference of

OKTAS cloud cover score ranging from '*Open Sky*' (0) to '*Overcast*' (8) (Figure 5.47). It should be noted that the length of the monitoring in *PT* was shorter than the other places due to the evening questionnaire session occurring after approximately 6.00 pm.

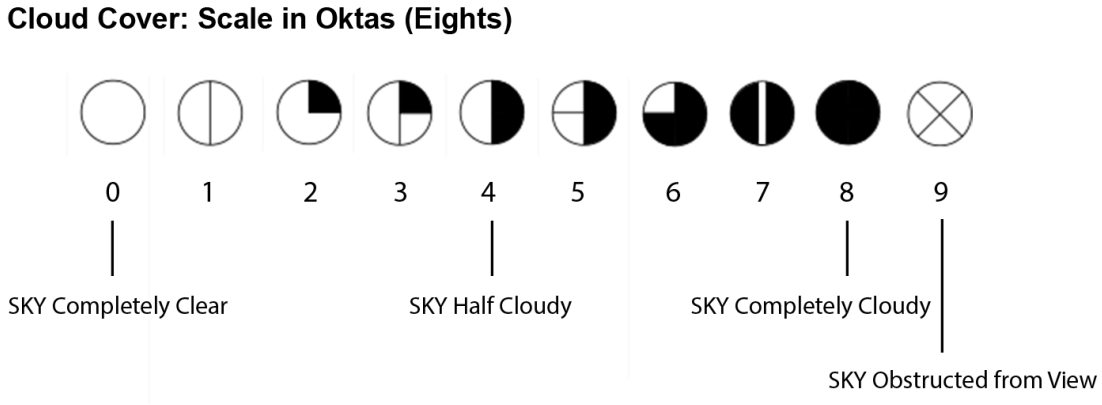


Figure 5.47: Cloud cover scale in Oktas

Moreover, a record of respondents' locations was conducted based on the locations of the questionnaire form, which is further discussed in the next subsection concerning the questionnaire survey method. All observation forms were created to record measured and observed data with a time scale of 30 minutes, as presented in Appendix C. A total of six observation forms were applied in this study:

- A sky condition evaluation form
- A surface T_r measurement form
- An evaluation of window and door operation form
- An evaluation of fan operation form
- An indoor *v* measurement form
- 1:50-scale key plans for subjects' sitting position observation

5.8.1.5 *Consideration of technology integration in the survey*

Due to the widespread utilisation of smartphones and tablets, many studies attempt to develop their survey methods by making use of these instruments for many reasons, including the potential for paperless surveys, saving space necessary for storing original documents, and improving control over access to

the data, which is more satisfactory in terms of ethical protocols. Furthermore, mobile applications also deduct laborious working process and time taken for data transcription, and minimise the potential for human error during this process. However, there are three justifications which demonstrate that the solution of employing personal mobile devices in the survey was considered inapplicable in this study:

- Unavailability of the internet signal in one of the sites. This challenge made the online application store and facilities inaccessible.
- Due to the nature of meditation practice, silence is essential. Use of personal mobile phones in meditation is prohibited.
- Based on the observation, some subjects are elderly and come from a low-income background. These conditions led to affordability and competency of technology operation issues, which might preclude some subjects from participating the survey.

Due to these challenges, it was impossible to concurrently collect the data from many respondents (approximate 15-50 subjects per site) due to the limited availability of the devices and time constraints (a 30-minute-period allowance for each survey). Based on these challenges, the concept of employing smartphones and tablets for this project was rejected and the paper-based conventional survey solution was adopted.

5.8.1.6 *Questionnaire survey method*

The survey was conducted after finishing the meditation session. At that moment, it was assumed that all the volunteers' bodies were already acclimatised to the local thermal environment when responding to the questions, since they had been within the halls for more than 15 minutes. The questionnaire survey method was designed based on a compromise between the requirements of the study and ethics protocol. Before the surveys were administered, consent from the authorities in the meditation centres was sought.

On the survey day, the researcher informed all the meditators in the halls about the survey, and the questionnaire package was distributed to those who consented to participate. While distributing the forms, the research aims and objectives and the requirements of the volunteers' participation will be explained, as Figure 5.48 shows. The subjects were moreover requested to leave the questionnaire package at the front of their last sitting places, so that their sitting locations were identifiable and could be paired with the measured environmental data of a nearest WBGT meter (Figure 5.49).



Figure 5.48: Brief presentation before starting the questionnaire session



VRW *PT* *KJS*

Figure 5.49: Examples of the forms left after finishing the survey

After the volunteers received the form, the structure of the form and solutions to respond to the questions were explained, especially the psychometric scale of the subjective thermal problem

s, before they started filling out the questionnaire. Each questionnaire session lasted approximately 30 minutes. Since the form-completing period may vary according to the individual's capability of reading and understanding the questions, four qualified assistants were trained to support the participants.

Regarding the method of observing the participants' sitting location, the completed questionnaire forms left after finishing the questionnaire session represented the last location of the subjects while filling out the questionnaire. The serial numbers and locations of the forms were recorded into the key plans with X and Y coordinates from the referent points in the halls, which were measured by metres distance (Figure 5.50).



Figure 5.50: Research assistants recording locations of the form into key plans

5.9 Questionnaire design and development

A questionnaire-surveying solution was employed to investigate participants' subjective thermal votes and personal information. Two major versions of the questionnaires utilized in the pilot and major studies are discussed in this section.

5.9.1.1 *Pilot study questionnaires*

Before discussing the details of the questions of the pilot study questionnaire, it should be mentioned that the initial aim of this research was to investigate change in subjective thermal votes of the same subjects when the indoor

thermal environment of the hall shifted from the morning to the afternoon. Thus, in this case, two versions of the anonymous self-evaluating questionnaire were created to be completed by the same subjects from different sessions. Those two versions of the forms were paired by the same serial numbers according to the numbered tags given in the morning, so that the data samples derived from the same subjects under different thermal settings could be tracked and compared.

Each consenting sample in the morning questionnaire session received a morning-version questionnaire package consisting of the questionnaire, a consent form, a pen and a numbered tag. All the subjects were informed to write the tag number into the form so that in the afternoon session, the afternoon-version forms would be distributed to the same participants who attended the morning sessions. In these circumstances, the subjects in the second questionnaire session were asked to note the same tag number into the forms so that the document from the two sessions could be paired.

The morning-version questionnaire contained a completed set of questions comprising three sections of which the first and second question investigate the subjects' current and past subjective thermal votes with adaptive solutions. The second section aimed to inquire about the subjects' meditation qualities, while the last section focused mainly on personal information. The afternoon-version forms still followed the same structure, but some personal information questions asked in the first questionnaire session were excluded to avoid redundancy and reduce the form-completing period.

- ***The first section: current subjective thermal vote and thermal adaptation***

The first section aimed to investigate subjects' current subjective thermal votes. The first question inquired about sample's current Actual Thermal Sensation (*ASV*) based on ASHRAE thermal sensation scale (ASHRAE Standard-55:2004 2004), of which the answers are laid on a seven-point Likert scale ranging from '*Cold*' (-3) to '*Hot*' (+3). The next question is Actual Thermal

Perception Scale (*APV*) developed based on the 'Thermal Pleasure Scale' of Parkinson, de Dear and Christhina (2015) of which the answers range from '*Very Pleasant*' to '*Very Unpleasant*' and the middle point is '*Indifferent*'.

Similarly, the answering options of an *APV* scale vary from '*Very Comfortable*' (-3) to '*Very Uncomfortable*' (+3), while the centre of the scale is '*Indifferent*' (0). The third question investigates subjects' Thermal Preference (T_p), which is mentioned in the RP-884 report (DeDear, Brager and Cooper 1997). The T_p scale comprises of three options which are '*Prefer Warmer*' (-1), '*No Change*' (0) and '*Prefer Cooler*' (+1). A summary of the scales employed in the pilot study is presented in Table 5.7.

Table 5.7: Summary of the subjective scales employed in the pilot study

	Scale						
	-3	**-2**	**-1**	0	**1**	**2**	**3**
ASV	*Cold*	*Cool*	*Slightly cool*	*Neutral*	*Slightly warm*	*Warm*	*Hot*
APV	*Very comfortable*	*Comfortable*	*Rather comfortable*	*Indifferent*	*Rather uncomfortable*	*Uncomfortable*	*Very Uncomfortable*
T_p	-	-	*Preferred cooler*	*No change*	*Preferred warmer*	-	-

Apart from the investigations of the current thermal states mentioned above, the participants' thermal adaptation on environmental and personal modifications were investigated by open-ended questions. The first investigation regarding the environmental adaptation asked the subjects if they modified environmental controls in the hall, namely windows, fans, or curtains, due to their thermal dissatisfaction. The subjects could answer '*Yes I did*' or '*No I didn't*'. If they confirmed performing the environmentally modifying action, they would go on to the subsequent question asking to provide more details about the adjustments made.

However, if they did not perform any environmentally adaptive action, they would be led to the sub-question asking to justify why the environment controls

were not modified. The answers to this sub-section were '*I am satisfied with the current thermal environment*' or '*I am not satisfied with the current thermal environment*'. If the former choice was selected, this section was completed. In contrast, if they were dissatisfied with the thermal environment, the subjects were asked to explain briefly why the environmental controls were not adjusted. A summary of the question sequence is illustrated in Figure 5.51.

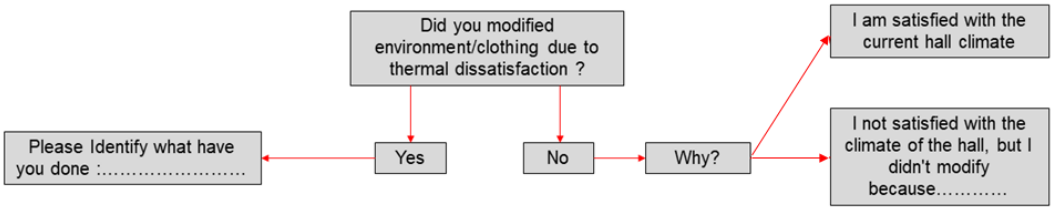


Figure 5.51: Summary of the question sequence of environmental and personal adaptations

The next set of questions in this section is an investigation of thermally personal adjustments focusing on *CLO* modification. The structure of the questions was similar to that applied in the environmental modification section, to allow the subjects to straightforwardly follow the sequence of the questions.

- ***The second section: past subjective thermal votes and meditation qualities***

The second section of the question investigates participants' subjective thermal votes and meditative qualities while meditating. The first set of the questions relates to past subjective thermal votes, such as Past Actual Thermal Sensation Vote (ASV_{past}), Past Actual Thermal Perception Vote (APV_{past}), and the performed adaptive actions. The structures and answering methods of this set of questions were similar to these employed in the first section. In contrast, the major difference of this section is sub-questions investigating personal meditative qualities.

It is a set of check-list questions developed based on facets of meditative quality mentioned in the first cluster of *MEDI* (Piron 2001), as discussed in Chapter 4. The questions ask the subjects directly if they experienced any aspects of the

meditative quality. Furthermore, this section requires the subjects to assess their breathing quality and satisfaction having just finished meditative activities. Appendix D shows full details of all the questions in the pilot study questionnaire.

- ***The third section: personal information and meditation background***

This section aims to explore participants' personal information and meditation background. The first question in this cluster asked volunteers to record the tag number followed by the following personal aspects:

- Province of residence and length of the stay
- Height, weight, gender, and religion
- Highest educational level and age cohort
- Currently adopted precept according to Buddhist precepts
- Daily ventilation background (before attending this session)
- Current health status and last night's sleep quality
- Length of meditation experience (in months and years)
- Usually meditating place and province
- Frequency of practice
- Aims of today's practice and achievement
- Assembly of current *CLO*
- Food and drink consumption

Subjects' *CLO* assemble later used in the *PMV* calculation was investigated by graphical checklist questions, as Figure 5.52 presents. The subjects were asked to select and mix the clothing which they were wearing from five categories covering parts of '*Head to Neck*', '*Arms*', '*Top*', '*Bottom*' and '*Feet*'. Besides, the subjects were required to state what furniture they were sitting on, such as a chair, meditation mat, or the floor.

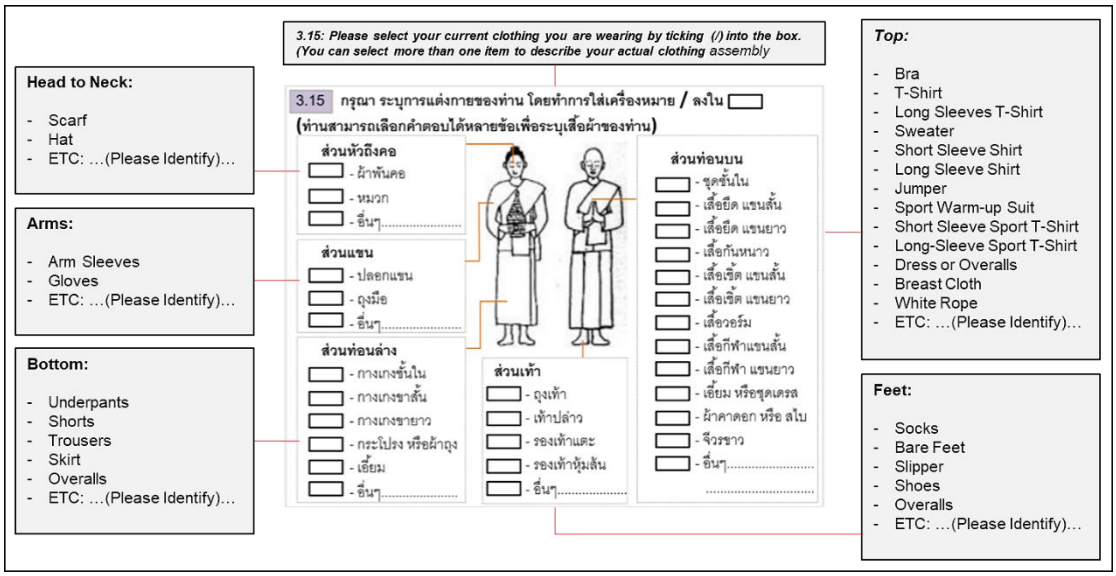


Figure 5.52: Graphical question of CLO assembly

Those aspects mentioned above are included in the complete set of the morning questionnaire. Some personal inquiries not directly related to thermal sensitivity, such as age range, place of residence, and education level, were excluded from the afternoon version of the form due to a redundancy of the data collection. However, the fourth section was added for investigating extra aspects regarding the survey method and questionnaire design, such as the size of the forms and texts, the period of form completion, and the number of the questions. The additional information was used in the questionnaire development for the main survey.

5.9.1.2 *Problems found in pilot study-version questionnaire and improvements*

After finishing the pilot study, the research method, operations of the research tools and the research staff members were analysed for troubleshooting to hone the final field survey approach. According to the analysis, the following amendments were made to the form:

- The first problem was missing number tags in the questionnaire. The pilot study avoided collecting personal identities by giving a serial number tag to identify each participant. This method allows the

researcher to be able to match the morning and afternoon-version forms contributed by the same volunteers. Although the subjects were asked to keep and reuse their tags in the second session, the evaluation of the results from completed forms revealed that a number of participants did not record their code in the form, and they left the tags with the questionnaires at their last sitting spots. Such an error might be attributable to: (i) some participants misunderstood the surveying procedures; and/ or (ii) some of them left the training after finishing the first meditation session.

Therefore, to avoid missing the numerical identities of participants in relation to their documents, the number-recording method was terminated. The final-version questionnaire was produced with a serial number stamped on the front. However, it should be noted that such a solution resulted in an inability to pair documents from the same participants from two sessions, and the same subjects who attended the morning survey were still required to repeat filling out their personal information in the later sessions.

- There were many skipped answers in the open-ended questions, especially the section of thermally adaptive actions. The lack of completion of some vital parts of the questionnaire led to missing some data for the analysis. To address this concern, the final-version questionnaire was improved by creating and developing items toward closed-ended questions, to reduce the period of form completion and focus participant responses.
- The first version of the subjects' *CLO*-investigating section was designed as a graphical question aiming to aid participants' understanding of the questions and reduce the length of the form-completing period. However, a review of the returned document showed that a number of subjects skipped or did not complete the task. Therefore, this pictorial interpretation was questioned, since it could have caused confusion and required a long period to properly understand the answering options. This section in the final-version questionnaire was simplified by using a

set of closed-ended questions to directly ask about the subjects' *CLO* assembly.

- The last major amendment of the document was in the section of meditative quality assessment, in which the analytical aspects were referred from the first of the six clusters of *MEDI* (Piron 2001), as mentioned in Chapter 3. The result obtained from the pilot-study version questionnaire seem unable to describe relations between the volunteers' meditation qualities and variation of indoor thermal environments. Thus, the questions were developed based on the method applied in the *APV* and *ASV* votes, of which the answering options were on a seven-point psychometric scale. This modification is discussed in the following sub-section.

5.9.1.3 *Final-version questionnaire*

The final-version questionnaire was developed based on the results obtained from the pilot study, as mentioned in the previous section. The questionnaire consists of 33 closed-ended questions, and one opened-ended one, categorised into three sections, as described below.

❖ ***The first section: current subjective thermal vote and thermal adaptation***

The first section investigates subjects' current subjective thermal votes experienced during filling-out the questionnaire form. The first three aspects are identical to those of pilot-study version which are *ASV*, *APV*, and T_p. Apart from those factors, the final version of the questionnaire also included seven questions in the first section, including:

- One investigation of thermal acceptability, which is a direct question inquiring the subjects if the current indoor thermal condition is acceptable.
- Four questions of environmental factor preferences, which are *v* Preference *(v_p)*, *RH* Preference *(RH_p)*, Day Lighting Preference *(LT_p)*, and Hall Density Preference *(D_p).*

- Two sets of questions regarding the subjects' thermally adaptive solutions.

The last task regarding the thermal adaptation requires volunteers to report and order the thermally adaptive actions which they expected to perform in the halls. All subjective scales applied in the first section of the questions are summarised and presented in Table 5.8. However, it should be noted that RH_p, LT_p, and D_p are not discussed in this thesis.

Table 5.8: Summary of the subjective scales applied in the first section

	Points on Likert scale						
	-3	**-2**	**-1**	**0**	**+1**	**+2**	**+3**
ASV	*Cold*	*Cool*	*Slightly cool*	*Neutral*	*Slightly warm*	*Warm*	*Hot*
APV	*Very comfortable*	*Comfortable*	*Rather comfortable*	*Indifferent*	*Rather uncomfortable*	*Uncomfortable*	*Very uncomfortable*
T_p	-	-	*Prefer cooler*	*No change*	*Prefer warmer*	-	-
v_p	-	-	*Prefer lower v*	*No change*	*Prefer higher v*	-	-
RH_p	-	-	*Prefer Less humid*	*No change*	*Prefer more humid*	-	-
LT_p	-	-	*Prefer lower intensity of light*	*No change*	*Prefer higher intensity of light*	-	-
D_p	-	-	*Prefer lower density*	*No change*	*Prefer higher density*	-	-

Regarding users' thermal adaptation investigation, the results derived from the pilot study reveal that many subjects skipped the open-ended questions, especially the sections of thermal adaptation investigations. Therefore, behavioural investigation section of the final-version questionnaire was developed from the open-ended to two closed-end responses as follows:

- What are three adaptive solutions the subjects may have expected to perform in the hall?
- What are the first three actions that the subjects performed in the halls?

The complete-set-answering options to the above questions consist of 16 adaptive actions. The first 13 adaptations in the list were referred from previous

similar studies conducted in residential buildings in India, published by Indraganti (2010a 2010b and 2011), and the last three unique solutions were mentioned by the subjects of the pilot study:

- Modifying clothing
- Changing sitting materials
- Loosening or tightening clothing
- Relocating to a cooler or warmer area
- Relocating to an area where there is a higher or lower airspeed
- Avoiding exposure to direct solar radiation
- Changing activity or posture
- Taking a short break to toilets or bathrooms
- Tying hair
- Consuming cool or warm drinks or foods
- Taking a nap
- Relocating closer to cooler or warmer objects
- Modifying the environmental condition by opening/closing the windows or using curtains and fans
- Accepting the current thermal stimuli as it is *('Accepting it')*
- Deviating focus from dissatisfying stimuli of the current thermal environment to other aspects *('Deviating focus')*
- Resisting dissatisfying stimuli of the current thermal environment *('Resisting it')*

One extra open-ended answer is available at the end of the list if the choices provided do not reflect the actual action the subjects performed. Finally, 17 answering options were created; Figure 5.53 presents the questions with the answering options in Thai and English. For the answering methods of the first set of questions (item 1.9 in the figure), which asks about the adaptations the subjects expected to perform. Participants were allowed to answer with up to three actions, but some of them might report only one solution, according to their actual experiences. The following question investigates the performed adaptation from the 16 adaptive actions listed in the previous section. This task

asks the subjects to order the first three adaptive solutions performed in the halls. Similar to the previous question, the number of performed adaptation may vary from one to three actions, to reflect the reality of the actions.

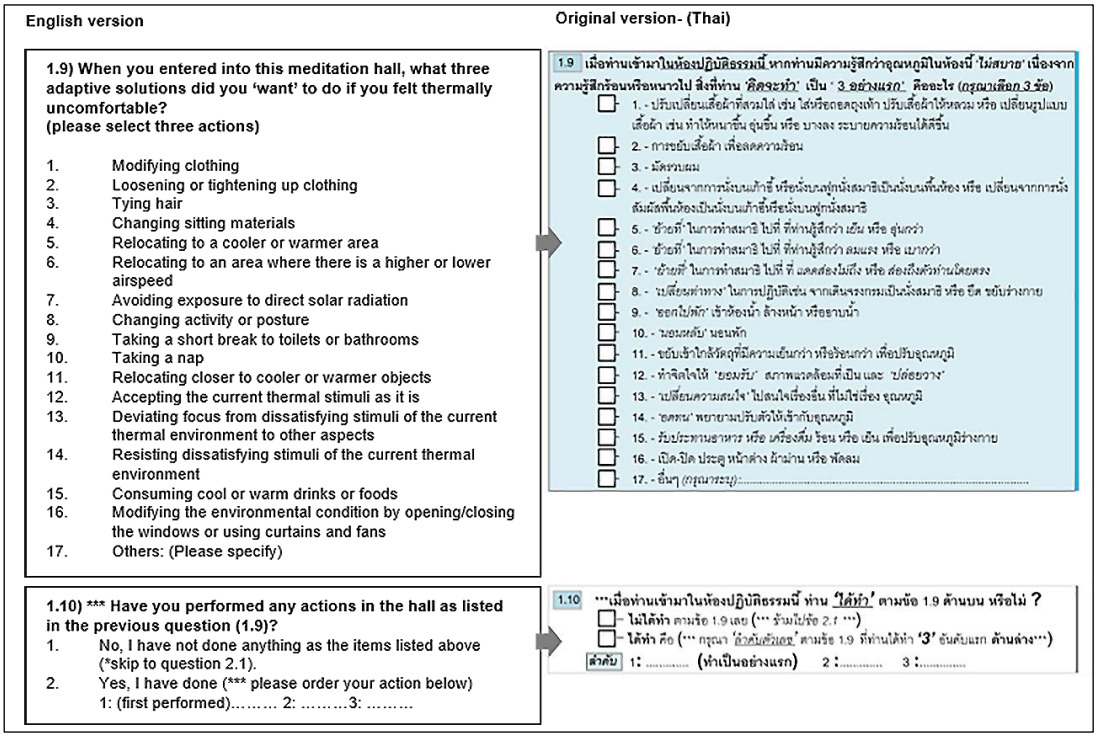


Figure 5.53: Two sets of thermal adaptation questions in the final-version questionnaire

❖ *The second section: past subjective thermal votes and meditation qualities*

The second section consists of 12 sub-questions, six of which investigate the subjects' past subjective thermal votes, and the other six of which focus on experiences of meditation quality during the training periods.

▪ *Subjective thermal votes during meditating*

The first six questions of this section relate to the past subjective thermal votes, of which the first two questions inquire the respondents' Past Thermal Sensation (ASV_{past}) and Past Thermal Perception (APV_{past}) during meditating. These subjects' thermal experiences were examined by the same answering methods as applied in the *ASV* and *APV* investigations of the first section. Moreover, the subjects were later asked to evaluate a difference between their

current thermal sensation when meditating. Besides, the other three questions ask about the previous meditation activity before filling out the questionnaire, direct solar exposure, and experience of numbness during engaging the activities during meditating.

- ***Investigation of meditation qualities***

After completing the past subjective thermal vote section, the subjects were asked about their meditation quality of the just finished practice. Such meditative experience consists of six meditation facets developed based the first of the five cluster of *MEDEQ* (Piron 2001), as discussed in Chapter 4. This categorisation pertains to six facets of meditation experience: sleepiness, boredom, feeling glad when the practice ends, relaxation perception, changing thoughts, and capability to follow the instructor's instruction (Table 5.9). These six *MEDEQ* questions are similar to three aspects of the '*Five Hindrances*' of Buddhism meditation techniques (see Chapter 4).

Choices of meditation experiences were laid on a five-point psychometric scale, as shown in Figure 5.54, in which the range of the answering options varies from '*Always Considerably Easy to Perceive*' (-2) to '*Always considerably difficult to perceive*' (+2), while the centre of the scale is '*Slightly difficult to perceive'* (0). It should be noted that only *DR* and *IFA* aspects are analysed in this study. It should be noted that the other aspects (*SP*, *BD*, *FG* and *CT*), however, are excluded from this study.

Table 5.9: Summary of questions of meditation-related experiences applied in this thesis

No.	Item No. on the *MEDEQ*	Aspects in *MEDEQ*	Self-evaluation of mediation qualities applied in this thesis	Abbreviation
1	12	Sleepiness	Feeling sleepy	*SP*
2	13	Boredom	Feeling moody, bored, and dissatisfied	*BD*
3	18	Feeling glad when the meditations end	Feeling delightful when finishing meditative activities	*FG*
4	1	Relaxation perception	Feeling difficulty in relaxation	*DR*
5	4	Changing thoughts	Feeling that thoughts were constantly in flux	*CT*
6	9	Capability of following instructions	Feeling rather difficult to follow the meditating method instructed by meditation instructors.	*IFA*

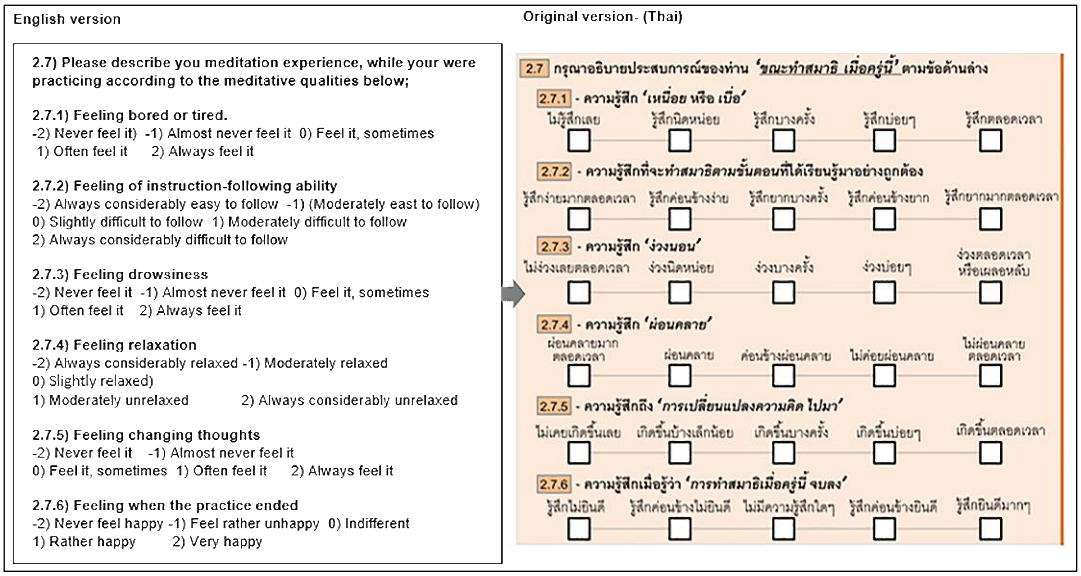


Figure 5.54: Self-evaluating main survey questions on meditation qualities

❖ *The third section: personal information and meditation background*

This section focuses on personal data collection regarding the subjects' general demographic information, ventilation background, and current *CLO* assembly data. A total of 27 closed-ended and one open-ended questions are included in this section for investigating respondents' personal information such as height, weight, age range, gender, province of residence, today's aim and achievement of practise, education level, health status, sleep quality, beverage and food consumptions, ventilation background, and experience of practice. For *MET*, the subjects' *MET* was not examined in this study, but was referred from the comparable values according to the ASHRAE Standard-55:2004 (2004). The approximated *MET* value of 1.0 for '*seated and quiet*' in the category of '*sedentary activity*' was applied for all participants.

The largest part of this questionnaire section belongs to a current *CLO*-assembling question inquiring about the subjects' current outfit. This query was developed from the graphical question of the pilot study to a checklist version of the main survey, as presented in Figure 5.55. The first question in this section asks the participants directly about their clothing characteristics, such as meditation uniform or casual attire. The next set of questions focuses on clothing details, such as types of top and bottom, and extra *CLO*, such as

second-layer clothing, socks, gloves, scarf, hat and pashmina/ shawl (see Appendix E for the final-version questionnaire).

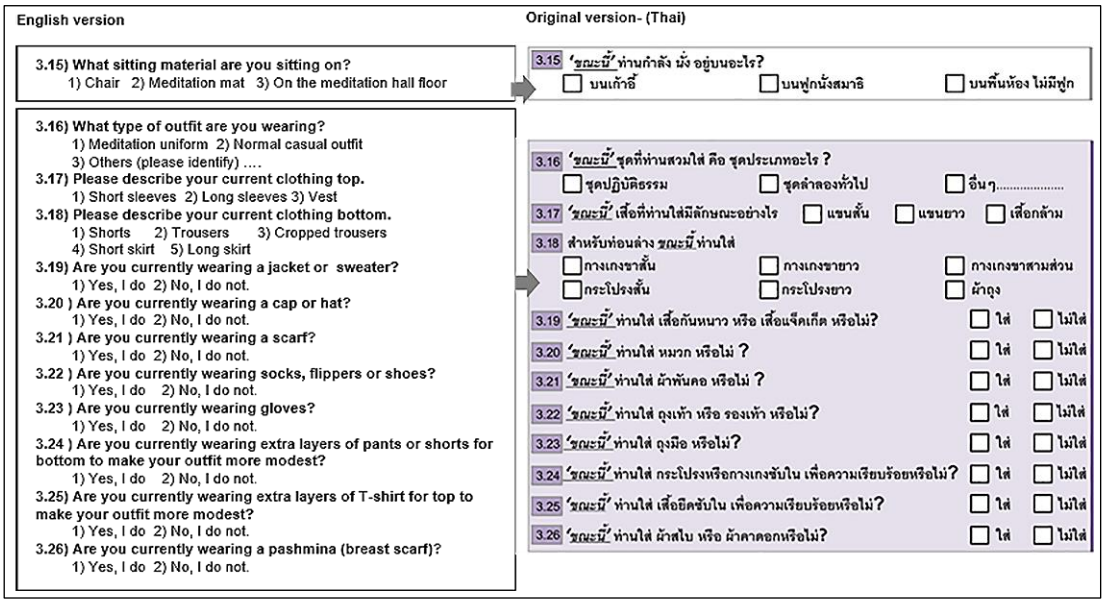


Figure 5.55: Self-evaluating question of the sample's CLO assembly for the survey

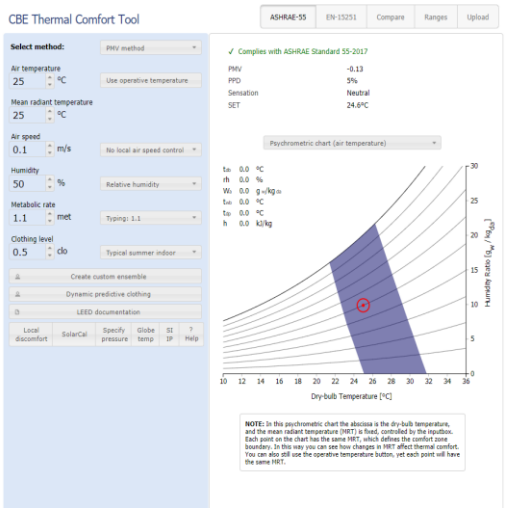
5.10 Calculating and analytical method

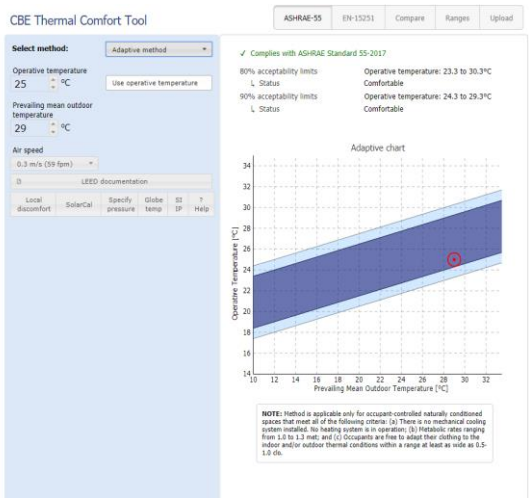
5.10.1.1 *Calculating method of the environmental variables*

This research employed T_{op} to describe thermal environment indoors and outdoors, as Eqn 54 and Eqn 55 present in Chapter 3. According to the equations, *v* is one of the important factors; however, *v* was only measured at WBGT B due to the limited number of anemometers. The results obtained from this device were calculated with the other variables were measured at WBGTs A, B, and C for *MRT* and T_{op}. The outdoor environmental variables applied in this study are expressed as Outdoor Dry Bulb Temperature (DBT_{out}) and Monthly Mean Outdoor Dry Bulb Temperature ($T_{monthly\text{-}av\text{-}out}$). DBT_{out} is the 30-minute average of the primary data collected by WBGT D during the survey. $T_{monrhtly\text{-}av\text{-}out}$ was calculated from secondary data of Khon Kaen provided by the Thailand Meteorological Department (2017), with the monthly (30-day) average outdoor *DBT* prior to each survey day.

5.10.1.2 *PMV and PDD calculations*

The prediction of *PMV* and *PPD* were calculated by the CBE thermal comfort tool (Hoyt et al. 2013). Figure 5.56 shows samples of the platform interface.





PMV and *PDD* calculations Adaptive thermal comfort assessment

Figure 5.56: Examples of CBE thermal comfort tool interface

Source: (Hoyt et al. 2013)

This tool was developed based on the ASHRAE Standard 55-2017 for adaptive thermal comfort evaluations and *PMV* and *PPD* assessments (Centre for the Built Environment 2016). Variables applied in the *CBE* thermal comfort tool include Fanger's six thermal comfort factors collected from the survey: *DBT* or T_{op}, *v*, *RH*, *MET* and *CLO.*

5.10.1.3 *Statistical analysis method*

The collected environmental and personal data were analysed in terms of descriptive and inferential statistics using Microsoft Office Excel and IBM SPSS version 24. The former solution aims to apply to describe the general data such as the mean, range, minimum and maximum values, and mode. Relations between variables were examined with linear and curvilinear regressions and Probit model. The data is exhibited in the form of bar charts, line graphs and tables.

5.11 Chapter conclusion

This chapter discussed research methodology, which includes all the research methods employed in this research. The research workflow shows a summary of seven major stages of this research, from the early stage focusing on defining research problems to submitting thesis. This study chose Khon Kaen as the studied province since it is located in the eastern region of Thailand, where the most significant number of meditation centres are found. Names of local meditation centres were listed, and finally, three meditation centres were selected, named *VRW*, *PT*, and *KJS.*

Regarding the outdoor thermal environment of Khon Kaen, the secondary data collected from the Thailand Meteorological Department shows that, in 2016, the lowest annual mean outdoor *DBT* was 23.96°C in February, and the highest was 32.71°C in April. The lower and upper limits of average *RH* were 51.77% in April and 83.06% in September. This research method and relevant document were reviewed and approved by the Research Ethics Committee of School Engineering, the University of Nottingham, before the fieldwork was initiated.

The measuring instruments for this research were selected based on the availability of the instruments available in the UK and Thai markets by comparing price, performance, and aftersales service. A set of instruments comprising four WBGT meters, one anemometer, two infrared thermometers, two distance meters, and one thermal camera were selected. The devices were calibrated by accredited laboratories and factories before applied in the project. All the WBGT meters which were set to automatically record data every 30 minutes were installed overnight to collect a 24-hour data of *DBT*, *RH*, and T_g from the installation to the last measuring periods. Three devices (WBGTs A, B, and C) were distributed inside the halls to cover the indoor spaces as extensive as possible, while one device (WBGT D) was placed outdoors.

The anemometer and *IR* thermometers were set to manually function at the same measuring interval of the WBGT meters for v and T_r measurements,

respectively. However, the manually functioned devices collected a shorter period from the beginning of the first survey sessions to the end of the last ones. Besides, this research observed changes of sky condition and environmental control operations which are fans, curtains, and windows at the same interval of the measuring instruments. The observations started and finished at the same measuring periods of the manually functioning devices. However, the sky observation activity finished at 6.00 pm due to the local sunset time, or at the last manual measurements before sunset.

The pilot study was conducted in the hottest month on the 5th of April 2015 in the *VRW* meditation hall. The results and research method of this pre-study were evaluated for further development of the main survey. The main field study was held in all the sites (*VRW*, *PT*, and *KJS*) from November 2016 to July 2017.

For the questionnaire distribution and collection, the consenting subjects were informed to leave the questionnaire at the front of their sitting places before leaving the halls. After that, the locations of the document with the form serial numbers were recorded into the observation forms so that the questionnaires could be paired with the environmental data of the nearest WBGT meters distributed in the halls.

Two methods were used to calculate indoor environmental data employed in thermal subjective vote and behavioural analyses. For the environmental data set applied in the former analysis, the filled-out questionnaires, of which their locations left in the halls were recorded, were linked to the one of the nearest three WBGT: A, B and C to retrieve the indoor environmental data (*DBT*, T_g, and *RH*). These physical variables, which represented indoor environmental conditions during questionnaire filling-out session, were averaged over 30-minute period of each measuring device when the participants started filling out the forms. However, *v*, which was measured at the WBGT B location, was applied for T_{op} and *MRT* calculations in all locations. Furthermore, based on the same measuring database, the indoor environmental factors applied in the behaviour study are averaged data of three WBGTs A, B, and C of each measuring interval (30 minutes).

In terms of the questionnaire design, two versions of the questionnaires were created for the pilot study and main survey. The final-version questionnaire comprised three main sections. The first and second parts aim to investigate the participants' current and past subjective thermal votes such as *ASV*, *APV*, and T_p, while the last section focuses on the investigation of subjects' personal information. The subjective scale applied for *ASV* analysis was referred from the ASHRAE thermal sensation scale. The *APV* investigation developed based on the thermal pleasure scale (Parkinson *et al.* 2015) was created to differentiate the thermal sensation from thermal perception. The subjects' data of *CLO* assembly were collected by a set of checklist-type questions. However, the subjects' *MET* was assumed to be constant at 1.00, inferred from sedentary activity as understood by ASHRAE Standard 55:2004.

The questions in thermal adaptation section were developed based on the pre-test results and past research. The results of the users' thermal adaptation of the pilot study reveal that apart from similar thermal adaptation reported by previous studies, the volunteers reported three unique psychological techniques: '*Accepting it*', '*Resisting it*', and '*Deviating attention to other aspects*'. Finally, these three mental adaptations were combined with the other 13 general adaptive techniques found in the previously published studies and included in the final-version questionnaire. Moreover, the survey investigated relationships between the respondents' meditation qualities and indoor thermal factors by developing a set of self-evaluation scales based on the first of the five clusters of *MEDEQ*

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Chapter 6

Results of the Pilot Study

Chapter 6: Results of the Pilot Study

The previous chapter discussed the research methodology describing the methods of the pilot and main surveys. This chapter focuses on the former study held in the *VRW* meditation hall on the 15th of April 2016. A total of 80 questionnaires were collected, of which only 29 were employed in the analysis and presented in this chapter. Although the results obtained from this study are excluded from the research database, the derived results and the challenges found are considered a foundation of main survey. Thus, before presenting the results of the pilot study, the unexpected difficulties found during this survey leading to an on-site amendment of the survey methods is reported. Besides, the number of distributed and returned questionnaires is summarised followed by a discussion of the results of the environmental measurements, behaviourally adaptive observation, and subjective thermal votes.

6.1 The amendment of the questionnaire distribution method

The pilot study was conducted in *VRW* during 4th to 5th of April 2016. The first day of the field research was devoted to installations of the WBGT meters and the targets of *IR* thermometers. The second day of the study (5th of April) was the survey day, on which the questionnaire session, behavioural observation, and thermal environmental measurements took place. As mentioned in Chapter 5, the method of the pilot-study questionnaire was designed based on the research problems. The results and problems found in the pilot study have an impact on shaping the research method, research aims, and questionnaire design of the main survey. This section discusses an amendment of the on-site questionnaire survey method. Before describing the amendments of the form-distributing process, the initial plan of the questionnaire distribution and to the problems found during the pilot survey are briefly explained.

6.1.1 Questionnaire distribution method for the pilot survey

One of the initial research aims was to investigate variation in participants' subjective votes and personal factors over the observed period. Thus, two

different types of the questionnaires were used for the morning and afternoon sessions. The main difference between these forms was the omission of personal inquiries in the afternoon version of the questionnaire, to avoid redundancy of the volunteers' information provision and for time-saving expediency. In this case, it was intended to examine the same 100 participants twice in different thermal settings of the hall by matching the completed questionnaires collected from the two sessions.

Thus, 100 sets of the morning questionnaire with numbered tags were distributed to the consenting subjects in the morning. They were asked to leave the filled-out forms at the front of their sitting locations, keeping the numbered tags with them so that they could later be used in the afternoon session. In this case, the completed forms from the two different sessions could be paired by matching the serial numbers. The paired data allows the researcher to monitor a variety of participants' subjective votes, personal factors, and meditation qualities over the periods. However, this initial research method was not achievable due to some difficulties encountered during the actual survey day, as discussed in the following section.

6.1.2 Challenges found during the survey

As mentioned in the previous section, one of the initial aims of this pre-study which influenced the first-version questionnaire design was to compare a subjects' *ASV* in the morning and afternoon questionnaire sessions. This aim led to a survey method design that required volunteers to answer the questionnaire twice in different indoor thermal settings (in the morning and afternoon sessions). However, this aim had to be eliminated due to the following difficulties:

1. Regarding the number of the participants and the capacity of the meditation hall, the number of the forms was created based on the observed number of attendees observed during initial visits in January 2016, before the pilot study started. For example, the pre-observation showed that approximately 70-80 meditators attended the practice

sessions in *VRW* centre. Thus, 100 forms were prepared for each morning and afternoon sessions. However, the number of meditators (approximately 150 participants) was unexpectedly greater than the number of produced questionnaires (100 sets) on the survey day. Indeed, the meditation hall could not accommodate such a large group of participants. That incidence resulted in a relocation of some meditators after the form distribution to a multi-purpose hall located on the ground floor, where no measuring instrument was installed. As a consequence, the completed documents from this area were excluded from the data set due to the lack of measured environmental data associated with those forms.

2. The error of the survey method may have been attributed to the subjects' misunderstanding of the researcher's instruction regarding the questionnaire survey method provided before the meditation session started. The subjects were informed to leave the form at the front of their last sitting points after filling it out the form while keeping the number tag with them for the afternoon survey session.

   However, after finishing the morning session, it was found that some participants did not follow the instruction, because some number tags were left at the sitting locations with the questionnaires. Besides, some meditators withdrew from the training after finishing the morning training, while the afternoon session was filled-in by new meditators who just registered for the practices. Misunderstanding of the instructions and withdrawing from the afternoon sessions caused mixing between the subjects of the morning session and the new participants, making it impossible to directly compare results between the two sessions for particular, individual participants.

3. Due to a change of subjects' consent in the afternoon session, it was clear that the aim to compare the subjects' *ASV* between the two sessions might not be entirely possible. According to the survey, some consenting subjects from the morning session refused to participate in the afternoon survey activity. Such a refusal to participate in the

subsequent activity also entailed a failure to match the forms between the sessions.

Such difficulties created an echo effect in the afternoon survey, since the plan to track the participants from the morning session was not achievable. Solutions to the identified problems were subsequently developed, as discussed in the next section.

6.1.3 Solutions to the on-site problems

Due to the challenges found in the survey day, the pilot study method has to be amended on site to minimise the impact of the problems. Firstly, the aim of comparing results from particular individuals had to be eliminated, to preserve the other primary research aims and to interrupt the participants as little as possible.

Furthermore, the limited number of the produced questionnaire needed to be carefully managed to ensure that the forms could be distributed in two sessions, as planned. Instead of using the morning and afternoon version of the forms to inquire the volunteers in the first and second meditation sessions, respectively, the 100 sets of the morning-version questionnaire (containing a complete set questions) were separated into 45 sets for the morning session, and 45 sets for the afternoon session, while the other ten documents were left as a spare document.

The first 45 packages of the morning version were distributed to the subjects in the first session. Later, the same volunteers who attended the morning-survey session would receive the afternoon-version form in the afternoon session. The other 45 morning-version questionnaires were given to new volunteers who had not yet attended the morning session in the afternoon activities. Figure 6.1 summarises the amended questionnaire distribution method.

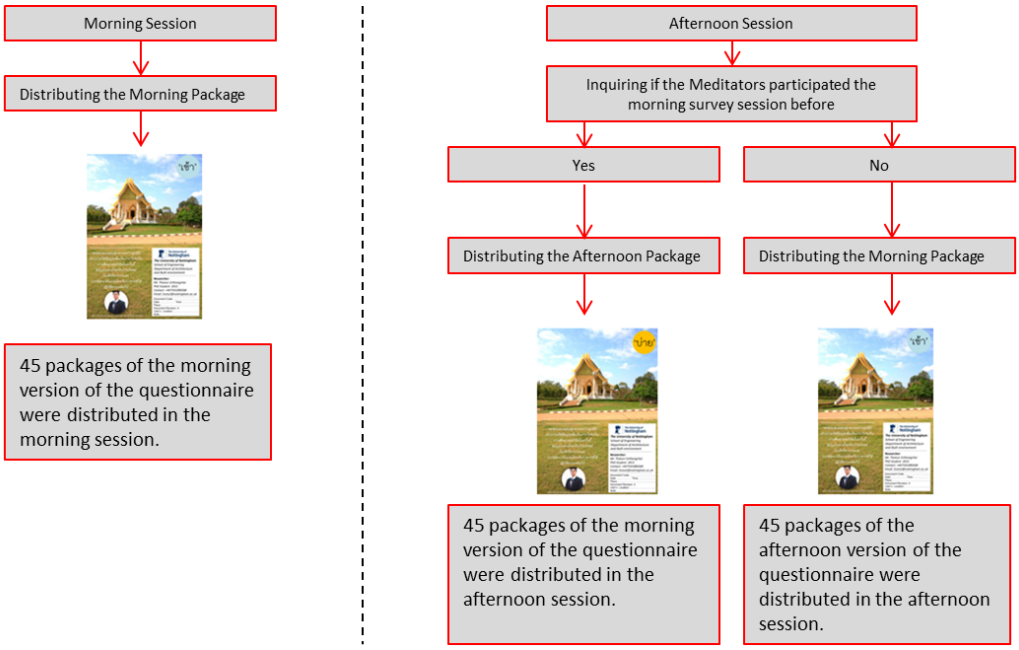


Figure 6.1: Summary of an amendment of the questionnaire distribution method

6.1.4 Summary of the number of distributed and collected forms

A total of 135 questionnaires, comprising 90 sets of the morning version and 45 sets of the afternoon version, were distributed in the pilot study. After completing the morning survey session, the collected forms were reviewed. It was found that 27 of 135 questionnaires (20%) were missing, especially from the afternoon session (n = 23, 17%) (Table 6.1). Some critical information in the forms was missing, such as the given number tag, subjective votes, and personal information. Besides, some subjects reported they were unhealthy or had undergone insufficient sleep.

Consequently, those missing and uncompleted forms led to the exclusion of the data and a decreased number of subjects in the pilot study. The fully completed questionnaire used in this analysis ('*Usable Forms*') included morning-version packages fully filled-out, location-tracked, and completed by healthy respondents who had experienced enough sleep in the preceding night before the survey day. According to the results of the data collection, the morning and afternoon survey sessions collected 15 and 14 *Usable Forms* from the participants, respectively. However, it should be noted that for the analysis of

subjects' thermal adaptation, all the adaptive actions reported by all the subjects were pooled and analysed.

Table 6.1: Summary of the questionnaire distributed and collected in the pilot survey

	Morning Session		Afternoon Session	
	Morning version	**Afternoon version**	**Morning version**	**Afternoon version**
Distributed	45	0	45	45
Returned	41	0	39	28
Usable Form	15	0	14	0

6.2 Results of the pilot study

6.2.1 Thermally environmental measurements

Thermal environmental variables are considered influential factors on human thermal comfort. This research applied a set of measuring instruments, which are four devices of WBGT meters, two *IR* thermometers, and one anemometer to measure *DBT*, T_g, T_r, *RH*, and *v*. Indoor and outdoor environmental data samples were transcribed, calculated, and analysed in Microsoft Excel. It should be noted that indoor *DBT*, *RH*, and T_g used in the pilot study were presented as averaged values of the three devices of WBGTs A, B, and C, named as $DBT_{av\text{-}in}$, $RH_{av\text{-}in}$, and $T_{g\text{-}av\text{-}in}$, respectively, while DBT_{out} was derived from only the WBGT D device, as mentioned in Chapter 5. The *WBGT* instruments were installed one day before the survey day to collect 24-hour data of indoor and outdoor *DBT*, T_g, and *RH*. However, this section focuses only on the environmental factors measured over the survey period, from 8.00 am to 6.00 pm on the 5th of April 2016 (Figure 6.2).

According to the environmental measuring data, the lower limits of $DBT_{av\text{-}in}$ and DBT_{out} were 31.51°C and 29.70°C at 8.00 am, then DBT_{out} gradually increased to reach the maximum (37.66°C) at 4.00 pm, while $DBT_{av\text{-}in}$ (37.27°C) was relatively lower by 0.29°C. The figure presents that there is a small difference between $DBT_{av\text{-}in}$ and $T_{g\text{-}av\text{-}in}$, which leads to an unnoticeable difference between indoor T_{op} and $T_{g\text{-}av\text{-}in}$, as the figure shows the overlapping trend lines between those factors. The lower and upper limits of indoor T_{op} are 31.50°C and 37.66°C and those of RH_{in} are 24.03% and 48.23%, respectively.

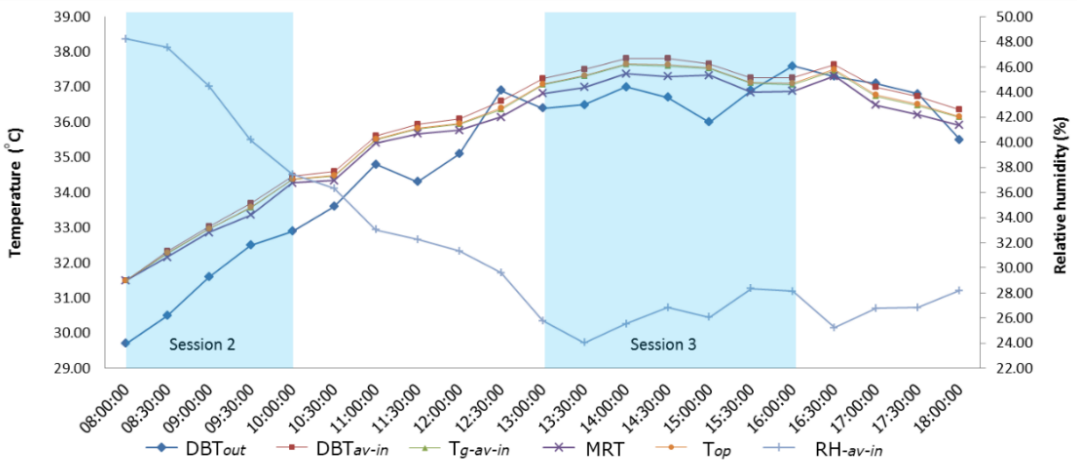


Figure 6.2: Ten-hour environmental data of $DBT_{av\text{-}in}$, DBT_{out}, $T_{g\text{-}av\text{-}in}$, MRT, $RH_{av\text{-}in}$ and T_{op} of the VRW hall

For indoor T_r, Figure 6.3 presents a comparison of a regular and thermal images of the *VRW* hall in different periods of the day. The range of temperatures in the thermal images varies from red to dark blue, representing the hottest and coolest indoor planes (respectively). The thermal images revealed that the ceiling was the hottest surface. Besides, a measuring result of T_r in the hall by the *IR* thermometers confirmed that the ceiling surface was the hottest amongst the other surfaces, as Figure 6.4 and Figure 6.5 present.

Figure 6.4 shows a variation T_r of each surface over the ten-hour observing period. T_r of the ceiling surface swung significantly over the observation, since the maximum and minimum T_r are 31.40°C and 43.80°C at 8.00 am and 1.00 pm, respectively. Besides, Figure 6.5 confirms that the ceiling was the hottest and the most thermally variable amongst the other surfaces, with a ten-hour average T_r of 39.83°C and *std* of 2.95°C. Moreover, the average T_r of the southern wall, which is a partition separating an instructors' room and the meditation hall, was coolest wall surface, since its ten-hour average T_r was 35.65°C with the least variable *std* of 1.01°C. The eastern side of the hall, an external wall exposed to the outdoor environment, was the hottest wall, accounting for 36.76°C of the ten-hour average T_r, with *std* of 2.25°C.

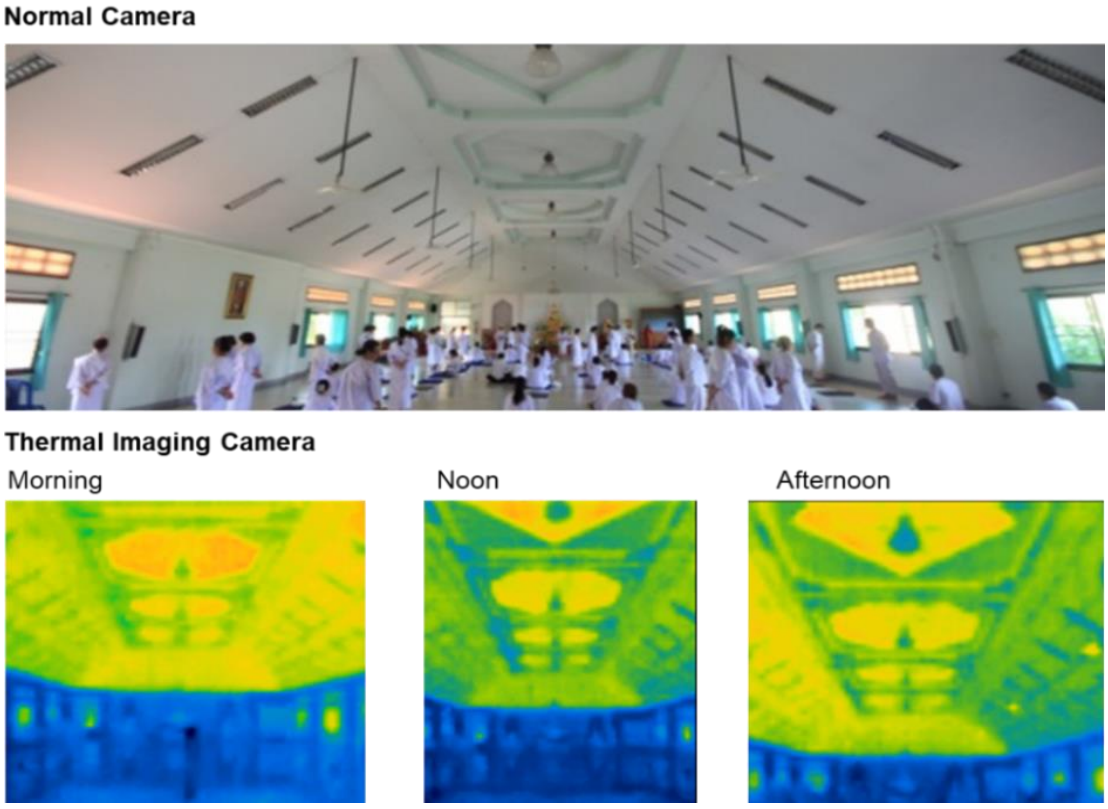


Figure 6.3: Comparison of normal photo of the hall (top) and thermal image in different periods (bottom)

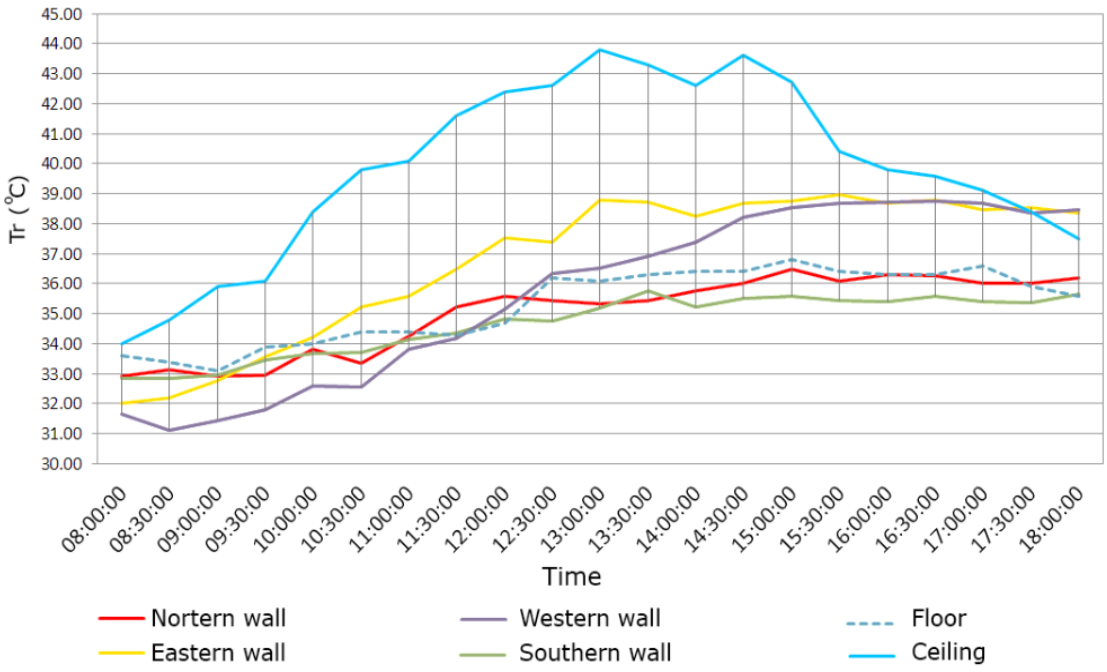


Figure 6.4: T_r of the VRW hall during the pilot study

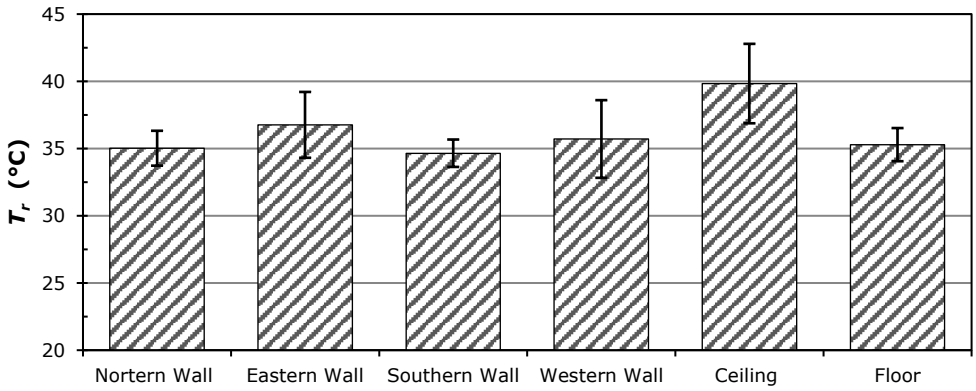


Figure 6.5: Ten-hour average T_r of the hall surfaces during the pilot study

The results revealed that indoor *v* measurement fluctuated over the observed period. Figure 6.6 presents that when the users occupied the hall, *v* was elevated due to the operation of electrical fans. Besides, each measurement presents a noticeable fluctuation of *v* over one-minute periods. The range of *v* over the observed time was 0.47 m/s, varying from 0.07 m/s to 0.54 m/s.

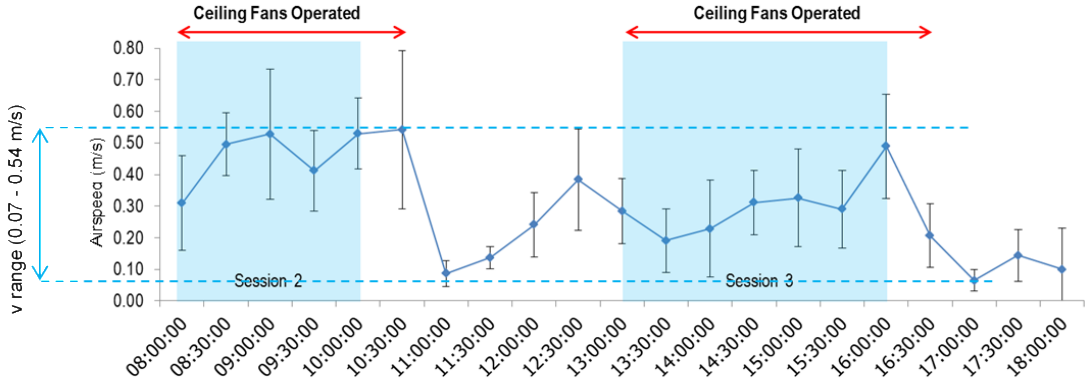


Figure 6.6: Average indoor v over the observed period

6.2.2 Subjects' thermal adaptation

6.2.2.1 *Environmental adaptation observation results*

It is widely accepted that human thermal comfort varies according to adaptive activities. Apart from the subjective thermal vote survey, this research also conducted a behavioural observation on the available environmental controls, namely fans, curtains, and windows. One video recorder was installed near the south wall of the hall to record the building users' behaviour and changes in the

physical environment over the observing period. The film of the observation was captured every 30 minutes, from 8.00 am to 6.00 pm, summarised in Figure 6.7.

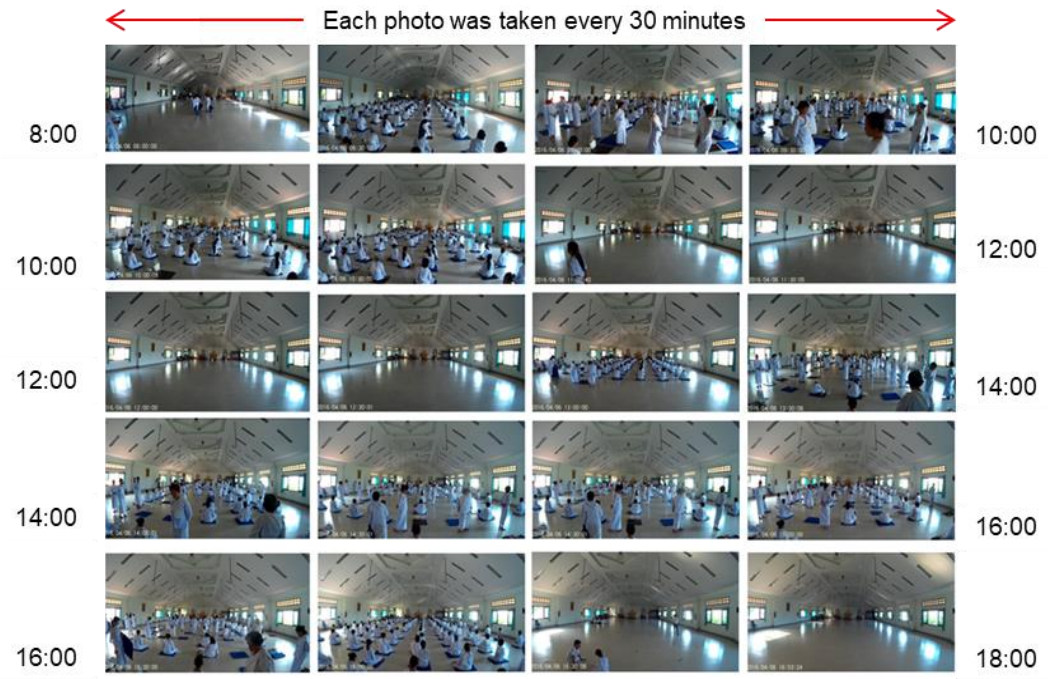


Figure 6.7: Summary of the screen captured photos of the video recorder

In terms of the observation of environmental adaptation, environmental controls (windows, ceiling-type fans, and curtains) (Figure 6.8) were observed and evaluated every 30 minutes, as summarised in Figure 6.9. It can be seen that the windows were left fully opened throughout the observation period, while the curtains seemed to function according to the different periods of the day. In the morning, the eastern curtains (EC-2 through to EC-6) were operated from 8.00 am to 11.00 am. After that, the majority of the curtains were closed from 11.30 am to 2.30 pm, except one western window (WC-1) that was left open due to inaccessibility caused by a furniture obstruction. The curtains were operated again after 2.30 pm until the end of the observation. It should be noticed that during summer, all the windows were left open to enhance natural ventilation in the hall. In contrast, the operation of the curtains varied according to the periods of the day for blocking direct solar radiation into the hall. Moreover, the results shows that the users seemed to consciously activate the fan system only when the hall was occupied for the training sessions, as Figure 6.9 presents.

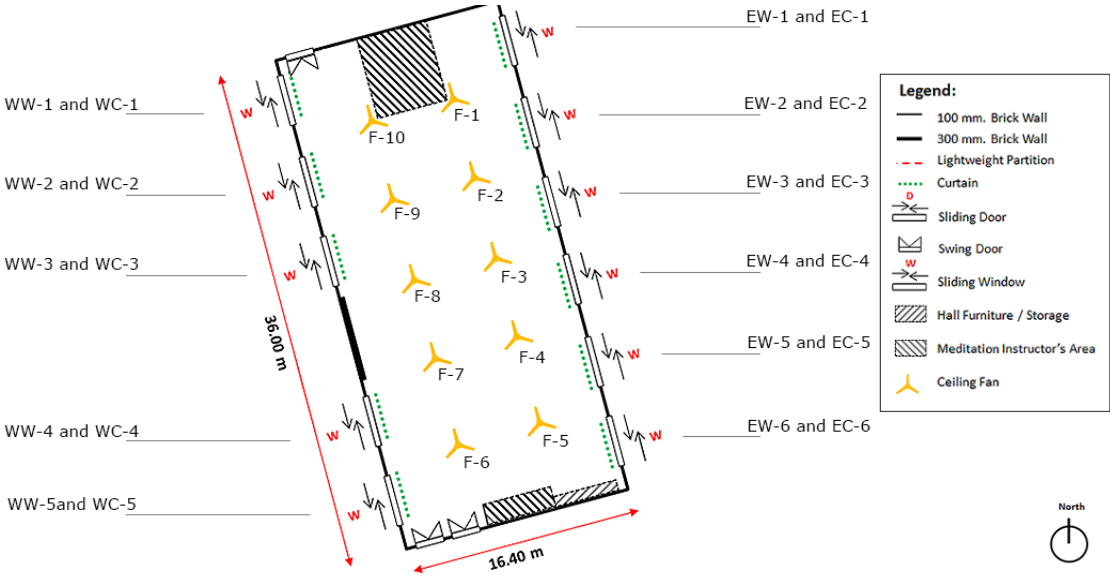


Figure 6.8:Key plan of the VRW hall with annotations of environmental controls

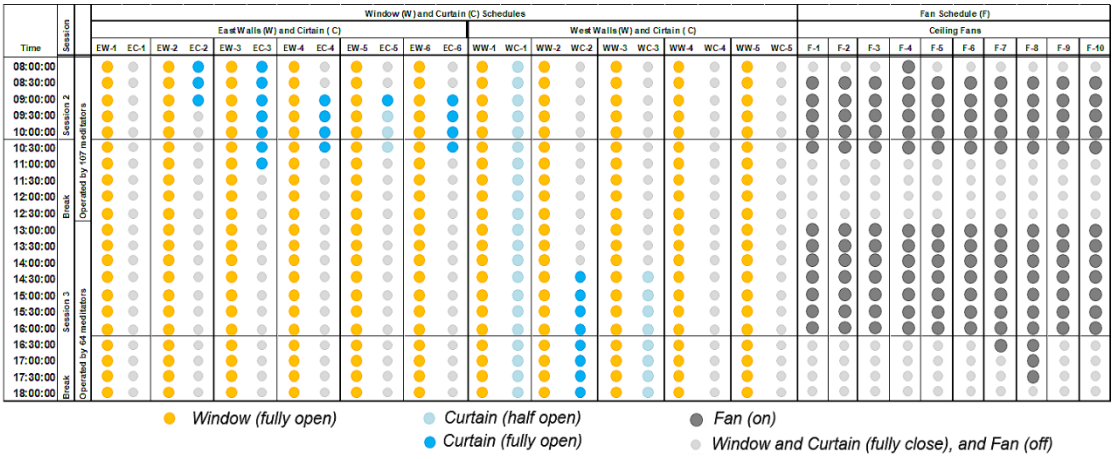


Figure 6.9: Summary of window, curtain and fan operations during the pilot study

6.2.2.2 *Questionnaire survey results on the subjects' adaptations*

The previous section described the observation results of the subjects' adaptive action in the hall. The results derived from the questions about environmental and personal adaptations are reported and discussed in this section. It should be noted that the total number of the subjects answering this set of questions differed due to their consent to answer. A total of 77 and 72 votes on environmental modifications during and after performing meditation were collected, respectively. The results reveal that 71 of 77 (92.2%) and 63 of 72 (87.5%) respondents mentioned that they did not modify the environmental

controls in the hall during and after practising (respectively), as Figure 6.10 presents.

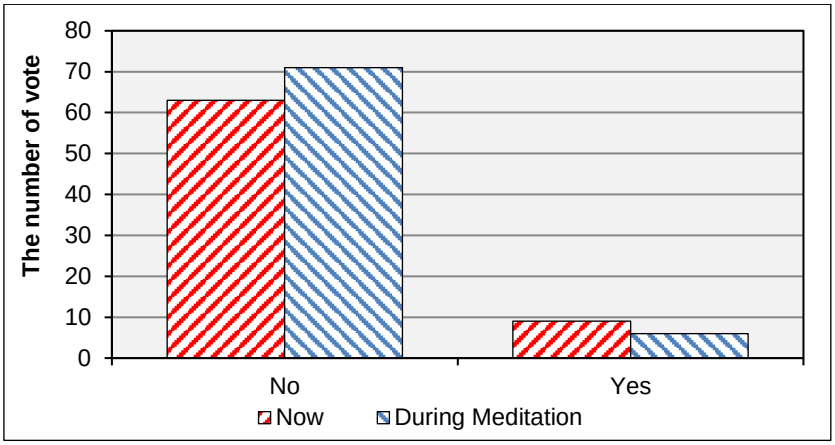


Figure 6.10: The number of the subjects performing environmental thermal adaptation

The results derived from the open-ended questions show that the volunteers performed personal adjustments, such as relocation to an airy area and taking a break to walk around the hall, rather than modifying the windows, fans, and curtains. The respondents who did not perform such environmental adaptation mentioned that the hall climate was acceptable, and the other reasons were reported and summarised below:

- **Nothing I can do:** The environments had been already modified, and it was beyond their ability to improve the current thermal environment of the hall.
- **Accepting it:** The subjects accepted whatever current thermal condition of the hall was. They realised that nothing in the hall was further modifiable. Thus, the solution which they preferred was to consider and accept the perceived thermal condition as it was. However, satisfying or dissatisfying thermal stimuli were, everything was *de facto* acceptable to them as they were not prepared to modify it. If the thermal environment was not satisfying, they perceived that there was nothing they could do and they tried to let it go.
- **Just ignoring it:** The meditators changed their attention to other aspects instead of the thermal dissatisfaction.

- **Thermal stimuli were not a problem**: The subjects reported that thermal dissatisfaction might not be a significant problem when their mind was not attached to it.
- **Being resistible:** The subjects mentioned that the hall thermal environment was not too extreme to be resistible.
- **Being self-disciplined:** They wanted to maintain discipline by remaining meditating and limit their movement until the practising session ended.
- **Attempting to acclimatize:** They tried to acclimatise to the hall thermal environment.
- **Do not want to distract the other meditators:** They mentioned that modifying the adjustable environments in the hall might have affected the other meditators who did not want the change.
- **Preferring personal to environmental modifications:** Rather than modifying the environmental factors, they preferred to perform personal adaptation, such as relocating to airy areas or taking a break by taking a walk.

The above paragraphs discussed the reasons not to modify the environmental factors of the hall. The subjects' *CLO* was investigated similarly. The results show that the majority of the subjects, specifically 65 out of 75 (88.7%) and 66 out of 75 (88%), they did not change or modify their *CLO* during and after finishing the meditation, respectively (Figure 6.11). For *CLO*-modifying actions, the other subjects reported adaptive techniques which affected their total *CLO* values, such as removing the shawl and moving clothes. In contrast, the volunteers reported *CLO* modifying techniques which may not affect the assembly of the personal insulation values, such as changing to a new extra layer of T-shirt, underpants, or shorts.

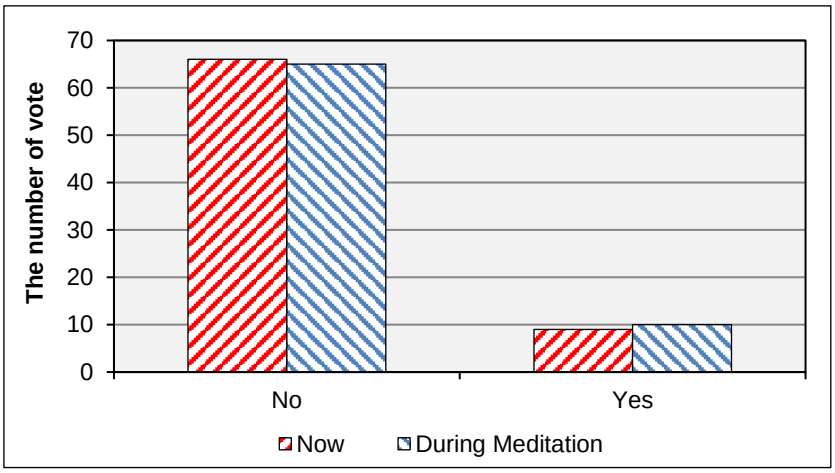


Figure 6.11: The number of the subjects performing personal thermal adaptation

According to the data, the majority of the respondents reported no *CLO* modification, since the climate was acceptable. Additional reasons cited for not modifying the *CLO* are noted below:

- **Accepting it and being self-disciplined:** These two factors were previously reported with regard to environmental adaptation investigation.
- **Preferring to perceive the thermal condition**: In this case, the subjects mentioned that they would like to perceive the current thermal environment as it was (as part of the mindfulness component intrinsic to the meditation rites).
- **Maintaining concentration**: They preferred to maintain their concentration on observing objects such as body and mind, rather than responding to thermal stimuli by modifying the personal factors.
- **The uniform of the centre:** The subjects mentioned that every meditator must wear the meditation uniform in this place as a rule of the centre.
- **Appropriateness:** It is reported that they would like to show respect for the Buddhist holy area by dressing appropriately and modestly, in which the modification of *CLO* might not be appropriate due to cultural etiquette.

- ***CLO* modification is limited by group psychology:** Some subjects mentioned that while staying in the hall they saw other meditators having an intense focus on the practice. Such group activity was reported as a driving force to motivate the subjects to remain unmoved and not to respond to the thermal stimuli by adjusting *CLO*.

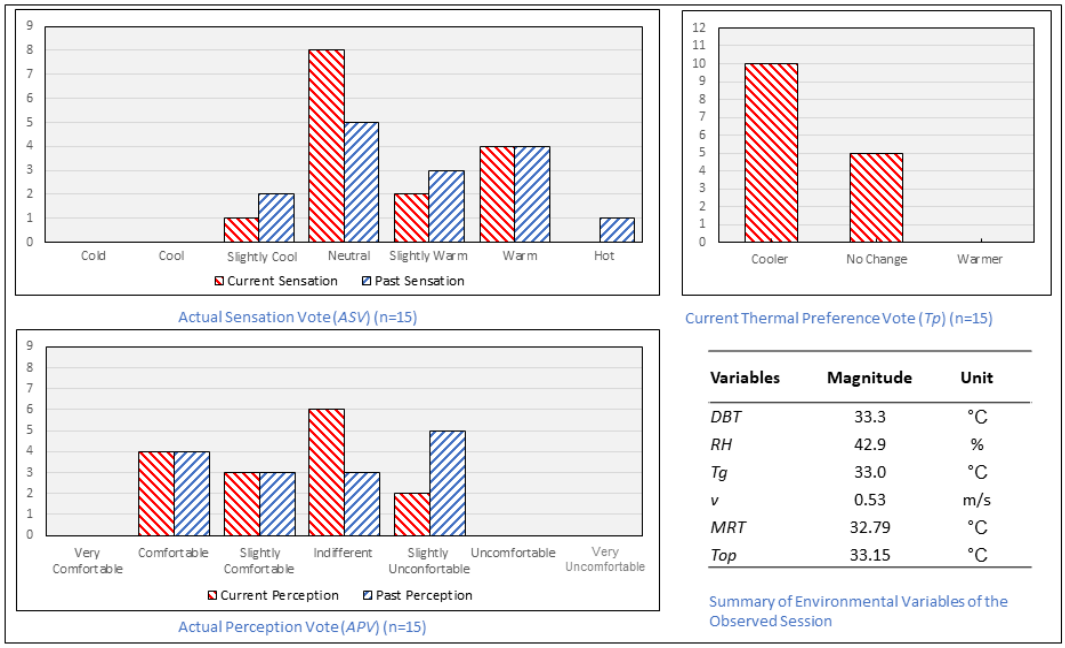
According to the results obtained from the pilot survey, it can be noticed that apart from the environmental and personal adaptations, the results reveal the respondents' psychological thermal adaptation, which is further investigated in the main survey.

6.2.3 Subjective thermal votes

This section discusses the survey results of participants' subjective thermal votes under the observed thermal environments of the hall. The morning questionnaire session was under the following thermal conditions:

- $DBT_{av\text{-}in}$: 33.3°C
- $T_{g\text{-}av\text{-}in}$: 33.0°C
- $RH_{av\text{-}in}$: 42.9%
- v: 0.53 m/s

Thus, *MRT* and T_{op} can be calculated as 32.79°C and 33.15°C, respectively. The results of the morning survey based upon the completed 15 questionnaires are presented in Figure 6.12. Over half of the votes, with 8 out of 15 votes (53.33%) selected '*Neutral*' (*ASV* = 0), and two (13.33%) and four (26.66%) subjects reported that they sensed '*Slightly warm*' and '*Warm*' (respectively) when answering the questionnaire. Ten respondents (66.66%) preferred a '*Cooler*' thermal environment, while the other five volunteers (33.33%) mentioned '*No change*'. Besides, the number of participants who mentioned thermal neutrality during meditation (ASV_{past} = 0) was slightly lower, by three votes compared to that of the current *ASV*.



Variables	Magnitude	Unit
DBT	33.3	°C
RH	42.9	%
Tg	33.0	°C
v	0.53	m/s
MRT	32.79	°C
Top	33.15	°C

Figure 6.12: Results of the participants' subjective thermal votes of the morning session

For current the *APV* results, the figure presents that the majority of the votes (13 out of 15 votes or 86.66%) was on '*Comfortable*' to '*Indifferent*' side of the *APV* scale where four, three and six subjects expressed '*Comfortable*', '*Slightly comfortable*' and '*Indifferent*', respectively. Besides, there are only two votes on '*Slightly uncomfortable*', but no extreme perception votes such as '*Very uncomfortable*' and '*Very comfortable*' were reported. Moreover, four and five subjects (26.66% and 33.33%) voted their APV_{past} on *'Indifferent'* and *'Slightly uncomfortable',* respectively. The afternoon questionnaire session was under the following thermal conditions:

- $DBT_{in\text{-}av}$: 36.9°C
- $T_{g\text{-}av}$: 37.3°C
- $RH_{av\text{-}in}$: 27.9%
- *v*: 0.57 m/s

Based on the calculating results, *MRT* and T_{op} were 37.58°C and 37.10°C, respectively. According to the survey, 14 useable questionnaires were collected, of which five subjects (35.71%) voted for the current *ASV* as both '*Neutral*' and '*Warm*' as Figure 6.13 presents. One and three respondents (7.14% and 21.43%) mentioned '*Slightly cool*' and '*Slightly warm*', respectively.

It can be seen that 13 of the 14 subjects (92.86%) voted between the '*Neutral*' to '*Warm'* of the *ASV* scale. Besides, the thermal preference study shows that the majority of them (11 of 14 subjects, 78.57%) preferred a '*Cooler*' environment. In contrast, only three subjects (21.43%) mentioned '*No change*' without a report of the '*Warmer*' preference. For the ASV_{past} investigation, the figure shows that 12 subjects voted on the '*Neutral*' to '*Warm*' of the scale while meditating. The majority (8 of the 14 subjects) voted '*Neutral'*, and two, one and three respondents reported '*Cool'*, '*Slightly warm'* and *'Warrm'*, respectively.

Furthermore, the results of the *APV* in the afternoon reveals that the subjects' current *APV* were dominated by '*Comfortable*' to '*Indifferent'* perceptions, and three (2.14%), four (2.86%) and four (2.86%) subjects voted on '*Comfortable*', '*Slightly comfortable*' and *'Indifferent'*, respectively. Only one vote for each category of '*Very Comfortable*', '*Slightly uncomfortable*', and '*Uncomfortable*' was reported. It should be noted that during meditating, all but one of the subjects (13 of 14 volunteers, 92.86%) voted between '*Comfortable*' to '*Indifferent*' on the APV_{past} scale, while the remaining participant voted '*Uncomfortable*'.

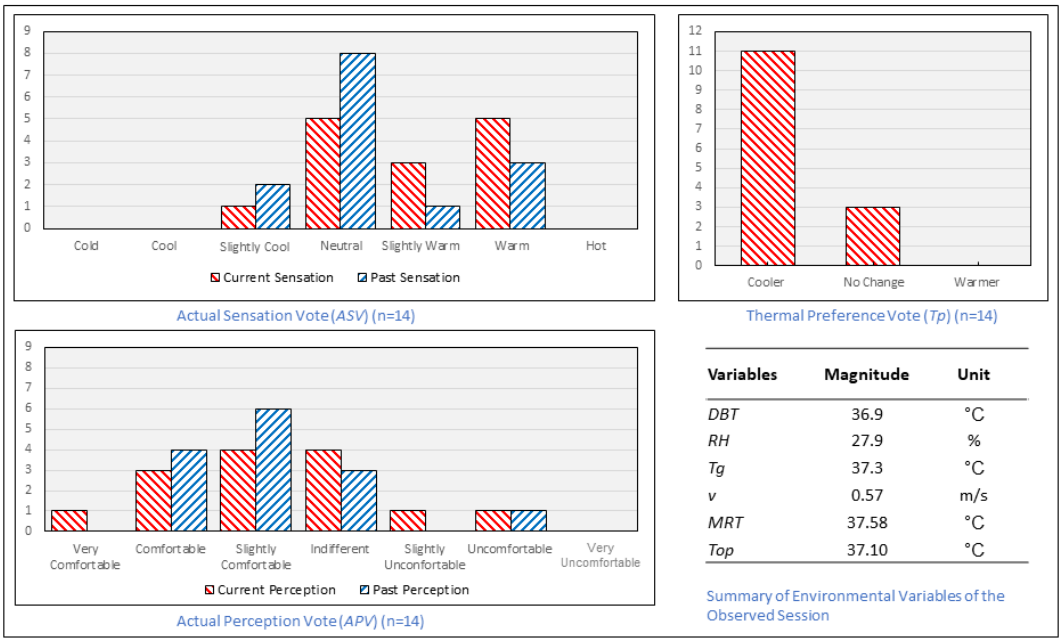


Figure 6.13: Results of the participants' subjective thermal votes of the afternoon session

The subjects' *ASV* results and the versions and usability of the forms, as presented in the previous paragraphs, were integrated with the observed data of the subjects' sitting location and presented in Figure 6.14. The circles representing locations of the forms are highlighted by a solid colour representing different subjects' *ASV* ranging from red (+3 *ASV*) to dark blue (-3 *ASV*), while the solid black circles represent the *Unusable Forms*. The *Usable Forms* (from the morning version of the filled-out questionnaire) were outlined by a solid red circle.

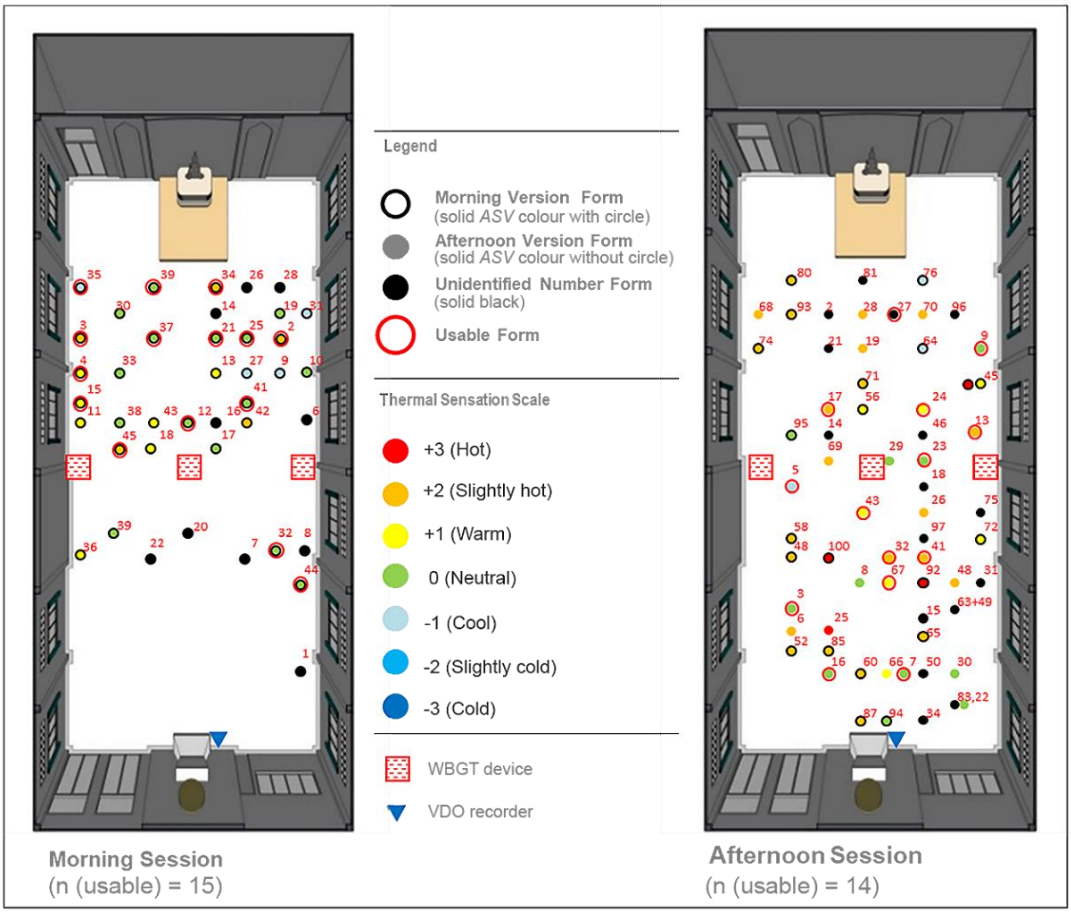


Figure 6.14: Locations of the questionnaires and the subjects' sensation votes in both sessions

6.3 Chapter conclusion

This chapter discussed the pilot study took place on the 5th of April 2015, in which 29 usable data sets were collected. The database comprises 15 morning and 14 afternoon data samples including subjective thermal votes, meditation

qualities, and personal information, paired with associated environmental data. The analytical results show that the majority of the subjects' *ASV*, *APV*, ASV_{past}, and APV_{past} were between '*Neutral*' to '*Warm*' sensations, and '*Indifferent*' to '*Comfortable*' perceptions in the morning and afternoon sessions, respectively. The T_p votes reveal that the largest group of the subjects preferred a '*Cooler*' environment without a vote of '*Warmer*' preference.

The thermally adaptive investigation of the subjects reveals that environmental controls (widows, electrical fans, and curtains) were used to improve the thermal condition in the hall. The windows were always left open throughout the observed period, while the fans were carefully operated only when the hall was occupied for the practising sessions. The operation of the curtains related to certain periods of the day.

Furthermore, the majority of the subjects might not perform environmentally and personally adaptations when meditating and staying in the hall, since they reported that the hall thermal environments were acceptable. On the other hand, some of them justified not modifying those factors from a psychological point of view for the following reasons:

- They accepted whatever thermal stimuli were, and did not consider modification of environmental factors possible.
- They preferred to resist the perceived thermal stimuli and tried to acclimatise to the current thermal environment.
- They deviated their focus from the dissatisfying thermal of the hall to other more preferred aspects.
- They mentioned that the centre rule, to which meditators are committed is making the most significant contribution to the practice. In this case, they preferred not to interrupt the practice by moving or modifying the environmental and personal factors.

These similar (overlapping) justifications were cited as reasons for not modifying personal and environmental factors. However, a more specific reason was mentioned, which was that environmental adjustments might affect the

other practitioners who might not require such change; thus, the building users preferred adjusting personal factors rather than the environmental controls.

Furthermore, the subjects mentioned two specific reasons not to modify their clothing to improve thermal comfort. First, when the subjects were in the meditation hall, they saw the other meditators having an intense focus on their practice. This situation motivated them not to end or interrupt the practice by moving or adjusting factors.

Second, regarding the cultural and organisational constraints existing in the context, the volunteers mentioned that the meditation uniform should not be modified, since it represents the unity of the group. Besides, the degree of *CLO*-modifying capability seems to be limited within a short range due to appropriateness and acceptability, which were influenced by cultural and organisational etiquette and mores.

Chapter 7

Environmental, Personal, and Subjective Vote Data

Chapter 7: Environmental, Personal, and Subjective Vote Data

This chapter discusses the results of data collection concerning the environmental measurements, observation, and questionnaire survey. Average indoor and outdoor *DBT*, *RH*, and T_g of Khon Kaen during the questionnaire-filling-out sessions are presented to demonstrate the thermal conditions of the halls over the meditation session periods. Besides, participants' demographic data and personal meditation background are exhibited followed by discussing two sets of environmental factors applied in the analyses of subjective votes and environmental control operations. Furthermore, a summary of the database of subjective thermal votes such as *ASV*, *APV*, T_p, and v_p, and meditation qualities such as *IFA* and *DR* is presented. Before concluding the chapter, subjects' sitting locations coloured according to the *ASV* votes are illustrated and discussed, and observation results of the environmental control operations are summarised.

7.1 Environmental data over the first to the second observed meditation sessions

As mentioned in Chapter 5 about the research method of the main survey, the automatic measuring instruments were installed in the halls and started measurements at least 6 hours before conducting the surveys, while the manually operated devices started measurements when the first observed meditation sessions began and finished at the end of the second observed sessions. This section presents and discusses the measuring results of all the instruments over the measuring periods of the manually operated devices (Table 7.1). According to the training schedule, the *VRW* centre organised four meditation sessions a day, while the first observed activity began at 8.00 am (second meditation session) and finished at 4.00 pm (third session). Similarly, the four sessions were organized by *PT* centre, but the first observed session

began at 1.00 pm (third meditation session) and finished at the end of the fourth session at 9.00 pm. The *KJS* centre organised only two sessions a day, which consequently comprised the entire period of study, in which the first session started at 10.00 am and ended at 3.00 pm.

Table 7.1: Summary of periods of the observed meditation sessions

Site	Date of the study	No. of session organized	Period of the observed meditation sessions	
			Start	Finish
VRW	26 November 2016 15 July 2017	4	8.00 (2nd Session)	16.00 (3rd Session)
PT	3 of December 2016 17 December 2016 8 June 2017 12 August 2017	4	13.00 (3rd Session)	21.00 (4th Session)
KJS	10 December 2016 14 January 2017 19 August 2017	2	10.00 (1st Session)	15.00 (2nd Session)

It should be noted here that the results of indoor *DBT*, *RH* and T_g shown in this section were averaged data derived from WBGTs A, B, and C. Such averages aim to present the overall picture of the environmental factors of the halls over the observed periods, but they are not applied in the further subjective vote analyses such as T_n, T_p, and T_c. In this case, the averages of indoor environmental variables are called Indoor Average Dry Bulb Temperature ($DBT_{av\text{-}in}$), Indoor Average Relative Humidity ($RH_{av\text{-}in}$), and Indoor Average Globe Temperature ($T_{g\text{-}av\text{-}in}$). In contrast, the outdoor environmental factors recorded by WBGT D are named Outdoor Dry Bulb Temperature (DBT_{out}), Outdoor Relative Humidity (RH_{out}), and Outdoor Globe Temperature ($T_{g\text{-}out}$).

Regarding $DBT_{av\text{-}in}$, the hottest (31.63°C) and coldest (24.67°C) indoor spaces were found in *PT* on the 12th of August 2018 and 17th of December 2017, respectively. The largest $DBT_{av\text{-}in}$ range (3.42°C) varies from 25.33°C to 28.75°C in *VRW* on the 26th of November 2016, while the narrowest $DBT_{av\text{-}in}$ range is 0.57°C from 30.00°C to 30.57°C in *PT* on the 8th of July 2017. Besides, the minimum and maximum DBT_{out} are in *PT*. The lower limit of the factor was

23.20°C found during 3.30 pm and 4.00 pm on the 17th of December 2016, while the upper limit was 32.00°C at 9.00 pm on the 12th of August 2017. *VRW* presented the largest variation of DBT_{out} varying from 24.10°C to 28.50°C over 8.00 am to 3.00 pm on the 26th of November 2016. In contrast, the minimum DBT_{out} of 1.2°C, varying between 30.50°C (at 9.00 pm) and 31.70°C (at 4.00 pm), was found in *PT* on the 8th of July 2017 (Figure 7.1).

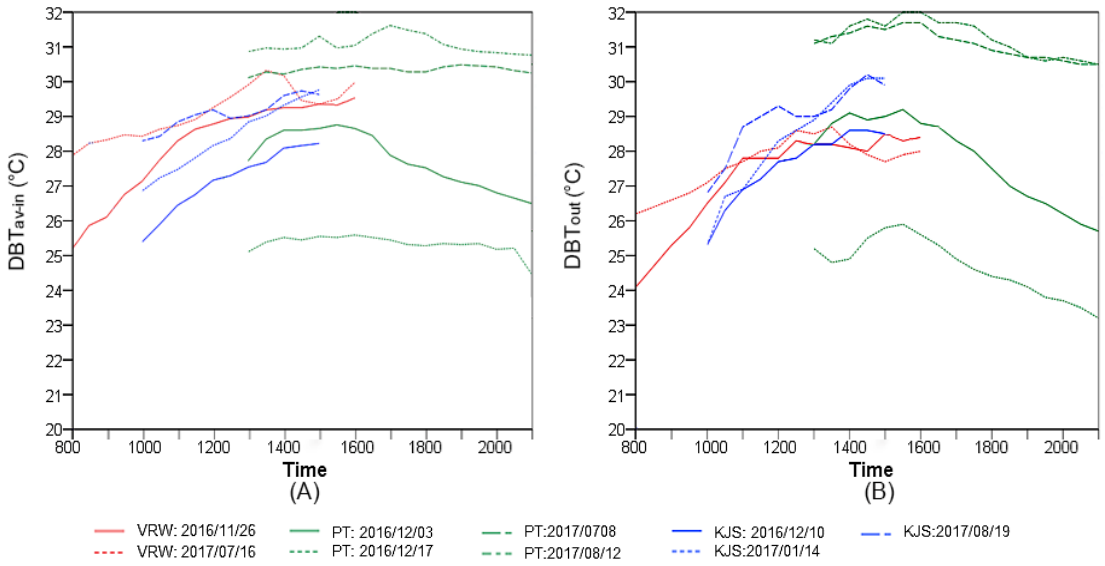


Figure 7.1: Line graphs of $DBT_{av\text{-}in}$ (A) and DBT_{out} (B) over the observed sessions

The lowest and highest indoor $T_{g\text{-}av\text{-}in}$ were 24.53°C and 31.20°C, found in *PT* at 9.00 pm on the 17th of December 2017 and 5.00 pm on the 12th of August 2017, respectively. The *VRW* hall presented the greatest variation of $T_{g\text{-}av\text{-}in}$ (4.37°C), varying from 29.40°C to 25.03°C on the 26th of November 2016, while the narrowest $T_{g\text{-}av\text{-}in}$ range found in *PT* on the 8th of July 2018 was 0.40°C, with minimum and maximum values of 29.87°C and 30.27°C, respectively, as shown in Figure 7.2 (A). The *PT* hall also accounted for the lowest and highest $T_{g\text{-}av\text{-}in}$ of 23.50°C and 32.50°C at 9.00 pm on the 17th of December 2016, and at 3.30 pm on the 12th of August 2017, respectively. Besides, Figure 7.2 (B) presents the maximum range of $T_{g\text{-}out}$ which was 4.40°C varying from 24.50°C to 28.90°C in *VRW* on the 26th of November 2016. Furthermore, the minimum $T_{g\text{-}out}$ was 1.2°C, varying from 30.50°C to 31.70°C in *PT* on the 8th of July 2017.

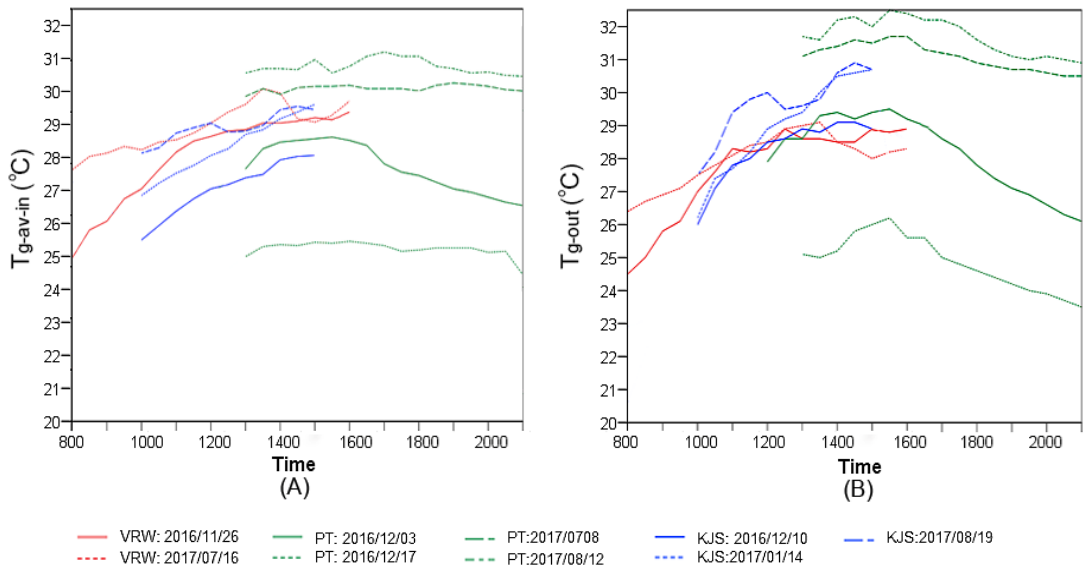


Figure 7.2: Line graphs of $T_{g\text{-}av\text{-}in}$ (A) and $T_{g\text{-}out}$ (B) variations over the observed sessions

Indoor and outdoor values of *RH* shift inversely to those of *DBT* values. According to Figure 7.3 (A) and (B), the minimum and maximum $RH_{av\text{-}in}$ values are 40.70% and 86.13%, found in *KJS* at 3.00 pm on the 10th of December 2016, and *VRW* at 8.00 am on the 16th of July 2017. The narrowest and broadest ranges of $RH_{av\text{-}in}$, 1.43% (54.17% to 55.60%) and 21.07% (57.03% to 78.10%), were found in *KJS* on the 10th of December 2016 and *VRW* on the 26th of November 2016. Moreover, the upper and lower limits of RH_{out} were found in the same places, dates, and times. The *VRW* shows the highest RH_{out} of 93.20% at 8.00 am on the 26th of November 2016, while *KJS* presents the lowest RH_{out} of 40.80% at 2.00 pm on the 10th of December 2016. The largest variation of RH_{out} was 23.00% (59.90% to 82.90%) in *VRW* on the 26th of November 2016, while the narrowest band of the factor was 7.00% (63.00% to 70.00%) in *PT* on the 8th of July 2017.

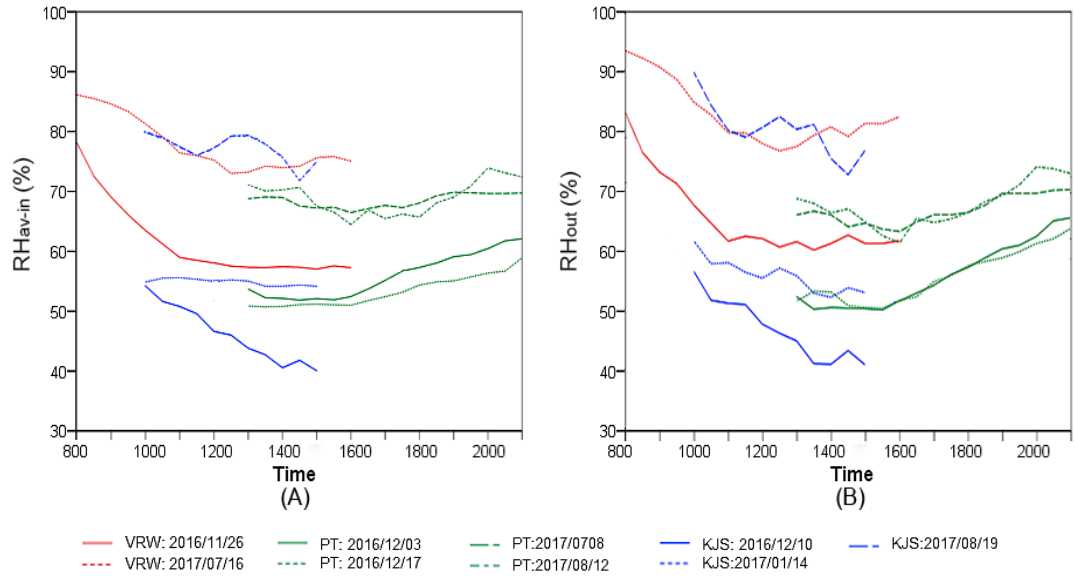


Figure 7.3: Line graphs of $RH_{av\text{-}in}$ (A) and RH_{out} (B) variations over the observed sessions

Figure 7.4 demonstrates indoor *v* fluctuations of the case studies over the monitored periods. The upper limit of *v* was 0.89 m/s in *PT* at 8.00 pm on the 8th of July 2017, while its lower limit was 0.03 m/s in *KJS* at 12.30 am on the 14th of January 2017. The broadest range of *v* was 0.78 m/s, varying from 0.03 m/s to 0.81 m/s, in *KJS* on the 14th of January 2017. On the other hand, the narrowest band was 0.30 m/s in *PT* on the 3rd of December 2016, where the maximum and minimum magnitudes were 0.06 m/s and 0.36 m/s, respectively.

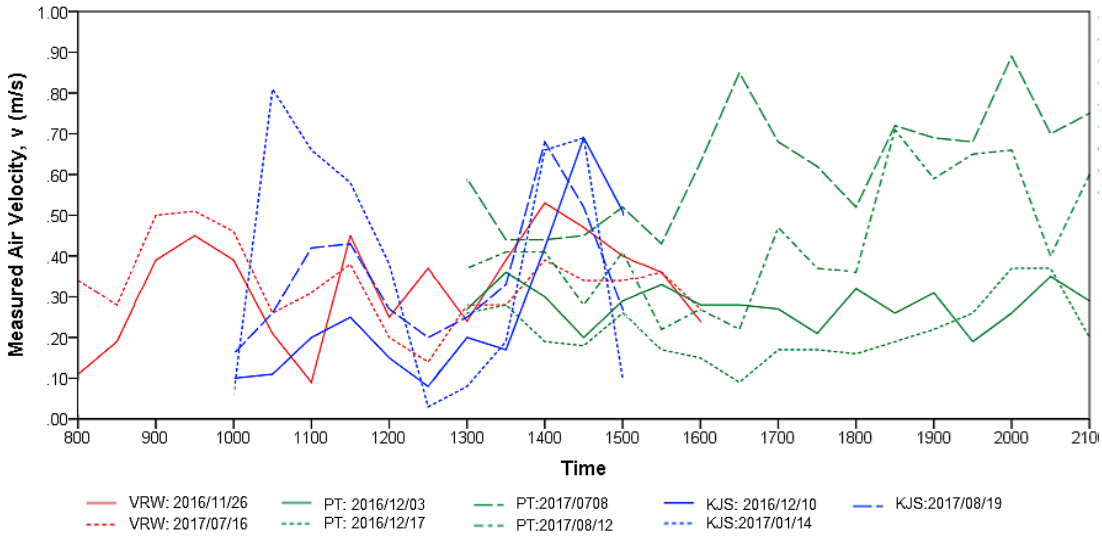


Figure 7.4: Line chart of indoor v over the observed sessions

For the sky condition, the observation of the sky openness started when beginning the first meditation session started and ended when finishing the second observing session for *VRW* and *KJS*, or until 6.00 pm, the local sunset time for *PT* during the fieldwork period. The observation results show that the largest range (7) of cloud cover was found at *PT* on the 8th of July 2017, where the maximum and minimum OKTA score were 8 and 1. On the other hand, the sky was completely clear (0) throughout the observed period of *PT* on 12th August 2017 and *KJS* on the 10th of December 2016, while the sky maintained a condition that was completely cloudy (8) during the observation at *VRW* on the 16th of July 2017.

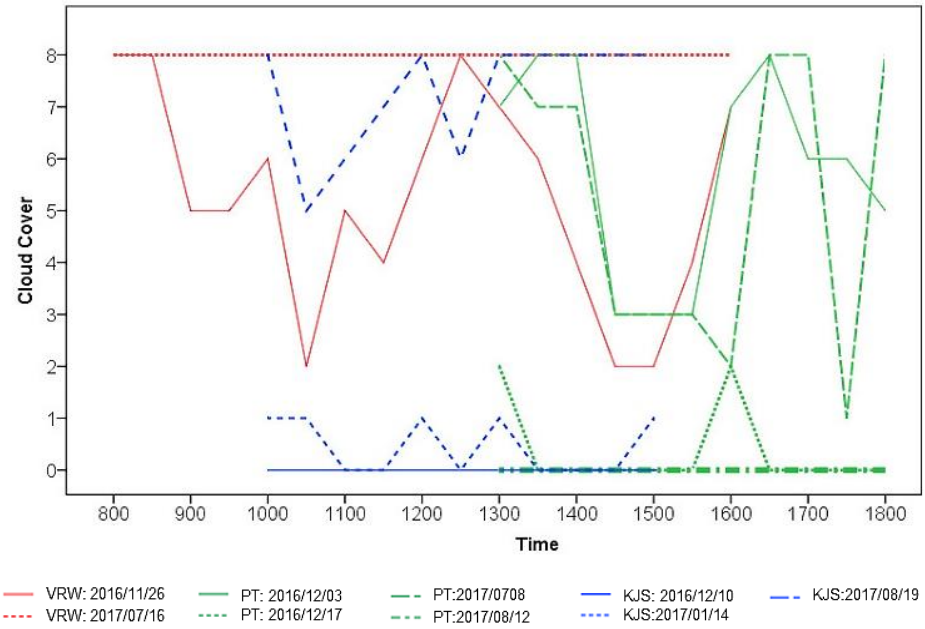


Figure 7.5: Line chart of cloud cover evaluation over the observed periods

7.2 Comparison of indoor and outdoor environmental factors

This section discusses the relationships between $DBT_{av\text{-}in}$ and DBT_{out}, $T_{g\text{-}av\text{-}in}$ and $T_{g\text{-}out}$, and $RH_{av\text{-}in}$ and RH_{out} when the halls were occupied for meditation sessions by a linear regression model. The data presented in this section is later utilised in the analysis of thermally behavioural adaptions in Chapter 10. The analytical results are presented as scatter plots, as shown in Figure 7.6 (A), (B), and (C).

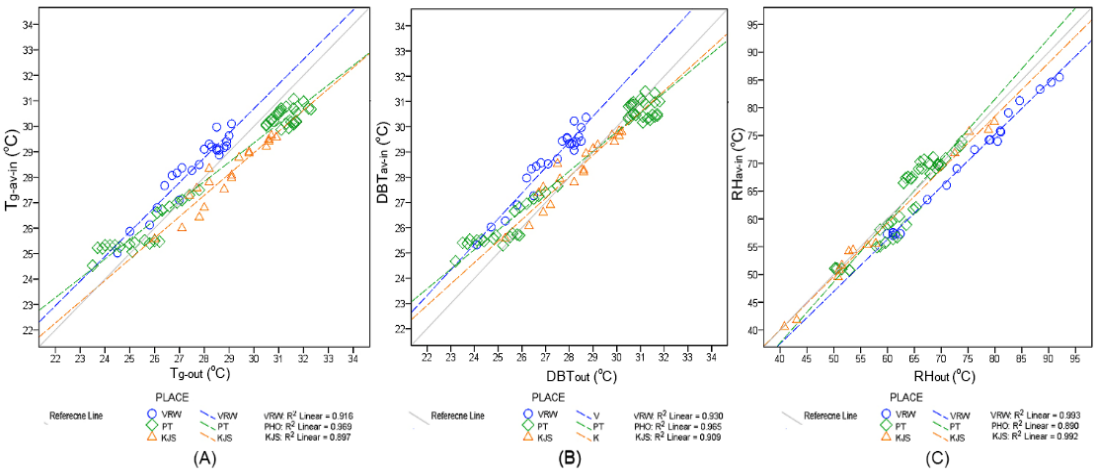


Figure 7.6: Linear regression of indoor and outdoor T_g (A), DBT (B) and RH (C)

Table 7.2 presents the results of nine correlation analyses with strong relationships between indoor and outdoor factors in all cases, since the *R*-values of all the models are over 0.900. According to the table, significant levels of the independent factors of the independent variables of the linear functions show that each indoor factor does not vary accidentally, but is related to its counterpart outdoor factor, since all *p*-values are lower than 0.001 ($p<0.001$).

According to Table 7.2, the models reveal that the *VRW* hall is the most sensitive to DBT_{out} shift, as the gradient factor of the independent variable is 1.014, which is higher than that of the *PT* (0.777) and *KJS* (0.850). Moreover, relations of $T_{g\text{-}av\text{-}in}$ present similar results, since a gradient factor of $T_{g\text{-}out}$ is 0.968, which is greater than that of *PT* (0.760) and *KJS* (0.863). According to the results, the *PT* hall is the least sensitive to the outdoor environment amongst the other halls due to wall thickness, the surroundings (i.e. shading of the hall by human-made and natural environments), the number of building storeys, and window materials. Concerning the indoor and outdoor *RH* relations, the coefficient of the independent variables *VRW*, *PT*, and *KJS* are 0.941, 1.086, and 0.961, respectively, which presents a small difference amongst the places. For all meditation halls, the gradient factor values of DBT_{out}, $T_{g\text{-}out}$, and RH_{out} are 0.760, 0.740, and 0.906 respectively, with significance levels lower than 0.001 ($p<0.001$).

Table 7.2: Summary of relations between Indoor and outdoor DBT, T_g, and RH of the meditation halls

Variable	Case Study	Function	*R*	R^2	*T*-value	*p*-value
DBT	All Cases	$DBT_{av\text{-}in} = 0.760\ DBT_{out} + 7.177$	0.945	0.893	9.060	<0.001
	VRW	$DBT_{av\text{-}in} = 1.014\ DBT_{out} + 1.010$	0.964	0.930	17.099	<0.001
	PT	$DBT_{av\text{-}in} = 0.777\ DBT_{out} + 6.486$	0.982	0.965	34.970	<0.001
	KJS	$DBT_{av\text{-}in} = 0.850\ DBT_{out} + 4.216$	0.953	0.909	13.030	<0.001
T_g	All Cases	$T_{g\text{-}av\text{-}in} = 0.740\ T_{g\text{-}out} + 7.250$	0.943	0.889	26.610	<0.001
	VRW	$T_{g\text{-}av\text{-}in} = 0.968\ T_{g\text{-}out} + 1.662$	0.957	0.916	15.489	<0.001
	PT	$T_{g\text{-}av\text{-}in} = 0.760\ T_{g\text{-}out} + 6.560$	0.984	0.969	37.464	<0.001
	KJS	$T_{g\text{-}av\text{-}in} = 0.863\ T_{g\text{-}out} + 3.880$	0.947	0.897	12.153	<0.001
RH	All Cases	$RH_{av\text{-}in} = 0.906\ RH_{out} + 4.769$	0.966	0.932	31.243	<0.001
	VRW	$RH_{av\text{-}in} = 0.941\ RH_{out} - 0.124$	0.996	0.993	49.240	<0.001
	PT	$RH_{av\text{-}in} = 1.096\ RH_{out} - 6.149$	0.943	0.890	17.520	<0.001
	KJS	$RH_{av\text{-}in} = 0.961\ RH_{out} + 1.557$	0.996	0.992	36.470	<0.001

7.3 Results of demographic survey

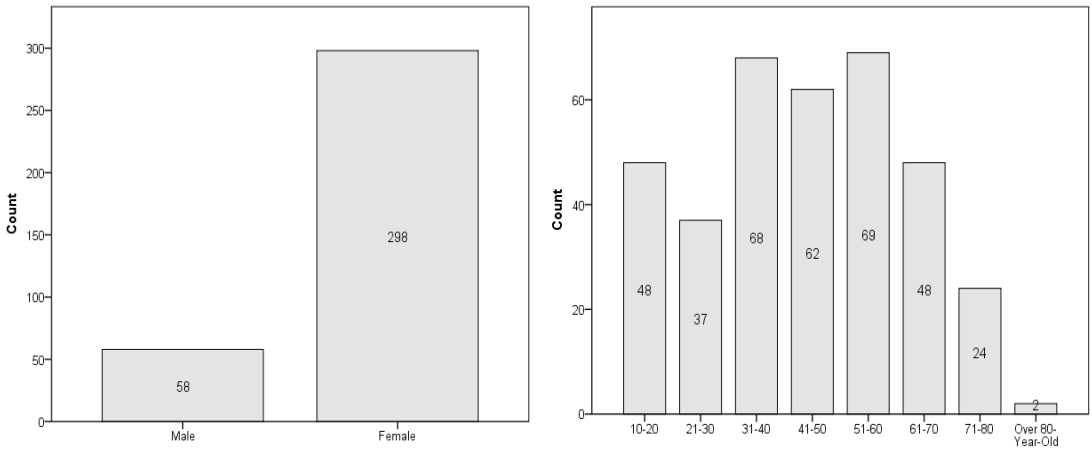
Concerning demographic data, the basic information of the participants is discussed to allow readers to understand the personal information of the building users of this building type. The survey took place from November 2016 to August 2017 over nine days, eight of which were on weekends. The consenting participants participated in the surveying sessions once or twice a day, depending on their consent. They were eligible to skip the questions which they do not prefer to answer.

Consequently, the number of respondents to each question and the total number of subjects was unequal. According to the survey, a total of 517 forms were contributed by 375 healthy volunteers over the fieldwork period. Figure 7.7 (A) presents that 356 users, comprising 58 (16.3%) males and 298 (83.7%) females, responded to the gender question.

According to the database, it can be seen that the results derived from this study are dominated by female subjects. The imbalance of the data distribution clustered by gender may not result from the unequal distribution of the population in Thailand. Official Statistics Registration Systems (2018) reports that a ratio of Thai male to female population is 0.96, representing a small difference between genders. Based on personal discussions with the local people, there are many reasons to explain this phenomenon, such as the influence of man-dominated culture in Thailand and different female traits, with expectations that women are more emotionally subtle and sophisticated.

However, a convincing justification for the greater number of women is the decline in the ordination of woman as nuns (*bhikkhuni*) in Theravada Buddhism from the tenth century CE onwards (Cook, 2010). While men can receive full ordination by a quorum of monks (*bhikkhu)*, successful ordination for a woman requires a quorum of male and female monks holding 227 and 311 precepts (respectively) to perform a formal ceremony. Additionally, it is traditionally expected that Thai men will enter a monastery for a certain period (typically for a few weeks or months) prior to getting married, while this is not expected for women, thus institutions have developed to facilitate male monks (e.g. in terms of dormitories etc.), while female nuns generally enter nunneries for life. Conversely, women are much more engaged in conventional, regular worship such as visiting temples and meditating in monasteries, taking eight precepts to follow the path of the Buddha.

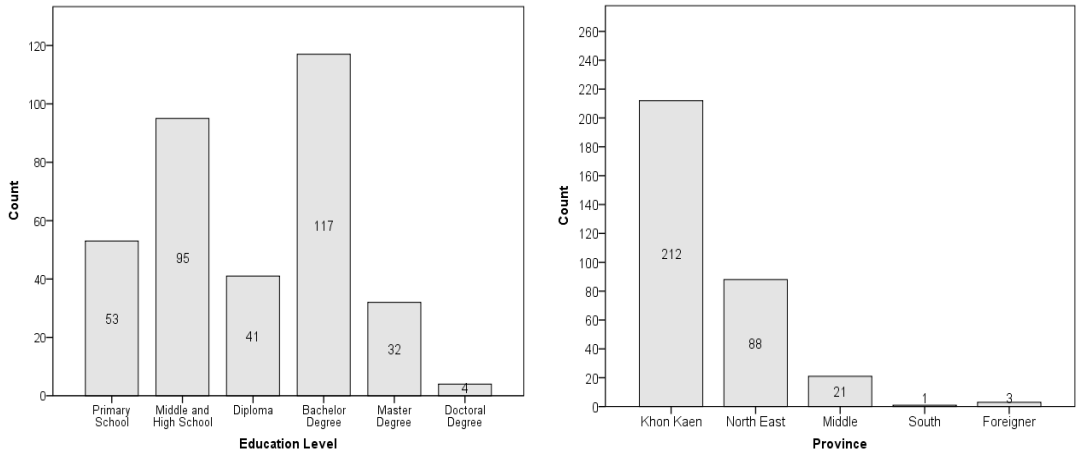
Furthermore, a total of 358 subjects noted their age range as presented in Figure 7.7 (B). More than half of the data (55.6%) was contributed by the building users aged between 31 to 60 years, while only two of the total subjects were aged over 80.



(A) Participants' gender (B) Participants' age range

Figure 7.7: Bar charts of the number of volunteers by gender and age range

For the subjects' educational level, Figure 7.8 (A) shows that 342 participants responded to this question, of whom 117 (34.21%), 32 (9.36%), and 4 (1.17%) had achieved bachelor's, master's, and doctoral degrees, respectively. Besides, the majority (*n* = 212, 65.23%) of 325 users were locals of Khon Kaen province, as Figure 7.8 (B) illustrates, while 88 participants (27.08%) were from the provinces in the north-eastern region of the country, and 22 subjects (6.77%) travelled from the other part of the country to participate in the activities. Only three participants (0.92%) were foreigners from the Laos People's Democratic Republic (Figure 7.8 (B)).



(A) Participants' educational level (B) Participants' province of residence

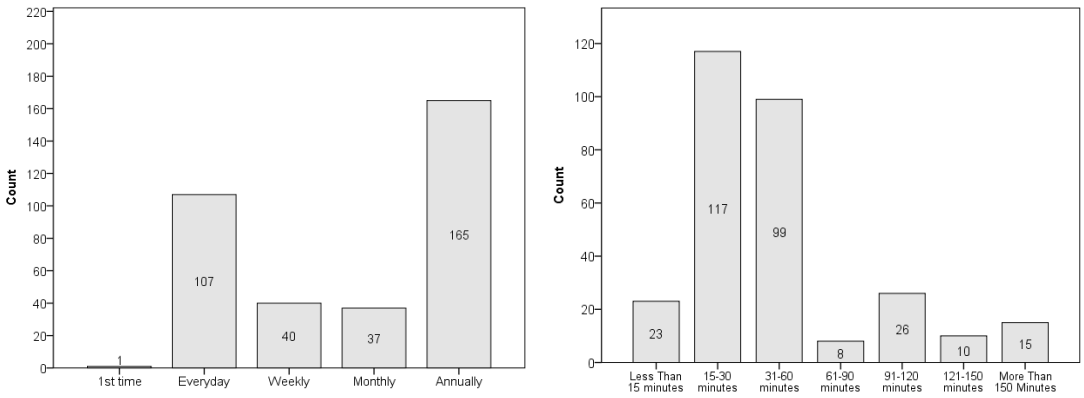
Figure 7.8: Bar charts of subjects' education level and province of residence

7.4 Subjects' meditation background

This research was conducted in meditation centres where meditation sessions are open to the public, thus it was expected that there might have been a mixture of inexperienced and experienced meditators to participate in the practising sessions. This section describes subjects' meditation backgrounds in terms of frequency of practice (*n* = 350), length of practice (*n* = 298), years of practice (*n* = 253) and achievement of today's training aims (*n* = 347).

Data regarding frequency of practice was contributed by 350 meditators, Figure 7.9 (A) presents that 165 subjects (47.15%) reported that they practised meditation every year, while only one (>1%) was new to these activities. Furthermore, 107 (30.57%), 40 (11.43%), and 37 (10.57%) participants claimed that they meditated daily, weekly, and monthly, respectively.

For practising length, a total of 298 participants responded to this question, of whom 216 volunteers (72.48%) maintain the period of meditation continuously for 16-60 minutes, and 59 (19.80%) performed a longer-period training which lasted more than an hour (Figure 7.9 (B)).



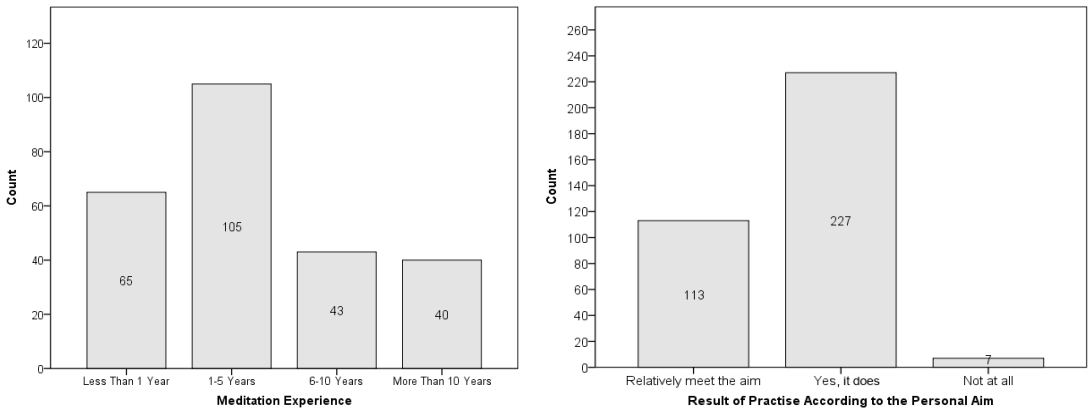
(A) Participants' frequency of practice (B) Participants' length of meditation

Figure 7.9: Bar charts of frequency of practice and length of meditation

Furthermore, the survey results contributed by 253 subjects reveal a variety of participants' meditation backgrounds, as Figure 7.10 (A) presents. 105 of them (40.70%) reported that they have been practising meditation for one to five years, while 65 of them (25.19%) mentioned that they were beginners with less

than one year's experience. Moreover, 43 (16.66%) and 40 (15.05%) participants claimed that they have been practising this activity for six to ten years and more than ten years, respectively.

With regard to practice, it should be noted that the questionnaire asked participants about their aims of practice and achievement of the 'just finished' meditative activities. Figure 7.10 (B) presents the survey results contributed by 347 meditators, of whom 227 (65.42%) claimed that the practice met all their expectations, 113 (33.56%) reported that the practice partially met some aspects of today's objectives, while only seven subjects (2.01%) reported that they could not achieve their practising aims.



(A) Participants' meditation experience (B) Participants' result of practice

Figure 7.10: Bar charts of subjects' meditation experience and results of practise

7.5 Summary of environmental and personal factors applied in statistical analyses

It should be noted here that there are two types of environmental data applied in the analyses for the operation of the environmental controls in the halls and subjective votes, as Table 7.3 and Table 7.4 present. Those sets of data were derived from different calculation methods based on the same environmental measuring database.

For the environmental control analysis, the indoor variables were an average data every 30 minutes from three devices, WBGTs A, B, and C, for $DBT_{av\text{-}in}$, $T_{g\text{-}av\text{-}in}$, and $RH_{av\text{-}in}$, while indoor *v* and the outdoor factors (DBT_{out}, $T_{g\text{-}out}$, and RH_{out})

were collected directly from the anemometer at the centre of the halls and WBGT D respectively. The minimum and maximum values of the indoor parameters are shown below:

- $DBT_{av\text{-}in}$: 24.67°C to 31.33°C
- $RH_{av\text{-}in}$: 40.57% to 85.5%
- $T_{g\text{-}av\text{-}in}$: 24.53°C to 30.97°C
- v: 0.10 m/s and 0.80 m/s

The minimum and maximum values of the outdoors parameters were:

- DBT_{out}: 23.20°C to 31.80°C
- RH_{out}: 40.80% to 92.00%
- $T_{g\text{-}out}$: 23.50°C to 32.30°C
- Cloud cover: 0.00 to 8.00

According to the analysis, $RH_{av\text{-}in}$ (*std* = 10.16%) and RH_{out} (*std* = 10.83%) present the largest variations amongst the other factors.

Table 7.3: Summary of indoor and outdoor environmental utilized in behavioural adaptation analyses

Category	**Environmental factors for behavioural adaptation analysis**							
	Indoor environmental factors				**Outdoor factors**			
Variable	$DBT_{av\text{-}in}$	$RH_{av\text{-}in}$	$T_{g\text{-}av\text{-}in}$	V	DBT_{out}	RH_{out}	$T_{g\text{-}out}$	*Cloud Cover*
Unit	°C	%	°C	m/s	°C	%	°C	-
Min	24.67	40.57	24.53	0.1	23.2	40.8	23.5	0
Max	31.33	85.5	30.97	0.8	31.8	92	32.3	8
Av	28.58	64.3	28.36	0.41	28.13	65.7	28.49	3.92
std.	1.96	10.16	1.92	0.18	2.46	10.83	2.46	3.68

The factors applied in the subjective vote analyses comprised environmental and personal variables. The variables in the former data set were 30-minuted average data of each measuring device. The subjective votes will be correlated with indoor T_{op} calculated based on the environmental variables DBT_{in}, $T_{g\text{-}in}$,

RH_{in}, v, and MRT measured by the nearest device, as explained in Chapter 5. According to Table 7.4, T_{op} ranges from 24.05°C to 31.32°C with an average of 1.67°C and *std* of 28.63°C. Besides, DBT_{in}, $T_{g\text{-}in}$, and MRT reach peaks at 24.20°C, 24.00°C, and 23.80°C, while touching their lowest values at 31.60°C, 31.20°C, and 37.74°C, respectively. RH_{in}, moreover, varies from 40.80% to 78.00% and a variation of v is limited within the range of 0.13 m/s to 0.58 m/s.

Table 7.4: Summary of indoor and outdoor environmental and personal data used in subjective vote analyses

Category	**Environmental factors for subjective vote analysis**							**Personal factors**	
	Indoor environmental factors						**Outdoor factors**		
Variable	DBT_{in}	RH_{in}	$T_{g\text{-}in}$	MRT	T_{op}	v	$T_{monthlyav\text{-}out}$	CLO	MET
Unit	°C	%	°C	°C	°C	m/s	°C	-	-
Min	24.2	40.8	24	23.8	24.05	0.13	25.02	0.24	1
Max	31.6	78	31.2	37.74	31.32	0.58	28.29	1.01	1
Av	28.83	65.77	28.58	28.28	28.63	0.31	27.08	0.55	1
std.	1.69	9.64	1.64	1.64	1.67	0.09	1.12	0.15	0

Monthly Average Outdoor Temperature ($T_{monthly\text{-}av\text{-}out}$) calculated by the secondary data provided by the local meteorological station ranges from 25.05°C to 28.29°C with averages of 27.08°C. CLO and MET, which are personal factors, were applied in PMV and PDD calculations. As mentioned in Chapter 5, MET was assumed to be a constant at 1.00 for sedentary activity. Besides, the range of CLO varies from 0.24 to 1.01 with an average of 0.55 and *std* of 0.15.

7.6 Summary of the number of subjective votes

According to the questionnaire survey, a total of 517 data samples were collected from 384 healthy volunteers. It was found that 18 sets of data had to be excluded from the database due to an absence of subjects' sitting location, leading to a loss of thermal environmental information. 499 respondents were utilised in the ASV analysis, and 480 data are employed in the PMV calculation,

while 37 samples were excluded from the *PMV* analysis due to missing the *CLO* and sitting location information.

For the database of *ASV* analysis, 499 *ASV* data were responded to by 360 respondents, of whom 221, 189, and 89 of the votes were collected from *VRW*, *PT*, and *KJS*, respectively. Besides, 231 and 268 data samples were contributed in the winter and monsoon seasons. The questionnaire survey was initially aimed to be conducted twice a day. However, due to some unexpected events, such as special lectures and religious activities on Buddhist holy days, some meditation sessions were omitted from the original survey schedule. Thus, such circumstances affected the survey plan, whereby only one survey a day could be conducted on the 3rd of December 2016 and 8th of June 2017, as Table 7.5 presents.

Table 7.5: Summary of data collection dates and times with the number of ASV data

Place	Date	Survey time	No. of data
		Winter	
VRW	26 November 2016	*10:00-10:30 and 16:00-16:30*	97
PT	3 of December 2016	*21:00-21:30*	39
KJS	10 December 2016	*16:00-16:30 and 21:00-21:30*	25
PT	17 December 2016	*11:30-12:00 and 14:30-15:00*	45
KJS	14 January 2017	*11:30-12:00 and 15:00-15:30*	31
		Monsoon	
PT	8 June 2017	*15:30-16:00*	34
VRW	15 July 2017	*10:30-11:00 and 15:30- 16:00*	124
PT	12 August 2017	14:30-15:00 and 21:00-21:30	71
KJS	19 August 2017	*11:00-11:30 and 14:00-14:30*	33
Total			***499***

In terms of the *ASV* votes, Figure 7.6 presents the data categorised in five aspects of subjective thermal votes, which are *ASV*, *APV*, T_p, and v_p; and two facets of meditation qualities, *IFA a*nd *DR*. For subjective thermal vote data, 241 of 499 *ASV* were '*Neutral*' (0), while 172 and 44 votes were on '*Slightly*

cool' (-1) and '*Slightly warm*' (+1). 183 (36.67%) and 75 (15.03%) data were on the '*Slightly cool*' to '*Cold*' and '*Slightly warm*' to '*Hot*' sides of the scale. Moreover, the data revealed that only one volunteer mentioned that the halls were '*Hot*' (+3). 457 samples (97.58%) voted -1, 0 and +1; this range is considered to comprise thermal comfort according to Bedford, as mentioned in the RP-884 report (DeDear, Brager and Cooper 1997).

Table 7.6: Summary of the data distribution of the subjective thermal votes and meditation experiences

Category	Subjective vote		Scale							Total
			-3	-2	-1	0	1	2	3	
Subjective thermal vote	*ASV*	Frequency	0	11	172	241	44	3	1	499
		%	0.00	2.20	34.47	48.30	8.82	6.01	0.20	100
	APV	Frequency	26	209	171	50	30	7	4	497
		%	5.23	42.05	34.41	10.06	6.04	1.41	0.80	100
	T_p	Frequency	-	-	154	303	38	-	-	495
		%	-	-	30.8	60.6	7.6	-	-	100
	v_p	Frequency	-	-	84	308	104	-	-	496
		%	-	-	16.94	62.10	20.97	-	-	0
Meditation quality vote	*IFA*	Frequency	-	188	139	141	23	6	-	497
		%	-	37.83	27.97	28.37	4.63	1.21	-	100
	DR	Frequency	-	122	169	160	38	9	-	498
		%	-	24.50	33.94	32.13	7.63	1.81	-	100

For *APV*, 497 participants' data were collected. The vast majority (*n* = 406, 81.69%) voted between '*Very comfortable*' (-3) to '*Rather comfortable*' (-1); 50 (10.06%) '*Indifferent*' (0), which can be interpreted as a condition of respondents feeling neither thermally comfortable nor uncomfortable in the halls; and 41 votes (8.25%) '*Rather uncomfortable*' (+1) to '*Very uncomfortable*' (+3).

Apart from the analysis of the subjective thermal votes, meditation qualities of Impaired Instruction-Following Ability (*IFA*) and Difficulty in Relaxation (*DR*) were investigated. As shown in Table 7.6, the results indicate that 497 data of

IFA and 498 data of *DR* were collected over the surveying periods. For *IFA*, the largest group of the subjects accounting for 188 respondents, 37.83% reported that their *IFA* were '*Always considerably easy to follow*' (-2), while only 6 (1.21%) votes were '*Always considerably difficult to follow*' (+2). Regarding *DR*, 169 respondents (33.94%) voted their *DR* experience on '*Moderately difficult to Perceive unrelaxed feeling*' (-1), while only 47 (9.44%) of the total *DR* votes present the negative meditative experiences. In this case, 38 (7.63%) and 9 (1.81%) of the total votes were '*Moderately easy to perceive unrelaxed feeling*' (+1) and '*Always considerably easy to perceive unrelaxed feeling*' (+2), respectively.

7.7 Subjects' sitting location and current *ASV*

After finishing each survey session, the subjects were asked to leave the questionnaire forms at the front of their last sitting locations. The locations and serial numbers of the forms were measured and recorded into a key plan of the *VRW*, *PT*, and *KJS* halls, as Figure 7.11, Figure 7.12, and Figure 7.13 illustrate (respectively). It can be seen that the questionnaire forms are presented as small orange square rectangles placed at the front of the meditation mats (70x70 cm), coloured according to the sample' *ASV* ranging from red (+3 or '*Hot*') to dark blue (-3 or '*Cold*'), while the green mats represent '*Neutral*' (*ASV* = 0).

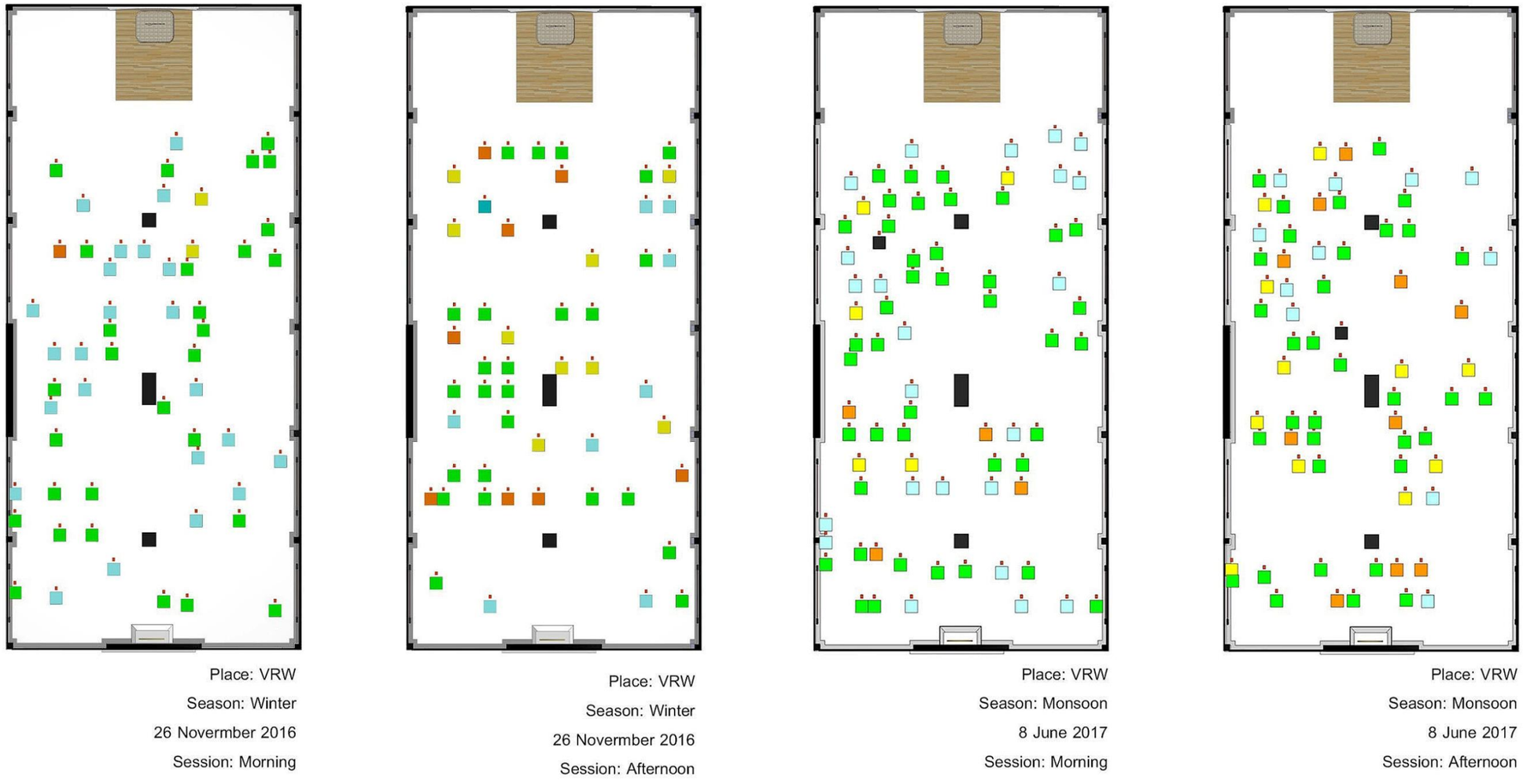


Figure 7.11: Key plan of VRW in different survey days with subjects' sitting locations coloured according to ASV results

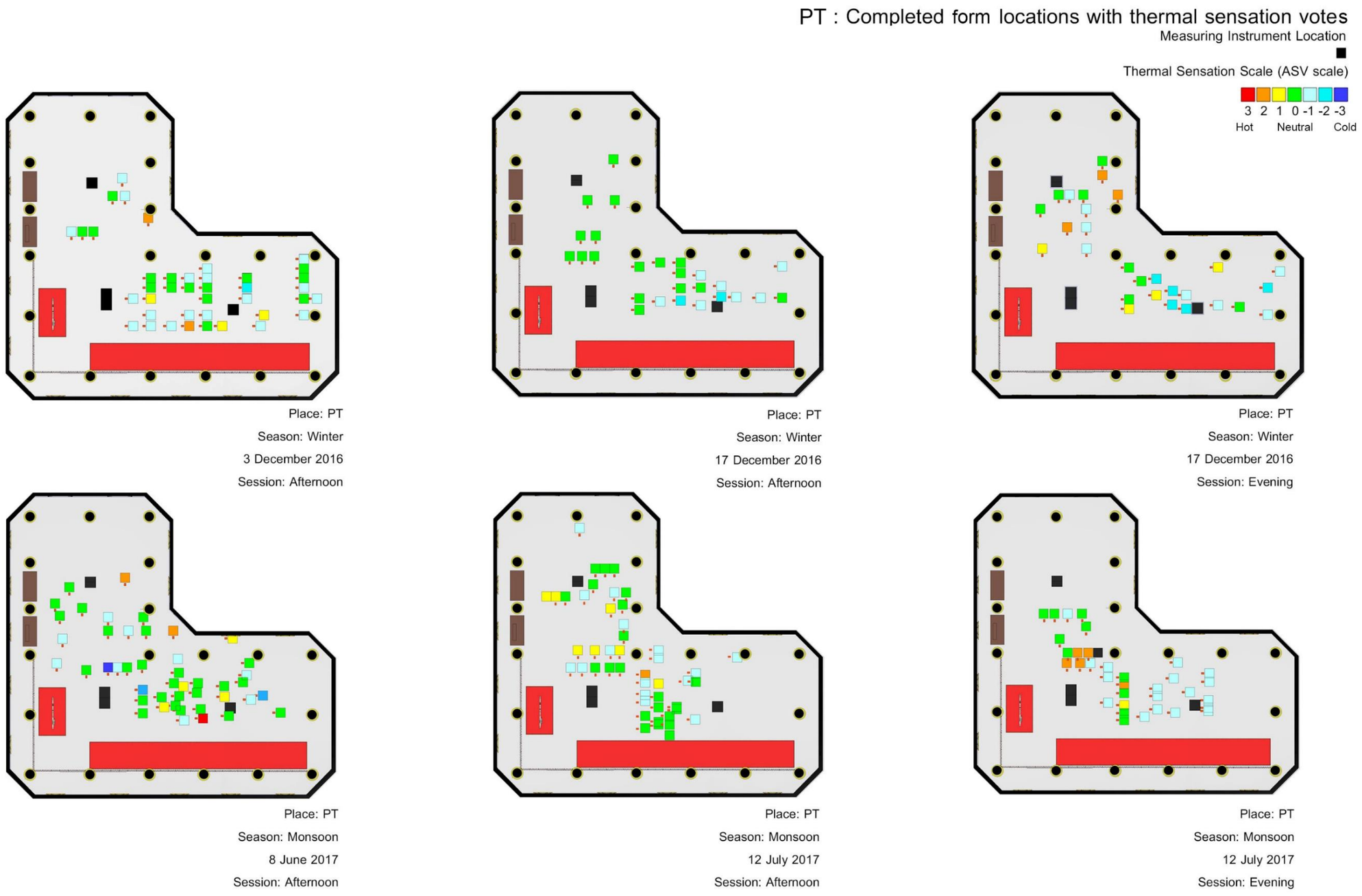


Figure 7.12: Key plan of PT in different survey days with subjects' sitting locations coloured according to ASV results

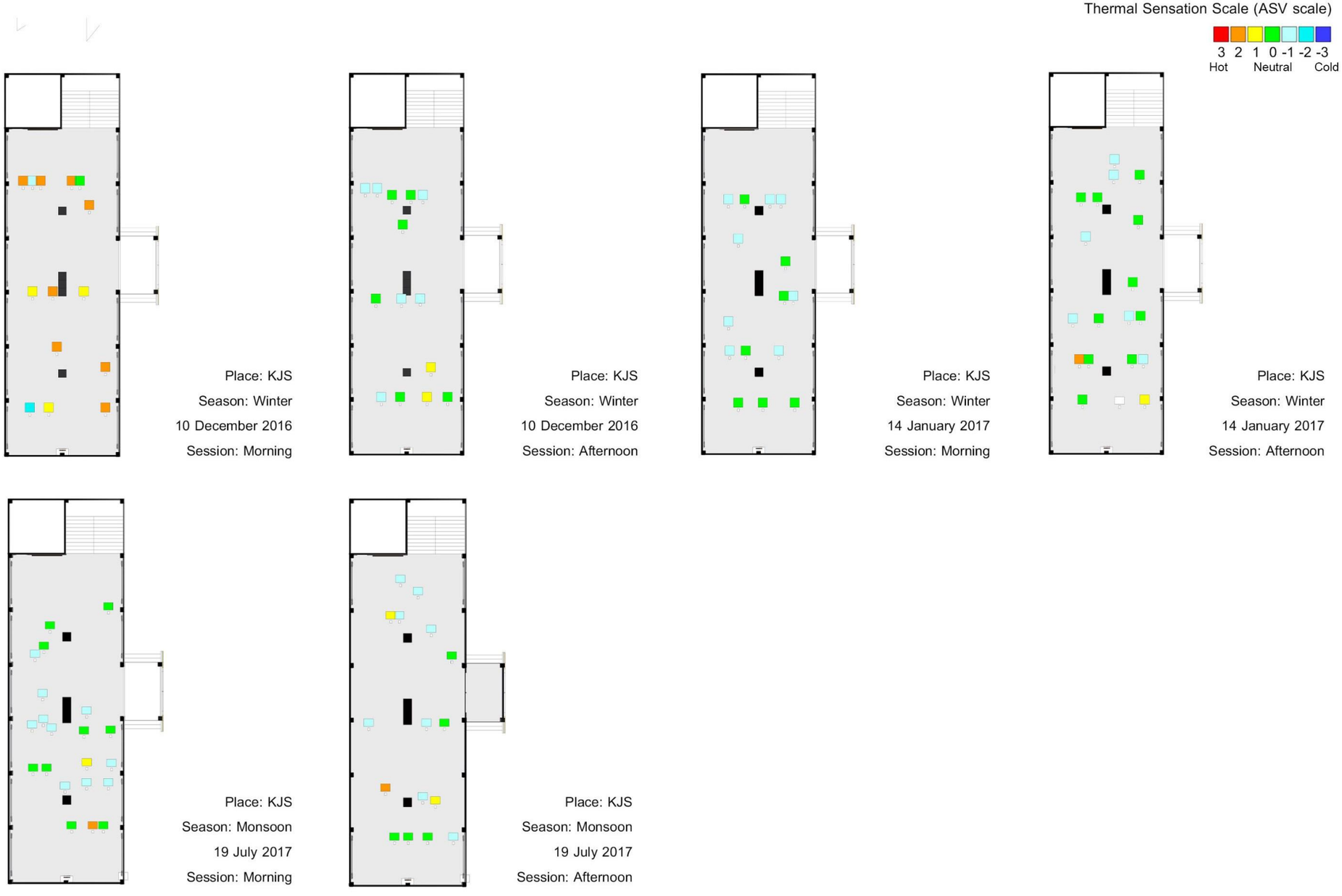


Figure 7.13: Key plan of KJS in different survey days with subjects' sitting locations coloured according to ASV results

The figures show that the majority of the mats are coloured in green, while some of them are in warm tone. It should be noted that the recorded sitting positions do not represent all the meditators engaging the activities in the spaces, but only the consenting participants. The graphics demonstrate that the subjects' sitting locations and the environmental factors in the halls may not be the only two influential factors on the users' *ASV*, due to no obvious pattern of *ASV* being distributed on the floor plans. In contrast, further investigations on quantifiable and non-quantifiable factors, such as personal factors of *CLO* and users' thermally adaptive solutions, are required.

For the environmental preference analyses, 495 and 498 data of T_p and v_p (Preferred Airspeed) were collected. The majority of participant votes indicated that 302 (60.01%) respondents preferred '*No change*' (0) to the current hall temperature, and 308 (62.10%) votes were on '*No change*' (0) for indoor airspeed. In contrast, minorities voted '*Prefer warmer*' (+1) and '*Prefer lower airspeed*' (-1), which accounted for 38 (7.68%) and 84 (16.94%) of T_p and v_p, respectively.

Besides, a total of 496 pairs of *ASV* and *APV* data samples were applied for statistical analysis, as presented in Table 7.7. According to the table, the range of the *ASV* and *APV* votes between -3 to -1 contains 371 respondents (74.80%). Such a data cluster reveals the majority of the votes located on the '*Cold*' to '*Cool*' sensations, where the subjects may have felt '*Very comfortable*' to '*Rather comfortable*'.

Table 7.7: Summary of ASV and APV data distribution

		ASV							
		-3	**-2**	**-1**	**0**	**1**	**2**	**3**	**Total**
APV	**-3**	1	11	13	1	0	0	0	26
	-2	5	109	82	10	2	0	0	208
	-1	3	41	106	13	8	0	0	171
	0	0	6	29	8	7	0	0	50
	1	1	3	6	11	9	0	0	30
	2	1	0	1	0	4	1	0	7
	3	0	1	2	1	0	0	0	4
Total									**496**

7.8 Summary of the environmental control operations

This section focuses on the building users' environmental adaptation on the operation of environmental controls (windows and fans) in the meditation halls. Observed data of the device operations collected during the same period as the environmental measurements (every 30 minutes) were later correlated with the indoor and outdoor environmental factors, as presented in Figure 7.4. All the environmental controls available in the halls were named '*Available Devices*' in this study. It should be noted that such a factor may not be directly applied in the analyses of environmental control operation due to device inaccessibility and malfunctions.

In contrast, the accessible and functional devices were named '*Effective Devices*'. Table 7.8 and Figure 7.9 present summaries of the total numbers of *Available Devices* and *Effective Devices* alongside with the number of observations. A total of 73 observations collected 20, 40, and 13 data sets from *VRW*, *PT*, and *KJS* respectively, which were later applied in the correlation analysis. The total scores of the fan and window operations of each 30 minutes, when the halls were occupied, were divided by the total number of the *Effective Devices* of their category to convert into a percentage of each device operation, according to the calculation methods mentioned in Chapter 5. Each operation percentage of the windows and that of the fans every 30 minutes were later correlated with indoor and outdoor environmental data in Chapter 10 for the behavioural adaptation study.

According to the observations, the total numbers of *Available Devices* of windows in *VRW*, *PT*, and *KJS* were 16, 20, and 14, respectively. The total number of *Effective Devices* in *VRW* was constant at 11 in all the observed periods. In contrast, such numbers of the others slightly vary according to the dates of the observation. The minimum and maximum numbers of *Effective Devices* were 9 and 10 in *PT* and 10 to 12 in *KJS*. The highest operation scores of the windows in *VRW*, *PT*, and *KJS* were 10.50, 7.70, and 8.50 found on the 15th of July 2017, 3rd of December 2016, and 19th of August 2017. On the other hand, the lowest scores of 8.70, 4.40, and 7.10 were found during the winter,

on the 26th of November 2016, 17th of December 2016, and 10th of December 2016, respectively.

Table 7.8: Summary of the window and door operations in the halls

Place	Date (DD/MM/YY)	Window and door operation score						No. of observation
		Actual operation score				Total No. of Available Devices	Total No. of Effective Devices	
		Max	Min	Mean	*std*			
VRW	26/11/2016	9.80	8.70	9.10	0.45	16	11	10
	15/07/2017	10.50	9.50	9.90	0.52	16	11	10
PT	3/12/2016	7.70	7.70	7.70	0.00	20	10	6
	17/12/2016	7.20	4.40	5.93	1.35	20	10	12
	8/7/2017	7.50	7.50	7.50	0.00	20	9	11
	12/8/2017	7.50	7.50	7.75	0.00	20	9	11
KJS	10/12/2016	7.80	7.10	7.66	0.31	14	12	5
	14/01/2017	8.30	7.50	8.10	0.40	14	12	4
	19/08/2017	8.50	8.40	8.48	0.05	14	10	4
Total								**73**

Table 7.9: Summary of the fan operations in the halls

Place	Date (DD/MM/YY)	Fan operation score						No. of observation
		Actual operation score				Total No. of *Available Devices*	Total No. of *Effective Devices*	
		Max	Min	Mean	*std*			
VRW	26/11/2016	12.00	4.00	9.10	0.38	15	15	10
	15/07/2017	16.00	15.00	15.50	0.53	17	17	10
PT	3/12/2016	14.00	5.00	12.33	3.61	19	19	6
	17/12/2016	5.00	1.00	2.92	1.37	19	19	12
	8/7/2017	18.00	13.00	15.55	2.21	19	19	11
	12/8/2017	16.00	9.00	13.09	2.70	19	19	11
KJS	10/12/2016	6.00	0.00	2.40	3.29	8	8	5
	14/01/2017	6.00	6.00	6.00	0.00	8	8	4
	19/08/2017	6.00	6.00	6.00	0.00	8	8	4
Total								**73**

No difference was found between the total number of *Available Devices* and *Effective Devices* for fan operation. However, the number of the devices in *VRW* increased from 15 to 17 on the 26th of November 2016 and 15th of July 2017 with extra portable fans being used, while the number of fans in the other case studies remained unchanged throughout the survey. The lower limits of the fan operation scores in *VRW*, *PT*, and *KJS* were 12, 5, and 6, while the upper limits were 16, 18, and 6, respectively.

7.9 Chapter conclusion

This chapter discusses a summary of environmental, demographic, personal and subjective vote data samples collected from the main survey from November 2016 to August 2017. The survey results indicate that the majority of volunteers comprised a group of females aged 31 to 70, who live in Khon Kaen. The highest education level was a doctoral degree, and the largest group of the subjects held a bachelor's degree. In terms of subjects' meditation background, the database was dominated by the subjects whose possesses one-year to five-year meditative experiences, while only 65 volunteers had been practising the activities for less than one year. Each training might last for 15 to 30 minutes, but 25 of 298 volunteers could maintain their mindfulness cultivation for more than two hours in each practice. Moreover, the largest and second largest groups of the participants reported that they meditated annually and daily.

The relationship between the indoor and outdoor environmental factors of the case studies reveal that the *VRW* hall is the most thermally sensitive to DBT_{out}. In contrast, analysis shows that the *PT* hall is the least variable according to a shift of DBT_{out} due to its wall thickness, the number of the floors, the location of the meditation hall, and the construction materials. Besides, the result of subjects' sitting locations show that this factor is not an influential variable affecting users' *ASV*, as evinced by there being no obvious *ASV* pattern presented on the key plans.

However, it should be noted that the measured environmental factors were calculated by two different calculation methods applied separately in the subjective vote and behavioural adaptation analyses (in Chapters 8, 9, and 10). A summary, the questionnaire survey, as a consequence, collected 499 *ASV*, 495 *APV* and T_p, 498 v_p, 497 *IFA*, and 498 *DR* samples. The research assistants created 73 data sets of environmental control modification on fans and windows observed every 30 minutes (the same measuring interval as the environmental measurements).

Chapter 8

Users' Subjective Thermal States and Adaptive Equation

Chapter 8: Users' Subjective Thermal States and Adaptive Equation

The previous chapter discussed the survey and observation results applied in the analyses. This chapter presents investigations of subjective thermal votes, which are T_n, T_p, semantic discrepancy (*SD*), and acceptable thermal temperature ranges. Different analytical methods (descriptive and inferential statistics) are used, as applied in previous studies, reporting data in bar charts, cross tabulation, linear correlation and Probit analysis. Furthermore, an adaptive equation and an adaptive model for this research are established and compared with those purposed by the ASHRAE Standard.

8.1 Subjects' suitable thermal environment analysis

This section investigates subjective thermal states such as T_n, T_p, *SD*, and thermal acceptability, as mentioned in the RP-884 report (DeDear, Brager and Cooper 1997). For the T_n analysis, two analytical methods were applied: binned analysis and linear regression. The latter solution is particularly important, since it is the most common analytical technique used in adaptive thermal comfort studies. However, before focusing on the regression analysis, the T_n calculated by the steady-state model is examined.

8.1.1 *PMV* application for meditation building users

Indoor environmental and personal data (T_{op}, v, RH_{in}, *MET*, and *CLO*) were transferred into *CBE* thermal comfort tool (Hoyt et al. 2013) for *PMV* and *PDD* predictions. The predictive results were plotted against T_{op}, as presented in Figure 8.1, for a variety of subjects' *PMV* according to $T_{op.}$ The linear correlation presents a positive relationship between two factors with a strong correlation coefficient (R = 0.843), as Eqn 62 presents. A gradient factor of the independent variable (T_{op}), which is 0.291 with a significant level of T-statistical study lower than 0.001 (p<0.001), shows that an increase of *PMV* does not occur by chance, but due to a rise of T_{op}. According to the regression model, the neutral

temperature based on *PMV* ($T_{n\text{-}PMV}$) is found at 26.24°C when *PMV* is 0.00. However, according to RP-884 report (DeDear, Brager and Cooper 1997), *PMV* and *PDD* methods were questioned in terms of their predictive accuracy when applied to evaluate the thermal sensation of building users in *AC* and *NV* spaces.

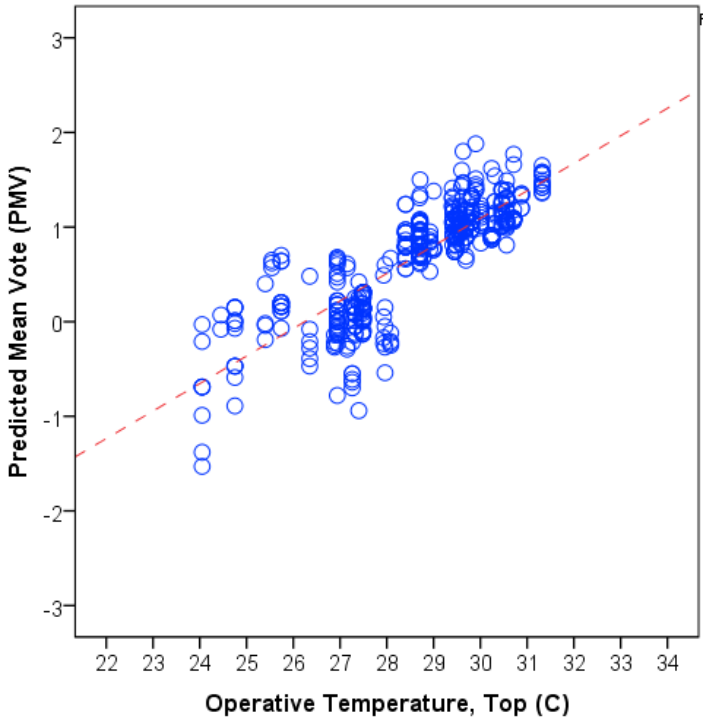


Figure 8.1: Scatter plot of PMV and T_{op} with a regression line

$$PMV = 0.291\ T_{op} - 7.636\ (R = 0.843,\ R^2 = 0.710) \qquad \text{Eqn 62}$$

8.1.2 Direct question of thermal acceptability

Due to the inaccurate prediction of the *PMV* method, as reported in the previous section, another analytical solution to investigate the neutral state should be considered. In this case, a direct question inquiring the sample about their thermal acceptability on the current environment was applied. A total of 261 respondents were collected, from whom 251 data items reported that the perceived current environments over the entire survey period were acceptable, while only ten subjects expressed that the hall condition was unacceptable. The derived result seems questionable, since the majority of the votes reported that

the current hall thermal environments were acceptable. Besides, since the results consist of a binary database, it was impossible to explore T_n of the users by the regression method. Thus, an indirect investigation was applied to explore the thermal state. This study shows an agreement with the statement of DeDear *et al.* (1997) and Parsons (2003) discussing the inapplicability of the directly investigating question solution of thermal acceptance.

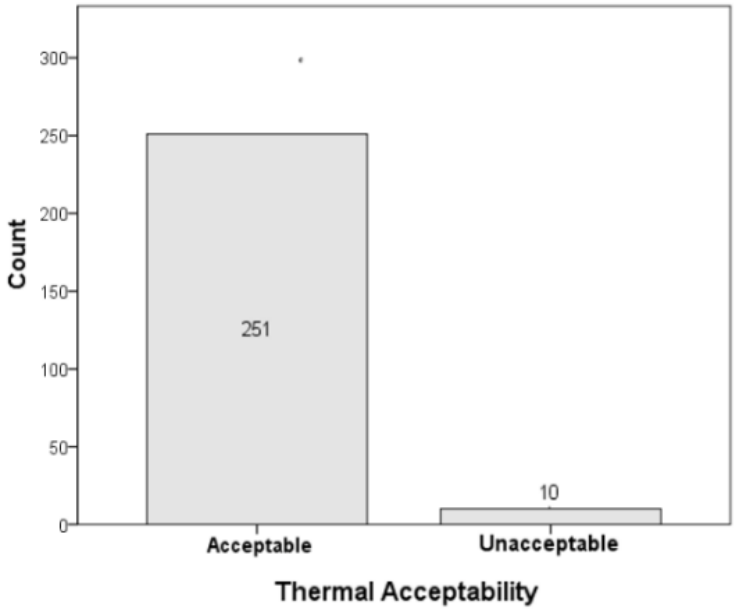


Figure 8.2: The number of direct thermal acceptance votes

8.1.3 Comparison between *ASV* and *PMV*

Thus, actual votes of the subjects' thermal sensation (*ASV*) are plotted against *PMV.* Figure 8.3 presents the observed *ASV* data, with a red-dashed line indicating the linear regression line of the subjects' *ASV* and *PMV*, and a grey-solid line showing expected regression when the *ASV* and *PMV* are indifferent (*ASV*=*PMV*). It is clear that there is a significant difference regarding the slopes between the two regressions. The model of *ASV* and *PMV*, as shown in Eqn 63, with an *R*-value of 0.265, reveals a large difference of the actual regression (0.40) and the reference line (1.0). Thus, this result presents an agreement that the physiological model may be unsuitable to evaluate thermal environments for occupants in *NV* spaces.

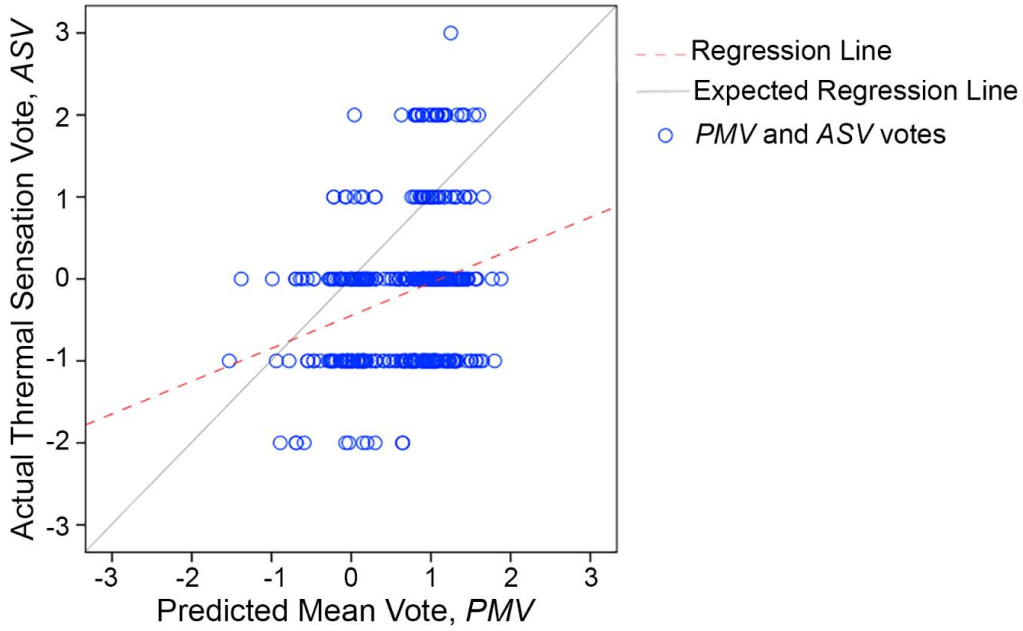


Figure 8.3: Scatter plot of ASV and PMV with regression lines

$$ASV = 0.40\ PMV - 0.447\ (R = 0.265,\ R^2 = 0.07) \qquad \text{Eqn 63}$$

8.1.4 Neutral temperature investigation

This research harnesses bin and linear regression methods to investigate the T_n of the subjects. The 499 *ASV* were binned at 2.5°C intervals. Table 8.1 presents three sets of data whereby which 51, 206, and 242 respondents' data were binned in 24.00°C to 26.50°C, 26.51°C to 29.00°C, and 29.01°C to 31.50°C clusters, respectively. Cross-tabulation reveals that, when the range of T_{op} shifts, the subjects' weighted average *ASV* increases accordingly.

Table 8.1: Weighted mean ASV in different temperature ranges

	Temperature (BIN = 2.5°C, n = 499)		
	24.00°C - 26.50°C	**26.51°C - 29.00°C**	**29.01°C - 31.50°C**
n	51	206	242
ASV Mean	-0.8	-0.3	0.6

According to the table, the average *ASV* increases from -0.80 to 0.60 alongside a rise of the T_{op} range, from 24.00°C to 26.50°C, to 29.01°C to 31.50°C. Such

mean sensation shifts with indoor temperature present a variation of thermal sensation from negative to positive values. In this case, the subjects' sensation seems to convert to the opposite thermal experience. Although this cross-tabulation technique allows the researcher to reveal evidence of the relationship between two factors, T_n has not yet been revealed by this analytical method.

Thus, linear regression was applied. The 499 *ASV* data samples were plotted against T_{op}. Figure 8.4 presents the observed data with regression line and reference threshold. The relationship between the factors expressed as Eqn 64 with *R*-value of 0.287 reveals that the subjects may be slightly sensitive to a shift of T_{op}, since the positive gradient factor of T_{op} is 0.149. Moreover, T-statistical analysis confirms the relationship between two factors, since the significance level of the slope factor is lower than 0.001 (p<0.001). Such statistical significance indicates that the change of *ASV* does not occur randomly, but due to the variation of T_{op}. Besides, according to the figure, the intersection between the regression and reference line suggests that the sample's T_n is found at 29.87°C.

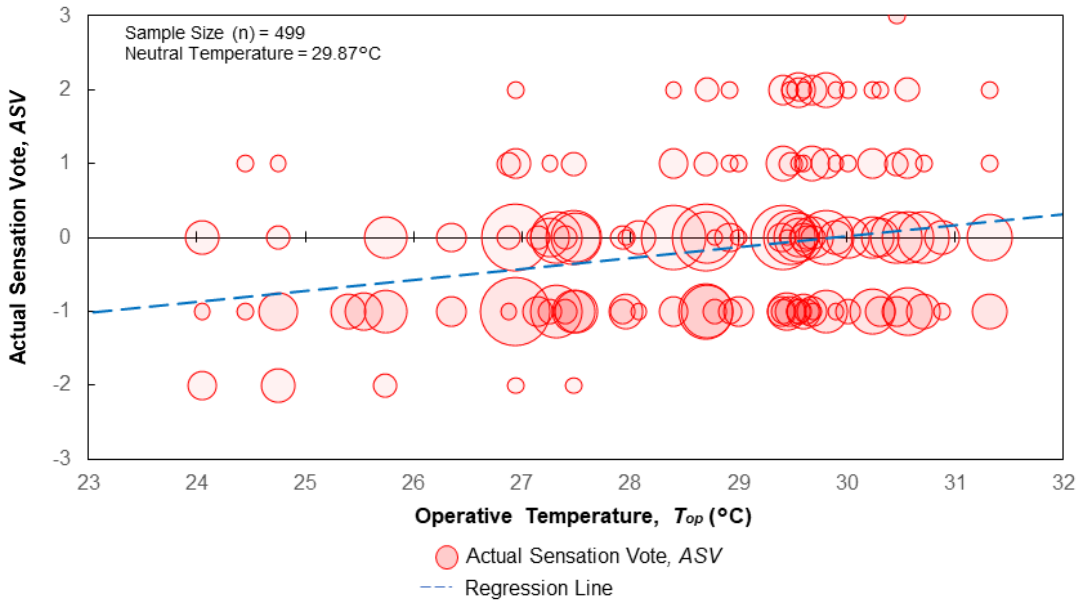


Figure 8.4: Scatter plot of ASV and T_{op} with a linear regression line

$$ASV = 0.149\ T_{op} - 4.451\ (R^2 = 0.083,\ R = 0.287) \qquad \text{Eqn 64}$$

Apart from the T_n exploration, this research investigates the other human subjective thermal conditions discussed in the RP-884 report (DeDear, Brager and Cooper 1997). In this case, the comfort condition ranging between ±1.00 *ASV* ('*Cool*' to '*Warm*' sensations) is assumed to be equivalent to '*Comfortable cool*' (-1) to '*Comfortable warm*' (+1) in Bedford's thermal comfort scale (Figure 3.4). Such a comfort interval is substituted in Eqn. 64, for which the result reveals that the Bedford thermal comfort range ($T_{c\text{-}Bedford}$ = ±1.00 *ASV*) found in this research may vary from 23.16°C to 36.58°C. Besides, the optimum temperature, as mentioned in the RP-884 report, can be expressed as 80% (±0.85 *ASV*) and 90% (±0.50 *ASV*) acceptable thermal ranges, which extend over 24.17°C to 35.58°C and 26.52°C to 33.23°C, respectively.

8.1.5 Preferred temperature and semantic discrepancy analyses

In addition to T_n and the acceptable ranges discussed in the RP-884 report, T_p and *SD* were also mentioned. A total of 495 T_p votes were categorised into two main groups, '*Prefer cooler*' and '*Prefer warmer*', which were analysed by a Probit model. According to the analytical results, the predicted regression lines of both thermal preferences presented alongside with the observed values are plotted against indoor T_{op}, as shown in Figure 8.5.

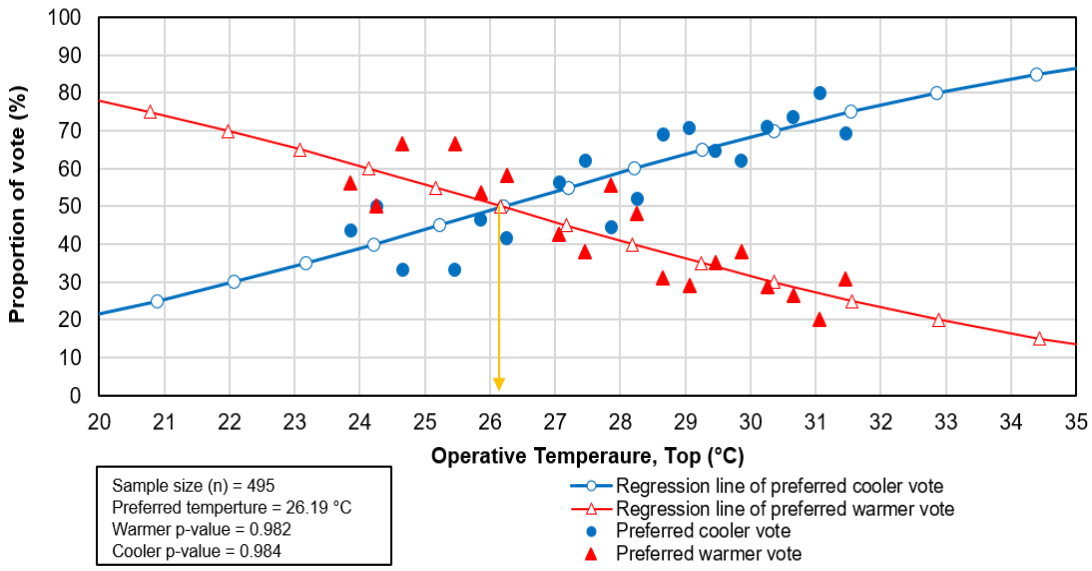


Figure 8.5: Probit analysis of T_p

An intersection between two lines which is found at 26.19°C is considered T_p is the condition where the proportion of '*Prefer cooler*' and '*Prefer warmer*' are equal (DeDear, Brager and Cooper 1997; Feriadi and Wong 2004). Furthermore, the analytical results present that Pearson's goodness-of-fit study shows that X^2 (Chi-square statistics) are 9.931 and 11.093, with *p*-value of 0.982 and 0.984 for the regression models of warmer and cooler preferences, respectively. As results of T_n and T_p, *SD* is found at 3.68°C, indicating that the meditation halls are located in warm environments (DeDear *et al.* 1997).

8.2 Adaptive equation and adaptive model

The adaptive model acknowledges that building users are capable of adapting themselves to local thermal environments when they perceive thermal dissatisfaction. Besides, in *FR* and *NV* buildings, subjects' neutral thermal vote (*ASV* = 0) varies according to the outdoor ambient temperature (Humphreys 1978; DeDear *et al.* 1997). This research conducted a correlation analysis based on this paradigm by correlating the neutral votes of *ASV* and Monthly Mean Outdoor Dry Bulb Temperature ($T_{monthly\text{-}av\text{-}out}$), as presented in ASHRAE Standard:55 (2010). Figure 8.6 presents a scatter plot of T_n plotted against $T_{monthly\text{-}av\text{-}out}$, varying between 25.02°C to 28.29°C with a linear regression line (R = 0.594) expressed as Eqn. 65. Furthermore, a *T*-statistical analysis of the gradient factor of the model reveals a significant level lower than 0.001 (p<0.001) confirming that a shift of subjects' T_n is related to a variation of $T_{monthly\text{-}av\text{-}out}$.

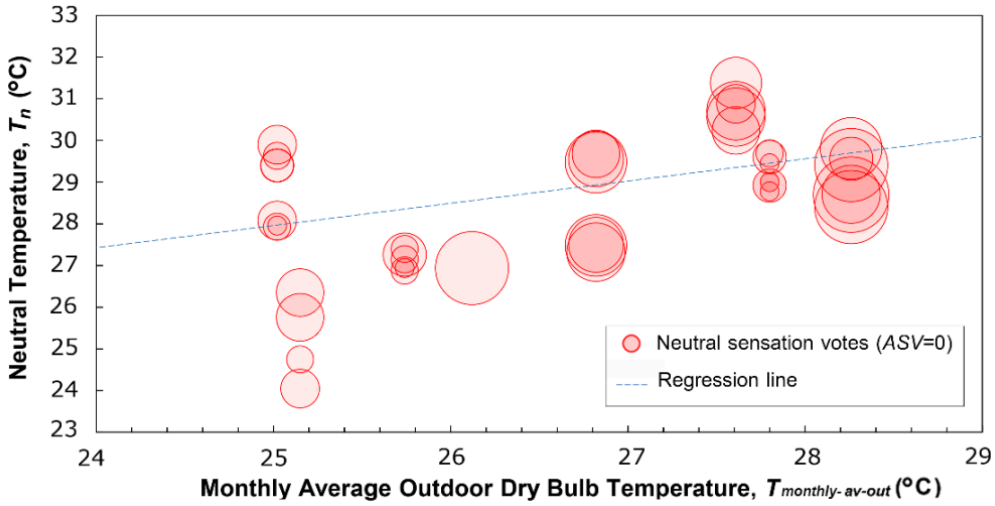


Figure 8.6: Correlation between T_n and $T_{monthly-av-out}$

$$T_n = 0.828\ T_{monthly-av-out} + 6.304\ (R = 0.594,\ R^2 = 0.353) \qquad \text{Eqn 65}$$

Eqn. 65 was substituted by the lower and upper limits of 80% (*ASV = ±0.75*) and 90% (*ASV = ±0.50*) thermal acceptable ranges, as stated in the RP-884 report. The 80 and 90% thermal acceptable ranges are ±3.355°C and ±5.705°C, respectively; these were derived from a substitution of *ASV* ranges of the RP-884 thermal acceptance (DeDear *et al.* 1997), as mentioned in Chapter 4.

Figure 8.7 displays an adaptive model of ASHRAE Standard 55 (2010) laid over that of the project, showing that the regression lines of T_n for this research are located at a higher temperature than those of the ASHRAE Standard. Furthermore, the regression function reveals that the gradient factor of the independent variable derived from the volunteers is higher than those of the American (ASHRAE) standard. Such a difference can be attributed to building users in this research being more thermally adaptive to a shift of $T_{monthly-av-out}$ than those of the ASHRAE. Besides, the current 80% and 90% acceptable thermal ranges are noticeably wider, and the acceptable zones cover a more extensive area in grey shade under the same conditions of $T_{monthly-av-out}$ compared to the ASHRAE counterpart.

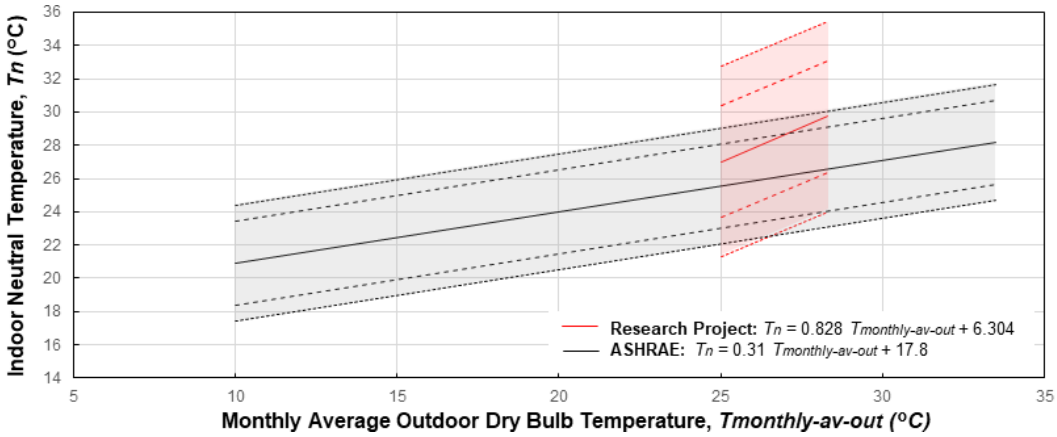


Figure 8.7: Acceptable thermal zones of the project and ASHRAE

Figure 8.8 shows a comparison of ASHRAE and the project 80% acceptable zones. An intersected area can be seen between the ASHRAE and the research projected shaded in red and grey, respectively. The overlap between the 80% acceptable thermal zone and that of the American standard accounts for the majority of the overlap (59.15%). This area reveals the capability of the international standard to describe the thermal requirement of the subjects of this study. The other 39.35% and 1.50% of the acceptable zone of the project are located outside the ASHRAE zone, over the upper and below the lower limits of the acceptable zone, respectively. The non-overlapping area (40.85%) demonstrates the thermal adaptive capabilities of the occupants to allow them to stay in a wider range of thermal environment without the assistance of *AC* systems beyond the suggestions of ASHRAE.

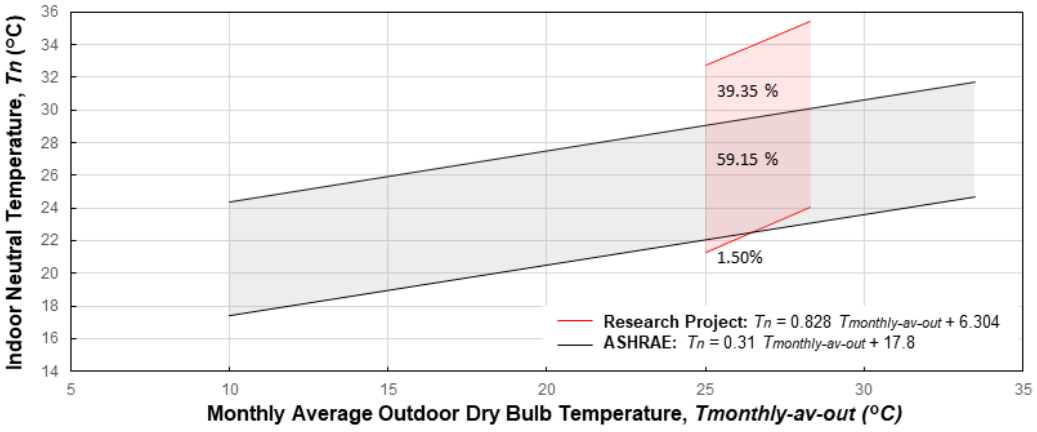


Figure 8.8: Comparison of 80% acceptable thermal zone of this project and ASHRAE

Furthermore, this research found a difference in users' adaptive level. The coefficient of the independent factor of the adaptive model of this study is 0.83, while that of the counterpart is 0.31. A comparison of two gradient factors between the models shows that for every 1°C increase of $T_{monthly\text{-}av\text{-}out}$, the subjects' T_n seems to increase 2.68 times higher than predicted by the ASHRAE database. Thus, it may be said that the ASHRAE thermal acceptable zone may not perfectly reflect the volunteers' requirements, and a local standard of the adaptive thermal comfort should be established. Furthermore, such a wide range of thermal acceptability is attributed to human thermal adaptive actions, which should be further investigated.

8.3 Discussion of chapter 8

8.3.1 *ASV* analysis and suggestions for further investigation

The result of *PMV* and T_{op} analysis confirms a positive correlation of subjects' *PMV* and indoor environmental factors: DBT_{in}, RH_{in}, $T_{g\text{-}in}$, and v. A variation of subjects' *PMV* could be justified by different thermal factors of the halls and personal *CLO*, while *MET* is assumed to remain equal in this study. The correlation of *ASV* and *PMV* reveals that the lab-based model may not provide a precise prediction in the *NV* meditation buildings. In this case, this inaccurate prediction might be caused by unquantifiable factors excluded from the laboratories, such as subjects' thermal background or thermal adaptive capability. Thus, this result presents an agreement with the RP-884 report, which suggests that the *PMV* method seems unsuitable to precisely evaluate occupants' thermal comfort in the *NV* buildings, while the adaptive model should be applied.

Besides, the results of the direct question of thermal acceptability applied in this research reveal that the majority of the subjects (96.17%) reported that the thermal environments of the halls were acceptable. This high percentage of the number of direct thermal acceptability votes is questionable due to its optimistic profile. Besides, this over-optimistic result may not lead to an exploration of acceptable temperatures, which is one of the research aims; thus, further study

is required. In this case, the *ASV* samples derived by the ASHRAE thermal sensation scale were analysed by the binned method and linear regression. The results derived from previous investigations show that subjects' thermal sensation increases with an increment of T_{op} range. Besides, the latter analysis confirms the positive relationship between *ASV* and T_{op}. A gradient factor of the regression model reveals that subjects' *ASV* is thermally sensitive to T_{op}, since *ASV* gradually changes according to a rise of T_{op}.

However, the model may not achieve a high correlation coefficient (R = 0.287) due to many reasons, including the following:

- Different individual thermal adaptive techniques, leading to a variation of *ASV* in the database.
- Environmental measuring methods; the number of measuring instruments cannot cover the entire area of the *NV* halls to represent the actuality of the indoor environmental factors, which varied dynamically.
- Environmental factors used in the analysis are represented by 30-minute average values, which partially represent the indoor thermal environment at the moment each subject responded to *ASV* or other subjective vote questions.
- The limited range of T_{op} in the database leads to a small cluster of *ASV* samples. In contrast, in harsh thermal environments, where the temperature is extremely low or high, the *ASV* samples may distribute more extensively from extreme votes for *'Hot'* (3) and *'Cold'* (-3). Such a widespread of *ASV* on the wide range of T_{op} may allow the regression to form a clearer linear relationship.

8.3.2 Comparison between the adaptive models of the ASHRAE and the research project

Concerning the relationship between neutral *ASV* votes and $T_{monthly\text{-}av\text{-}out}$, the results of this research present an agreement with the past studies of Humphreys (1978) and DeDear *et al.* (1997). Besides, the adaptive model of this project was established and compared with that of ASHRAE Standard-

55:2004 (2004). The comparison reveals differences between two adaptive models:

- The range of $T_{monthly\text{-}av\text{-}out}$ of the current research (25.02°C to 28.29°C) is narrower than that of the ASHRAE Standard (10.00°C to 33.50°C). Such a range of $T_{monthly\text{-}av\text{-}out}$ leads to a limited predictive capability for the indoor T_n.
- The adaptive model of this study presents that the subjects in the meditation halls seem to be more thermally adaptive to environmental warmth, since its regression line is located at the higher temperature and shows steeper regressions than that of the counterpart.
- T_n predicted by the adaptive equation of this project is also higher than that of the ASHRAE (2004). At the lower limit of $T_{monthly\text{-}av\text{-}out}$ of the project adaptive model (25.02°C), T_n found in this study (27.02°C) is 1.46°C higher than that of the ASHRAE (2004) (25.56°C). Besides, when $T_{monthly\text{-}av\text{-}out}$ increases to 28.29°C (the upper limit), the T_n of the volunteers (29.73°C) is 3.16°C higher than that of their ASHRAE counterparts (26.57°C). Besides, the database also reveals a wider thermal acceptance among respondents. The 80% and 90% acceptable ranges are 11.41°C and 6.71°C, which are broader than the ASHRAE ranges of 7.00°C and 5.00°C, respectively.

8.3.3 Recommendation of the environmental measuring method

This research investigates relationships between the users' subjective perceptions and variations of thermal environments in large spaces of the *NV* meditation halls. Thus, this study suggests that measurements of thermal environment in such large spaces may require a greater number of measuring devices distributed throughout the entire area of the halls, so that the obtained results can represent the entire indoor thermal landscapes as clearly as possible. Besides, all measuring devices should operate automatically and should not be moved from their initially set locations, to avoid errors regarding the synchronisation of the measuring times and to maintain the same locations and heights of the measurements.

8.4 Chapter conclusion

This chapter discusses the investigation of the subjects' suitable indoor thermal environment in meditation halls. A total of 499 *ASV* samples were collected from three meditation centres during the winter and monsoon seasons. The analysis reveals the inaccuracy of the *PMV* in predicting subjects' thermal sensation in *NV* meditation halls. The study shows that the prediction of the steady-state model seems to overestimate subjects' thermal sensation. The physiological model predicts that when the *ASV* is '*Neutral*' (0), the subjects' *PMV* is 1.12, which is just over the '*Warm*' (+1) sensation. Besides, *PMV* and *ASV* were correlated, and the relation between the factors can be expressed as shown in the equation below:

$$ASV = 0.40\ PMV - 0.447$$

Moreover, this study found a relationship between *ASV* and indoor T_{op} in binned and linear correlation analyses. Both analytical methods present similar results, showing a shift of *ASV* according to an increase of T_{op}. The linear model of *ASV* and T_{op} can be expressed as presented below:

$$ASV = 1.49\ T_{op} - 4.451$$

According to the equation above, for every 1.00°C increase in temperature, subjects' sensation will increase by around 1.49 *ASV*. This research found T_n to be 29.87°C with 80% and 90% acceptable thermal ranges, varying from 24.17°C to 35.58°C, and 26.52°C to 33.23°C, respectively. A Probit model was utilized to explore T_p based on thermal preference votes. The intersection between the positive and negative sigmoid curves of those who preferred '*Cooler*' or '*Warmer*' represent T_p at 26.19°C. The *SD* of this project is +3.68°C, indicating that the subjects are in a warm environment. This research found a relation between T_n and $T_{monthly\text{-}av\text{-}out}$, as represented in the equation below:

$$T_n = 0.828\ T_{monthly\text{-}av\text{-}out} + 6.304$$

This relation leads to an establishment of the adaptive equation and adaptive model for *NV* meditation halls in Thailand. Besides, the comparative result between the current models and ASHRAE reveals that the regression line of T_n found in this study is noticeably higher, and the 80% and 90% ranges of thermal acceptability are wider than those of their counterparts.

Furthermore, the volunteers seemed to be more adaptive to a variation of the outdoor thermal factors than suggested by the ASHRAE database, since the gradient factor of the current adaptive model is 0.83, while the counterpart is 0.31. The results indicate that 40.85% of the 80% acceptable thermal zone of this research is located outside that of the ASHRAE in the comparable $T_{monthly\text{-}av\text{-}out}$ range (25.02°C to 28.29°C). Such a difference presents a scenario for users to stay thermally comfortable by relying only on autonomous thermal adaptations, without the assistance of *AC* systems. Finally, it can be concluded that although the ASHRAE Standard was established based on global data resulting in the more extensive range of the outdoor thermal data, it seems not to entirely reflect the actual thermal comfort requirement of users in these *NV* mediation buildings. Thus, this research suggests that local thermal comfort standards based on actual thermal comfort needs should be established.

Chapter 9

Respondents' Thermal Perceptions of Indoor Environments in Meditation Halls

Chapter 9: Respondents' Thermal Perceptions of Indoor Environments in Meditation Halls

Subjective thermal terms such as T_n and T_p were discussed in the previous chapter, which questioned the value of T_n in *ASV* analysis with regard to subjects' perceived thermal comfort in a neutral state. This chapter discusses the investigation of Thermal Comfort Sensation (*TCS*) to develop the current thermally comfortable and the acceptable thermal ranges for the subjects in *NV* meditation buildings. To explore T_c, apart from employing the Bedford's comfort state, this study creates Actual Thermal Perception Vote (*APV*) scale for $T_{c\text{-}APV}$ (thermal comfort temperature by *APV*). The obtained *APV* samples were correlated with T_{op} explore $T_{c\text{-}APV}$ and its range, followed by an investigation of *TCS*, which is a correlation between *ASV* and *APV* samples. The subjective thermal terms and ranges derived from this and the previous sections are compared and analysed before suggestions for the modification of the existing thermal acceptable ranges are provided. Besides, relationships between two meditation qualities and T_{op} will be analysed. The analytical results also allow this research to explore what thermal environment where the better meditative qualities can be found.

9.1 Suggestion for extension of the acceptable thermal ranges

The previous chapter discussed subjects' subjective thermal conditions, which are T_n and T_p, which were widely mentioned in the past research. However, the question of the thermally neutral state is raised, concerning whether such conditions are comfortable. The objective results of thermal sensation votes which lead to an exploration of T_n seem to ignore the pleasant of perceived temperature, which should be considered significant in thermal comfort.

According to ASHRAE Standard 55 (2004) and CIBSE Guide A (2006), thermal comfort is simply defined as a state of mind expressing the subjective evaluation of the current thermal environment, as mentioned in Chapter 3. On the other hand, the subjects' thermal experience is sometimes relatively difficult to differentiate between sensation and perception. The sensation is a physiological process of bioelectric signal transmission from receptors to the human brain. In contrast, the perception is described as a psychological process integrating multi-variate factors from external stimuli to personal interpretation, based on their background. In this case, it is questionable whether T_n derived from individual votes based on the ASHRAE thermal sensation scale is comfortable.

This section discusses Comfort Temperature ($T_{c\text{-}APV}$) derived by an Actual Thermal Perception (*APV*) scale, developed from a Thermal Pleasure Scale (Parkinson *et al.* 2015). Besides, the data samples of *APV* are correlated with those of *ASV* to examine their relationships and explore Thermal Comfort Sensation (*TCS*). All subjective thermal terms are derived, comprising T_n, $T_{n\text{-}PMV}$, T_p, $T_{c\text{-}Bedford}$, and $T_{c\text{-}APV}$; thermally acceptable and $T_{c\text{-}Bedford}$ ranges are then compared and illustrated. The comparison leads to an improvement of the acceptable thermal ranges to reflect the subjects' actual thermal comfort requirement. Moreover, $T_{c\text{-}APV}$ and T_n are examined to explore which thermal state can contribute to better meditative experiences: Difficulty in Relaxation (*DR*) or Impaired Instruction-Following Ability (*IFA*).

9.1.1 Actual thermal perception *(APV)* analysis

A total of 497 *APV* samples were correlated with T_{op} in linear and quadratic regressions. Figure 9.1 presents dashed blue and green lines representing linear and quadratic regressions, respectively. The comfort threshold, a horizontal grey dash line, was set at -1*APV* ('*Rather Comfortable*') perception, which is assumed as a threshold where the positive thermal attitude is initially experienced. The scatter plot shows that 406 (81.69%) of the 497 *APV* samples voted their comfortable condition between -3 ('*Very Comfortable*') to -1 ('*Rather Comfortable*'). Besides, the correlation reveals that *R* of the linear relation (*R* =

0.16) is 0.3 lower than that of the quadratic regression (R = 0.19) as presented in Eqn 66 and Eqn 67, respectively.

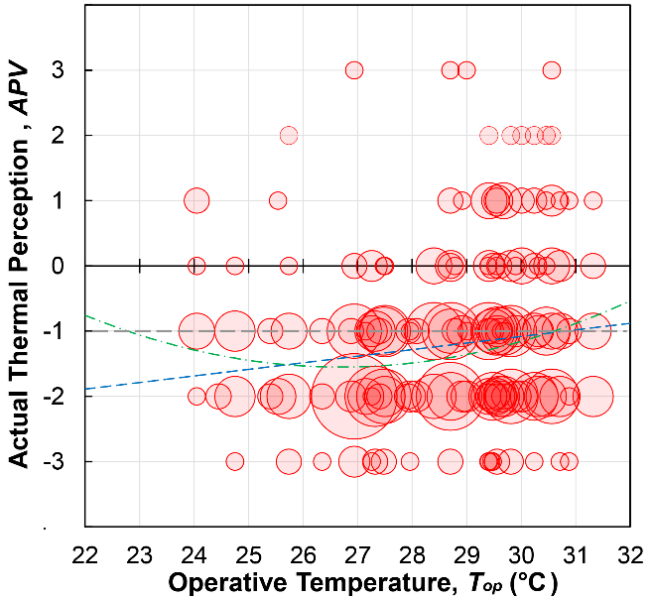


Figure 9.1: Scatter plot of APV and Top with regression lines

$$APV = 0.101\ T_{op} - 4.112\ (R = 0.16,\ R^2 = 0.02) \qquad \text{Eqn 66}$$

$$APV = 0.036\ T_{op}{}^2 - 1.922\ T_{op} + 24.103\ (R = 0.19,\ R^2 = 0.04) \qquad \text{Eqn 67}$$

T-test of both functions presents that a variation of *APV* may not occur by chance, but relate to a shift in T_{op}, since the significance levels of the independent and square-independent variables of the linear and quadratic models are at 0.001 (p = 0.001) and lower than 0.001 (p<0.001) (respectively). Although both models are statistically significant, this study selects the curvilinear relation to represent the relation between the factors due to slightly greater R-value and the higher significant level of the independent and square independent variables of the quadratic model.

According to Eqn 67 and Figure 9.1, the subjects' comfort condition seems not to be characterised as a single thermal condition, but a range due to two intersections between the quadratic regression and threshold comfort lines. In this case, the $T_{c\text{-}APV}$ (±1.00 *APV*) extends over 22.78°C to 30.60°C. The most comfortable perception ($T_{c\text{-}APV}$), which is the lowest point of the curvilinear

regression, is 26.69°C, found at -1.55 *APV*, which can be interpreted in terms of the participants feeling that they are in between '*Rather Comfortable*' and '*Comfortable*'.

9.1.2 Thermally comfortable sensation *(TCS)* analysis

Moreover, a relation between *ASV* and *APV* is correlated in linear and quadratic models, as shown in Figure 9.2, which displays a scatter plot of 496 pairs of *APV* and *ASV* data sets. The size of the bubbles represents the different number of the votes on between the two subjective scales. A dashed-grey line set the comfort threshold at -1 *APV* ('*Rather Comfortable*'), determined on the graph above 405 data (81.65%).

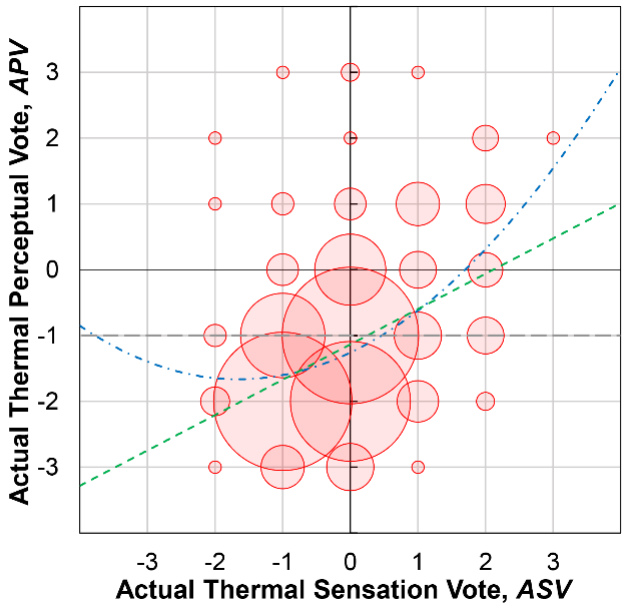


Figure 9.2: Scatter plot of ASV and APV with regression lines

$$APV = 0.537\ ASV - 1.135\ (R = 0.43,\ R^2 = 0.19) \qquad \text{Eqn 68}$$

$$APV = 0.148\ ASV^2 + 0.490\ ASV - 1.259\ (R = 0.45,\ R^2 = 0.21) \qquad \text{Eqn 69}$$

The results of the correlations reveal that the linear and quadratic relations can be expressed as shown in Eqn 68 and Eqn 69, of which the *R*-values are 0.43 and 0.45, respectively. The results of T-test of the independent and square independent factors show that both regression models have the same

significant levels lower than 0.001 (p<0.001) presenting that the change of *APV* does not occur accidentally, but relates to an increase of *ASV*. Consequently, the quadratic model with a slightly higher *R*-value is selected for describing the relationship.

According to the figure, two intersections of the reference (*APV* = -1) and quadratic regression lines found below -3 *ASV* and at 0.46 *ASV* cover the *ASV* scale from the '*Cold*' to '*Slightly cool*' side, to in-between '*Neutral*' and '*Slightly warm*' sensations. This range can be interpreted whereby volunteers may have a positive attitude toward the thermal environment when they feel '*Slightly cool*' to '*Cold*'. However, such an optimistic perspective may gradually decrease and disappear when they sense relative warmth (0.46 *ASV*). Furthermore, the lowest point of the regression representing the most thermally comfortable sensation (*TCS*) is found at the bottom of the quadratic regression line, where *ASV* and *APV* are equal at -1.66, which is in-between '*Slightly cool*' (-1 *ASV*) and '*Cool*' (-2 *ASV*) votes, and in-between '*Rather comfortable*' (-1 *APV*) and '*Comfortable*' (-2 *APV*) votes.

9.1.3 Comparison of subjective thermal votes

As reported previously, subjective thermal states such as T_n, T_p, $T_{c\text{-}Bedford}$, and $T_{c\text{-}APV}$ were investigated, as well as acceptable thermal ranges. Such terms define different subjective experience, describing thermally environmental states subjects may perceive. This section compares differences amongst those terms to establish a suggestion for an improvement of the acceptable thermal ranges for the *NV* meditation buildings.

Figure 9.3 presents a comparison of the subjective thermal terms obtained in the analysis: $T_{n\text{-}PMV}$ (26.24°C), T_n (29.87°C), and T_p (26.19°C). It is obvious that there is a large discrepancy (3.63C°) between T_n and $T_{n\text{-}PMV}$, while gaps between $T_{n\text{-}PMV}$ and T_p, T_p and $T_{c\text{-}APV}$, and $T_{n\text{-}PMV}$ and $T_{c\text{-}APV}$ are noticeably smaller at 0.05°C, 0.50°C, and 0.45°C, respectively. In this case, it can be mentioned that $T_{c\text{-}APV}$, $T_{n\text{-}PMV}$, and T_p present minor differences among the factors, while there is a noticeable discrepancy between these and T_n.

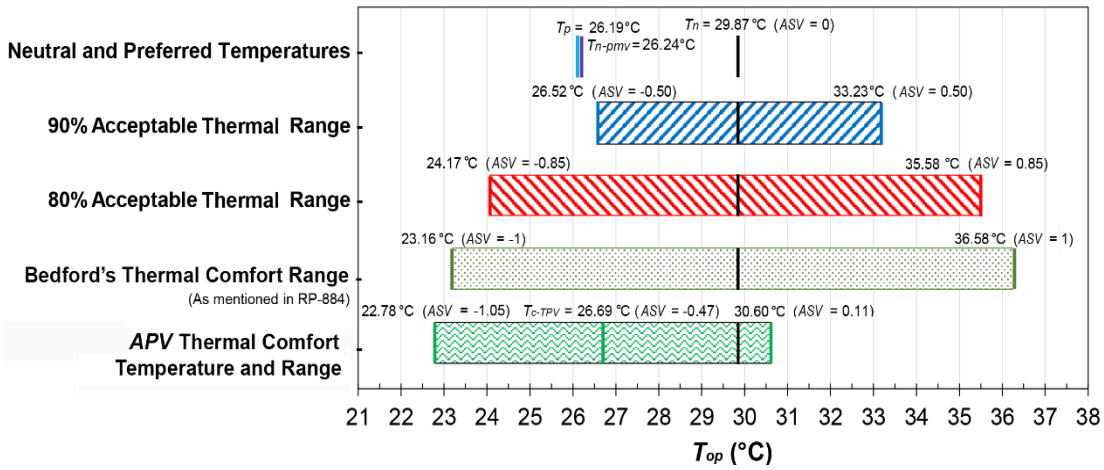


Figure 9.3: Comparison of subjective thermal terms of the project

Moreover, the 80% and 90% thermally acceptable ranges, which are ±0.85 *ASV* and ±0.5 *ASV*, extend from 26.52°C to 33.23°C and 24.17°C to 35.58°C, respectively. Those ranges are markedly narrower than that of the Bedford's thermal comfort ($T_{c\text{-}Bedford}$) range (±1 *ASV*) varying (23.16C°<*ASV*<36.58C°). According the $T_{c\text{-}APV}$ range (22.78°C and 30.60°C), its lower limit of $T_{c\text{-}APV}$ range (22.78°C) extends over the minimum value of $T_{c\text{-}Bedford}$ (23.16°C), and these of the 80% and 90% acceptable thermal ranges (24.17°C and 26.52°C), while the upper limit of the $T_{c\text{-}APV}$ range (30.60°C) covers just 0.73°C over T_n (29.87°C).

According to the comparison, it can be seen that T_n is located near the upper limit of $T_{c\text{-}APV}$ range. Such a location of T_n demonstrates that the subjects may perceive thermally comfortable and still have a positive attitude toward the environment, but not the most comfortable perception. If the temperature is higher than the upper limit of $T_{c\text{-}APV}$ but within the limits of the acceptable thermal ranges, the thermal environment is considered acceptable, but without thermal pleasure.

Furthermore, it is clear that minimum $T_{c\text{-}APV}$ extends below all the other lower limits. In this case, the cooler sides of T_n in the 80% and 90% acceptable ranges present not only thermal acceptability but also positive feedback toward the thermal environment, since they overlap with the $T_{c\text{-}APV}$ range. Thus, such an analytical result of the $T_{c\text{-}APV}$ range reveals different meanings of temperature

on each side of T_n. In this case, this study suggests that the acceptable ranges should not be equally weighted.

Based on the results of the *APV* analysis and extension of the $T_{c\text{-}APV}$ range over the lower limits of the other arrays, this study presents a possibility to extend the acceptable ranges toward the minimum value of the $T_{c\text{-}APV}$ band, since it demonstrates subjects' positive attitudes toward the thermal environment. In this case, it is suggested that the ASHRAE lower limit of acceptable ranges may be expanded close to the lower limit of the $T_{c\text{-}APV}$ band (approximately -1.05 *ASV*) when the adaptive model is applied in the *NV* meditation halls. However, please note that this is just an assumption to show the conceptual model of the imbalance acceptable thermal ranges, which is still in an early stage. Therefore, further research is required to establish these extended ranges.

9.2 Relationship of meditation qualities and indoor thermal factors

The previous section reveals that the respondents may have perceived a better thermal comfort at a lower temperature than T_n. This section investigates relationships between T_{op} and two meditation qualities (*IFA* and *DR*) to explore what thermal states between T_n and $T_{n\text{-}APV}$ the subjects may experience better meditation qualities.

Regarding the relationship of meditative qualities and a variation of indoor thermal environments, 497 and 498 data of *IFA* and *DR* data samples were plotted against T_{op} with linear and quadratic regression lines, presented as blue-dashed and red-dashed lines in Figure 9.4 (A) and (B) respectively, whose regressions can be expressed as shown in Eqn 70, Eqn 71, Eqn 72, and Eqn 73. According to the correlations, the analytical results reveal that the quadratic models of *DR* and *IFA* cannot better describe the relations between the factors than those of the simple linear regression, due to only a small difference in the third decimal number of R^2 between the models. Therefore, the linear and quadratic models are almost identical in this analysis.

As presented in Eqn 70 and Eqn 71, the R and R^2 of the correlation between DR and T_{op} are 0.34 and 0.113 for linear regression and 0.34 and 0.116 for the quadratic model, respectively. It can be seen that such a difference of R^2-values in the third decimal number between the two models may not considerably influence R. Likewise, in the *IFA* analysis, both regression models present the identical R (0.27) and R^2 (0.075), as shown in Eqn 72 and Eqn 73. Thus, for the sake of simplicity, this study selects the linear regression for representing the relationship between the factors.

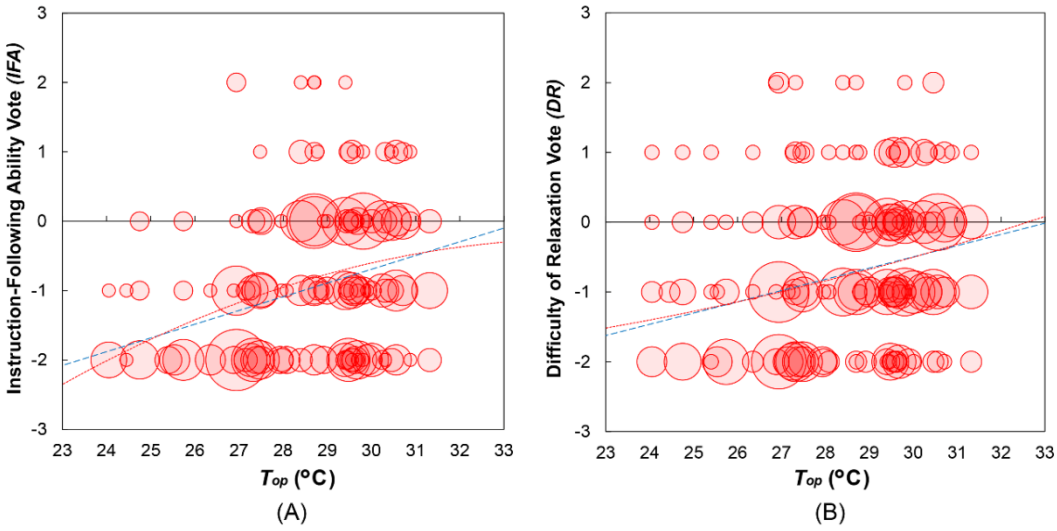


Figure 9.4: Scatter plots of IFA and T_{op} (A) and DR and T_{op} (B) with regression lines

$$IFA = 0.198\ T_{op} - 6.633.\ (R = 0.34,\ R^2 = 0.113) \quad \text{Eqn 70}$$

$$IFA = 1.045T_{op}^2 - 0.15\ T_{op} - 18.453.\ (R = 0.34,\ R^2 = 0.116) \quad \text{Eqn 71}$$

$$DR = 0.161\ T_{op} - 5.328.\ (R = 0.27,\ R^2 = 0.075) \quad \text{Eqn 72}$$

$$DR = 0.005T_{op}^2 - 0.12T_{op} - 1.402.\ (R = 0.27,\ R^2 = 0.075) \quad \text{Eqn 73}$$

According to the correlations, gradient factors of the independent variable (T_{op}) are 0.198 for the *IFA* model and 0.161 for the *DR* model. Besides, the models present that the respondents' meditative qualities gradually change according to an increase of T_{op}. T-statistic of the gradient factors shows that subjects' *IFA* and *DR* vary according to a shift of T_{op}, since significance levels of the coefficient of the independent variable (T_{op}) are lower than 0.001 (p<0.001).

Such statistical significances of both correlations can be interpreted in terms of the variations in meditative qualities not occurring coincidentally, but due to a shift in T_{op}. Furthermore, at T_n (29.87°C), *IFA* is -0.75, indicating that the subjects may experience in-between '*Moderately easy to follow*' (*IFA* = 0) and '*Slightly easy to follow*' (*IFA* = 0). Besides, at the same thermal state, *DR* is -0.52 which is in-between '*Moderately relaxed*' (*DR* = -1) and '*Slightly relaxed*' (*DR* = 0).

On the other hand, when T_{op} shifts from T_n to $T_{c\text{-}APV}$ (26.69°C), the scores of *IFA* and *DR* drop to -1.35 and -1.03, respectively. This improvement demonstrates that the subjects may perceive just over '*Moderately easy*' for *IFA* and '*Moderately relaxed*' for *DR*. Such reductions of meditative scores lead to a conclusion that the subjects in *NV* mediation halls in Thailand might perceive better meditative experience when they are in lower temperatures than T_n. Consequently, it can be concluded that T_n may not characterise the most comfortable thermal perception, and it may not provide better meditative quality than $T_{c\text{-}APV}$.

9.3 Discussion of chapter 9

9.3.1 Anticipation of the *ASV* and *APV* regression variation in different thermal conditions

Based on the quadratic regression of *TCS* (see Figure 9.2), the result reveals that the subjects seem to have a positive attitude toward a range of '*Cold*' (-3 *ASV*) to the '*Slightly warmer*' (0.46 *ASV*). Perceiving over the +0.46 *ASV* which is in-between '*Neutral*' and '*Warm Sensation*' may result in thermal discomfort due to warmth. This analysis demonstrates that when the subjects are in a warm environment or when the value of *SD* is positive, cooler than neutral thermal sensation may lead to thermally comfortable perception. This study found that the curvilinear regression line touches a bottom at the cooler sensation than T_n. Besides, the *TCS* extends over the entire area of the '*Cool*' to '*Cold*' sensation to just over the thermal neutrality state (0.46 *ASV*). However, according to the results obtained from the *ASV* and *APV* analysis of this chapter, it is anticipated

that the lowest point of the regression line may be shifted opposite to the different climatic conditions as the behaviour of *SD*, as discussed in the RP-884 report.

For example, when the subjects are in a moderate climatic environment, where temperatures are neither '*Warm*' nor '*Cool*', the bottom point of the quadratic regression line may be approximate to the neutral sensation (*ASV* = 0), with an equal extension of the $T_{n\text{-}APV}$ range from T_n. In contrast, when the subjects reside in cool to cold environments, the lowest point of the curve is expected to be shifted toward the warm side in the positive value of *ASV* scale, and act inversely to the results obtained from this study. Thus, further field studies in a cool or cold environment are recommended to be conducted.

This research found that this hypothesis seems to link with the theory of '*alliesthesia*' (Cabanac 1971), describing the satisfaction of the perceived contrast stimuli to the existing internal state of the human body. This phenomenon is considered to be a driving force in human thermal comfort behavioural adaptation, aiming to achieve a higher level of thermal pleasure, which is a significant primal activity of humans.

9.3.2 Modification of the acceptable thermal ranges

The comparisons of all the derived thermal sensation states show that the $T_{c\text{-}APV}$ range expands out of the other lower limits of 80% and 90% acceptable thermal ranges, and that of $T_{c\text{-}Bedford}$. Such an extension toward low temperature indicates a possibility to extend the acceptable zone to the minimum value of $T_{c\text{-}APV}$ range, since it still contains a positive attitude toward the thermal environment. Furthermore, the results of the *DR* and *IFA* analyses also support this conceptualisation of the acceptable range modification, since the better qualities of meditation can be found when the temperature is lower than T_n. However, the upper limit of thermal acceptability located outside the $T_{c\text{-}APV}$ range is still questionable in terms of whether it should remain unchanged or be narrowed down toward the maximum range of the $T_{c\text{-}APV}$.

9.4 Chapter conclusion

This section compares the derived subjective thermal states, which are T_n, $T_{n\text{-}PMV}$, T_p and $T_{c\text{-}APV}$, $T_{c\text{-}APV}$ range, and acceptable thermal ranges. A total of 499 subjective votes obtained during the survey were analysed in linear and quadratic models in this section. The results reveal that subjects' T_n (29.87°C) is significantly higher than $T_{n\text{-}PMV}$ (26.24°C) and T_p (26.19°C). Furthermore, the 80% and 90% acceptable thermal ranges, $T_{c\text{-}Bedford}$ range, and $T_{c\text{-}APV}$ range were compared. The comparison shows that the $T_{c\text{-}APV}$ range (22.78°C to 30.60°C) extends over the lower limits of the other ranges. Besides, the upper limit of the $T_{c\text{-}APV}$ range (30.60°C) is higher than that of T_n by 0.73°C.

The quadratic regression of *APV* and T_{op} relationship presents that $T_{c\text{-}APV}$ (26.69°C) is located closer to T_p (26.19°C) and $T_{n\text{-}PMV}$ (26.24°C) than T_n (29.87°C). In this regard, it can be interpreted that T_n may not provide the most comfortable thermal condition for the subjects, while the lower temperature than such a neutral state may be more preferred and comfortable. Besides, the $T_{c\text{-}APV}$ range also reveals that both sides of the acceptable ranges should not be equally weighted. Temperatures lower than T_n and thermal sensations cooler than thermal neutrality seem to contain positive feedback toward the perceived thermal environments for the subjects in the *NV* meditation halls. In contrast, the other thermal condition found outside the $T_{c\text{-}APV}$ range may be considered just '*Acceptable*', without pleasure toward the thermal environments. Furthermore, the correlations present positive relationships between T_{op} and subjects' meditation qualities (*IFA* and *DR*) demonstrating that the respondents may perceive better meditative experience when staying in $T_{c\text{-}APV}$ than T_n.

Besides, results suggest a possibility to extend lower limits of the acceptable thermal ranges toward the minimum value of the $T_{c\text{-}APV}$ range. However, it is an assumption based on the T_n and $T_{c\text{-}APV}$ analyses; therefore, this can be a research gap for further research to explore the actual limits of the extended ranges.

Chapter 10

Thermally Adaptive Solutions of Meditators

Chapter 10: Thermally Adaptive Solutions of Meditators

The previous chapter discussed the user's capability to stay in the space in a broader range of thermal environments without the assistance of *AC* systems. The wider thermal acceptance and higher thermal neutrality of the subjects were supposed to be ascribed to be attributed by human thermal adaptions. In this chapter, subjects' thermally adaptive techniques were collected from the questionnaire survey and observations are reported and discussed. The analysis covers subjects' behavioural and psychological thermal adaptations, such as an analysis of the most performed mode of adaptation and sequences of actions, variation of subjects' *CLO*, and the impact of unquantifiable factors on the subjects' thermal assessment. It should be noted that physiological factors are omitted in this research.

10.1 Survey results of users' thermal adaptation

10.1.1 Subjects' thermally adaptive actions

As mentioned in Chapter 7, this research found that the T_n derived from the subjects' *ASV* is higher than $T_{n\text{-}PMV}$, and the acceptable thermal ranges of the adaptive model of this project are wider than that of the international standard (ASHRAE). Such variations are supposed to be attributed to subjects' thermal adaptive abilities in meditation halls, which were investigated by questionnaire survey and behavioural observation, as discussed in this section.

The questionnaire asked participants about thermal adaptations they expected to perform, and which they had already performed in the halls after finishing meditations. The answers to first question (expected to performed actions) consist of 17 choices, as mentioned in Chapter 5. The users could provide only one or two answers depending on their thoughts. After that, the following question asked the subjects to rank the order of the first three actions performed in the halls.

A total of 223 performed adaptive action votes were collected. It can be noticed that the number of samples is noticeably lower than that of *ASV* (499 samples). This may result from a long period of the subjects' understanding and finishing the question and answers. Such difficulties also seemed to require great effort to read and complete this task, and consequently many participants intentionally skipped this section.

According to the database, 223, 200, and 185 data samples of the first, second, and third sequences of thermal adaptations (respectively) were collected, as shown in Figure 10.1. The most performed solution (28.3%) in the first sequence of action is '*Accepting the thermal environment as it is*', followed by '*changing posture and gesture*' (11.2%), then '*modifying environment*' (10.8%). Similarly, 20.0% of the subjects reported the solution of accepting the current environmental condition as the most performed in the second sequence of action, followed by '*Resist the thermal environment*' (16.0%) and '*Deviating attention from the thermal environment to other topics*' (15.5%) for the second and third most performed actions. The most performed action in the third sequence was '*Resist the thermal environment*' (28.60%), followed by '*Accepting the current thermal condition*' (14.60%). Shared third place among the most voted actions in this category were changing activity, deviating focus, and modifying environment, each with 7.6%. In conclusion, it can be seen that acceptance of the current thermal environment is the most voted solution in the first two sequences of adaptations, while thermally dissatisfied tolerance is the most reported adaptive action in the third sequence.

To explore the most performed mode of thermal adaption, all the votes of the performed actions presented in Figure 10.1 were categorised into three major groups: personal, psychological, and environmental adjustments, as shown in Figure 10.2. According to the analytical results, personal adjustments such as relocation, *CLO* modification, changing *MET*, and taking a break might play an important role in the first sequence of adaptation, since these collectively accounted for 53.15% of participant selections, followed by psychological and

environmental adaptations, accounting for 36.04% and 10.81% of the votes, respectively (Figure 10.3).

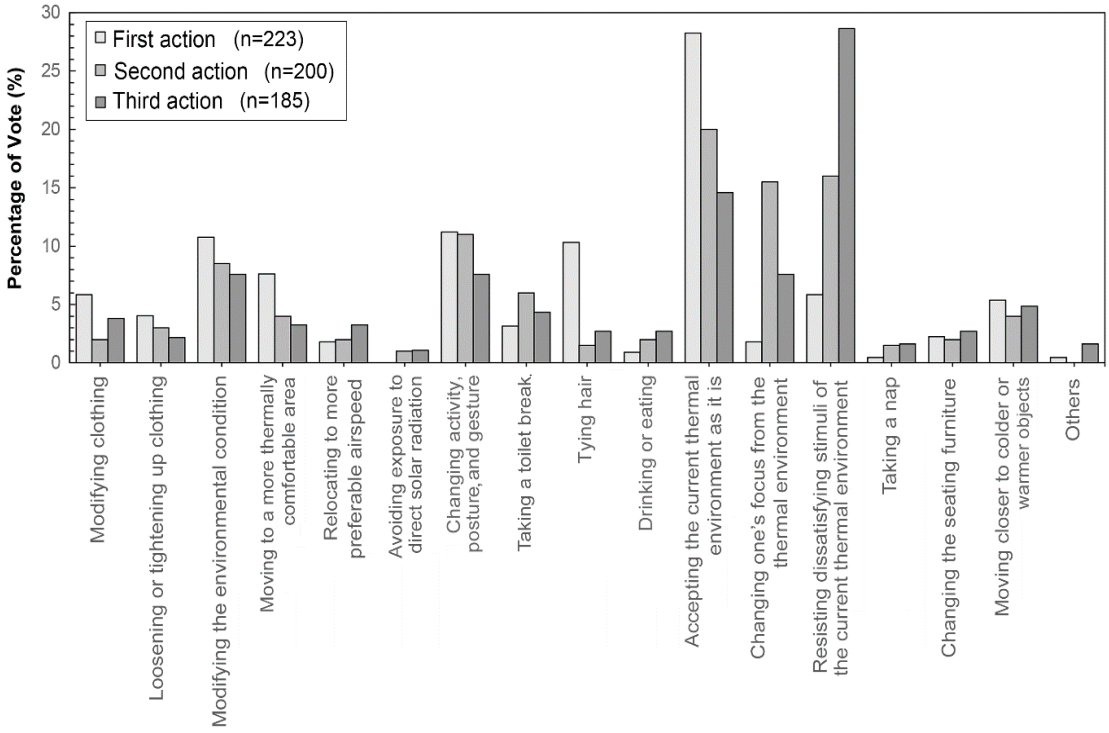


Figure 10.1: Percentage of subjects' thermal adaptations performed found in the meditation halls

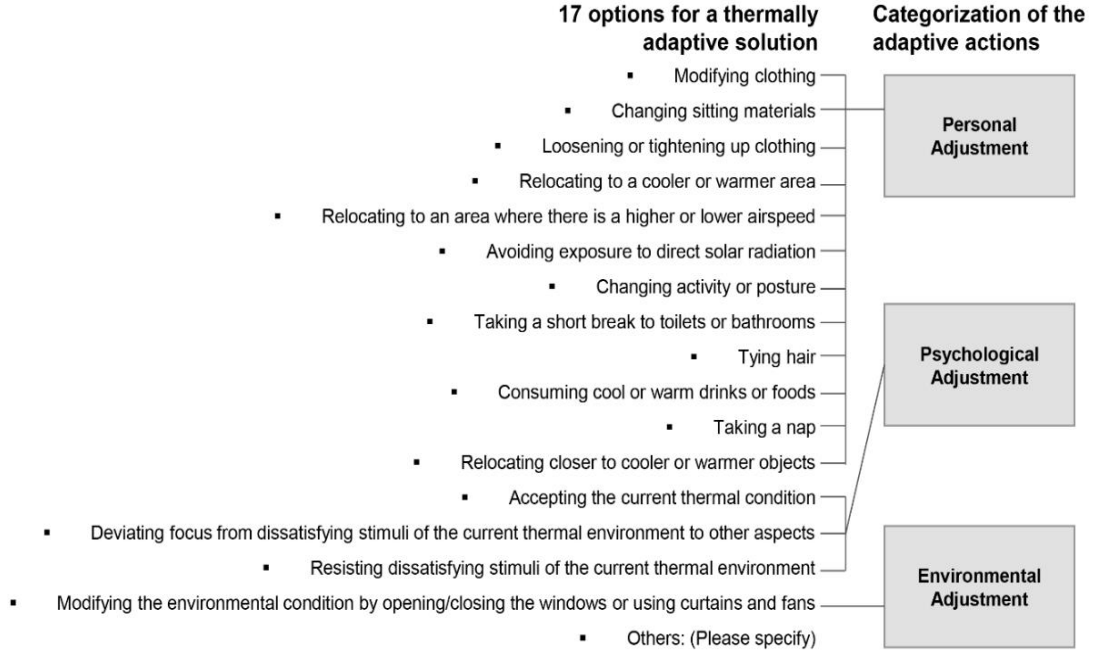


Figure 10.2: Categorization of the adaptive action votes

Moreover, the most performed solution shifts from personal modification to psychological adjustment in the second and third sequences of the adaptive actions, accounting for 51.50% and 51.65% of the respondents, respectively. According to the figure, it can be seen that the environmental modification is still not the most performed action in the second and third sequences, accounting for only 8.50% and 7.69%, respectively.

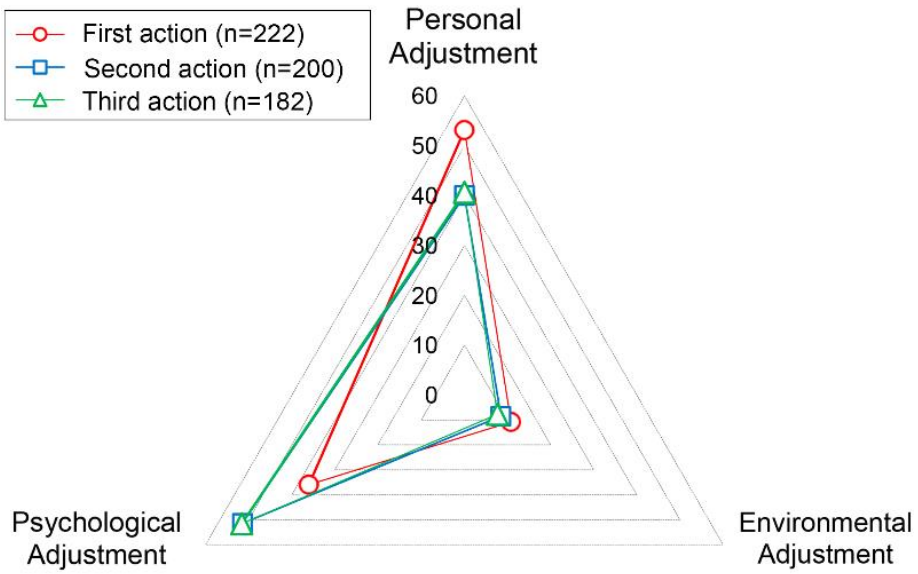


Figure 10.3: Percentage of performed thermal adaptations clustered into three major groups

The data were also further clustered into two major groups, psychological and behavioural adaptations, derived from the three modes of thermal adaptation identified by DeDear *et al.* (1997) (as discussed in Chapter 4). In this case, the aspects of environmental modification are included in the cluster of behavioural adjustment. Figure 10.4 presents that in the first sequence of the adaptive actions, 63.96% of the subjects may have modified their personal and environmental factors before adjusting their psychological variables, accounting for 36.04% of the votes. However, the psychological adaptation may have played a pivotal role in the later sequences. The percentage of behavioural adaptation drops to 48.50% and 48.35%, while the votes of the counterpart increase to 51.50% and 51.65% in the second and third sequences of the actions, respectively.

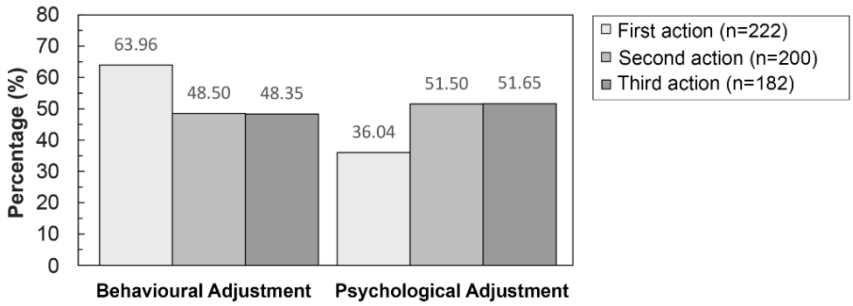


Figure 10.4: Percentage of performed thermally adaptive actions clustered into two major groups

10.1.2 Adjustment of subjects' *CLO* under the cultural and organizational conditions

Clothing insulation value (*CLO*) is an influential factor in the users' thermal sensation. Suitable *CLO* may lead to thermal comfort, and it is considered an adaptive opportunity which may extend acceptable thermal ranges of the users. However, Brager and DeDear (1998) mentioned that the ability of thermal adaptation is performed under an adaptive opportunities and constraints which may encourage or discourage subjects' capability of adaptation. Such factors may finally result in a variation of personal thermal sensation assessment. Thus, it is questioned how much the users' can adapt their *CLO* under cultural and organisational conditions of meditation centres. The *CLO*-calculating method is referred from the standard values as indicated in the CIBSE Guide: A (2006) and ASHRAE Standard-55:2010 (2010) (see Chapter 5). The statistical analysis reveals that an average *CLO* is 0.56 and the lower and upper limits of all subjects' *CLO* are 0.24 and 1.01, respectively.

It should be noted that due to various organisational rules, practising attire differed among case study sites. The *VRW* centre requires the participants to wear a meditation uniform, to ensure appropriate dress throughout the training periods, while clothing choices in *PT* and *KJS* are optional. Men's basic uniform found in *VRW* comprises of a white, short-sleeved shirt with long trousers, while women wear a long-sleeved blouse with a pashmina (shawl), and a long skirt or trousers, as Figure 10.5 presents. Additional layers such as shorts and T-shirts might be added for extra modesty.



Figure 10.5: Example of male and female general meditation uniform in VRW

The minimum *CLO* of men's meditation uniform found in *VRW* was 0.33, comprising the following:

- Underpants (*CLO* = 0.03)
- A short-sleeve shirt (*CLO* = 0.15)
- Trousers (*CLO* = 0.15)

In contrast, the woman' lowest *CLO* meditation uniform, which is slightly higher than that of the men, was 0.39, comprising:

- Underpants (*CLO* = 0.04)
- A long-sleeve shirt (*CLO* = 0.20)
- A long skirt (*CLO* = 0.15)

Besides, an extra 0.10 of *CLO* accounting for the insulation value of a meditation mat is included in the total insulation value of participants who applied it. Although such a practising uniform is not compulsory in *PT* and *KJS*, the subjects' outfit was carefully selected based on appropriateness and respect of cultural etiquette. For instance, the top must not be revealing and must cover shoulders. In some monasteries, where strict cultural rules exist, clothing may be required to cover the elbows. Tight-fitting pants are not allowed, and length of bottoms must cover the knees. The survey results of subjects' *CLO* in all case studies are presented in Table 10.1.

Table 10.1: Summary of subjects CLO categorized by gender and place of study

Category	Place	*n*	*CLO*			
			Min	**Max**	**Mean**	***std***
Male	*VRW*	28.00	0.43	0.58	0.47	0.05
	PT	19.00	0.24	0.95	0.52	0.22
	KJS	28.00	0.33	1.00	0.49	0.17
Female	*VRW*	189.00	0.39	1.01	0.56	0.09
	PT	163.00	0.34	1.01	0.58	0.18
	KJS	59.00	0.34	1.01	0.58	0.18
Season	Winter	228.00	0.24	1.01	0.60	0.17
	Monsoon	259.00	0.24	1.01	0.52	0.12

10.1.2.1 *CLO of the VRW volunteers*

The minimum woman's *CLO* assembly of *VRW* is 0.39, which slightly is lower than that of the men (0.43), since the female subjects sat directly on the floor without a meditation mat. In contrast, the upper limits of male and female *CLO* are 0.58 and 1.01. Table 10.2 presents a summary of maximum and minimum *CLO* assembly in different sites.

No training attire was required in *PT*. Both meditation uniforms and casual outfits are allowed, depending on individual preferences. However, the majority of the building users seemed to prefer to dress in the training uniform. The survey result presents that the lower and upper limits of female *CLO* are higher than those of the male. The minimum and maximum women's *CLO* found in this site were 0.34 and 1.01, while those of males were 0.24 and 0.95, respectively.

10.1.2.2 *CLO of the KJS volunteers*

For *KJS* subjects' *CLO* values, the majority of participants dressed casually. The maximum and minimum male *CLO* values were 0.33 and 1.00, whereas female *CLO* extremes were slightly higher at 0.34 and 1.01, respectively, as

shown in Table 10.2. It should be noted that the lower and upper limits of female *CLO*-assembling values in *KJS* are identical to these of the *PT*.

Table 10.2: Summary of maximum and minimum CLO assembly

Item	*CLO*	Male						Female					
		VRW		***PT***		***KJS***		***VRW***		***PT***		***KJS***	
		Max	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
Female underpants	0.04							✔	✔	✔	✔	✔	✔
Men underpants	0.03	✔		✔	✔	✔	✔						
Short-sleeve shirt	0.15	✔		✔	✔		✔		✔		✔		✔
Long sleeve shirt	0.20					✔		✔		✔		✔	
T-shirt	0.09	✔		✔		✔		✔	✔				
Jacket	0.35			✔		✔		✔		✔		✔	
Shorts	0.06				✔								
Extra layer of shorts	0.06	✔		✔		✔		✔		✔		✔	
Trousers	0.15	✔	✔	✔		✔	✔	✔					
Long sleeve skirt	0.15									✔	✔	✔	✔
Socks	0.02			✔		✔		✔		✔		✔	
Meditation mat	0.10	✔		✔		✔		✔		✔		✔	
Total		**0.58**	**0.33**	**0.95**	**0.24**	**1.00**	**0.33**	**1.01**	**0.39**	**1.01**	**0.34**	**1.01**	**0.34**

10.1.2.3 *Seasonal variation of CLO*

CLO variation over the winter and monsoon seasons is presented in Table 10.1. A total of 487 *CLO* data were analysed, of which 228 and 259 data samples were collected in the winter and monsoon seasons, respectively. The results reveal that the subjects' maximum and minimum *CLO* values seem not to be affected by a seasonal variation, since the lower and upper limits remain unchanged at 0.24 and 1.01 in both seasons. However, it can be noticed that there is a 0.08 difference of subjects' average *CLO* between the seasons. The mean *CLO* slightly drops by 0.08 from 0.60 in winter to 0.52 in the monsoon season, with *std* of 0.17 and 0.12, respectively.

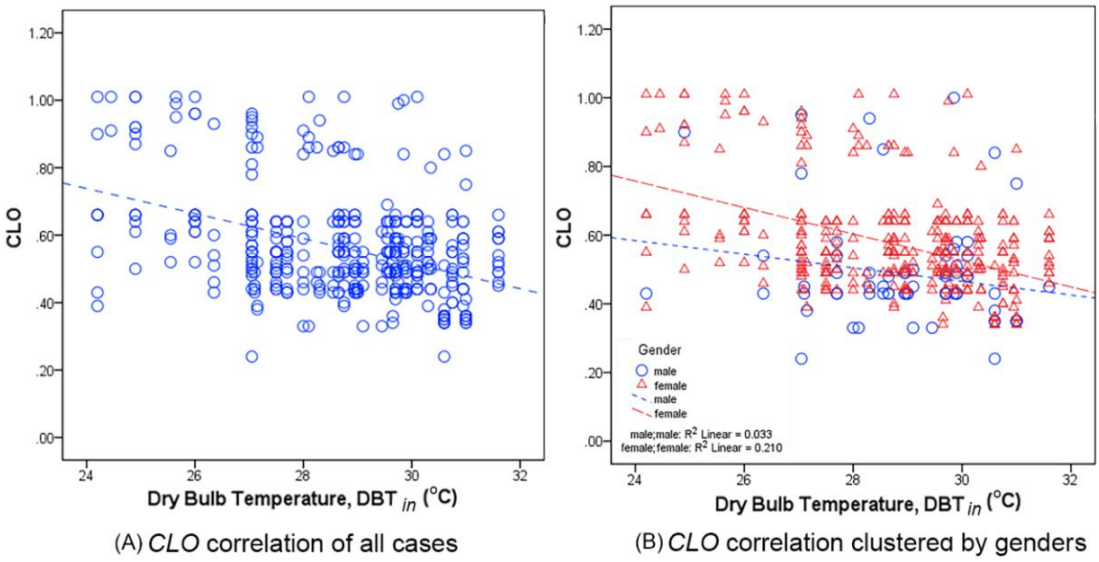
10.1.3 Relationship between subjects' *CLO* and DBT_{in}

The previous discussion presented variations of subjects *CLO* by places, genders, and seasons. This section focuses on a relationship of DBT_{in} and subjects' *CLO*. 486 out of 487 *CLO* data samples' CLO_{all} were plotted against DBT_{in} in a scatter plot (Figure 10.6(A)). A linear regression presents a decrease of CLO_{all} according to an increase of DBT_{in}. The relation of such factors can be expressed as Eqn 74 (R = 0.42), which presents that for every 1°C increment of DBT_{in}, *CLO* may decrease by 0.037 comparable to the *CLO* of female underpants (*CLO* = 0.04). A T-test of the coefficient of the independent variable reveals that significant of such a factor is lower than 0.001 (p<0.001), confirming the relationship between CLO_{all} and DBT_{in}.

$$CLO_{all} = -0.037\ DBT_{in} + 1.629\ (R = 0.42,\ R^2 = 0.17) \quad \text{Eqn 74}$$

$$CLO_{male} = -0.020\ DBT_{in} + 1.058\ (R = 0.18,\ R^2 = 0.03) \quad \text{Eqn 75}$$

$$CLO_{female} = -0.39\ DBT_{in} + 1.682\ (R = 0.46,\ R^2 = 0.21) \quad \text{Eqn 76}$$



(A) *CLO* correlation of all cases (B) *CLO* correlation clustered by genders

Figure 10.6: Correlations of DBT_{in} and CLO_{all} (A) and DBT_{in} and CLO clustered by gender (B)

Furthermore, CLO_{all} were categorised by gender and analysed in a scatterplot, as shown in Figure 10.6(B). The graph demonstrates different slopes of the

regression lines of male *CLO* (CLO_{male}) and female *CLO* (CLO_{female}), by which their relation can be expressed as shown in Eqn 75 and Eqn 76, with *R* of 0.18 and 0.46, respectively.

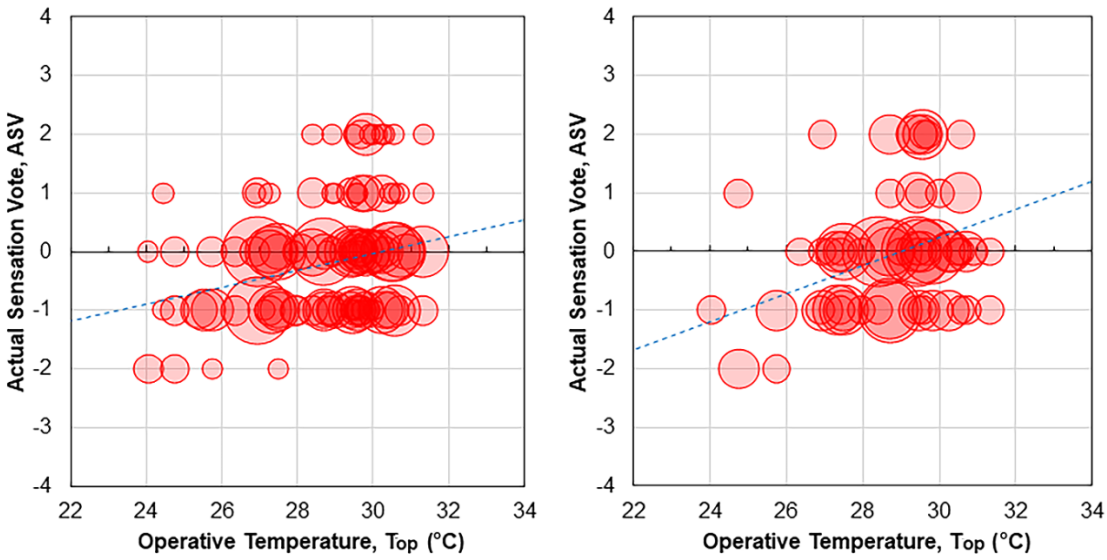
A significant level of T-test of the coefficient of an independent factor for the female model reveals that variations of CLO_{female} do not occur accidentally, but due to a shift of DBT_{in} since significance level is lower than 0.001 (p<0.001). However, the CLO_{male} model fails to reach this significance, since the *p*-value is 0.117 (p>0.05). This indicates that a variation of CLO_{male} may not relate to a DBT_{in} shift. In this case, although the slope factors of the two regression lines between gender are noticeably different at -0.020 (Eqn 75) and -0.390 (Eqn 76), they are not comparable in this analysis due to the statistical insignificance of the CLO_{male} model.

10.1.4 Relationship between personal ventilation background and thermal sensation evaluation

Apart from the psychologically adaptive actions reported by the subjects, this research found that subjects' ventilation background may influence thermal sensation vote. 299 and 122 *ASV* samples were collected from the subjects who mentioned that they spent their daily life in *NV* and *AC* spaces.

Figure 10.7 (A) and (B) shows scatter plots of *ASV* laid against T_{op} for the subjects from *NV* and *AC* backgrounds, respectively. According to the figure, the regression lines present positive relations between the factors in both cases. The linear relationships between T_{op} and subjects' *ASV* from *NV* and *AC* backgrounds can be expressed as shown in Eqn 77 and Eqn 78, with *R*-values of 0.289 and 0.348, respectively. According to the functions, *NV* people may be less thermally sensitive than those of *AC*, since the gradient factors of the independent variables of the *NV* group (0.143) is less than that of the *AC* (0.239). T-test of the gradient factors of T_{op}, reveals significance lower than 0.001 (p<0.001) for both relations, which can be interpreted in terms of changes in subjects' thermal sensation not occurring accidentally, but in relation to a variation of T_{op}. In this case, the T_n of the volunteers accustomed to *AC* spaces

($T_{n\text{-}AC}$ = 29.00°C) may require 1.23°C more cooling to achieve comfortable thermal conditions than suggested by *NV* scales ($T_{n\text{-}NV}$ = *30.23*°C).



(A) ASV_{NV} *analysis (n = 299)* *(B)* ASV_{AC} *analysis (n = 122)*

Figure 10.7: Scatter plots of the subjects from NV (A) and AC (B) background

$$ASV_{NV} = 0.143\ T_{op} - 4.322\ (R = 0.289,\ R^2 = 0.084) \quad \text{Eqn 77}$$

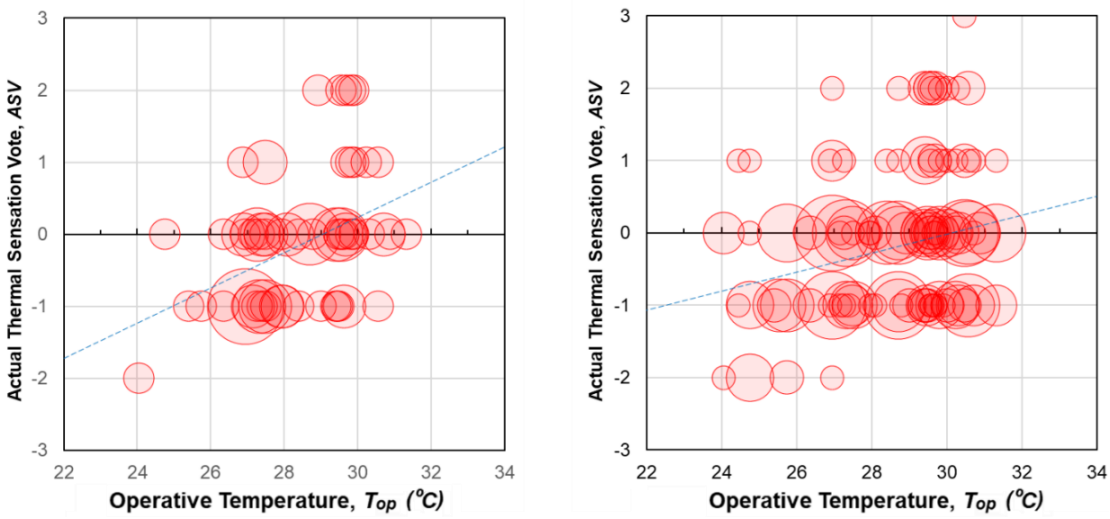
$$ASV_{AC} = 0.239\ T_{op} - 6.931\ (R = 0.348,\ R^2 = 0.121) \quad \text{Eqn 78}$$

The analytical results discussed in this section lead to the conclusion that the subjects seem to perform not only single adaptive action, but a combination of solutions, which are both behavioural and psychological adaptions. Differences of personal thermal assessment may be unconsciously affected by personal ventilation background.

10.1.5 Relationship between meditation experiences and T_n

Apart from the influence of personal ventilation background on T_n, this research found a variation of T_n between two groups of meditators according to their meditation experiences. The 373 of the 499 *ASV* samples were clustered into two groups, of which 88 and 285 votes were categorized in less than one-year experience (ASV_{inexp}), and more than one-year experience (ASV_{exp}), respectively. Figure 10.8 (A) and (B) present regressions of ASV_{in} and ASV_{inexp}

ploting against T_{op}, which relations can be expressed as shown in Eqn 79 and Eqn 80, with 0.426 and 0.268 *R*-values, respectively.



(A) ASV_{inexp} *analysis (n = 88)* *(B)* ASV_{exp} *analysis (n = 285)*

Figure 10.8: Regression analyses of ASV_{inexp} *(A) and* ASV_{exp} *(B)*

$$ASV_{inexp} = 0.245\ T_{op} - 7.115\ (R = 0.426,\ R^2 = 0.181) \qquad \text{Eqn 79}$$

$$ASV_{exp} = 0.131 T_{op} - 3.948\ (R = 0.268,\ R^2 = 0.072) \qquad \text{Eqn 80}$$

T-statistical studies present significant levels of the coefficient of independent variable lower than 0.001 (p<0.001) in both cases. Such significance can be interpreted in terms of changes in ASV_{inexp} and ASV_{exp} being attributable to a variation of T_{op}. Besides, the functions of ASV_{inexp} and ASV_{exp} reveal a difference of T_n by 1.09°C between the experienced ($T_{n\text{-}exp}$ = 30.14°C) and inexperienced ($T_{n\text{-}inexp}$ = 29.05°C). Furthermore, the latter group presents greater thermal sensitivity, since the slope factor of the ASV_{inexp} function is 0.245, which is 0.114 lower than that of the ASV_{exp} function (0.131).

10.2 Observation of subjects' environmental interaction

Thermal environmental adaption of building users may be caused by thermally dissatisfied perception triggering adaptive behaviour to improve the thermal environment. It is pervasively known that an elevation of indoor airspeed can

alleviate thermal dissatisfaction of the building users caused by air temperature, thus environmental controls such as fans, curtains, and windows are commonly provided in *NV* buildings in Thailand. In this section, the functions of windows, doors, and electrical fans available in the halls are investigated.

10.2.1 Internal driving force of environmental adaptation

Before analysing the observation data of the environmental modifications, this section discusses the survey and observation results to investigate the most influential driving forces on the building users' environmental modification. The main focus is v, since it is the only thermal environmental factor adjustable in the halls. Thus, a scale of airspeed preference (v_P) was created, with a three-point Likert scale (Chapter 5). The analytical method of this question concerns T_p. In this case, the votes of '*No Change*' at each v interval were split into half and combined with data of '*Prefer Higher Airspeed*' and '*Prefer Lower Airspeed*', then the data clusters were analysed in linear and quadratic regressions, and a Probit model with environmental factors of v and DBT_{in}, binned by 0.05 m/s and 0.6°C, respectively.

Regression models, which are linear and quadratic regressions, and Probit model, were employed to analyse relationships between v_p and v, and v_p and $DBT_{av\text{-}out}$ as Figure 10.9 (A) and (B) present. T-test of the linear and quadratic regressions of v_p and v presents significance levels at 0.801 and 0.206 (p>0.05), respectively, representing that a change of v_p does not relate to v. Similarly, the Probit model supports this since a significance level of Chi-square (x^2) is 0.592 (p>0.05). In contrast, Figure 10.9 (B) reveals that the proportion of v_p seems to increase linearly according to DBT_{in} since p-value is 0.04 (p<0.05), which is lower than that of the quadratic regression (p = 0.17 (p>0.05)). This analysis demonstrates that the proportion of v_p does not vary accidentally but relates to a shift in DBT_{in}. Therefore, this result can be interpreted in terms of DBT_{in} being an internal driving force to trigger human behavioural adaptation.

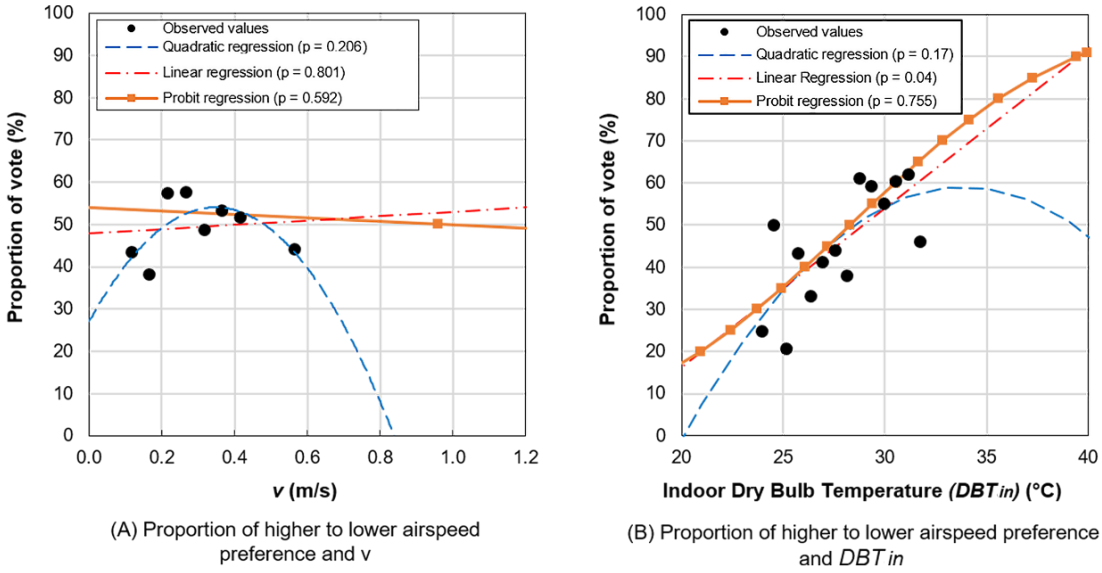


Figure 10.9: Probit model of v_p and v (A) and v_p and $DBT_{in\text{-}av}$ (B)

10.2.2 Environmental factors and controls

As mentioned in the previous section, the proportion of v_p votes seems more varied to DBT_{in} than *v.* Such a preference seems to be able to consider an internal driving force to trigger users' adaptive behaviour to improve the current hall thermal condition. In this case, this research found that in addition to the DBT_{in} presenting a positive relation with v_p, the elevation of the indoor *v* also relates with $DBT_{av\text{-}in}$, as indicated in Eqn 81 (R = 0.60).

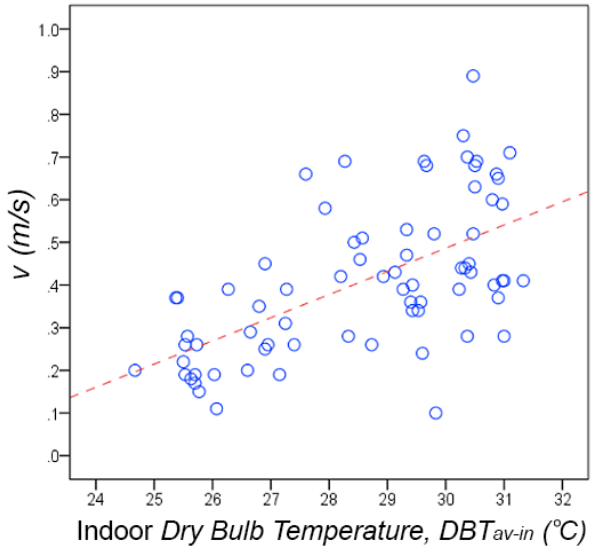


Figure 10.10: Linear regression of $DBT_{av\text{-}in}$ and v

$$v = 0.054\ DBT_{av\text{-}in} - 1.143\ (R = 0.60,\ R^2 = 0.36) \quad \text{Eqn 81}$$

The gradient factor of the independent variable of $DBT_{av\text{-}in}$ shows that, for every 1°C increment, v may be elevated by approximately 0.05 m/s. T-test also shows that the independent variable is significant (p<0.001), which suggests that a rise of v may not occur accidentally, but due to a shift of $DBT_{av\text{-}in}$.

Furthermore, the increasing incidence of v is questioned if it is attributed to the operations of the environmental controls, which are the windows and fans. The percentage of window function (F_{window}) and fan function (F_{fan}) were correlated, as shown in Figure 10.11 for both devices, and this relationship can be expressed as shown in Eqn 82 (R = 0.68). T-test of the coefficient of the independent variable shows statistical significance lower than 0.001 (p<0.001), revealing that F_{window} does not occur by chance, but relates to F_{fan}.

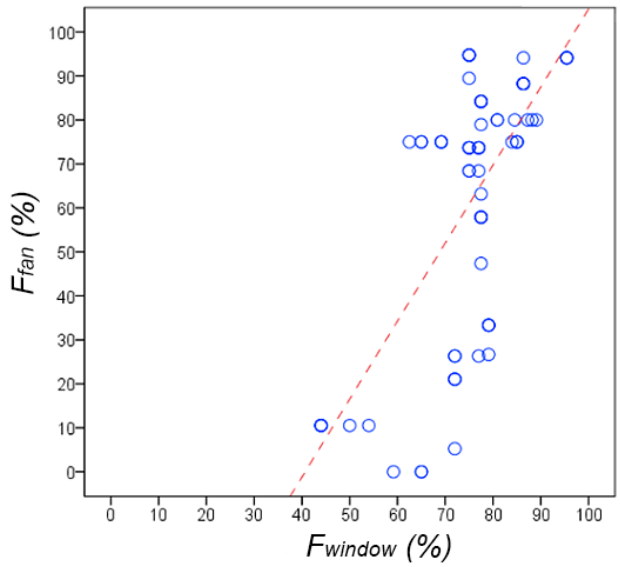


Figure 10.11: Percentage of fan and window operations

$$F_{fan}\ (\%) = 1.773\ F_{window}\ (\%) - 72.127\ (R = 0.68,\ R^2 = 0.47) \quad \text{Eqn 82}$$

10.2.3 External driving factors on subjects' environmental adaptation

The previous section discussed the relation of F_{fan} and F_{window}, investigating causal factors of operation. This section analyses relations of the environmental control functions and indoor and outdoor environmental variables.

10.2.3.1 *Correlation between environmental controls and indoor thermal factors*

F_{fan} and F_{window} were correlated with $DBT_{av\text{-}in}$, $T_{g\text{-}av\text{-}in}$ and v, as presented in Figure 10.12. The components within the figure correspond to equations with R values, as follows:

(A) Eqn 83, R = 0.76

(B) Eqn 84, R = 0.76

(C) Eqn 85, R = 0.52

(D) Eqn 86, R = 0.49

(E) Eqn 87, R = 0.50

(F) Eqn 88, R = 0.26

According to the coefficient of correlations, it can be seen that F_{fan} presents higher R-values than those of the F_{window} when correlated with the same environmental factors. The best predictive factors of the fan operation in this analysis are $DBT_{av\text{-}in}$ and $T_{g\text{-}av\text{-}in}$. Moreover, it should be noted that the T-test of independent variables reveals that all the regression models between the device operations with indoor environmental factors present significance lower than 0.001 (p<0.001) in all cases. Such results indicate that shifts of the percentages of device operations may not occur by chance, but relate to its variation of the indoor environmental factors.

According to the results, F_{fan} is more environmentally sensitive than F_{window}. When those operations were correlated with $DBT_{av\text{-}in}$, $T_{g\text{-}av\text{-}in}$, and v, the gradient factors of the independent variables of the F_{fan} are 11.541, 11.911, and 86.781, while those of F_{window} are 2.872, 2.988, and 17.154, respectively. It should be noted that although the operations varied according to the environmental factors, the devices functioned differently. According to Eqn 83 and Eqn 85, it can be predicted that the fan system may start operating when $DBT_{av\text{-}in}$ and $T_{g\text{-}av\text{-}in}$ are 23.24°C and 23.19°C, respectively. Besides, the maximum operations might be expected to be found when $DBT_{av\text{-}in}$ is 31.91°C, and $T_{g\text{-}av\text{-}in}$ is 31.58°C.

On the other hand, according to the survey, when the halls were occupied, a minimum F_{window} may have been required despite the low temperature of the halls. It should be noted that window-operating model cannot predict the

minimum requirement of the window function, due to no observed incidents in which all windows were closed during the observed periods.

Furthermore, Eqn 87 and Eqn 88 show that the fan function may play a more important role in an increase of indoor *v* than the windows, since the gradient factor of the F_{fan} model (86.781) is significantly higher than that of the counterpart (17.154). Thus, it can be mentioned that when indoor $DBT_{av\text{-}in}$ and $T_{g\text{-}av\text{-}in}$ shift, the windows and fans tended to be accordingly operated to elevate *v* in the halls. However, F_{fan} may have contributed a greater impact indoor *v* more than F_{window}.

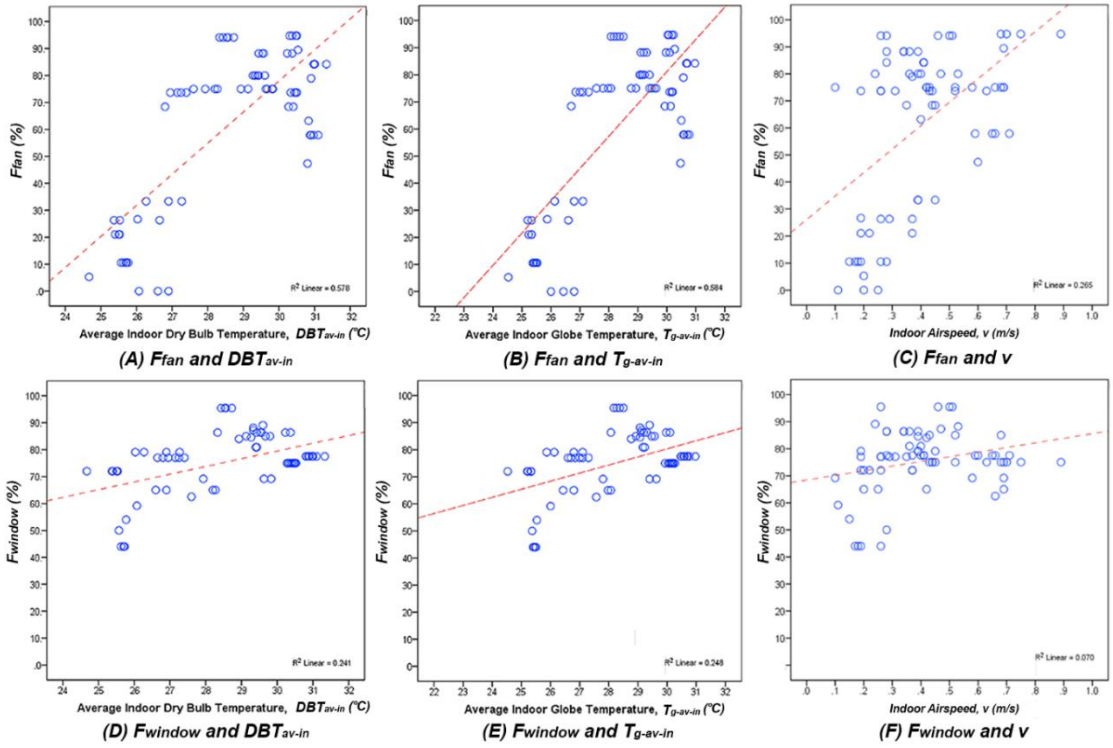


Figure 10.12: Linear regressions of the environmental controls and indoor environmental factors

$$F_{fan}\ (\%) = 11.541DBT_{av\text{-}in} - 268.240\ (R = 0.76,\ R^2 = 0.58) \quad \text{Eqn 83}$$

$$F_{window}\ (\%) = 2.872DBT_{av\text{-}in} - 6.667\ (R = 0.49,\ R^2 = 0.23) \quad \text{Eqn 84}$$

$$F_{fan}\ (\%) = 11.911T_{g\text{-}av\text{-}in} - 276.164\ (R = 0.76,\ R^2 = 0.58) \quad \text{Eqn 85}$$

$$F_{window}\ (\%) = 2.988T_{g\text{-}av\text{-}in} - 9.297\ (R = 0.50,\ R^2 = 0.25) \quad \text{Eqn 86}$$

$$F_{fan} = 86.781v + 26.112 \ (R = 0.52, R^2 = 0.27) \quad \text{Eqn 87}$$

$$F_{window}\ (\%) = 17.154v + 68.413 \ (R = 0.26, R^2 = 0.07) \quad \text{Eqn 88}$$

10.2.3.2 *Correlation between environmental controls and outdoor thermal factors*

This section is an analysis between the environmental controls and the outdoor environmental variables, which are DBT_{out}, $T_{g\text{-}out}$ and cloud cover. The observed operation scores and environmental data were correlated as shown in Figure 10.13, in which the component parts' functions correspond to equations as follows:

(A) Eqn 89, R = 0.62

(B) Eqn 90, R = 0.26

(C) Eqn 91, R = 0.62

(D) Eqn 92, R = 0.27

(E) Eqn 93, R = 0.44

(F) Eqn 94, R = 0.55

All the illustrations show the observed values of the device operations and outdoor environmental data with positive regression lines. According to the analytical results, the R of F_{fan} and DBT_{out} is 0.62, which is the same as that of F_{fan} and $T_{g\text{-}out}$, while that of F_{fan} and cloud cover is lower at 0.44. The coefficient of the gradient factors of the Eqn 89, Eqn 91, and Eqn 93 present that F_{fan} is also more environmentally sensitive to outdoor $DBT_{out\text{-}av}$ and $T_{g\text{-}out}$ shifts than a change of sky clearness. The slope factors of the F_{fan} and DBT_{out} models and F_{fan} and $T_{g\text{-}out}$ models present slight differences of 7.528 and 7.474, respectively, while that of the F_{fan} and cloud cover model is 3.992. The T-test analysis of the models shows that all the outdoor environmental factors may relate to the variation of F_{fan}, since the significance levels of the gradient factors are lower than 0.001 (p<0.001).

The window operation presents a strong relation with cloud cover score, since the R-values of the model is 0.74. In contrast, the correlation analyses presents lower R-values when F_{window} is correlated with DBT_{out} (R = 0.26) and $T_{g\text{-}out}$ (R = 0.27). Besides, the gradient factors of the F_{window} models reveal that the slope

factor of the function of F_{window} correlated with cloud cover is significantly higher (3.013) than that with DBT_{out} (1.219) and $T_{g\text{-}out}$ (1.259). This result shows that a variation of F_{window} is more relevant to a change of cloud cover than the outdoor temperatures. The T-test study furthermore reveals significant levels of the coefficient of the independent variable lower than 0.001 (p<0.001) in all the cases. Consequently, this study found that the variation of the window operation relates to the outdoor environmental variables, which are DBT_{out}, $T_{g\text{-}out}$, and cloud cover.

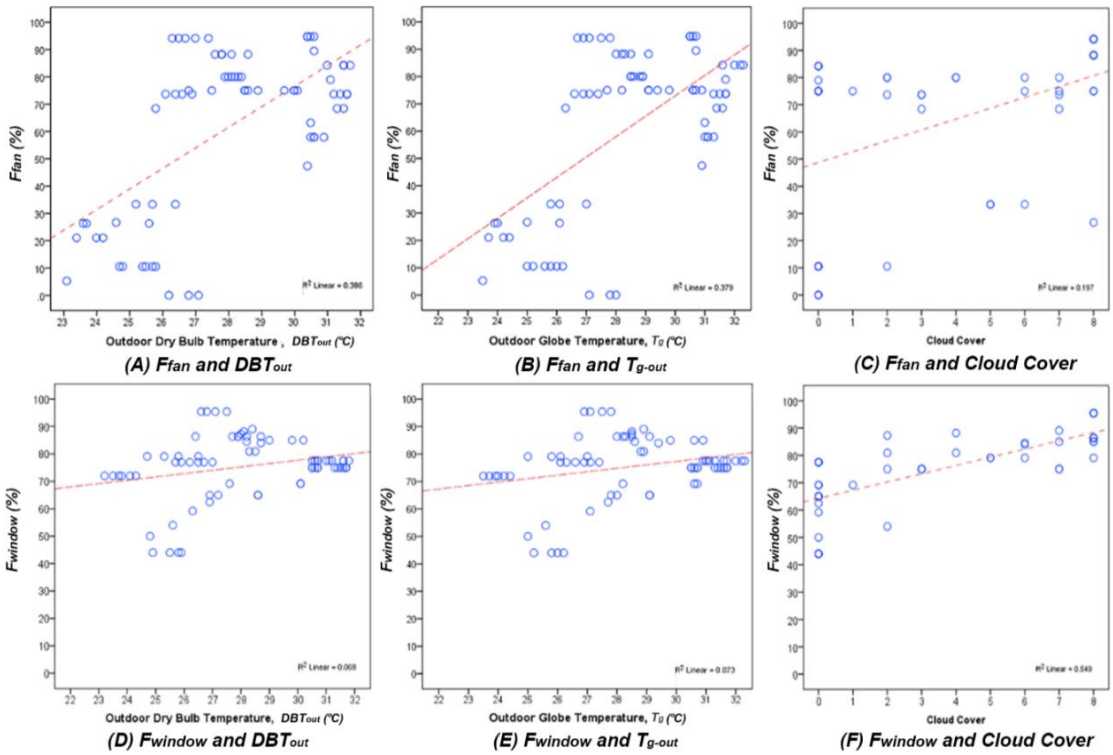


Figure 10.13: Scatter plots of the environmental controls and outdoor environmental factors

$$F_{fan}\ (\%) = 7.528\ DBT_{out} - 150.111\ (R = 0.62,\ R^2 = 0.39) \qquad \text{Eqn 89}$$

$$F_{window}\ (\%) = 1.219\ DBT_{out} + 41.137\ (R = 0.26,\ R^2 = 0.07) \qquad \text{Eqn 90}$$

$$F_{fan}\ (\%) = 7.474\ T_{g\text{-}out} - 151.250\ (R = 0.62,\ R^2 = 0.38) \qquad \text{Eqn 91}$$

$$F_{window}\ (\%) = 1.259\ T_{g\text{-}out} + 39.576\ (R = 0.27,\ R^2 = 0.07) \qquad \text{Eqn 92}$$

$$F_{fan}\ (\%) = 3.992\ \text{Cloud Cover} + 48.730\ (R = 0.44,\ R^2 = 0.20) \qquad \text{Eqn 93}$$

$$F_{window}\ (\%) = 3.013\ Cloud\ Cover + 64.251\ (R = 0.74,\ R^2 = 0.55) \quad \text{Eqn 94}$$

10.2.3.3 *Summary of relations between environmental factors and the environmental controls*

All 12 *R*-values mentioned in the analyses presented in the previous subsections are summarized in Table 10.3 and categorized into three groups based on *R*-values' relationships: strong (1.0≤ *R* >0.7), moderate (0.7≤ *R* ≥0.3), and weak (0.3< *R* ≥0.0). Three cases (namely F_{fan} correlated with $DBT_{av\text{-}in}$ and $T_{g\text{-}av\text{-}in}$ and F_{window} correlated with cloud cover) were categorized into the group of the strong relationship. In contrast, the three cases of F_{window} correlated with DBT_{out}, $T_{g\text{-}out}$, and indoor *v* were clustered in the weak correlations.

Table 10.3: Summary of R-values of the environmental control operations and environmental factors

	Indoor Variables			**Outdoor Variables**		
	$DBT_{av\text{-}in}$	$T_{g\text{-}av\text{-}in}$	*v*	DBT_{out}	$T_{g\text{-}out}$	**Cloud Cover**
F_{window}	0.49	0.50	0.26	0.26	0.27	0.74
F_{fan}	0.76	0.76	0.52	0.62	0.62	0.44

The results of the *R*-value categorisation were summarised and illustrated as presented in Figure 10.14. It can be concluded according to the diagram that F_{fan} strongly relates to $DBT_{av\text{-}in}$ and $T_{g\text{-}av\text{-}in}$, while F_{window} presents a significant correlation with sky openness. Besides, it should be noted here that the windows and fans operate accordingly with a moderate relationship.

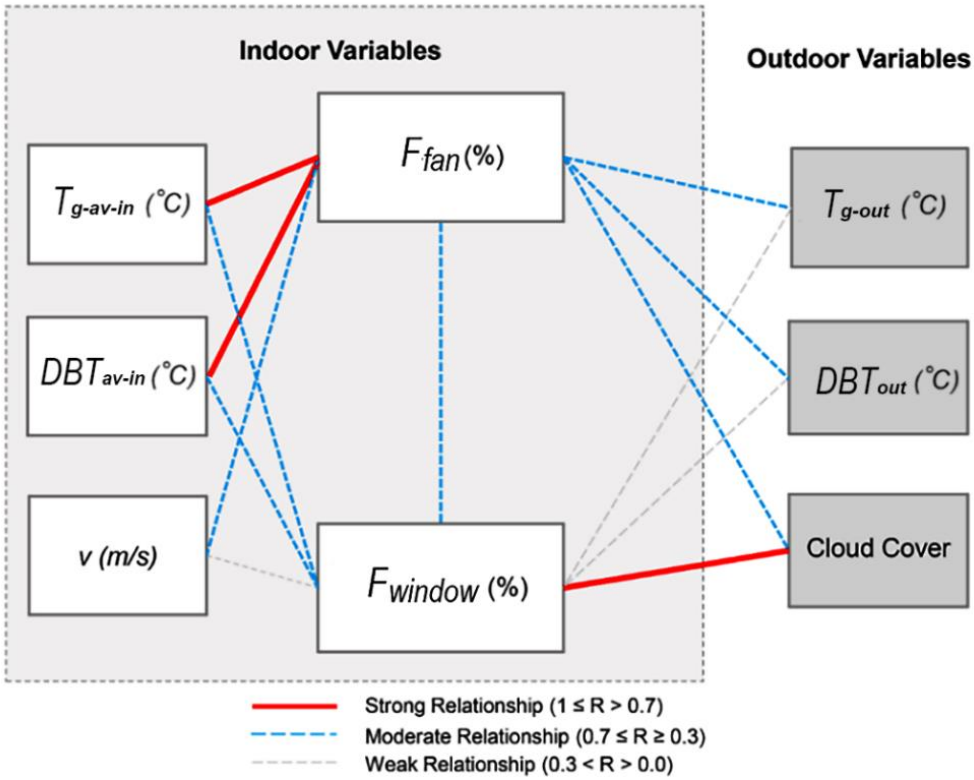


Figure 10.14: Diagram of relations between the operation of the environmental control and the environmental factors

10.3 Discussion of chapter 10

10.3.1 Cultural influence on subjects' thermal adaptation

According to the analytical results obtained from the questionnaire and observation, this research discovered unique psychological techniques of volunteers' psychologically thermal adaptation, including '*Accepting thermal environment as it is*', '*Resisting thermal dissatisfaction*', and '*Changing attention from thermal dissatisfied stimuli toward other aspects*'. Thermal acceptance seems to be linked to religious ideation in terms of a positive psychological disposition for wellbeing improvement. The perspective of a wide acceptance may affect the individual expectation toward current thermal stimuli, which therefore psychologically influence subjects' thermal evaluation. However, it should be noted that this study cannot quantify the extent to which such adaptations are effective. Thus, further researches of both lab-base and field studies are required.

10.3.2 Calculation of *CLO* and extra layer the meditation uniform

10.3.2.1 *CLO-assembling calculation*

The calculation is limited by the *CLO* data available in the international standards, while some pieces of the uniform such as *CLO* values of the pashmina were ignored, and the meditation mat was assumed. Besides, the information of the available *CLO* is estimated with values based on the standard values stated in the ASHRAE Standard, regardless of thickness or type of fabric. Thus, there is an opportunity for the future studies to investigate the actual *CLO* for the meditation uniform and mat.

10.3.2.2 *Constant range of CLO over a seasonal variation*

Based on the results, the users in the halls still seek a solution to modify their clothing, subject to cultural and organisational constraints. Besides, users' *CLO* changes according to a variation indoor temperature. Regardless of gender difference, the upper and lower limit of *CLO* found in this research remains constant at 0.24 to 1.01 in both winter and monsoon seasons. However, the *VRW* centre, where a meditation uniform is required, presents the highest minimum values of *CLO* amongst the case studies. The uniform, in this case, seems to limit the capability of the users' personal modification. Besides, these results show agreement with DeDear *et al.* (1997) and Brager and DeDear (1998), who mentioned the adaptive constraints on personal adaptation caused by organisational rules.

10.3.2.3 *Meditation uniform material and modesty of dress*

Although the meditation uniform was designed to ensure that users dress modestly, it can be seen that the female volunteers may prefer to add extra layers of T-shirts and shorts to make their dress more modest and less revealing. The main issue which the research team found pertaining to the uniform is its fabric. The material seems to be designed with lightweight fabrics to discharge heat from the body easily, and to ensure good ventilation, while white colour is required. The fabric of the budget uniform is thin but translucent, which does not provide users with sufficient the confidence with regard to

modest dressing. As a consequence, the users preferred to add extra layers of clothing, which increases insulation values.

10.4 Chapter conclusion

The section discussed the investigation of subjects' thermal adaptation techniques. The results reveal that the subjects performed a combination of thermal adaptions in the meditation halls. This section is concluded based on the obtained data derived from the questionnaire survey and subjects' behavioural observations.

10.4.1 Questionnaire survey results

The analytical results of this section derived from the self-evaluating questionnaire can be concluded as three-major aspects, as described below.

10.4.1.1 *Performed adaptive techniques and actions sequence*

The results were obtained by the two sets of questions, of which 16 answers of thermally adaptive solutions were provided. The respondents were asked to select and order the first three actions they performed in the halls. Three techniques of psychological adjustment were mentioned by the volunteers: '*Accepting thermal environment as it is*' ('*Accepting it*'), '*Resisting thermal dissatisfaction*' ('*Resisting it*'), and '*Deviating attention from thermal dissatisfied stimuli to other aspects*'. The technique '*Accepting it*' was the most voted performed solution in the first action sequence, followed by '*Changing Posture*' and '*Modifying the Environment*'.

The votes, moreover, were categorised into two main modes of adaptation, behavioural and psychological adjustments. The analytical results reveal the significance of behavioural adaptation, since the subjects may have firstly adjusted their personal and the environmental factors. After that, psychological adjustments seemed to play a significant role in the second and third sequences of the adaptive actions respectively.

It might be concluded that the least performed action was the environmental adaptation in this study. By the personal interview with the consenting subjects after finishing the survey sessions, it can be justified by two reasons:

- The available environmental controls were fully functioned; therefore, no further operation could be performed.
- Any environmental modification on fans and windows may have affected the other participants who might not prefer the changes. In this case, the personal adjustments such as relocating and loosening or tightening-up clothing seems more preferred compared to the environmental modifications.

10.4.1.2 *CLO modification*

The analytical results of the users' *CLO* assembly reveal that the female meditators may have higher average *CLO* than that of the male subjects in all the sites. Such higher personal insulation values may be caused by extra layers of their clothing to allow dressing modesty, which is influenced by cultural and organizational constraints. However, despite these subjective limitations, the subjects still managed to adjust their attire according to a variation of $DBT_{in\text{-}av}$.

10.4.1.3 *T_n variations by personal ventilation background and meditation experience*

Apart from *CLO* variation, this study found that different backgrounds of ventilation, which is considered a psychological factor, may have influenced the *ASV* and thermal sensitivity of the respondents. In this case, the volunteers who are accustomed to *AC* spaces may require lower T_n by 1.23°C, and they are more thermally sensitive than those subjects who are familiarised to *NV* spaces. Moreover, the result shows that users' meditation experience may have also led to a variation subjects' T_n. The beginner meditators who have less than one year's experience ($T_{n\text{-}inexp}$ = 29.05°C) may require 1.10°C lower T_n than those with more experience ($T_{n\text{-}exp}$ = 30.14°C).

10.4.2 Observation result

The observation data relating to percentages of environmental controls operation and a variation of v_p according to $DBT_{in\text{-}av}$ and v were analysed. The analytical results can be concluded as two major aspects as described below.

10.4.2.1 *Subjective driving force on environmental interaction*

The observation result of respondents' behavioural adaptation shows environmentally adaptive solutions which might be attributed to internal and external driving factors. A proportion of the subjects' higher to lower v_p increases according to a shift of $DBT_{in\text{-}av}$. Such a result can be interpreted in terms of a proportion of the respondents preferring higher v increasing according to $DBT_{in\text{-}av}$. Besides, the analytical results reveal a relationship between a rise of $DBT_{in\text{-}av}$ and an elevation of v in the halls. An actual increment of v indicates a consequence of environmental control operation, and in this case the result shows that the fans and windows functioned accordingly. Consequently, the subjects' v_p can be considered an internal driving force to elevate v by triggering environmental modifications, due to the impact of an increase of $DBT_{av\text{-}in}$.

10.4.2.2 *Environmental factors and controls*

Indoor and outdoor environmental variables were analysed to explore the strongest relationship between the device operations and environmental variables. Six environmental factors were correlated with F_{fan} and F_{window}: $DBT_{in\text{-}av}$, $DBT_{out\text{-}av}$, $T_{g\text{-}in\text{-}av}$, $T_{g\text{-}out\text{-}av}$, v, and cloud cover. Analytical results reveal that the operation of fans relates strongly to the variations of DBT_{indoor} and $T_{g\text{-}indoor}$, while the window operation presents a significant correlation with sky openness. Therefore, it can be concluded that each device operation presents different relationships with the environmental factors, which can be considered as external driving forces to trigger users' interaction to modify their environmental factors.

Chapter 11

Conclusion

Chapter 11: Conclusion

This chapter concludes this thesis, discussing the derived results from the previous chapters to address the major research questions established in Chapter 1. The questions consist of three major sections, concerning exploration of the building users' suitable thermal environments in the meditation halls, thermal comfort sensation, and subjects' thermal adaptations. Besides, a summary of demographic data of the volunteers and the physical information of the meditation halls is given. The primary research questions consist of three major sections, which are addressed based on the results obtained from the empirical investigation. At the end of the chapter, the knowledge gained from this study is used to formulate suggestions for local standards on human thermal comfort in meditation buildings and further research.

11.1 Summary of the demographic data of the subjects

The majority (83.7%) of participants were female, aged 31 to 70 years old (69.0%), residing in Khon Kaen (65.23%). The volunteers' education level varied from a primary school to doctoral degree, but the largest group of the volunteers held a bachelor's degree. The majority of the participants reported they had approximately one to five years of experience in meditation, and each practising period might last approximately for 15 to 30 minutes, while the experienced meditators reported a longer period of training, with some specifying over 150 minutes. The majority of the volunteers practised meditation annually, followed by the second largest group who reported that they meditated daily.

11.2 Summary of the physical information of the halls

The *VRW* hall is the most thermally sensitive to a variation of outdoor *DBT*, since it is located on the first floor of the two-storey building, exposed to attic space, which directly gains solar radiation. The *VRW* hall is also the largest

meditation space among the sites. In contrast, the *PT* hall seems to be the least thermally sensitive to the outdoor environmental shift, since the building has the highest thermal inertia property among the other case studies due to its wall thickness. Besides, the *PT* hall is recessed from direct solar radiation by a 1.7 m corridor, and it is located on the ground floor of a three-storey building, whereby heat from the roof surface is blocked. Two types of environmental data samples derived from the on-site measurement were categorised based on different calculation methods employed for investigating subjects' thermal adaptation and subjective states (see Chapter 5).

11.3 Conclusions of the data samples

The analyses were conducted based on the data collected from main survey held in the winter and monsoon seasons. The questionnaire survey collected the subjects' samples, yielding the following data packets for each type:

499 *ASV*	498 v_p
497 *APV*	497 *IFA*
495 T_p	498 *DR*

Those votes were analysed with environmental data measured inside and outside meditation halls. The indoor environmental factors used in the subjective vote analyses were converted into T_{op}, which in this research is calculated from the 30-minute average data of DBT_{in}, $T_{g\text{-}in}$, and RH_{in} measured by WBGTs A, B, and C, with *v* measured by an anemometer at the same location as WBGT: B. For the adaptive equation and adaptive model analyses, outdoor environmental condition is expressed as a Monthly Average Outdoor Temperature ($T_{monthly\text{-}av\text{-}out}$), calculated based on the secondary data collected at the local meteorological station. For environmental control-operation analysis, two sets of 73 observations of fan and window functions were collected at the same measuring interval of the environmental data. These device-operating data samples were correlated with the average indoor and outdoor environmental factors ($DBT_{av\text{-}in}$, DBT_{out}, $RH_{av\text{-}in}$, RH_{out}, $T_{g\text{-}av\text{-}in}$, $T_{g\text{-}out}$, *v,* and cloud cover).

11.4 Reflection on the research questions

This section of the conclusion addresses the three major research questions pertaining to suitable indoor temperature, as established in the first chapter.

11.4.1 The first major question: Comfortable thermal environments

This main question aims to investigate the comfortable thermal environments of the meditation halls for the users. In this case, four sub-questions are posed and addressed below.

1.1. Can the steady-state model precisely predict subjects' thermal sensation in meditation buildings?

The *PMV* and *ASV* correlation analysis revealed noticeably different expected and actual regression lines, demonstrating that *PMV* seems not to precisely predict subjects' actual thermal sensation. Thus, it can be concluded that the steady-state model may not be the most accurate for evaluating solutions for *NV* meditation hall users. This result is also in agreement with the RP-884 report and past studies, such as Nikolopoulou and Steemers (2003), Feriadi and Wong (2004), Humphreys *et al.* (2007), and Yao *et al.* (2009), which mentioned that *PMV* and *PDD* should not be applied for evaluating users' thermal sensation in *FR* and *NV* buildings. In this case, the inaccuracy of the steady-state model may be attributed to users' adaptive activities comprising the major modes of adaptations: psychological, psychological, and behavioural adjustments. Therefore, an adaptive model which includes these comfort factors is advised.

1.2. What are suitable thermal conditions for subjects in meditation buildings?

The previous question (1.1) inquired about the applicability of the *PMV* and *PDD* methods in the *NV* meditation spaces. Thus, it can be said that *PMV* may not a suitable predictive solution, while other analytical techniques are examined. In

this case, the analytical results derived from a bin method and linear regression reveal similar consequences, in that subjects' *ASV* slightly varies according to $T_{op.}$ The survey database also demonstrates that the linear relationship between the two factors can be expressed as shown below.

$$ASV = 0.149\ T_{op} - 4.451$$

The equation reveals that subjects' T_n, (29.87°C, with an 80% acceptable range varying between 23.16°C to 36.58°C) is 3.63°C higher than that of $T_{n\text{-}PMV}$ (26.24°C). Although T_n is considered a comfort temperature according to the RP-884 report (DeDear, Brager and Cooper 1997), T_p (26.19°C) indicates that the respondents may prefer temperatures approximately 3.68°C lower than T_n. Besides, the *APV* analysis reveals that thermally comfortable perception can be expressed as a range varying between 22.78°C to 30.60°C, whereby the most comfortable temperature ($T_{c\text{-}APV}$) of the volunteers is found at 26.69°C. In this case, this temperature point seems approximate for $T_{n\text{-}PMV}$ (26.24°C) and T_p (26.19°C).

Thermal Comfortable Sensation *(TCS)* analysis demonstrates that thermally comfortable sensation ranges from below -3 *ASV* ('*Cold*') to 0.46 *ASV* (in-between '*Neutral*' and '*Warm*'), covering the entire the '*Cool*' to '*Cold*' area of the *ASV* scale. *TCS* is achieved when *ASV* and *APV* are equal at -1.66, in-between '*Slightly cool*' and '*Cool*' sensation, and in-between '*Rather Comfortable*' and '*Comfortable*' perception, respectively.

Furthermore, the analytical results of the two meditative qualities analyses, which are *DR* and *IFA*, reveal that the cooler the temperature relative to the neutral state (*ASV* < 0), the better qualities of meditation the meditators may experience. It should be noted that these conditions were found under the survey context of *NV* meditation halls, where T_{op} ranges from 24.05°C to 31.32°C with respondents who are local meditators. Besides, the environments and circumstances must encourage an adaptive opportunity to allow the users to regain or maintain their thermal comfort by adjusting their personal,

environmental, and mental factors subject to cultural and organisational constraints.

Thus, when investigating suitable thermal conditions for building users in *NV* meditation buildings, ranges of temperature wherein the thermally comfortable level varies can be explored. In this case, if the target indoor temperature is aimed at acceptable thermal states, the wide 80% (26.52°C to 33.23°C), and 90% (23.16°C to 36.58°C) acceptable ranges proposed by ASHRAE Standard-55 should be considered, since they are wide enough to cover T_n and some areas of the $T_{c\text{-}APV}$ band.

However, if aiming to achieve thermally comfortable environments with better meditation qualities, the $T_{c\text{-}APV}$ range (22.78°C to 30.60°C) is suggested, since it contains a subjects' positive attitude toward thermal stimuli. Moreover, based on the results derived from the ASHRAE acceptable thermal and $T_{c\text{-}APV}$ ranges, this research suggests modifying the lower limits of the acceptable ranges close to the minimum temperature of the $T_{c\text{-}APV}$ band (*ASV* = -1.05). However, it should be noted that, this is just an assumption to show the conceptual model of the imbalance acceptable thermal ranges. Therefore, further research to establish the actual ranges is still required.

1.3. What is an adaptive equation and model for this building type? Compared with the ASHRAE adaptive model, to what extent do international standards reflect local needs?

The adaptive equation of this research is established based on the relationship between the neutral thermal sensation votes (*ASV* = 0) and *Monthly Average Outdoor Temperature* ($T_{monthly\text{-}av\text{-}out}$), which will be expressed as:

$$T_n = 0.828\ T_{monthly\text{-}av\text{-}out} + 6.304$$

As a consequence, the adaptive model with 80% and 90% thermal acceptable ranges expanding over ±0.75 *ASV* and ±0.50 *ASV* is established as shown in Figure 8.7. It should be noted that the predictive range of the model is limited

within 25.02°C to 28.29°C of $T_{monthly\text{-}av\text{-}out}$, based on the collected secondary data.

Comparing the ASHRAE Standard-55:2004 adaptive model (2004, 2010) with the results of this research project reveal different regression lines of T_n and 80% and 90% acceptable thermal ranges. ASHRAE suggests a relationship between indoor and outdoor environmental variables as $T_{n\text{-}ASHRAE\text{-}55} = 0.31T_{monthly\text{-}av\text{-}out} + 17.8$, while that of this project can be expressed as shown in question 1.3. The gradient factor of the ASHRAE Standard (0.31) shows that its subjects are less adaptive to the outdoor thermal environment and more thermally sensitive than those of this research project (0.83). Besides, a comparison between the models of the project and the ASHRAE reveals that its outdoor environmental factor covers a more extensive range of $T_{monthly\text{-}av\text{-}out}$ (10.00°C to 33.50°C) than that identified in this research project (25.02°C to 28.29°C), due to the actual observed data derived from the survey.

Furthermore, it is evident that the acceptable thermal ranges found in this research are noticeably more extensive than those of ASHRAE. Under the same range of outdoor thermal conditions (25.02°C to 28.29°C), 56.15% of the 80% acceptable thermal zone intersects with that of ASHRAE, while 43.85% is correspondingly located outside it. This outer zone of the international standard indicates that the subjects of this research may be more adaptive to a warmer thermal environment.

Thus, it can be seen that if the ASHRAE standard of adaptive thermal comfort is applied in the *NV* meditation halls, the adaptive equation may partially reflect the local users' requirements. However, the research reveals that if the equation is developed based on the respondents' actual thermal sensations under the adaptive opportunities and constraints as mentioned in this thesis, there is a possibility to extend the acceptable thermal ranges, as discussed in question 1.2. Such expansions may minimise energy requirements caused by *AC* system operations in this building type.

11.4.2 The second major question: Thermal states and meditation

In thermal comfort study, the ASHRAE thermal sensation scale is widely used to explore T_n. However, the obtained results seem to be questionable if the subjects could perceive comfort under such a state of thermal neutrality. Based on the second major issue established in the first chapter, sub-questions are recapitulated and addressed below.

2.1. What thermal states may the subjects experience as thermally comfortable, and do the subjects perceive the thermal neutrality state to be comfortable?

This set of questions was addressed based on the results derived by *APV* and *TCS* analyses. Results reveal a quadratic relation between *APV* and T_{op} whereby the thermally comfortable range extends over 22.78°C to 30.60°C. $T_{c\text{-}APV}$ is considered the most comfortable temperature, found at 26.69°C, 3.18°C lower than T_n (29.87°C). In this case, T_n is still in the range of $T_{c\text{-}APV}$; however, the respondents with thermal neutrality may not perceive thermally environmental stimuli as the most thermal comfort. In this state, they seem to feel thermally comfortable with a positive attitude toward the thermal environment near the upper limit of the comfort level, at 30.60°C (the upper limit of $T_{c\text{-}APV}$).

Regarding *TCS*, a correlation between *APV* and *ASV* demonstrates that the most comfortable thermal sensation is found at the cooler than neutral sensation (*ASV* = -1.66), which in this case is in-between '*Cool*' (-2) and '*Slightly cool*' (-1) sensations. Moreover, the finding also presents an agreement with the T_p result (26.19°C), which suggests that the subjects may prefer lower temperatures than T_n when *SD* is +3.68°C, representing the warm environment of the halls.

2.2. Does a shift of thermal environment relate to meditative qualities, and in which thermal condition can subjects achieve better meditative experiences?

To address this question, two data sets of meditation qualities, *DR* and *IFA*, were correlated with T_{op}, and the results present positive relations between the factors demonstrating that subjects' meditative qualities in $T_{c\text{-}APV}$ are better than T_n. Moreover, the *APV* analytical results reveal that the respondents' positive attitude is found when stimulated by T_{op} between 22.78°C and 30.60°C ($T_{c\text{-}APV}$ range). In this case, it might be inferred that the lower temperatures of the hall are, the better meditation qualities the meditators may perceive, but this should not be lower than the minimum temperature of the $T_{c\text{-}APV}$ range.

11.4.3 The third major question: Thermal adaptation

As discussed at the end of the first major question, the difference between *ASV* and *APV* is attributed to human thermal adaptation. This set of questions investigates the users' adaptive solutions performed in the halls. It should be noted that physiological adaptation, which is one of the three major thermal adaptive modes, was excluded in this research.

3.1. What are the subjects' thermally adaptive actions performed in the halls and what are the subjects' three most-performed adaptations in different sequences of actions found in the meditation halls?

Thermally adaptive actions performed in the halls

The volunteers' thermal adaptation survey showed that 13 of the offered 16 answer options were selected by participants, and these were similar to actions reported by past studies conducted in office and residential buildings in India by Indraganti (2010a, 2010b, 2011). However, this research found another three unique psychological adaptations which the meditators reported in the pilot study. Finally, the following 16 adaptive techniques were reported:

- Modifying clothing
- Changing sitting materials
- Loosening or tightening-up clothing
- Relocating to a cooler or warmer area
- Relocating to an area with higher or lower airspeed
- Avoiding exposure to direct solar radiation
- Changing activity or posture
- Taking a short break to toilets or bathrooms
- Tying hair
- Consuming cool or warm drinks or foods
- Taking a nap
- Relocating closer to cooler or warmer objects
- Accepting the current thermal stimuli as it is *('Accepting it')*
- Deviating attention from dissatisfying stimuli of the current thermal environment to other aspects *('Deviating attention')*
- Resisting dissatisfying stimuli of the current thermal environment *('Resisting it')*
- Modifying the environmental condition by opening/closing the windows or using curtains and fans

Furthermore, subjects' *CLO*-assembling data collected by the questionnaire were analysed by cross-tabulation and regression analysis. Analysis of the results revealed that the subjects' *CLO* values varied according to gender, place of survey, and seasons. Female average *CLO* values in all sites present higher magnitudes than those of men, by 0.09, 0.06, and 0.09 in *VRW*, *PT*, and *KJS*, respectively. The *VRW* respondents who were required to wear the meditation uniform seemed less flexible in a *CLO* variation than the others, since the *std* values of male and female *CLO* of *VRW* were 0.05 and 0.09, while those of the *PT* were 0.22 and 0.18, and those of *KJS* were 0.17 and 0.18, respectively. The lower and upper limits of all the female *CLO* were 0.34 and 1.01 (0.67 range), while those of all the men were 0.24 to 1.00 (0.76 range), respectively.

Such results present that the men have a minimum *CLO*, lower than that of the women by 0.10, while there is a small difference (0.01) of the maximum *CLO* between genders. Besides, it is found that subjects' *CLO* increases according to a shift of indoor T_{op}. Furthermore, a seasonal variation also seems to influence users' average *CLO*, since winter *CLO* is greater than that found in the monsoon season by 0.08. Thus, it can be concluded that, under the intensive culture and organisational conditions of meditation buildings, the subjects still managed to modify their clothing in response to the thermal conditions.

Three most-performed adaptations

The previous section discussed the volunteers' performed adaptive actions. The three most-performed actions in three sequences are slightly different. For the first sequence, the most performed adaptations reported by users were '*Accepting it*', followed by '*Changing posture*' and '*Modifying environment*' in the second and third places, respectively. The most reported solution in the second sequence is still unchanged, which is '*Accepting it*', followed by '*Resisting it*', then '*Deviating attention*'. Finally, the most performed action in the third sequence is '*Resisting it*', while the second and third most performed solutions are '*Accepting it*', followed by three solutions shared the same third place, which are '*Changing activity*, *posture and gesture*', '*Deviating attention*', and '*Modifying environment*'. According to the results, it can be seen that the psychologically adjusting techniques were the most performed actions in the first adaptive solutions of each action sequence in the *NV* meditation halls.

3.2. What are the subjects' most performed mode of adaptation in the first-three sequence actions while staying in meditation halls?

All the results of the votes as mentioned in the previous question were categorised into two of the three major adaptive modes, which are behavioural and psychological modifications. It is found that the building users may have first performed behavioural adjustments such as modifying the environmental

controls, changing activity, relocating to better thermal conditions, and modifying their clothing. In contrast, mental adjustments such as '*Accepting it*', '*Deviating attention*', and '*Resist it*' play a more important role in the second and the third sequences of actions.

It can be seen that the least performed adaptation was the environmental adjustments in this research. It can be justified by two reasons: (i) Since the available environmental controls were fully operated, no further modification could be made. (ii) Furthermore, any environmental modification on the environmental controls may have affected the other hall users who might not prefer the changes; therefore, the subjects preferred personal adjustments to environmental modifications.

3.3. Regarding psychological adaptation, do different ventilation profiles result in a variety of subjects' thermal sensitivity and T_n outcomes?

This question inquires about the influence of respondents' ventilation background and length of meditation experience on thermal sensation. The analytical results of the *ASV* and T_{op} correlation of the subjects who spent most of the time in *NV* and *AC* spaces were compared to reveal that the *NV* background subjects were less sensitive to the T_{op} variation, since the slope factors of independent variables were noticeably lower for them than for their counterparts acclimatised to *AC* spaces, as equations ASV_{NV} and ASV_{AC} present. These equations also reveal different T_n between two groups of subjects, by which $T_{n\text{-}AC}$ (29.00°C) is 1.23°C lower than $T_{n\text{-}NV}$ (30.23°C).

Moreover, the comparison of thermal sensation and T_{op} between two groups of subjects is shown in the relationships of ASV_{inexp} and ASV_{exp}. Those with more than one year of experience demonstrate less thermal sensitivity than those with less experience than this, since the gradient factor of the ASV_{exp} model (0.131) is lower than that of the counterpart (0.245). T_n values derived from the ASV_{inexp} and ASV_{exp} relations also demonstrate that $T_{n\text{-}inexp}$ (29.05°C) is 1.09°C lower than $T_{n\text{-}exp}$ (30.14°C).

$$ASV_{NV} = 0.143\ T_{op} - 4.322$$

$$ASV_{AC} = 0.239\ T_{op} - 6.931$$

$$ASV_{inexp} = 0.245\ T_{op} - 7.115$$

$$ASV_{exp} = 0.131 T_{op} - 3.948$$

Based on these results, it can be concluded that the background of ventilation and length of meditation experience can mediate human thermal assessment.

3.4 What are relationships amongst environmental variables and environmental controls available in the halls?

Twelve relationships were derived from linear correlations between environmental factors ($DBT_{av\text{-}in}$, $DBT_{av\text{-}out}$, $RH_{av\text{-}in}$, $RH_{av\text{-}out}$, $T_{g\text{-}av\text{-}in}$, $T_{g\text{-}av\text{-}out}$, v, and cloud cover), and the percentages of environmental control operations (F_{fan} and F_{window}). A total of 12 R-values were compared to reveal that F_{fan} presents strong relationships ($R > 0.7$) with $T_{g\text{-}av\text{-}in}$ and $DBT_{av\text{-}in}$, while moderate relations ($0.5 < R < 0.7$) are found when correlated with v and $T_{g\text{-}av\text{-}out}$, $DBT_{av\text{-}out}$ and cloud cover.

On the other hand, F_{window} presents a strong relation ($R > 0.7$) when correlated with the sky condition scores, and moderate relations ($0.5 < R < 0.7$) when correlated with $DBT_{av\text{-}in}$ and $T_{g\text{-}av\text{-}in}$. In contrast, low R-values were found when F_{window} was correlated with indoor v and $T_{g\text{-}av\text{-}out}$ and $DBT_{av\text{-}out}$, demonstrating weak relations between the factors. Besides, the observation results show that the minimum percentage of window operation was required when the subjects entered into the meditation halls, regardless of indoor temperature. Consequently, it might be concluded that the fan operation has strong relationships with $T_{g\text{-}av\text{-}in}$ and $DBT_{av\text{-}in}$, while the window function presents a significant relationship with the sky condition (Figure 10.14).

11.5 Addressing the research hypothesis

The results support the formulated hypothesis as mentioned in Chapter 1:

'Under the intensive cultural and organisational constraints of NV meditation buildings in the hot and humid climate of Thailand, meditator subjects have broader ranges of thermal acceptance and higher neutral temperature compared to normal subjects due to their adaptive activities. Besides, suitable thermal conditions of meditation halls will promote meditation activities which allow the meditators to achieve better meditative qualities.'

This research, based on the interpretivist paradigm, confirms that human thermal comfort is subjective concerning individual experience and interpretation, which is manifest in subjects' tangible and intangible adaptive actions (environmental and personal modifications, and psychological adjustment). The analytical results of the current database show pieces of evidence demonstrating that the meditator subjects who have more than one year of practising experience seem to have less thermal sensitivity and T_n than the counterpart group of subjects who have less experience.

Comparison of the results from the adaptive model presented in this research and the ASHRAE-standard: 55 (2004), which was established based on global database contributed by normal building users, supports the research hypothesis. The 80% acceptable thermal zone of this research expands more extensively in the comparable range of $T_{monthly\text{-}av\text{-}out}$ (25.02-28.28ºC). Besides, 43.9% of the non-overlapping zone of 80% thermal acceptability indicates superior capability of subjects' thermal adaptation compared to ASHRAE's values. The regression of the subjects' T_n located at higher temperatures with a steeper slope demonstrates that the subjects are more thermally adaptive than reflected in the American standard.

Furthermore, the analytical results of this thesis also suggest that the suitable thermal conditions for *NV* meditation spaces promote the quality of meditation. This research examines meditative qualities in different thermal subjective states, including T_n, T_p, $T_{c\text{-}APV}$, and the 80% and 90% thermal acceptable, and $T_{c\text{-}APV}$ ranges. The results demonstrate that the lower hall temperatures are, the more positive meditation qualities the building users can experience. Moreover,

it is obvious that outside the $T_{c\text{-}APV}$ upper limit, *DR* and *IFA* show lower quality meditation experiences for subjects compared to outcomes that T_n, $T_{c\text{-}APV}$, and T_p provide. Besides, T_p and $T_{c\text{-}APV}$; located at the cooler side of T_n, also confirms that the thermal states where building users prefer and perceive thermal comfort may result in better outcomes of meditative practice. Consequently, the hypothesis that suitable indoor thermal environments of *NV* meditation spaces in a hot and humid climate can encourage subjects' meditative activities resulting in more satisfying outcomes of mediation qualities is confirmed.

11.6 Research scalability

In addition to physiological and physical variables, this research also explored psychological aspects. Mixed methods were employed to investigate meditator subjects' thermal perception and meditative qualities, including environmental interaction. It should be noted that this research aims to fill in the identified research gap of surveying human thermal comfort in meditation buildings, and it may be considered to be a bridge between the human thermal comfort and meditation fields, in addition to contributing more generally to studies of thermal comfort in religious structures. This section explains the scalability of the outcomes of this research, and suggests possible areas for further studies.

As mentioned in the previous section, this research identified three psychological adaptations: *'Accepting it'*, *Resisting it'*, and *'Deviating focus'*. This research reveals an opportunity for future studies to investigate the impact of these mentally adaptive techniques on human thermal perception. In this regard, this research highly recommends examining this issue based on the positivist stance, using a parametric study in a lab-based environment, where environmental variables and personal and psychological factors are well controlled. In this case, with a small number of subjects and flexible period of study, alongside with the conventional method of using questionnaire, it is possible to develop the research toward the next level by employing *EEG* to observe the electrical activity of subjects' brains.

Replication for future field research can be expanded over the unexplored area. For example, there is a possibility to examine thermal sensitivity of the other meditative qualities presented in the first cluster of *MEDEQ* (Piron, 2001); *BD*, *FG*, *CG*, and *SP* (see Chapter 4), which were not investigated in this thesis. Moreover, since the outdoor temperature found in this study is limited within a narrow range (24.67-31.33ºC), the regression seems not to be clearly formed, resulting in R^2 values. In this case, the expansion of the research area toward more extreme conditions (hotter and colder temperatures) and in different climatic conditions might reveal more decisive results.

Furthermore, this research found that the subjects' better meditation qualities can be found at the state near T_p or $T_{c\text{-}APV}$ in *NV* meditation buildings in the hot and humid climate when *SD* is 3.7ºC (positive value). This condition results in a positive trend of the *IFA* and *DR* regression lines when correlated with T_{op}. However, for future field studies, it is hypothesized that the regression trends of the *DR* and *IFA* in cooler environmental conditions may behave inversely (a positive trend with T_{op}) to the results presented in the thesis when *SD* is negative, and positions of T_p and $T_{c\text{-}APV}$ are located at the warmer side of T_n.

As reported in Chapter 7 regarding the demographic data, the votes of this thesis were dominated by the preponderance of female participants. Future replicated studies should examine male meditator subjects in similar conditions so that the results between gender can be compared and pooled. Also, it is suggested to conduct research using similar research methods with Buddhist monks and nuns, given the findings in this study of the impact of meditation experience, as they generally have more considerable meditation experience than laypeople and a capability to attain higher stages of meditation depth, which can be examined in terms of other *MEDEQ* clusters (Piron, 2001).

Moreover, this cross-sectional survey observing momentary effects of meditation on human thermal perception right after finishing meditation sessions did not apprehend effects observed in previous longitudinal studies (as mentioned in Chapter 4), which confirm the long-lasting effect of meditation on practitioners in their daily lives. In this case, there is a possibility to replicate

a field survey using long-period research to monitor the effect of meditation on subjects' thermal perceptions in daily life. If meditations can change the subjects' attitude outside meditation halls, there will be a possibility to employ this technique as an energy-conserving solution.

Finally, regarding the research gap, human thermal comfort studies in religious buildings are required. This study can only focus on the Buddhist meditation spaces where religious philosophy is an influential factor on users' thermal perception, behaviour, and practice qualities. It is strongly encouraged to survey based upon the interpretivist standpoint in other religious buildings with different believers, as well as Buddhist meditation halls in other climates.

11.7 Suggestions for the local standard on thermal comfort in mediation buildings and further surveys

As discussed above, the optimum adaptive thermal set point and ranges stipulated in the ASHRAE Standard-55 (2004) do not adequately reflect user requirements for thermal comfort in *NV* meditation buildings discovered in this study. Thailand established the national building rating system (*TREES*) in 2009, but the thermal comfort section seems to lack actual information on local thermal comfort requirements, since it entirely adopts the ASHRAE Standard-55 (2004), whose database refers to only three *NV* buildings in Thailand. Therefore, the application of the adopted manual seems questionable, since the building users may perceive thermal environments differently under local thermal conditions, and with different cultural and organisational influences.

This field-based research was conducted in three *NV* meditation buildings in Thailand from 2015 to 2017. The analytical results present a noticeable difference of T_n and thermal acceptable ranges between the ASHRAE Standard and the research project. Such variations reveal that the current subjects are more thermally tolerable and adaptive compared to those analysed in the RP-884 report (DeDear, Brager and Cooper 1997). Participants also reported 16 adaptive actions, 13 of which are similar to these mentioned in the past studies of residential and office buildings by Indraganti (2010a, 2010b, 2011), while

there are three other unique techniques classified as psychological adaptations that were particularly found in the current study.

Moreover, unquantifiable factors such as cultural and contextual influences attached to each place lead to diverse adaptive opportunities and constraints that affect human adaptive behaviours. Thus, rather than directly employing the international standard, this research suggests that the national standard should be developed based on an understanding of the local context and the actual thermal comfort characteristics of users in Thailand. This research focuses on a human adaptive thermal comfort in a particular space; therefore, more data is needed to construct a database from field research, contributed by different groups of users in different spaces, in order to guide engineers and architects in designing structures that meet the thermal comfort needs of users in Thailand.

Furthermore, this research confirms that psychological factors can affect subjects' thermal evaluation, since the results reveal that the users' different ventilation backgrounds and lengths of meditation experience may lead to a shift in T_n. In this case, these non-thermal factors show a possibility to vary T_n and its acceptable ranges. However, their effectiveness on human thermal comfort has not yet been examined. Thus, this presents an opportunity for lab-based studies to investigate how much each factor can affect users' thermal perceptions.

Finally, this study would like to highlight that, apart from considerations of subjects' physiological and environmental factors, their psychological and contextual variables should always be taken into account when discussing human thermal comfort in the adaptive approach. An exploration of actual thermal comfort requirements provides building designers with design information for indoor thermal spaces, and useful information for building managers to monitor variations in indoor temperature and understand indoor thermal limits for user comfort, for efficient and sustainable maintenance, before deciding to improve indoor environments or employ *AC* systems in less cost-effective ways. Finally, this research underlines that, with conscious utilisation

of resources, it is possible to minimise energy consumption to promote future sustainability while maintaining necessary levels of user comfort in buildings in Thailand.

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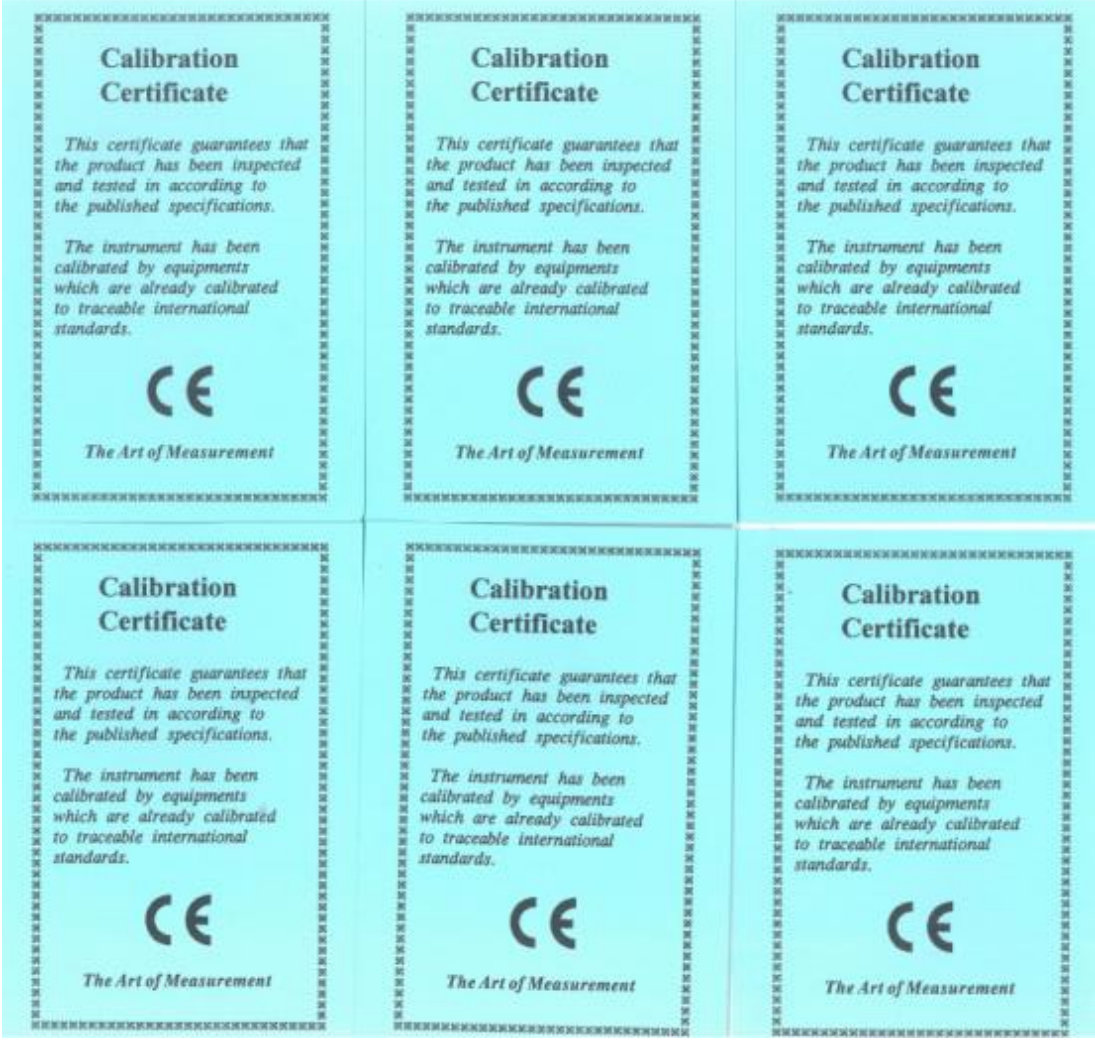
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Appendix A: Calibration Certificates

I. Calibration certificate cards for the two IR thermometers and four WBGT meters by Lutron



II. Calibration certificate of WBGT: A (Device serial No.: AI.17255)



CALIBRATION CERTIFICATE

Item : HEAT INDEX WBGT METER

Model : WBGT-2010SD

Serial No. : AI.17255

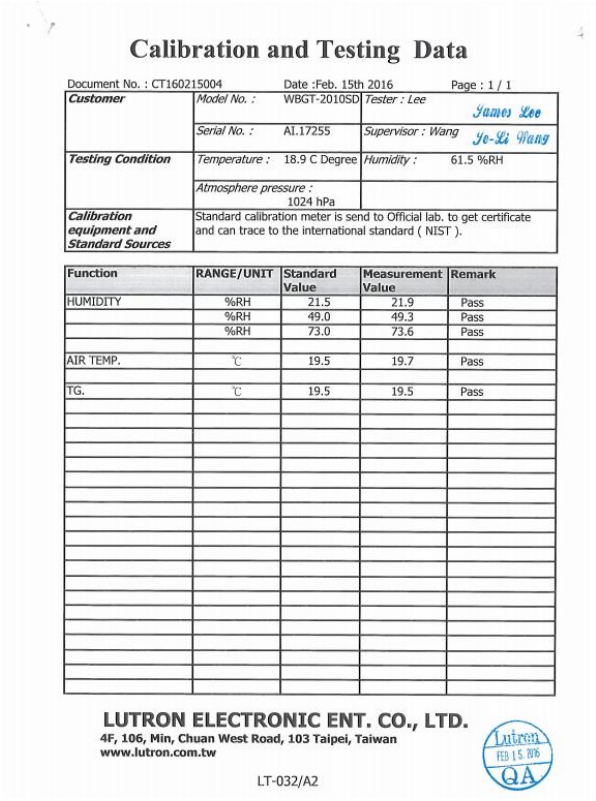
Date : Feb. 15th 2016

Lutron FEB 15 2016 QA

LUTRON ELECTRONIC ENT. CO., LTD.

The Art of Measurement

III. Calibration testing data of WBGT: A (Device serial No.: AI.17255)



Calibration and Testing Data

Document No. : CT160215004 Date :Feb. 15th 2016 Page : 1 / 1

Customer	*Model No. :*	WBGT-2010SD	*Tester : Lee*	James Lee
	Serial No. :	AI.17255	*Supervisor : Wang*	Ye-Li Wang
Testing Condition	*Temperature :*	18.9 C Degree	*Humidity :*	61.5 %RH
	Atmosphere pressure :	1024 hPa		
Calibration equipment and Standard Sources	Standard calibration meter is send to Official lab. to get certificate and can trace to the international standard (NIST).			

Function	RANGE/UNIT	Standard Value	Measurement Value	Remark
HUMIDITY	%RH	21.5	21.9	Pass
	%RH	49.0	49.3	Pass
	%RH	73.0	73.6	Pass
AIR TEMP.	℃	19.5	19.7	Pass
TG.	℃	19.5	19.5	Pass

LUTRON ELECTRONIC ENT. CO., LTD.

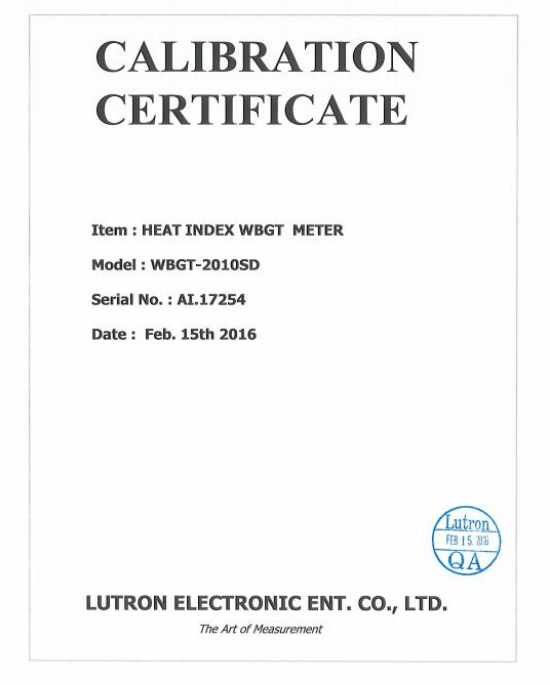
4F, 106, Min, Chuan West Road, 103 Taipei, Taiwan

www.lutron.com.tw

Lutron FEB 15 2016 QA

LT-032/A2

IV. Calibration certificate of WBGT: B (Device serial No.: AI.17254)



CALIBRATION CERTIFICATE

Item : HEAT INDEX WBGT METER

Model : WBGT-2010SD

Serial No. : AI.17254

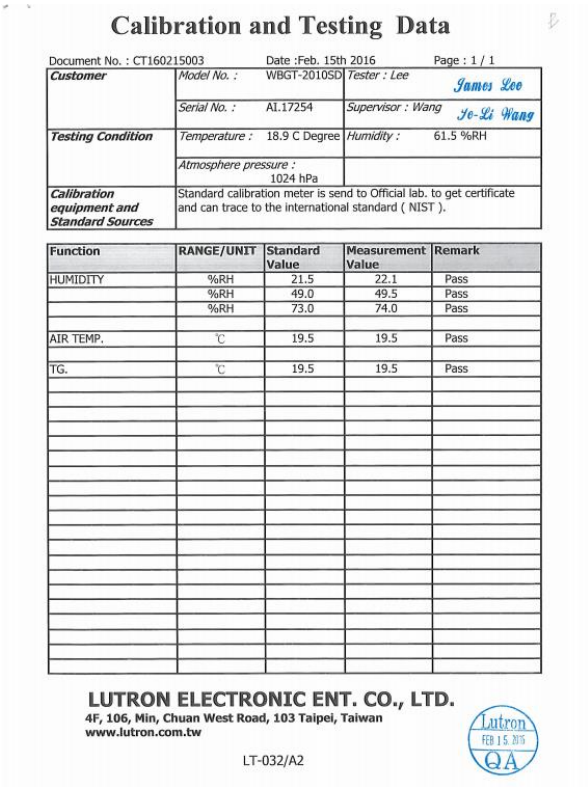
Date : Feb. 15th 2016

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The Art of Measurement

V. Calibration testing data of WBGT: B (Device serial No.: AI.17254)



Calibration and Testing Data

Document No. : CT160215003 Date :Feb. 15th 2016 Page : 1 / 1

Customer	*Model No. :*	WBGT-2010SD	*Tester : Lee*	*James Lee*
	Serial No. :	AI.17254	*Supervisor : Wang*	*Ye-Li Wang*
Testing Condition	*Temperature :*	18.9 C Degree	*Humidity :*	61.5 %RH
	Atmosphere pressure :	1024 hPa		
Calibration equipment and Standard Sources	Standard calibration meter is send to Official lab. to get certificate and can trace to the international standard (NIST).			

Function	RANGE/UNIT	Standard Value	Measurement Value	Remark
HUMIDITY	%RH	21.5	22.1	Pass
	%RH	49.0	49.5	Pass
	%RH	73.0	74.0	Pass
AIR TEMP.	℃	19.5	19.5	Pass
TG.	℃	19.5	19.5	Pass

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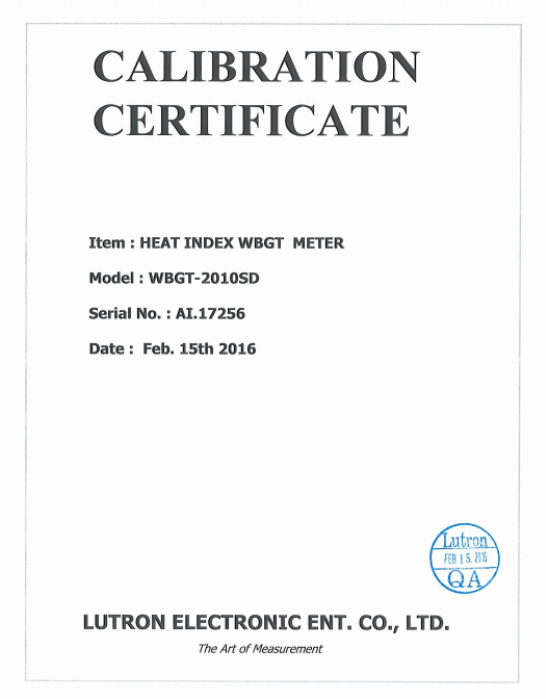
4F, 106, Min, Chuan West Road, 103 Taipei, Taiwan

www.lutron.com.tw

LT-032/A2

Lutron FEB 15. 2016 QA

VI. Calibration certificate of WBGT: C (Device serial No.: AI.17256)



CALIBRATION CERTIFICATE

Item : HEAT INDEX WBGT METER

Model : WBGT-2010SD

Serial No. : AI.17256

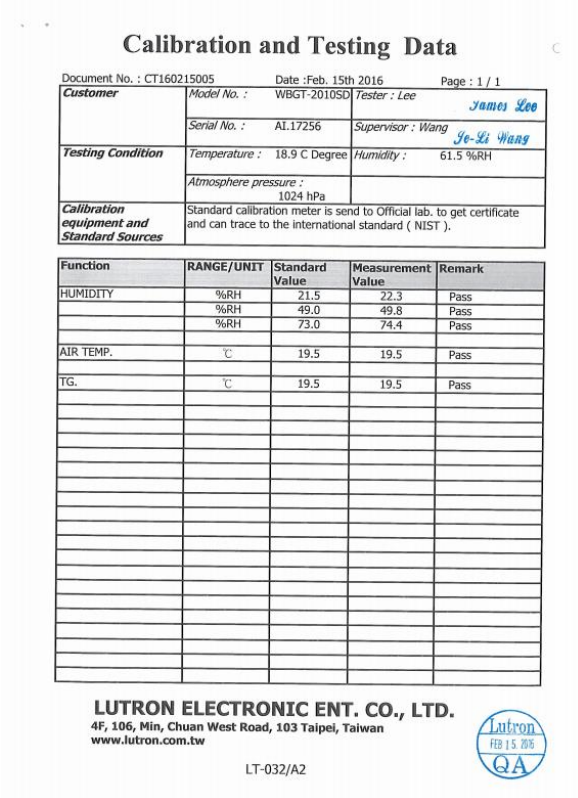
Date : Feb. 15th 2016

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VII. Calibration testing data of WBGT: C (Device serial No.: AI.17256)



Calibration and Testing Data

Document No. : CT160215005 Date :Feb. 15th 2016 Page : 1 / 1

Customer	*Model No. :*	WBGT-2010SD	*Tester : Lee*	James Lee
	Serial No. :	AI.17256	*Supervisor : Wang*	Ye-Li Wang
Testing Condition	*Temperature :*	18.9 C Degree	*Humidity :*	61.5 %RH
	Atmosphere pressure :	1024 hPa		
Calibration equipment and Standard Sources	Standard calibration meter is send to Official lab. to get certificate and can trace to the international standard (NIST).			

Function	RANGE/UNIT	Standard Value	Measurement Value	Remark
HUMIDITY	%RH	21.5	22.3	Pass
	%RH	49.0	49.8	Pass
	%RH	73.0	74.4	Pass
AIR TEMP.	℃	19.5	19.5	Pass
TG.	℃	19.5	19.5	Pass

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VIII. Calibration certificate of WBGT: D (Device serial No.: AI.17253)



CALIBRATION CERTIFICATE

Item : HEAT INDEX WBGT METER

Model : WBGT-2010SD

Serial No. : AI.17253

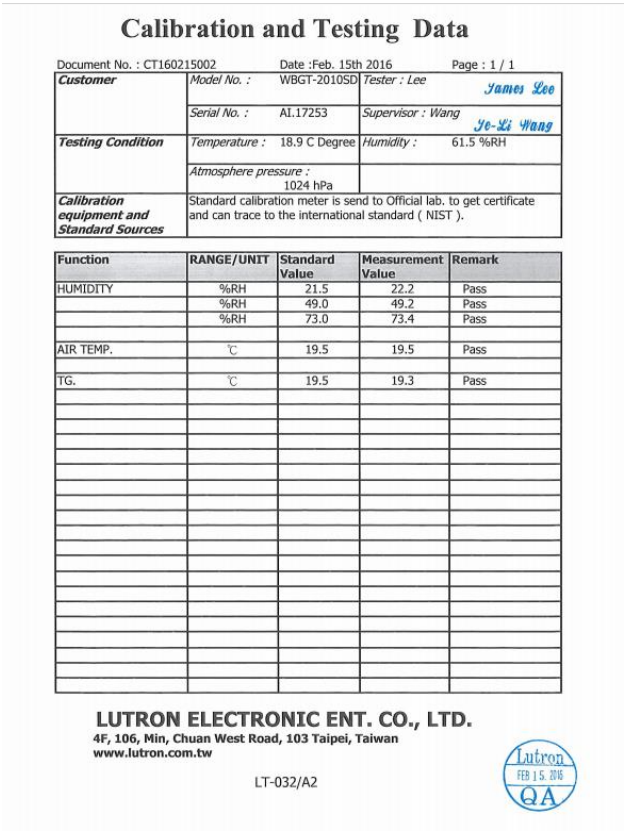
Date : Feb. 15th 2016

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IX. Calibration testing data of WBGT: D (Device serial No.: AI.17253)



Calibration and Testing Data

Document No. : CT160215002 Date :Feb. 15th 2016 Page : 1 / 1

Customer	*Model No. :*	WBGT-2010SD	*Tester : Lee*	*James Lee*
	Serial No. :	AI.17253	*Supervisor : Wang*	*Ye-Li Wang*
Testing Condition	*Temperature :*	18.9 C Degree	*Humidity :*	61.5 %RH
	Atmosphere pressure :	1024 hPa		
Calibration equipment and Standard Sources	Standard calibration meter is send to Official lab. to get certificate and can trace to the international standard (NIST).			

Function	RANGE/UNIT	Standard Value	Measurement Value	Remark
HUMIDITY	%RH	21.5	22.2	Pass
	%RH	49.0	49.2	Pass
	%RH	73.0	73.4	Pass
AIR TEMP.	℃	19.5	19.5	Pass
TG.	℃	19.5	19.3	Pass

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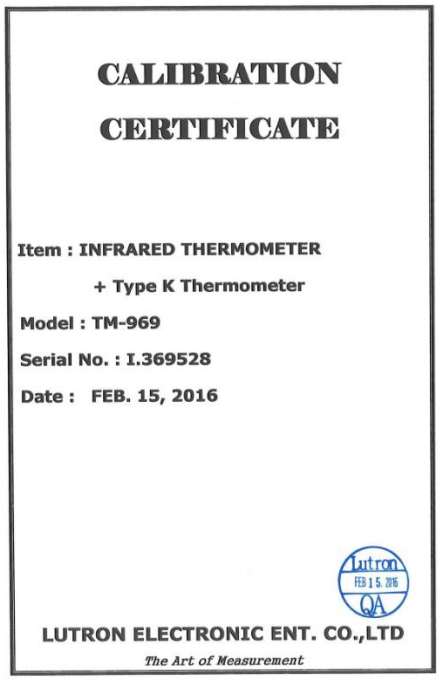
4F, 106, Min, Chuan West Road, 103 Taipei, Taiwan

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X. Calibration certificate of IR thermometer: A (Device serial No.: I.369528)



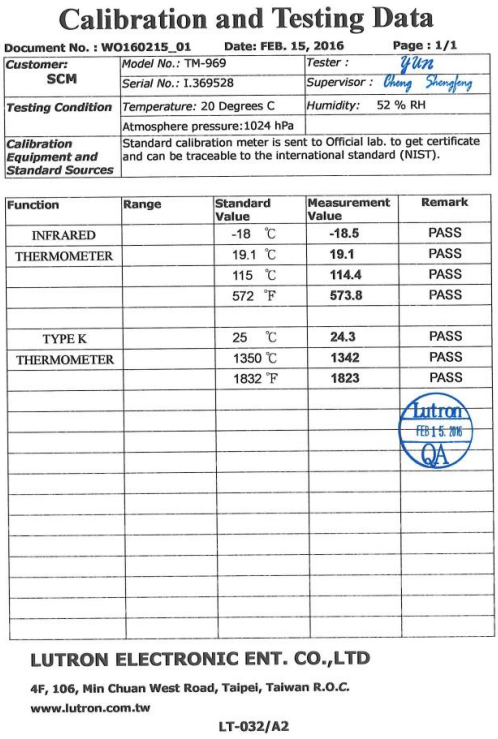
CALIBRATION CERTIFICATE

Item : INFRARED THERMOMETER
+ Type K Thermometer
Model : TM-969
Serial No. : I.369528
Date : FEB. 15, 2016

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The Art of Measurement

XI. Calibration testing data of IR thermometer: A (Device serial No.: I.369528)



Calibration and Testing Data

Document No. : WO160215_01 **Date: FEB. 15, 2016** **Page : 1/1**

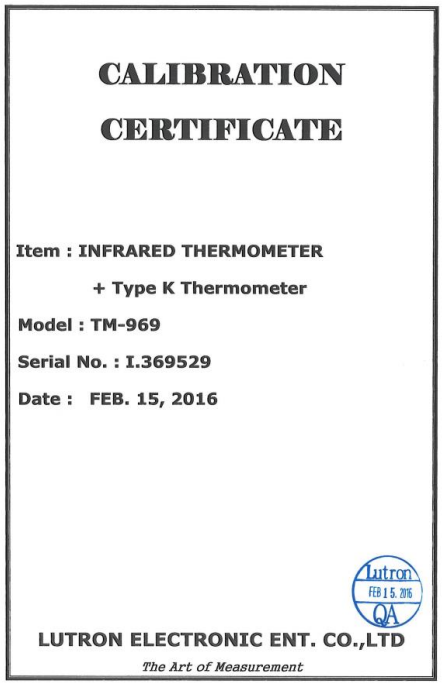
Customer: SCM	*Model No.:* TM-969	*Tester :*
	Serial No.: I.369528	*Supervisor :* Cheng Shengfeng
Testing Condition	*Temperature:* 20 Degrees C	*Humidity:* 52 % RH
	Atmosphere pressure:1024 hPa	
Calibration Equipment and Standard Sources	Standard calibration meter is sent to Official lab. to get certificate and can be traceable to the international standard (NIST).	

Function	Range	Standard Value	Measurement Value	Remark
INFRARED		-18 ℃	**-18.5**	PASS
THERMOMETER		19.1 ℃	**19.1**	PASS
		115 ℃	**114.4**	PASS
		572 ℉	**573.8**	PASS
TYPE K		25 ℃	**24.3**	PASS
THERMOMETER		1350 ℃	**1342**	PASS
		1832 ℉	**1823**	PASS

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4F, 106, Min Chuan West Road, Taipei, Taiwan R.O.C.
www.lutron.com.tw
LT-032/A2

XII. Calibration certificate of IR thermometer: B (Device serial No.: I.369529)



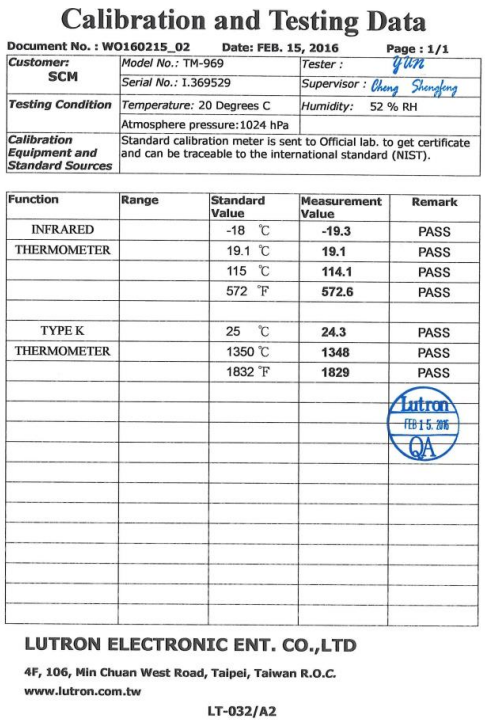
CALIBRATION CERTIFICATE

Item : INFRARED THERMOMETER
+ Type K Thermometer
Model : TM-969
Serial No. : I.369529
Date : FEB. 15, 2016

Lutron FEB 15. 2016 QA

LUTRON ELECTRONIC ENT. CO.,LTD
The Art of Measurement

XIII. Calibration testing data of IR thermometer: A (Device serial No.: I.369529)



Calibration and Testing Data

Document No. : WO160215_02 **Date: FEB. 15, 2016** **Page : 1/1**

Customer: **SCM**	*Model No.:* TM-969	*Tester :* Yun
	Serial No.: I.369529	*Supervisor :* Cheng Shengfeng
Testing Condition	*Temperature:* 20 Degrees C	*Humidity:* 52 % RH
	Atmosphere pressure:1024 hPa	
Calibration Equipment and Standard Sources	Standard calibration meter is sent to Official lab. to get certificate and can be traceable to the international standard (NIST).	

Function	Range	Standard Value	Measurement Value	Remark
INFRARED		-18 ℃	**-19.3**	PASS
THERMOMETER		19.1 ℃	**19.1**	PASS
		115 ℃	**114.1**	PASS
		572 ℉	**572.6**	PASS
TYPE K		25 ℃	**24.3**	PASS
THERMOMETER		1350 ℃	**1348**	PASS
		1832 ℉	**1829**	PASS

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4F, 106, Min Chuan West Road, Taipei, Taiwan R.O.C.
www.lutron.com.tw
LT-032/A2

XIV. Tasco Anemometer Calibration Certificate (Certificate No.: L1601-428)



MIRACLE INTERNATIONAL TECHNOLOGY CO., LTD.
214 Bangwaek Rd. Bangpai Bangkae Bangkok 10160
Tel. : 0-2865-4647-8 Fax : 0-2865-4649 http://www.mit.in.th

CALIBRATION CERTIFICATE

Certificate No. : L1601-428
Date Issued : 08-Feb-16

Customer : Thanun Srithongchai
45/82 Thepphasuk Road,
T.Naimuang, A.Muang Khonkaen, Thailand 40000

Equipment : Anemometer
Manufacturer : TASCO
Model : TMS350
Serial No. : 000000073
ID No./Tag No. :
Date Received : 20-Jan-16
Date Calibrated : 02-Feb-16
Ambient Temperature : (23 ± 2) °C
Relative Humidity : (50 ± 15)%RH
Calibrated by : Mr. Panat Chuachil

Calibration Method or Calibration Procedure Used

In-house method MIT-CP-37 based on IEC-61400-12-1: by direct comparing against Standard Anemometer in Wind Tunnel .
This certificate is traceable to national standards, which realize the units of measurement according to the International System of Units (SI).

Result of Calibration

The results of calibration are given in table 1 on page 2 of this report.

The reported uncertainty of measurement was based on standard uncertainty multiplied by a coverage factor k = 2, providing a level confidence approximately 95 percent.

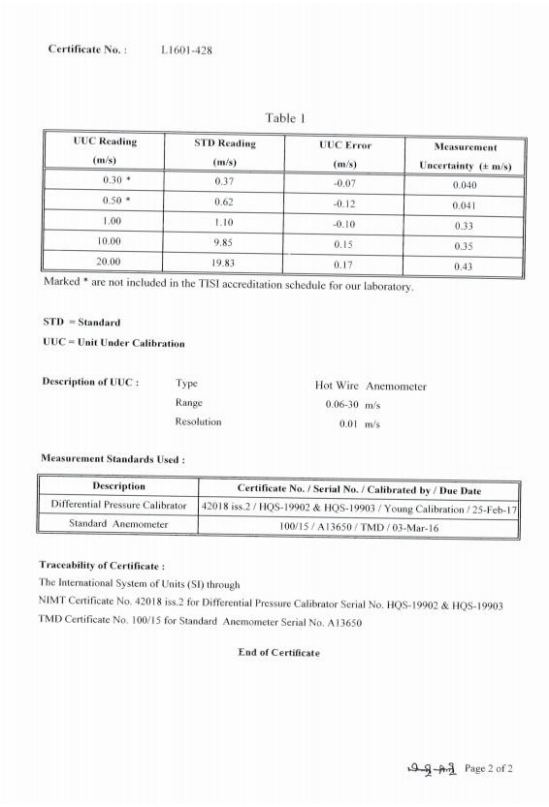
This certificate may not be reproduced other than in full except with the prior written approval of the Technical Manager, Miracle International Technology Company Limited.

Approved by : (Mr. Tassanai Suksukon)

CERTIFIED MIT

Page 1 of 2

XV. Calibration testing data of Tasco Anemometer



Certificate No. : L1601-428

Table 1

UUC Reading (m/s)	STD Reading (m/s)	UUC Error (m/s)	Measurement Uncertainty (± m/s)
0.30 *	0.37	-0.07	0.040
0.50 *	0.62	-0.12	0.041
1.00	1.10	-0.10	0.33
10.00	9.85	0.15	0.35
20.00	19.83	0.17	0.43

Marked * are not included in the TISI accreditation schedule for our laboratory.

STD = Standard
UUC = Unit Under Calibration

Description of UUC : Type Hot Wire Anemometer
Range 0.06-30 m/s
Resolution 0.01 m/s

Measurement Standards Used :

Description	Certificate No. / Serial No. / Calibrated by / Due Date
Differential Pressure Calibrator	42018 iss.2 / HQS-19902 & HQS-19903 / Young Calibration / 25-Feb-17
Standard Anemometer	100/15 / A13650 / TMD / 03-Mar-16

Traceability of Certificate :
The International System of Units (SI) through
NIMT Certificate No. 42018 iss.2 for Differential Pressure Calibrator Serial No. HQS-19902 & HQS-19903
TMD Certificate No. 100/15 for Standard Anemometer Serial No. A13650

End of Certificate

Page 2 of 2

XVI. Infrared Imaging thermometer calibration certification (Flir, TG165, 15-TG165-048301)



ELECTRICAL AND ELECTRONICS INSTITUTE
FOUNDATION FOR INDUSTRIAL DEVELOPMENT
975 Moo 4, Bangpoo Industrial Estate, Soi 8, Sukhumvit Road km 37
Phraek Sa, Mueang Samut Prakan, Samut Prakan 10280
Tel: +66 2709 4860-8 Fax: +66 2324 0917-8

Certificate No.: 0097TE16
Operation No.: 5901ACTE0213

Certificate of Calibration

Equipment:	Thermal Imager
Manufacturer:	FLIR
Model/Type:	TG165
Serial No.:	15-TG165-048301
ID No.:	-
Customer:	Thanun Srithongchai
Address:	64 Moo 5, Bangna-Trad KM 37 Bangsamak, Bangpakong Chachoengsao 24180
Received Date:	20 January 2016
Calibrated Date:	25 January 2016
Issued Date:	28 January 2016
Calibrated by:	Mr. Thossapon Jitthai

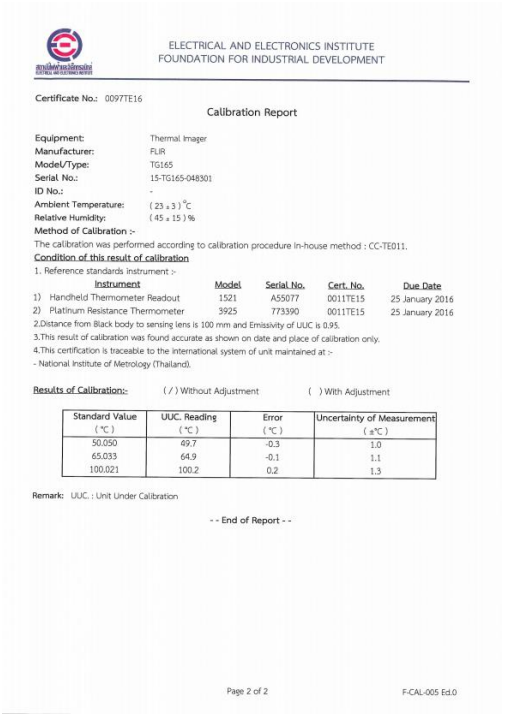
Approved by: (Mr. Pongpat Phanpeam)
Group Manager (Act.)

The reported uncertainty of measurement was based on standard uncertainty multiplied by a coverage factor $k = 2.00$, providing a level of confidence of approximately 95%. This certificate may not be reproduced other than in full except with the prior written approval of the Electrical and Electronics Institute, Foundation for Industrial Development.

Page 1 of 2

F-CAL-004 Ed.0

XVII. Calibration testing data of Infrared Imaging thermometer calibration (Flir, TG165, 15-TG165-048301)



ELECTRICAL AND ELECTRONICS INSTITUTE
FOUNDATION FOR INDUSTRIAL DEVELOPMENT

Certificate No.: 0097TE16

Calibration Report

Equipment: Thermal Imager
Manufacturer: FLIR
Model/Type: TG165
Serial No.: 15-TG165-048301
ID No.: -
Ambient Temperature: (23 ± 3) °C
Relative Humidity: (45 ± 15) %
Method of Calibration :-
The calibration was performed according to calibration procedure in-house method : CC-TE011.
Condition of this result of calibration
1. Reference standards instrument :-

Instrument	Model	Serial No.	Cert. No.	Due Date
1) Handheld Thermometer Readout	1521	A55077	0011TE15	25 January 2016
2) Platinum Resistance Thermometer	3925	773390	0011TE15	25 January 2016

2.Distance from Black body to sensing lens is 100 mm and Emissivity of UUC is 0.95.
3.This result of calibration was found accurate as shown on date and place of calibration only.
4.This certification is traceable to the international system of unit maintained at :-
- National Institute of Metrology (Thailand).

Results of Calibration:- (/) Without Adjustment ( ) With Adjustment

Standard Value (°C)	UUC. Reading (°C)	Error (°C)	Uncertainty of Measurement (±°C)
50.050	49.7	-0.3	1.0
65.033	64.9	-0.1	1.1
100.021	100.2	0.2	1.3

Remark: UUC. : Unit Under Calibration

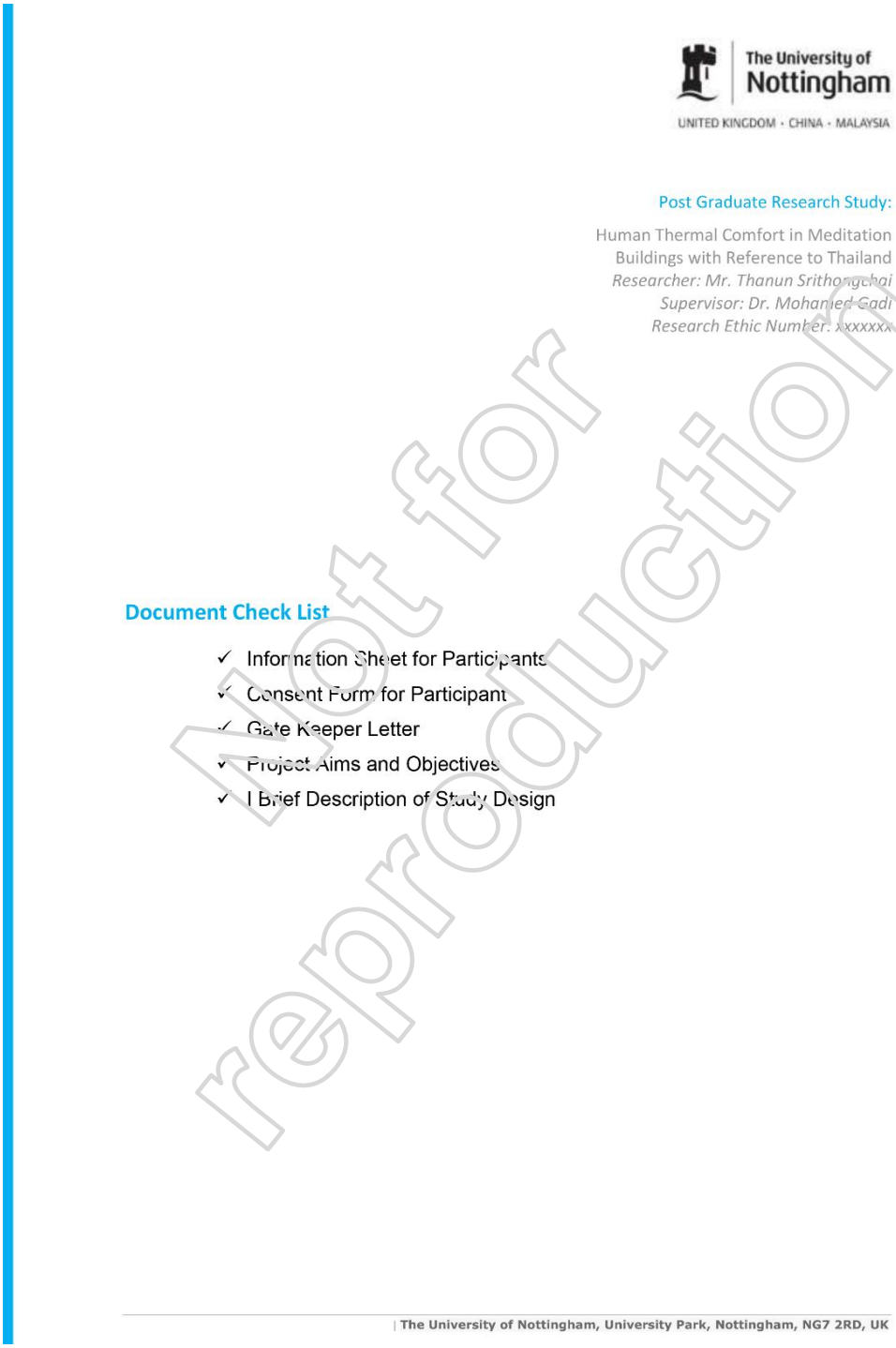
- - End of Report - -

Page 2 of 2

F-CAL-005 Ed.0

Appendix B: Ethical Observance Documents

I. Document Checklist



The University of Nottingham
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Post Graduate Research Study:

Human Thermal Comfort in Meditation Buildings with Reference to Thailand
Researcher: Mr. Thanun Srithongchai
Supervisor: Dr. Mohamed Gadi
Research Ethic Number: xxxxxxx

Document Check List

- ✓ Information Sheet for Participants
- ✓ Consent Form for Participant
- ✓ Gate Keeper Letter
- ✓ Project Aims and Objectives
- ✓ Brief Description of Study Design

The University of Nottingham, University Park, Nottingham, NG7 2RD, UK

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II. Consent form (English)

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Post Graduate Research Study:

Research Title: Human Thermal Comfort in Meditation Buildings with Reference to Thailand

Participant's Consent Form

- According to the participant information sheet and verbal explanations by the researcher, I have read and understand project nature and purpose before participating and involving in it.
- I understand that I may withdraw from this study whenever I wish and it will not impact my present or future status.
- I understand that when the research results are disseminated, my personal information provided in this research will be confidential and anonymous.
- I understand that there will be video recording and photos taking during the observation.
- I understand that information which are original document and other related electronic data and from the study will be kept in a secured place where the researcher and supervisors can access to them.
- I understand that if further information about the project is required or I want to complain about my research involvement, I may contact the Research Ethics Coordinator of the School of Education, University of Nottingham.

If you would like to take a part in the study, please insert a check mark (/) into the ☐

☐ **I understand all information provided by the researcher and agree to take a part in this study.**

Document Serial Number ..... **Date** .....

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Contact details

- Researcher :*Thanun Srithongchai PhD Student, School of Engineering, Faculty of Architecture and Built Environment, The University of Nottingham, Tel: +447541089268*
  Contact: Ezxts2@nottingham.ac.uk
- Supervisor : Dr. Mohamed B. Gadi, Contact: Mohamed.gadi@nottingham.ac.uk

III. Consent form (Thai)

The University of Nottingham
UNITED KINGDOM • CHINA • MALAYSIA

การศึกษาระดับปริญญาเอก:
สภาวะน่าสบายของผู้ปฏิบัติธรรมในอาคารปฏิบัติธรรม: อ้างอิงกลุ่มตัวอย่างผู้ใช้อาคารในประเทศไทย
ผู้ทำวิจัย: นาย ฐานันดร์ ศรีธงชัย
อาจารย์ที่ปรึกษา: Dr. Mohamed Gadi
หมายเลขการรับรองจริยธรรมการศึกษาวิจัยในมนุษย์
.....

แบบยินยอมของอาสาสมัคร

- ตามที่ได้ระบุไว้ในเอกสารข้อมูลพื้นฐาน สำหรับผู้เข้าร่วมโครงการและการอธิบายทางวาจา ข้าพเจ้ามีความเข้าใจเกี่ยวกับ ข้อมูลพื้นฐานและจุดประสงค์ของงานวิจัยนี้ก่อนที่จะตัดสินใจเข้าร่วมกรศึกษา
- ข้าพเจ้าทราบว่าข้าพเจ้ามีสิทธิในการถอนตัวจากการศึกษาได้ตลอดเวลาและการถอนตัวนั้นจะไม่กระทบต่อข้าพเจ้าในอนาคต
- ข้าพเจ้าทราบว่าการวิจัยในครั้งนี้มีการบันทึกภาพนิ่ง และภาพเคลื่อนไหว
- ข้าพเจ้าทราบว่า เมื่อผลของการศึกษาในครั้งนี้ถูกเผยแพร่ ข้อมูลส่วนตัวของข้าพเจ้าที่ได้ระบุในการวิจัยครั้งนี้จะถูกปกปิดเป็นความลับ
- ข้าพเจ้าทราบว่า ข้อมูลแบบสอบถามต้นฉบับงานวิจัยครั้งนี้จะถูกเก็บไว้ในที่ที่ปลอดภัย ซึ่งผู้วิจัยและอาจารย์ที่ปรึกษาของโครงการนี้เท่านั้นที่จะสามารถเข้าถึงแหล่งข้อมูลดังกล่าวได้
- ข้าพเจ้ารับทราบว่าหากข้าพเจ้าต้องการสอบถามหรือร้องเรียนการวิจัยที่ข้าพเจ้าได้เข้าร่วมนี้ ข้าพเจ้าสามารถติดต่อตามข้อมูลด้านล่าง

กรุณาทำเครื่องหมาย / ลงใน ☐ ด้านล่าง

☐ ข้าพเจ้ามีความเข้าใจข้อมูลต่างๆที่ได้มีการชี้แจงจากผู้ทำวิจัย และยินดีที่จะเข้าร่วมโครงการด้วยความเต็มใจ

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ข้อมูลการติดต่อ

ผู้วิจัย : นาย ฐานันดร์ ศรีธงชัย E-mail: Ezxts2@nottingham.ac.uk
อาจารย์ที่ปรึกษา : Dr. Mohamed B. Gadi E-mail: Mohamed.gadi@nottingham.ac.uk

IV. Information sheet for participants (English)

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Post Graduate Research Study:

Human Thermal Comfort in Meditation Buildings with Reference to Thailand

Researcher: Mr. Thanun Srithongchai

Information Sheet for Focus Group of Participants

As I am conducting research under the title of 'Human Comfort Study in Meditation Buildings in Thailand', this invitation is offered to you. For making a decision to participate in this study, it is necessary to understand fundamental information of the project. Please kindly spend your time to understand the information below. If there is any aspect you wish to discuss this research activity or you might require more information about the project, please do not hesitate to contact the research staffs or the main researcher. Please take your time to make a decision for research participation.

Thank you for spending your time considering this.

Research Aim: According to the past researches in this field, there has been widely investigating human thermal comfort of people in both laboratory and in real environments. Various buildings type has been examined such as office, residential buildings, school and factories and religious buildings. However, buildings for meditation which are a new building type have never been investigated yet. The main aim of research is to investigate thermal sensation and perception of mediators in meditation buildings under a hot and humid climate in Thailand. This project will explore optimum temperature this group of people and that will be compares with that of the similar researches conducted in comparable locations.

Participating Requirement: This project requires participant to complete the questionnaire which comprises of 3 main sections. The first section will ask the participants about your thermal sensation and perception while answering the questionnaire and ask you if there is any modification of your personal clothing and environment around you. For the second section, the questionnaire will ask in similar way but it will ask you about those questions while your perform meditation. In this section, it will also ask about your personal experience during meditating. For the last section, the questionnaire will focus on your

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personal information such as your clothing, experience on meditation and frequency of practice. That activity will take place after finishing meditation before taking a break.

The expected time spent on this activity is approximately 15 minutes. Once you complete the questionnaire, please kindly do not return this form to the staffs while leaving it at the front of you. The staff will collect the form and record your sitting location. Please note that during the study, there will be a VDO recorder filming changes of the environment by participants such as operations of windows, curtains, lightings and fans.

Anonymity/Participation: your Identity indicated in the document will be protected. The exploration of this research might be used in academic purpose such as in academic journals or presented in academic conferences. In terms of data protection, the information you provided will not be able to identify, and it will be anonymous.

The results obtained from the study will not focus individually, while it will be analysed and expressed statistically. For personal images that your identity might appear in the report, it will be modified to protect your information. Your consent form which has your identity will be kept in a separated secured location for avoiding data association. Moreover, the original questionnaires will be kept securely in an access-control room where a password is required for at least 7 years. For this participation, please note that,

- You can feel free to withdraw from the activity during the survey.
- You can skip the questions which you might not wish to.
- In case that you complete the form, but you change your mind in not to participate, you can contact the researcher as the information provided.

Finally, if this study harmed you, you can contact the University of Nottingham as the details below;

Researcher's Name: Thanun Srithongchai
Email: Ezxts2@Nottingham.ac.uk
Supervisor's Name: Dr. Mohamed Gadi
Email: Mohamed.Gadi@Nottingham.ac.uk

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V. Information sheet for participants (Thai)

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

การศึกษาวิจัยระดับปริญญาเอก

การเรื่องสภาวะน่าสบาย ในอาคารปฏิบัติธรรม ในประเทศไทย

ผู้ทำการวิจัย: นายฐานันดร์ ศรีธงชัย

ข้อมูลวิจัยพื้นฐานสำหรับผู้เข้าร่วมโครงการ

เนื่องจากข้าพเจ้ากำลังทำการศึกษาเกี่ยวกับ 'สภาวะน่าสบายของผู้ปฏิบัติธรรมในอาคารที่ใช้ปฏิบัติธรรม' ข้าพเจ้าขอความอนุเคราะห์ท่านในการร่วมการตอบแบบสอบถามเพื่อใช้เป็นข้อมูลพื้นฐานในการวิเคราะห์ ดังนั้นก่อนที่ท่านจะตัดสินใจในการเข้าร่วมตอบแบบสอบถาม ท่านควรทำความเข้าใจข้อมูลพื้นฐานเกี่ยวกับการวิจัยครั้งนี้ซึ่งข้าพเจ้าได้ระบุไว้ตามข้อความด้านล่าง หากท่านสงสัยในหัวข้อใด หรือมีข้อซักถามเพื่อความเข้าใจ กรุณาติดต่อผู้ช่วยวิจัยหรือข้าพเจ้า ขอขอบพระคุณในการเข้าร่วมการตอบแบบสอบถามครั้งนี้

จุดประสงค์ของการศึกษา

เนื่องจากจากปัจจุบันได้มีการศึกษาสภาวะน่าสบายของมนุษย์อย่างแพร่หลายทั้งในห้องปฏิบัติการและสถานที่จริง ผู้ใช้อาคารในอาคารประเภทต่างๆ เช่น อาคารบ้านพักอาศัย สำนักงาน โรงเรียน โรงงาน แม้กระทั่ง อาคารทางศาสนา ได้ถูกทดสอบเพื่อค้นหาสภาวะดังกล่าวเพื่อเป็นข้อมูลพื้นฐานในการออกแบบอาคารเพื่อให้อาคารนั้นมีสภาวะเชิงอุณหภูมิที่เหมาะสมกับกิจกรรมต่างๆ อย่างไรก็ตามอาคารที่ใช้ในการปฏิบัติธรรมซึ่งเป็นอาคารที่เกิดขึ้นใหม่เพื่อตอบสนองกิจกรรมทางศาสนาที่มีการใช้งานเป็นเวลานานและมีผู้ใช้อาคารเป็นจำนวนมาก อาคารชนิดนี้ยังไม่เคยมีการศึกษาถึงสภาวะดังกล่าว ดังนั้นการศึกษาในระดับปริญญาเอกครั้งนี้ เป็นการศึกษาเพื่อที่ค้นหาสภาวะที่เหมาะสมของผู้เข้าร่วมปฏิบัติธรรมภายใต้สภาพแวดล้อมในเขตร้อนชื้นของประเทศไทย ผลการทดลองจะนำถูกนำไปเปรียบเทียบกับการศึกษาที่ผ่านมา ซึ่งได้มีการศึกษาภายใต้สภาวะที่ใกล้เคียงกัน

การขอความอนุเคราะห์ในการตอบแบบสอบถาม

กิจกรรมในการศึกษาสำหรับผู้เข้าร่วมโครงการการขอความร่วมมือในการตอบแบบสอบถามภายหลังจบการปฏิบัติธรรมโดยใช้เวลาประมาณ 10-15 นาที ซึ่งในแบบสอบถามนั้นจะมีการแบ่งคำถามเป็น 3 ส่วนเป็นคำถามเกี่ยวกับความรู้สึกด้านอุณหภูมิในขณะตอบแบบสอบถามและในระหว่างการปฏิบัติธรรมและคำถามทั่วไปประกอบเพื่อการวิเคราะห์ ระหว่างการตอบคำถาม ท่านสามารถถามคำถามกับผู้ช่วยวิจัยได้ เมื่อท่านทำแบบสอบถามเสร็จแล้ว กรุณาวางแบบสอบถามไว้ด้านหน้าพื้นที่ที่ท่านนั่งปฏิบัติธรรม การศึกษาครั้งนี้มีการบันทึกภาพเพื่อเป็นการศึกษาการปรับเปลี่ยนสิ่งแวดล้อมทางกายภาพ เช่น ผ้าม่าน หน้าต่าง พัดลม เป็นต้น

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การเก็บรักษาและการเผยแพร่ข้อมูลจากการศึกษา

ข้อมูลส่วนตัวที่ท่านได้ตอบในแบบสอบถามจะถูกเก็บรักษาในสถานที่ที่ปลอดภัย และจะไม่มีการแสดงตัวตนของท่าน การรายงานผลการศึกษานั้นจะเป็นการรายงานในภาพรวมของการศึกษาในเชิงสถิติ ซึ่งไม่ได้มีการเจาะจงในผู้เข้าร่วมท่านใดท่านหนึ่ง ในกรณีที่การรายงานต้องมีการใช้ภาพที่สามารถบ่งชี้ตัวตนของท่าน ทางผู้ทำวิจัยจะทำปรับปรุงภาพแก้ไขเพื่อให้ภาพนั้นไม่บ่งบอกตัวตนของท่าน เอกสารการตอบรับเข้าร่วมศึกษาของท่านจะถูกแยกกับแบบสอบถามเพื่อป้องการการบ่งชี้ตัวตน เอกสารต้นฉบับและข้อมูลทางอิเล็คโทรนิคทั้งหมดจะถูกเก็บอย่างปลอดภัยในห้องที่มีการควบคุมการเข้า-ออกที่อาคาร SRB และมีเพียงผู้ทำวิจัยและอาจารย์ที่ปรึกษาเท่านั้นที่สามารถเข้าถึงเอกสารต้นฉบับได้ ข้อมูลทั้งหมดจะถูกเก็บไว้ทั้งหมด 7 ปีก่อนจะถูกทำลาย ในการเข้าร่วมโครงการท่านสามารถ

- ถอนตัวจากโครงการได้เมื่อไหร่ก็ตามที่ท่านต้องการ
- ท่านสามารถข้ามการตอบคำถามที่ท่านไม่ยินดีที่จะให้ข้อมูล
- ในกรณีที่ท่านเปลี่ยนใจหลังจากท่านได้ให้ข้อมูลไปแล้ว ท่านสมารถยกเลิกการเข้าร่วมโครงการได้โดยการติดต่อผู้ทำการวิจัยตามที่อยู่ที่ด้านล่าง ข้อมูลของท่านจะถูกทำลายทันที

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VI. Gatekeeper's letter (English)

The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

Post Graduate Research Study:

Human Thermal Comfort in Meditation Buildings with Reference to Thailand

To whom it may concern,

My name is Thanun Srithongchai, a PhD student in faculty of Architecture and Built Environment, the University of Nottingham, The University of Nottingham. I am conducting research which is an investigation of human thermal comfort of meditators in meditation buildings in a tropical climate with reference to the Eastern region of Thailand. Now the project is in the process of data collection. This study aims to explore the thermal perception of human in real context by measuring thermal variables in real environments and asking subjective vote of thermal perception by questionnaire. Thus, I send you this email to kindly consider the consent of researching your facilities. The survey and measuring will be conducted from November to December, while the other one will take place during July and August.

To achieve that, it should consider both measurable variables such as air temperature, wind speed, mean radiant temperature and relative humidity and non-measurable variable such as asking for the subjective vote of participants by applying questionnaire and observing their activities to improve their thermal comfort. With regard to environmental assessment, measuring instruments such as WBGT thermometers, Infrared thermometers and anemometers are used.

As far as ethics approval is concerned, under that of the university research committee, this research conduction complies with the Code of Research Conduct and Research Ethics of the UK. Moreover, this investigation will conduct in involuntary way without coercion under their consent. Thus, they have the right to withdraw whenever they wish to. For data security, personal information of the participants involving in this activity will be anonymous and their data collected will be kept in a secured place to conceal their identities at least for seven years before it will be terminated. Finally, the results of this study will be disseminated for academic purposes only such as publishing in academic journals or presenting in academic conferences. The outcomes of this study can be significant data for architectural design for this building type and a database for this research field for further researches.

Sincerely,

Mr. Thanun Srithongchai
PhD Student, School of Engineering, Faculty of Architecture and Built Environment, the University of Nottingham

The University of Nottingham, University Park, Nottingham, NG7 2RD, UK

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VII. Gate keeper's letter (Thai)

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

การศึกษาในระดับปรอญญาเอก:

เรื่อง การศึกษาสภาวะน่าสบายในอาคารปฏิบัติธรรม ในเขตพื้นที่จังหวัดขอนแก่น ประเทศไทย

เรียนท่านผู้รับผิดชอบในอาคารปฏิบัติธรรม

ข้าพเจ้า นาย ฐานันดร์ ศรีธงชัย นักศึกษาระดับปริญญาเอก ใน คณะสถาปัตยกรรม และสิ่งแวดล้อมสรรค์สร้าง ณ มหาวิทยาลัย The University of Nottingham ระเทศอังกฤษ ขณะนี้ ข้าพเจ้ากำลังทำกรศึกษาวิจัย เกี่ยวกับสภาวะน่าสบายในอาคารที่ใช้ปฏิบัติธรรม ในเขตจังหวัดขอนแก่น ประเทศไทยซึ่งเป็นภูมิอากาศแบบร้อนชื้น จุดประสงค์ในการศึกษาครั้งนี้ เพื่อที่จะศึกษาสภาวะการรับรู้สภาพอากาศของมนุษย์ในสภาพแวดล้อมจริง โดยการตรวจวัดค่าตัวแปรที่ส่งผลในการรับรู้เชิงอุณหภูมิและการตอบแบบสอบถาม ดังนั้นข้าพเจ้าจึงเขียนหมายขอความอนุเคราะห์ฉบับนี้เพื่อขอความร่วมมือในการศึกษาวิจัยครั้งนี้ โดยการศึกษานั้นจะดำเนินช่วงพฤศจิกายนถึงช่วงธันวาคมสำหรับการเก็บข้อมูลในช่วงหน้าหนาว และกรกฎาคมถึงสิงหาคมสำหรับการเก็บข้อมูลช่วงหน้าฝน

เพื่อที่จะดำเนินการศึกษาและสรุปข้อมูลครั้งนี้ การศึกษาจะมีการตรวจวัดข้อมูลตัวแปรทางกายภาพเชิงตัวแปรที่ต้องทำการตรวจวัดนั้นคือ อุณหภูมิกระเปราะแห้ง ความเร็วลม ค่าเฉลี่ยการแผ่รังสีความร้อน ความความชื้นสัมพัทธ์ และเก็บข้อมูลที่ไม่สามารถวัดค่าได้ เช่น การตอบแบบสอบถาม การสำรวจกิจกรรมระหว่างการปฏิบัติธรรมที่เกี่ยวข้องกับปรับเปลี่ยนเพื่อลดความไม่สบายเชิงอุณหภูมิของผู้เข้าร่วมโครงการ สำหรับการตรวจวัดทางวิทยาศาสตร์นั้น เครื่องมือที่ใช้ในการตรวจวัด มีดังนี้คือ WBGT thermometer, Infrared Thermometer และ Anemometer

โครงการวิจัยนี้ได้ผ่านการตรวจสอบและพิจารณาจากคณะกรรมการการวิจัยในมนุษย์ของมหาวิทยาลัย The University of Nottingham นอกจากนั้นการศึกษาในครั้งนี้จะดำเนินการเฉพาะผู้ที่ต้องการเป็นอาสาสมัครโดยปราศจากการบังคับภายใต้ความยินยอมส่วนบุคคลของผู้เข้าร่วมโครงการ ดังนั้นผู้เข้าร่วมโครงการมีสิทธิ์ที่จะถอนเมื่อไหร่ก็ตามที่พวกเขามีความต้องการ สำหรับการเก็บรักษาข้อมูลวิจัย ข้อมูลต่างๆที่ได้เก็บมานั้นจะถูกรักษาอย่างปลอดภัยในห้องที่มีการควบคุมการเข้าถึงเพื่อปกปิดการแสดงการบ่งชี้ข้อมูลส่วนบุคคล การเป็นข้อมูลนั้นจะทำการเก็บเป็นระยะเวลา 7 ปี ก่อนที่ข้อมูลทุกอย่างจะถูกทำลาย สุดท้ายนี้ ข้อมูลจากการศึกษาจะทำการเผยแพร่ในการประชุม สัมมนาทางวิชาการ และตีพิมพ์ในวารสารทางวิชาการเท่านั้น ผลการวิจัยครั้งนี้มีความสำคัญเป็นอย่างมากในการพัฒนาการออกแบบสถาปัตยกรรมที่เกี่ยวข้องกับอาคารในประเภทนี้ และข้อมูลพื้นฐานสำคัญสำหรับการวิจัยในอนาคต

ด้วยความเคารพ

นาย ฐานันดร์ ศรีธงชัย

นักศึกษาระดับปริญญาเอก คณะสถาปัตยกรรมและ
สิ่งแวดล้อมสรรค์สรรค์สร้าง มหาวิทยาลัย The
University of Nottingham

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VIII. Project aims and objectives

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

Post Graduate Research Study:

Human Thermal Comfort in Meditation Buildings with Reference to Thailand
Researcher: Mr. Thanun Srithongchai
Research Ethic Number: xxxxxxx

Research Aims

This research aims to explore thermal comfort in meditation buildings in dynamic thermal condition of a hot and humid climate. Thermal comfort condition of this group of people has never been mentioned or investigated in any standard as it is a specific activity, while in psychological treatment; the activity has been being investigated since the 1960s. This building type is large public buildings which can be commonly found in Thailand. Each centre can accommodate around 20 to 250 people. It is an activity which practitioners require to engage for a long period; moreover, some people tend to spend their time for 3-7 days and each day, practising time might take more than 2 to 8 hours in such a large space. Some of the places also provide participants with accommodation, clothing and foods.

Moreover, mindfulness cultivation by mediation which is at first glance, it might be just common sedentary activities and might be referred to other similar metabolic rates as indicated in standards. However, meditation is relatively different from those, and it can be proved by researches as practitioners present changes in psychological and physiological aspects, and it is nowadays applied in mental therapy as an integrated intervention psychological medication. Thus, the optimum temperature of participants should be explored.

Furthermore, this study aims to explore the thermal comfort of occupiers engaging meditative activities in this type of buildings. Results derived from this investigation might allow researchers in this field to gain more understanding about the influence of places and building types in human thermal comfort. That is a non-thermal factor which might influence the thermal perception of human as the idea of an adaptive model with respect to psychological and behavioural aspects. If people who are in this space and practising meditation can perceive differently in terms of thermal comfort, it might result in changes in human perspective on energy and mechanical usage.

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Research Objectives

According to the aim of the study as mentioned above, this research objective is as follows;

- To investigate thermal sensation, perception and comfort of meditators in meditation buildings.
- To compare aspect derived from the above item with previous studies conducted in other types of buildings in similar climate condition.
- To explore thermal comfort and neutral temperatures for meditators in meditation building in the hot and humid climate.
- To explore adaptive solutions applied by meditators in the buildings to improve their thermal comfort level.

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Research Aims, Questions and Data Generation Instruments

No.	Research Questions	Aims	Data Generation Instruments	Notes
1	According to Knez et al. (2009) conceptual model of thermal perception, meditation places where is related to non-thermal factors such as religious believe, local culture and norm, rules, and meditative activities, how much it can influence human thermal sensation perception and	To explore thermal sensation, perception and acceptance of meditators in meditation buildings.	Using information derived from the quesiotnnaire such as thermal sensation, perception and preference votes. Those will be satatistically analyzed and expressed in graphics.	One hypothesis of this study is that there must be some differences between thermal sensation and perception of people in this building type. Thus, questions about how they sense and perceive by using Linkert-scale of vote are used in this
2	Comparing with people performing sedentary activities in other types of building, how different is sensation and perception of the meditators in meditation buildings?	To compare aspect derived from the item 1 with previous studies conducted in other types of building in similar climate condition.	Using questionnaire inquiring sensation and perception of meditators in real situation. Derived results such as neutral temperatures and thermal preference will be compared and contrasted with the	The research conducted in similar methods and climate conditions will be referred to compare especially ones which are conducted in Thailand and neighbouring areas.
3	What is optimum thermal condition for this building type in hot and humid context?	To explore thermal comfort and neutral temperatures for meditators in meditation building in hot and humid climate	Applying both physical measurements of the environment to explore thermal condition of the buildings by utilising WBGT, Anemometer, IR image camera. The data from environmental measurements will be compared with the result of subjective votes completed by participants.	Different temperatures and humidifies are required to explore human thermal perception in different environment conditions. Morning and afternoon thermal conditions in 2 different seasons are expected to be observed.
4	Under the cultural conditions set in the meditation places, what are adaptive solutions of meditators possibly applied and what are constraints to improve their thermal comfort in different meditation buildings in common?	To explore adaptive solutions applied by meditators in the buildings to improve their thermal comfort level.	By using VDO camera and camera ro observe interation between human and environments	For this study, there will not be interruption or distraction during the meditative activities. Moreover, the researcher will not ask for extra time for the survey activities. The researcher allows participants will do activities as usual. The research staffs will be informed that they cannot change improve or move things such as shutting windows and curtains or turn on-off lights and fans because we are observing the change in the context.

Not to quote

IX. A brief description of study design

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Post Graduate Research Study:

Human Thermal Comfort in Meditation Buildings with Reference to Thailand
Researcher: Mr. Thanun Srithongchai
Research Ethic Number: xxxxxxx

A Brief Description of the Study Design

- ***Number and type of participants***

As the number of participants is significant to reduce error in statistical analysis, 300 data in three meditation buildings is expected to acquire. There are two major surveys which one will take place in winter from November to December, while the other one will conduct in rainy season during July and August. It should be noted that the summer survey is omitted since some of the places do not organise the activity. Thus, 50 data is expected to obtain for each building in each season.

- ***Number and duration of activities participants will be involved in***

As mentioned above, this research requires exploring human thermal perception in real contexts. Rather than controlling indoor condition mechanically to examine human in different thermal conditions in the climate control experiment, seasonal and natural variation of temperature and humidity allow the research team to examine participants in naturally ventilated conditions. In each building, according to the observation, around 50-80 meditators will participate in the practice. In each day of the survey, the questionnaire will be spread 2 times in the morning and in the afternoon which each activity will last for 10-15minutes after finishing meditative activities before taking a break. Each surveying time will expect to obtain at least 25 – 30 data. Thus, in one day of a survey in one building, a minimum of 50 data has to be acquired for 2sessions. For the afternoon session, as this report aims to obtain thermal comfort vote from individuals in once a day, it should be noted the assistants will ask the participants before handing them the form if they were voluntary in the morning survey are not eligible to fill the afternoon survey again.

- ***Equipment and procedures to be applied***

Thermal comfort as stated in ASHRAE standard 55 (2004, 2010) is a subjective expression under the condition of mind. To measure environmental variables solely might not

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be a practical solution to investigate the problem. Instead, this study requires investigation of human thermal perception by subjective vote, while measuring those thermal variables. Therefore, this study aims to employ field survey based on the adaptive model to explore the optimum thermal condition for meditation building users. According to Yao et al. (2009), 'Black Box Theory' was applied in a field study to explore the adaptive solution of people in the real context. By observing the interaction of human in modifying their operable variables available in buildings, this project refers to this method to investigate human thermal comfort in meditation buildings in Thailand.

With regard to the measurement of environmental variables, according to Brager and DeDear literature review (Brager and DeDear, 1998), measurement in thermal comfort can be classified into three types which are I, II and III. For this research, it is identical to class II which measurements can be applied in thermal comfort investigation, but it is not necessary to meet accuracy as mentioned in ASHRAE standard as mentioned. Instead of controlling indoor thermal variables as a laboratory study, this field study will explore human thermal perception in the dynamic environment in real events and contexts. Scientific instruments applied in this research are WBGT for DBT, RH and TG measurements, anemometer with dumbbell probe for wind speed measurement, Infrared thermometer for surface temperature measurement and Thermal image camera for thermal graphics. That measurement will be manually and automatically recorded with a 30-minute interval starting from 07.30am to 6.00pm.

In terms of the subjective vote, this survey will investigate human thermal perception in the adaptive model method. Moreover, they are potential to adapt themselves to the condition that they find comfortable if there is a possible mean to implement. In the adaptive model concept, people can adapt themselves by three modes of adaptation which are physiological, behavioural and psychological adaptations (Brager & DeDear 1998). Thus, those can influence thermal comfort of people which cannot be ignored. In this study, rather than asking meditators how they sense and perceive by filling the questionnaire, this research will observe human behaviour while they occupy the meditation room. VDO cameras are used to monitor human behaviour during the survey time.

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- ***Information about how participants will be recruited***

Before recruiting participants, the researcher will contact the responsible person of the places to acquire consent to research the places. After that, before the main survey starts, participants will be informed about the activity about to happen. At this moment, the purpose of the study, the process of survey and measuring instruments used during the study will be explained. The research assistants will approach to participants to seek their consent for joining the survey.

- ***Whether participants will be paid (state how this will be done)***

As far as compensation paid to the participants is concerned, there is a controversy the result obtaining from unpaid and paid project. Thus, this issue should be carefully considered. As this project will be conducted in Thai Buddhism monastery, people come to this place to train to purify their mind and learn the path of the Buddha. In general, they come to make merit. Money is not a suitable issue of conversation to discuss in this holy area. Besides, the monasteries also provide foods and accommodation without any charge. It can be said that it will not need to spend any money during practice. Moreover, the place instructs the meditators not to bring valuable properties into the place. Thus, the researcher tries to avoid discussing this aspect in the area.

However, according to the observation, meditation retreats or organisers are non-profitable organisation. The places rely on donations to organise activities, manage their people, and support other operational costs. Thus, for that reason, instead of giving compensation to each participant, this study aims to donate the participated meditation retreats to support their activities as compensation after finishing each survey. That money will be paid to one responsible for this task. Consequently, this project aims to conduct involuntarily. There will not be any compensation to individuals.

- ***Plans to ensure participant confidentiality and anonymity***

There will be 3 documents used in this research which are consent document, As this research requires consent from participants, they are required to give their initial to confirm their consent and understanding about the research as demonstrated. As the name of the participants is not used in this analysis, their name will not be asked, while the consent form

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will ask them if they understand all information and their right for this study provided by the researcher and then give a check mark into the box. Each document is unique as it contains a different serial number and that will be the document code for participants when they want to contact the researcher. Moreover, the consent form will be separated from the main questionnaire after completing the survey. The document consent forms and questionnaires will be securely kept in different folders in a locked cabinet to avoid identifying any individual. The document will be matched by document serial number only.

- ***Plans for storage and handling of data***

Information of participant identities as indicated in the consent form will be separated from the questionnaire to conceal that private information. The original forms derived from the survey will be shipped back to the UK with the main researcher, and those will be solely managed by the main researcher and supervisors. The original questionnaires collected will be reviewed and transformed to an electronic format; after that, the original files will be securely kept in a personal locked cabinet in the SRB building where the password is required for accessibility. For the electronic data, it will be saved in personal computers and an external hard drive which ID and password of the main user are required to log in.

- ***Information about what will happen to the data after the study***

According to the Code of Research Conduct and Research Ethics of the University of Nottingham, the collected information will be kept as mentioned above until the project has been completed. After that, they will be transferred to the main supervisor. After 7 years, they will be terminated.

- ***information about how any data and images may be used***

The data obtained from this research will be only used in academic purposes such as written in this PhD thesis, published in academic papers and presented in academic conferences. Personal information of the participants will be concealed as this project will focus on the overall picture of thermal comfort vote in buildings as statistical analysis, not one particular person. In case that, if there is a picture containing obvious personal identities, those will be censored to avoid disclosing personal information.

- ***State whether it will be possible to identify any individuals***

It is impossible as there is no name record in this research. All information is anonymous.

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X. Ethics committee reviewer's decision

Ethics Committee Reviewer Decision

This form must be completed by each reviewer. Each application will be reviewed by two members of the ethics committee. Reviews may be completed electronically and sent to the Faculty ethics administrator (Jo Deeley) from a University of Nottingham email address, or may be completed in paper form and delivered to the Faculty of Engineering Research Office.

Applicant full name Thanun Srithongchai

Reviewed by: **Robert Houghton**

Name

Signature (paper based only) .....

Date 07/10/2016

☐ Approval awarded - no changes required

☐ Approval awarded - subject to required changes (see comments below)

☐ Approval pending - further information & resubmission required (see comments)

☐ Approval declined – reasons given below

Comments:

Approved subject to removing references to school of education and also ticking box three.

Please note:

1. The approval only covers the participants and trials specified on the form and further approval must be requested for any repetition or extension to the investigation.
2. The approval covers the ethical requirements for the techniques and procedures described in the protocol but does not replace a safety or risk assessment.
3. Approval is not intended to convey any judgement on the quality of the research, experimental design or techniques.
4. Normally, all queries raised by reviewers should be addressed. In the case of conflicting or incomplete views, the ethics committee chair will review the comments and relay these to the applicant via email. All email correspondence related to the application must be copied to the Faculty research ethics administrator.

Any problems which arise during the course of the investigation must be reported to the Faculty Research Ethics Committee

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Appendix C: Observation Forms

I. Airspeed examination: form A (maximum, minimum and average v)

Observation Form: Thermal Comfort in Meditation Centre in Hot and Humid Climate

Date : ..... Time:.....

Site : *VRW / PT / KJS*

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Name of the observer: .....

			v (m/s)		
	Surface Name		Range(mins after measurements)		
No.	Time	NV / PT / KJS	Min (in 1 minute)	Max (in 1 minute)	Average
1	07:30:00				
2	08:00:00				
3	08:30:00				
4	09:00:00				
5	09:30:00				
6	10:00:00				
7	10:30:00				
8	11:00:00				
9	11:30:00				
10	12:00:00				
11	12:30:00				
12	13:00:00				
13	13:30:00				
14	14:00:00				
15	14:30:00				
16	15:00:00				
17	15:30:00				
18	16:00:00				
19	16:30:00				
20	17:00:00				
21	17:30:00				
22	18:00:00				
23	18:30:00				
24	19:00:00				
25	19:30:00				
26	20:00:00				
27	20:30:00				
28	21:00:00				
29	21:30:00				

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II. Airspeed examination: form B (maximum, minimum and average v)

Observation From: Thermal Comfort in Meditation Centre in Hot and Humid Climate

Date : .....

Site : *VRW / PT / KJS*

Name of the observer: .....

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Airspeed Examination

Time: ..... //// Ventialtion Type : NV / Fan Assist

Location		A	B	C	D	E	F	G	H	I	J	K	Note
No.	Interval	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	
1	5 s												
2	10 s												
3	15 s												
4	20 s												
5	25 s												
6	30 s												
7	35 s												
8	40 s												
9	45 s												
10	50 s												
11	55 s												
12	60 s												

Time: ..... //// Ventialtion Type : NV / Fan Assist

Location		A	B	C	D	E	F	G	H	I	J	K	Note
No.	Interval	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	In / Out	
1	5 s												
2	10 s												
3	15 s												
4	20 s												
5	25 s												
6	30 s												
7	35 s												
8	40 s												
9	45 s												
10	50 s												
11	55 s												
12	60 s												

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III. Sky condition evaluation form

Observation From: Thermal Comfort in Meditation Centre in Hot and Humid Climate

Date : .....
Site : **VRW / PT / KJS**

Time: .....

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Name of the observer: .....

Cloud Cover

No.	Time	Name								Note
1	07:30:00									
2	08:00:00									
3	08:30:00									
4	09:00:00									
5	09:30:00									
6	10:00:00									
7	10:30:00									
8	11:00:00									
9	11:30:00									
10	12:00:00									
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21	17:30:00									
22	18:00:00									
23	18:30:00									

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IV. Surface T_r measurement form

Observation From: Thermal Comfort in Meditation Centre in Hot and Humid Climate

Date... Time:.......................................

Site . *VRW / PT / KJS*

Instrument Number IR A IR B

Name of the observer: ....

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Surface Temperature

	Name															
No.	Time								C							
1	08:00:00															
2	08:30:00															
3	09:00:00															
4	09:30:00															
5	10:00:00															
6	10:30:00															
7	11:00:00															
8	11:30:00															
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24	19:30:00															
25	20:00:00															
26	20:30:00															
27	21:00:00															
28	21:30:00															

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V. Evaluation of environmental control operation form

a. Windows and Doors

Observation From: Thermal Comfort in Meditation Centre in Hot and Humid Climate

Date : ..... Time:.....

Site : *VRW / PT / KJS*

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Name of the observer: .....

Windows and Doors

No.	Name / Time																													
	Please identify or enlarge area (fully close) 0.0, 0.1, 0.2, 0.3,...1.0 (fully open)																													
1	08:00:00																													
2	08:30:00																													
3	09:00:00																													
4	09:30:00																													
5	10:00:00																													
6	10:30:00																													
7	11:00:00																													
8	11:30:00																													
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24	19:30:00																													
25	20:00:00																													
26	20:30:00																													
27	21:00:00																													
28	21:30:00																													

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b. Electric fan

Observation From: Thermal Comfort in Meditation Centre in Hot and Humid Climate

Date : ..... **Time:**.....

Site : *VRW / PT / KJS*

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Name of the observer: .....

Electric Fan

No.	Name / Time													Note
		Please identify power (off, 1, 2, 3)												
1	08:00:00													
2	08:30:00													
3	09:00:00													
4	09:30:00													
5	10:00:00													
6	10:30:00													
7	11:00:00													
8	11:30:00													
9	12:00:00													
10	12:30:00													
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25	20:00:00													
26	20:30:00													
27	21:00:00													
28	21:30:00													

Not for reproduction

Date:.....

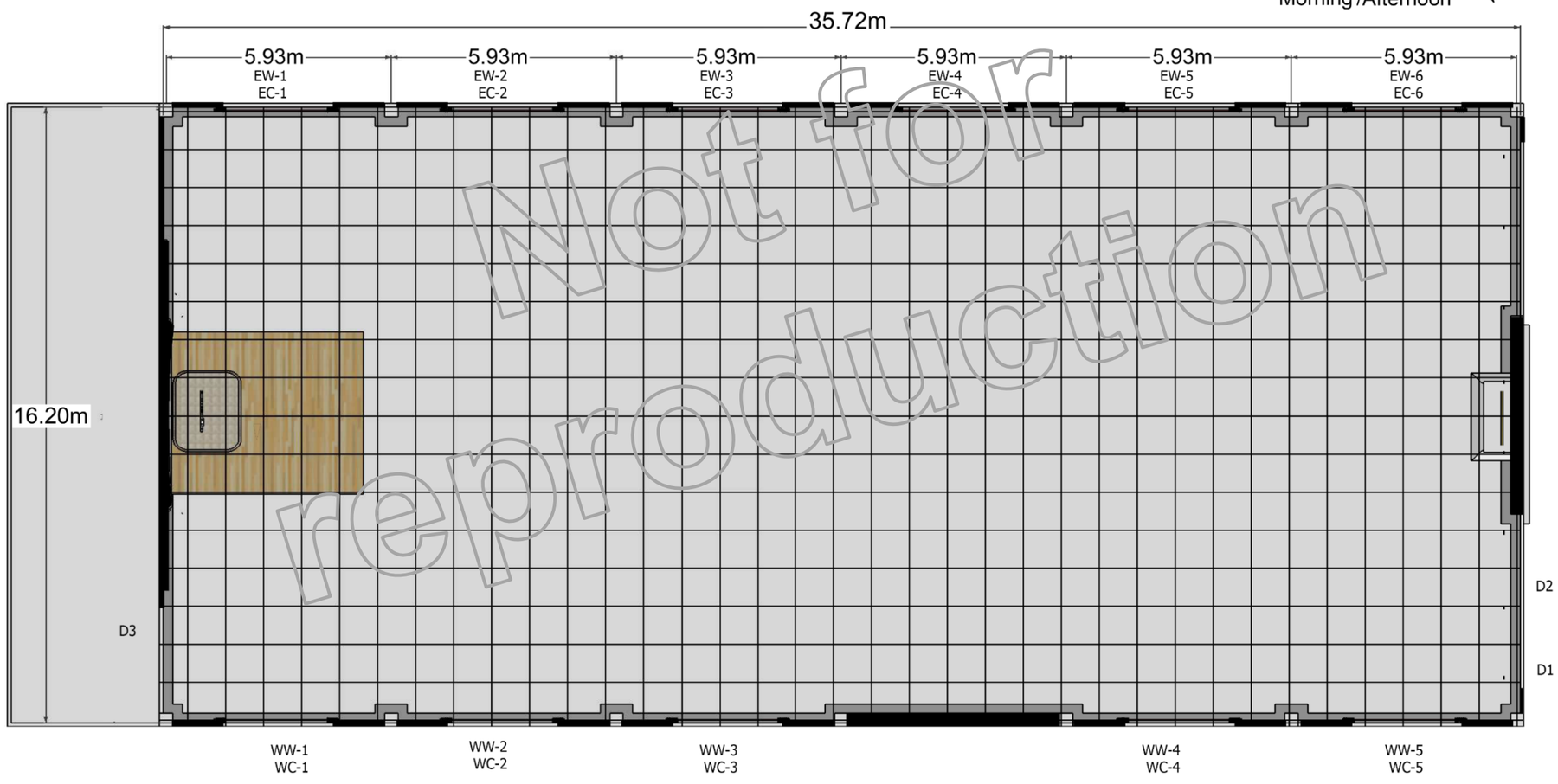
Time:.....

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00 01 03 06

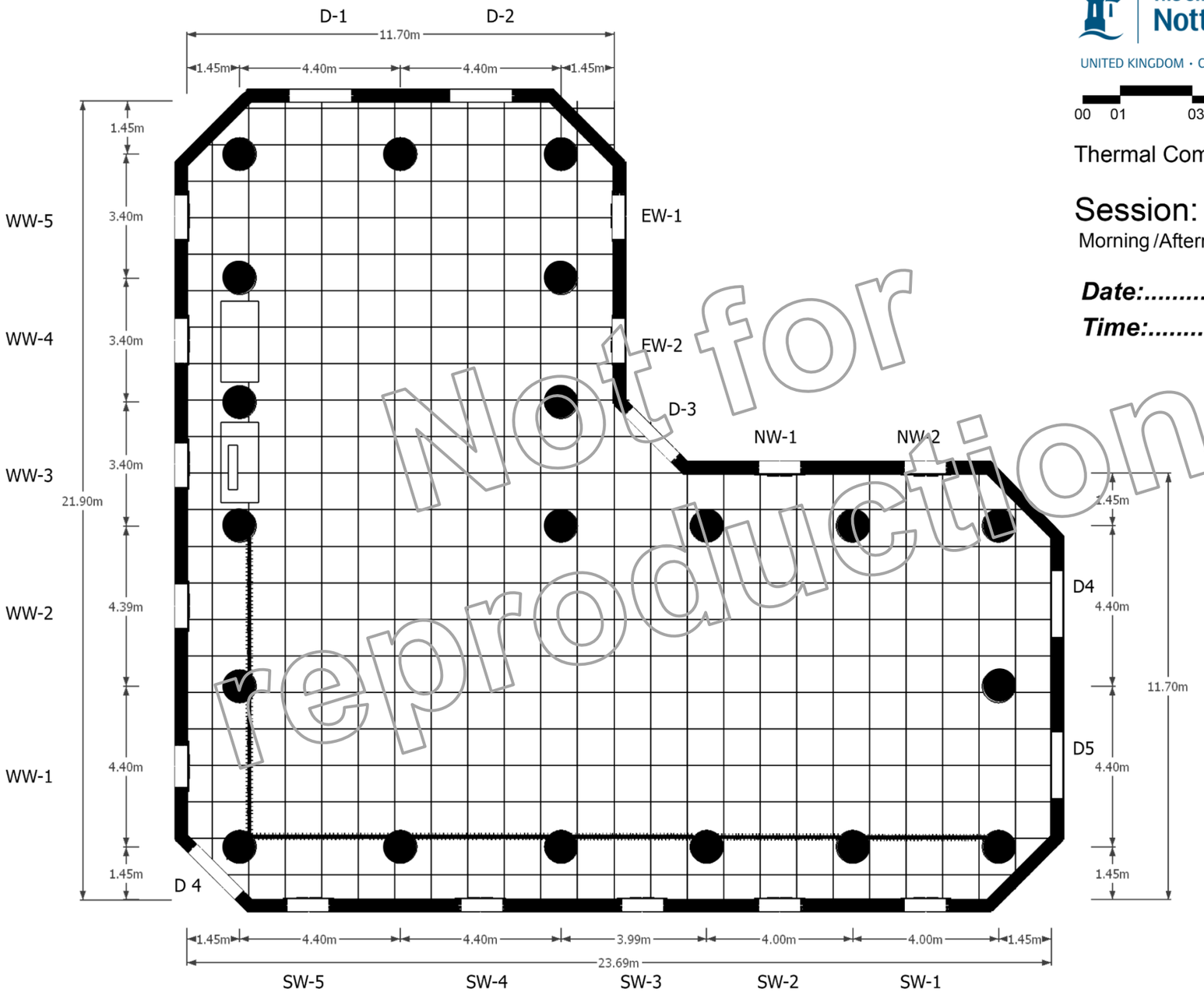
Thermal Comfort Study

Session:
Morning /Afternoon



Not for reproduction

b. Key plan of PT meditation hall



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00 01 03 06

Thermal Comfort Study

Session:
Morning /Afternoon

N

Date:.....

Time:.....

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c. Key plan of VRW meditation hall

Date .....

Time .....

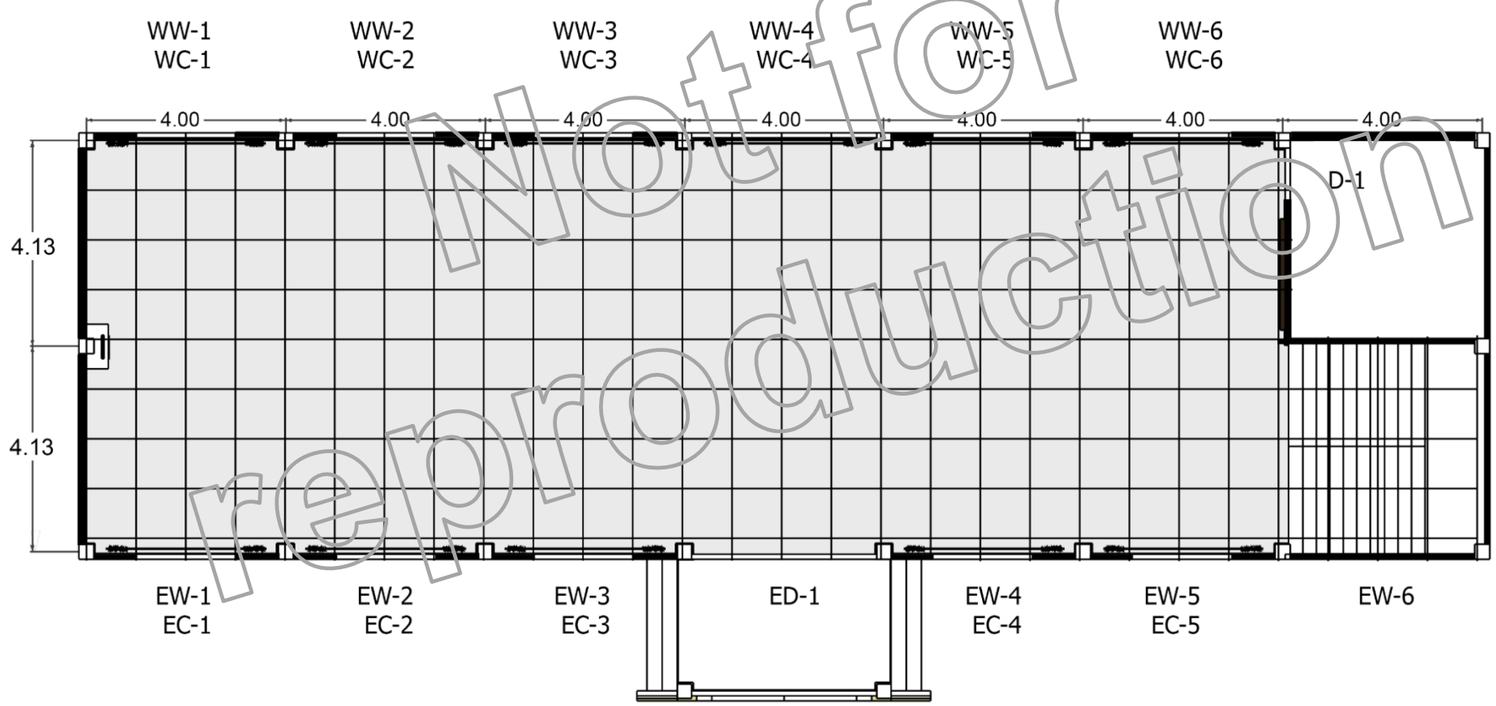
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00 01 03 06

Thermal Comfort Study

Session:
Morning /Afternoon



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Appendix D: Pilot Study Questionnaire

I. Morning Package (Thai version)

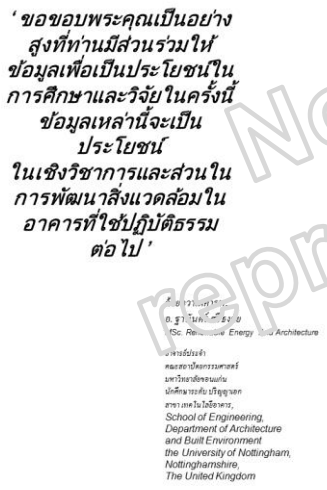
a. Cover pages

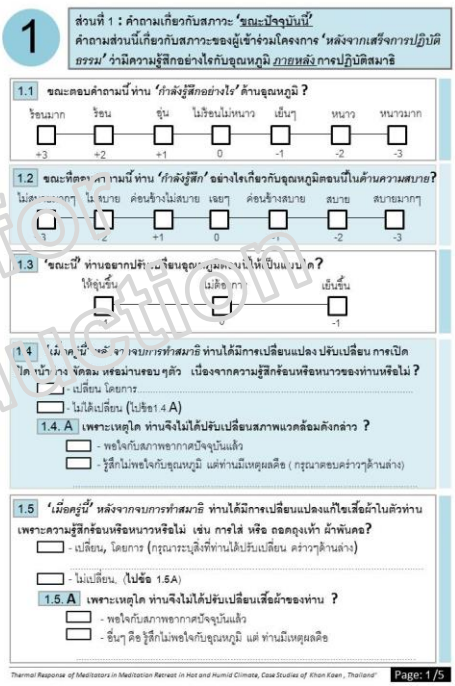




Not for reproduction

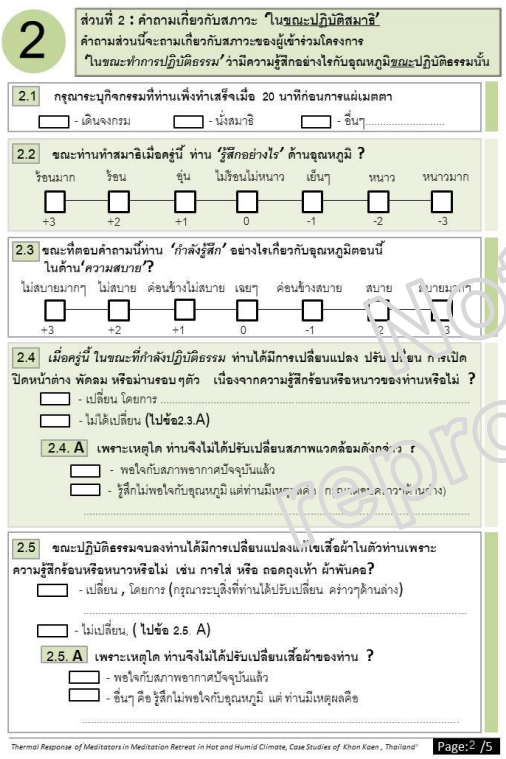
b. Acknowlegdement and questionnaire page 1/5





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c. questionnaire pages 2/5 and 3/5



ส่วนที่ 2 : คำถามเกี่ยวกับสภาวะ 'ในขณะปฏิบัติสมาธิ'
คำถามส่วนนี้จะถามเกี่ยวกับสภาวะของผู้เข้าร่วมโครงการ 'ในขณะทำการปฏิบัติธรรม' ว่ามีความรู้สึกอย่างไรกับอุณหภูมิขณะปฏิบัติธรรมนั้น

2.1 กรุณาระบุกิจกรรมที่ท่านเพิ่งทำเสร็จเมื่อ 20 นาทีก่อนการแผ่เมตตา
☐ - เดินจงกรม ☐ - นั่งสมาธิ ☐ - อื่นๆ.....

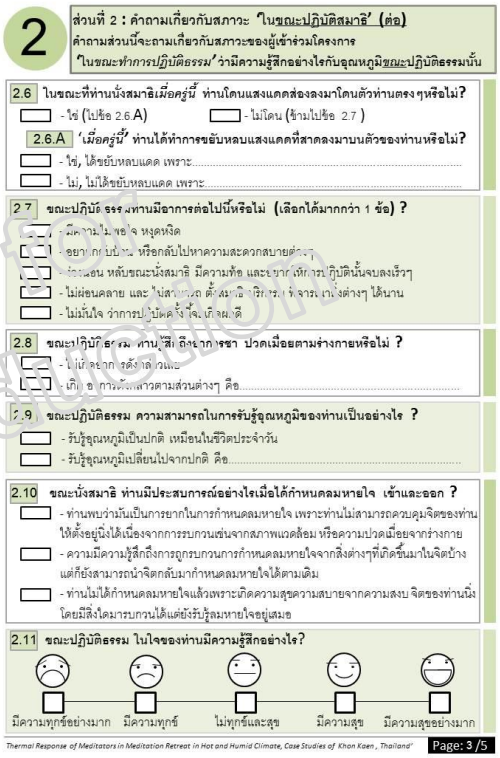
2.2 ขณะท่านทำสมาธิเมื่อครู่นี้ ท่าน 'รู้สึกอย่างไร' ด้านอุณหภูมิ ?
ร้อนมาก (+3) ร้อน (+2) อุ่น (+1) ไม่ร้อนไม่หนาว (0) เย็นๆ (-1) หนาว (-2) หนาวมาก (-3)

2.3 ขณะที่ตอบคำถามนี้ท่าน 'กำลังรู้สึก' อย่างไรเกี่ยวกับอุณหภูมิตอนนี้ ในด้าน'ความสบาย'?
ไม่สบายมากๆ (+3) ไม่สบาย (+2) ค่อนข้างไม่สบาย (+1) เฉยๆ (0) ค่อนข้างสบาย (-1) สบาย (-2) สบายมากๆ (-3)

2.4 เมื่อครู่นี้ ในขณะที่กำลังปฏิบัติธรรม ท่านได้มีการเปลี่ยนแปลง ปรับ ปรุง แก้ไข เปิด ปิดหน้าต่าง พัดลม หรือม่านรอบๆตัว เนื่องจากความรู้สึกร้อนหรือหนาวของท่านหรือไม่ ?
☐ - เปลี่ยน โดยการ .....
☐ - ไม่ได้เปลี่ยน (ไปข้อ2.3.A)
2.4. A เพราะเหตุใด ท่านจึงไม่ได้ปรับเปลี่ยนสภาพแวดล้อมดังกล่าว ?
☐ - พอใจกับสภาพอากาศปัจจุบันแล้ว
☐ - รู้สึกไม่พอใจกับอุณหภูมิ แต่ท่านมีเหตุผลอื่น (โปรดระบุด้านล่าง)
.....

2.5 ขณะปฏิบัติธรรมจนถึงท่านได้มีการเปลี่ยนแปลงแก้ไขเสื้อผ้าในตัวท่านเพราะความรู้สึกร้อนหรือหนาวหรือไม่ เช่น การใส่ หรือ ถอดถุงเท้า ผ้าพันคอ?
☐ - เปลี่ยน , โดยการ (กรุณาระบุสิ่งที่ท่านได้ปรับเปลี่ยน ดังต่อไปด้านล่าง)
.....
☐ - ไม่เปลี่ยน (ไปข้อ 2.5 A)
2.5. A เพราะเหตุใด ท่านจึงไม่ได้ปรับเปลี่ยนเสื้อผ้าของท่าน ?
☐ - พอใจกับสภาพอากาศปัจจุบันแล้ว
☐ - อื่นๆ คือ รู้สึกไม่พอใจกับอุณหภูมิ แต่ท่านมีเหตุผลคือ
.....

Thermal Response of Meditators in Meditation Retreat in Hot and Humid Climate, Case Studies of Khon Kaen , Thailand' Page:2 /5



ส่วนที่ 2 : คำถามเกี่ยวกับสภาวะ 'ในขณะปฏิบัติสมาธิ' (ต่อ)
คำถามส่วนนี้จะถามเกี่ยวกับสภาวะของผู้เข้าร่วมโครงการ 'ในขณะทำการปฏิบัติธรรม' ว่ามีความรู้สึกอย่างไรกับอุณหภูมิขณะปฏิบัติธรรมนั้น

2.6 ในขณะที่ท่านนั่งสมาธิเมื่อครู่นี้ ท่านโดนแสงแดดส่องลงมาโดนตัวท่านตรงๆหรือไม่?
☐ - ใช่ (ไปข้อ 2.6.A) ☐ - ไม่โดน (ข้ามไปข้อ 2.7)
2.6.A 'เมื่อครู่นี้' ท่านได้ทำการขยับหลบแสงแดดที่สาดลงมาบนตัวของท่านหรือไม่?
☐ - ใช่, ได้ขยับหลบแดด เพราะ.....
☐ - ไม่, ไม่ได้ขยับหลบแดด เพราะ.....

2.7 ขณะปฏิบัติธรรม ท่านมีอาการต่อไปนี้หรือไม่ (เลือกได้มากกว่า 1 ข้อ) ?
☐ - มีความไม่ [illegible] หงุดหงิด
☐ - อยากเดินไปมา หรือกลับไปหาความสะดวกสบายต่างๆ
☐ - ง่วงนอน หลับขณะนั่งสมาธิ มีความท้อ และอยากเลิกปฏิบัตินั้นลงเร็วๆ
☐ - ไม่ผ่อนคลาย และไม่สามารถตั้งสมาธิได้ เพราะมีเสียงต่างๆ ได้นาน
☐ - ไม่มั่นใจ ว่าการปฏิบัติครั้งนี้จะเกิดผลดี

2.8 ขณะปฏิบัติธรรม ท่านรู้สึกอึดอัดจากการนั่งขัดสมาธิ ปวดเมื่อยตามร่างกายหรือไม่ ?
☐ - ไม่ [illegible]
☐ - เกิด อาการปวดเมื่อยตามส่วนต่างๆ คือ.....

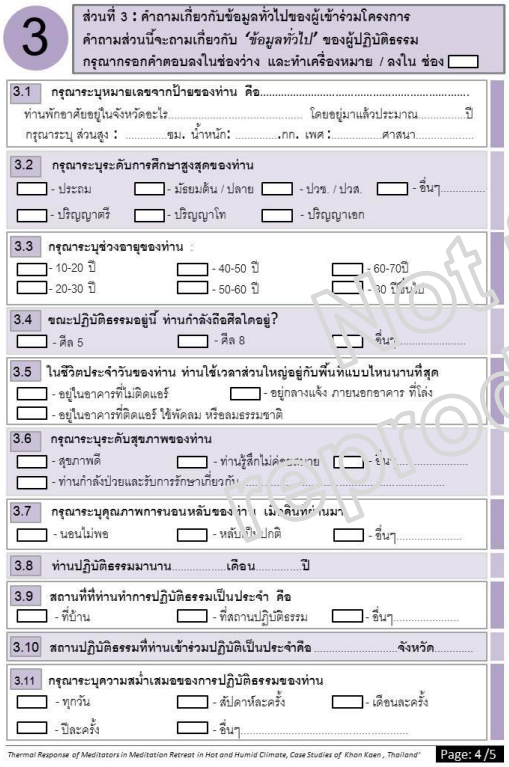
2.9 ขณะปฏิบัติธรรม ความสามารถในการรับรู้อุณหภูมิของท่านเป็นอย่างไร ?
☐ - รับรู้อุณหภูมิเป็นปกติ เหมือนในชีวิตประจำวัน
☐ - รับรู้อุณหภูมิเปลี่ยนไปจากปกติ คือ.....

2.10 ขณะนั่งสมาธิ ท่านมีประสบการณ์อย่างไรเมื่อได้กำหนดลมหายใจ เข้าและออก ?
☐ - ท่านพบว่ามันเป็นการยากในการกำหนดลมหายใจ เพราะท่านไม่สามารถควบคุมจิตของท่านให้ตั้งอยู่นิ่งได้เนื่องจากการรบกวนเช่นจากสภาพแวดล้อม หรือความปวดเมื่อยจากร่างกาย
☐ - ความมีความรู้สึกถึงการถูกรบกวนการกำหนดลมหายใจจากสิ่งต่างๆที่เกิดขึ้นมาในจิตบ้าง แต่ก็ยังสามารถนำจิตกลับมากำหนดลมหายใจได้ตามเดิม
☐ - ท่านไม่ได้กำหนดลมหายใจแล้วเพราะเกิดความสุขความสบายจากความสงบ จิตของท่านนิ่งโดยมีสิ่งใดมารบกวนได้แต่ยังรับรู้ลมหายใจอยู่เสมอ

2.11 ขณะปฏิบัติธรรม ในใจของท่านมีความรู้สึกอย่างไร?
มีความทุกข์อย่างมาก | มีความทุกข์ | ไม่ทุกข์และสุข | มีความสุข | มีความสุขอย่างมาก

Thermal Response of Meditators in Meditation Retreat in Hot and Humid Climate, Case Studies of Khon Kaen , Thailand' Page: 3 /5

d. questionnaire pages 4/5 and 5/5



ส่วนที่ 3 : คำถามเกี่ยวกับข้อมูลทั่วไปของผู้เข้าร่วมโครงการ
คำถามส่วนนี้จะถามเกี่ยวกับ 'ข้อมูลทั่วไป' ของผู้ปฏิบัติธรรม
กรุณากรอกคำตอบลงในช่องว่าง และทำเครื่องหมาย / ลงใน ช่อง ☐

3.1 กรุณาระบุหมายเลขจากป้ายของท่าน คือ.....
ท่านพักอาศัยอยู่ในจังหวัดอะไร..... โดยอยู่มาแล้วประมาณ.....ปี
กรุณาระบุ ส่วนสูง : .....ซม. น้ำหนัก: .....กก. เพศ :.....ศาสนา.....

3.2 กรุณาระบุระดับการศึกษาสูงสุดของท่าน
☐ - ประถม ☐ - มัธยมต้น / ปลาย ☐ - ปวช. / ปวส. ☐ - อื่นๆ.....
☐ - ปริญญาตรี ☐ - ปริญญาโท ☐ - ปริญญาเอก

3.3 กรุณาระบุช่วงอายุของท่าน :
☐ - 10-20 ปี ☐ - 40-50 ปี ☐ - 60-70ปี
☐ - 20-30 ปี ☐ - 50-60 ปี ☐ - 70 ปีขึ้นไป

3.4 ขณะปฏิบัติธรรมอยู่นี้ ท่านกำลังถือศีลใดอยู่?
☐ - ศีล 5 ☐ - ศีล 8 ☐ อื่นๆ.....

3.5 ในชีวิตประจำวันของท่าน ท่านใช้เวลาส่วนใหญ่อยู่กับพื้นที่แบบไหนนานที่สุด
☐ - อยู่ในอาคารที่ไม่ติดแอร์ ☐ - อยู่กลางแจ้ง ภายนอกอาคาร ที่โล่ง
☐ - อยู่ในอาคารที่ติดแอร์ ใช้พัดลม หรือลมธรรมชาติ

3.6 กรุณาระบุระดับสุขภาพของท่าน
☐ - สุขภาพดี ☐ - ท่านรู้สึกไม่ค่อยสบาย ☐ - อื่น.....
☐ - ท่านกำลังป่วยและรับการรักษาเกี่ยวกับ.....

3.7 กรุณาระบุคุณภาพการนอนหลับของท่าน เมื่อคืนที่ผ่านมา
☐ - นอนไม่พอ ☐ - หลับได้ปกติ ☐ - อื่นๆ.....

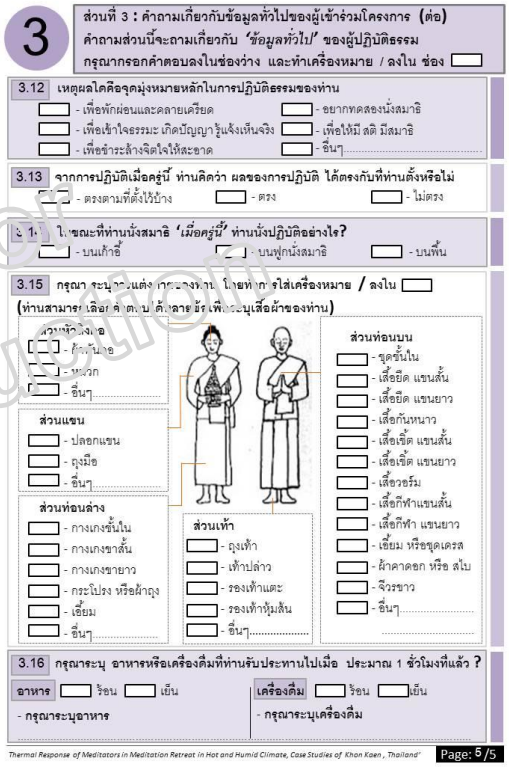
3.8 ท่านปฏิบัติธรรมมานาน.....เดือน.....ปี

3.9 สถานที่ที่ท่านทำการปฏิบัติธรรมเป็นประจำ คือ
☐ - ที่บ้าน ☐ - ที่สถานปฏิบัติธรรม ☐ - อื่นๆ.....

3.10 สถานปฏิบัติธรรมที่ท่านเข้าร่วมปฏิบัติเป็นประจำคือ.....จังหวัด.....

3.11 กรุณาระบุความสม่ำเสมอของการปฏิบัติธรรมของท่าน
☐ - ทุกวัน ☐ - สัปดาห์ละครั้ง ☐ - เดือนละครั้ง
☐ - ปีละครั้ง ☐ - อื่นๆ.....

Thermal Response of Meditators in Meditation Retreat in Hot and Humid Climate, Case Studies of Khon Kaen , Thailand' Page: 4 /5



ส่วนที่ 3 : คำถามเกี่ยวกับข้อมูลทั่วไปของผู้เข้าร่วมโครงการ (ต่อ)
คำถามส่วนนี้จะถามเกี่ยวกับ 'ข้อมูลทั่วไป' ของผู้ปฏิบัติธรรม
กรุณากรอกคำตอบลงในช่องว่าง และทำเครื่องหมาย / ลงใน ช่อง ☐

3.12 เหตุผลใดคือจุดมุ่งหมายหลักในการปฏิบัติธรรมของท่าน
☐ - เพื่อพักผ่อนและคลายเครียด ☐ - อยากทดลองนั่งสมาธิ
☐ - เพื่อเข้าใจธรรมะ เกิดปัญญารู้แจ้งเห็นจริง ☐ - เพื่อให้มีสติ มีสมาธิ
☐ - เพื่อชำระล้างจิตใจให้สะอาด ☐ - อื่นๆ.....

3.13 จากการปฏิบัติเมื่อครู่นี้ ท่านคิดว่า ผลของการปฏิบัติ ได้ตรงกับที่ท่านตั้งหรือไม่
☐ - ตรงตามที่ตั้งไว้บ้าง ☐ - ตรง ☐ - ไม่ตรง

3.14 ในขณะที่ท่านนั่งสมาธิ 'เมื่อครู่นี้' ท่านนั่งปฏิบัติอย่างไร?
☐ - บนเก้าอี้ ☐ - บนฟูกนั่งสมาธิ ☐ - บนพื้น

3.15 กรุณาระบุการแต่งกายของท่าน โดยท่านสามารถใส่เครื่องหมาย / ลงใน ☐ (ท่านสามารถเลือกได้มากกว่า 1 ข้อ เพื่อระบุเสื้อผ้าของท่าน)
ส่วนหัวและหน้า: ☐ - ผ้าคลุมหน้า ☐ - หมวก ☐ - อื่นๆ.....
ส่วนแขน: ☐ - ปลอกแขน ☐ - ถุงมือ ☐ - อื่นๆ.....
ส่วนท่อนล่าง: ☐ - กางเกงขายาว ☐ - กางเกงขาสั้น ☐ - กางเกงขายาว ☐ - กระโปรง หรือผ้าถุง ☐ - เอี๊ยม ☐ - อื่นๆ.....
ส่วนเท้า: ☐ - ถุงเท้า ☐ - เท้าเปล่า ☐ - รองเท้าแตะ ☐ - รองเท้าหุ้มส้น ☐ - อื่นๆ.....
ส่วนท่อนบน: ☐ - ชุดชั้นใน ☐ - เสื้อยืด แขนสั้น ☐ - เสื้อยืด แขนยาว ☐ - เสื้อกันหนาว ☐ - เสื้อเชิ้ต แขนสั้น ☐ - เสื้อเชิ้ต แขนยาว ☐ - เสื้อวอร์ม ☐ - เสื้อกีฬา แขนสั้น ☐ - เสื้อกีฬา แขนยาว ☐ - เอี๊ยม หรือชุดเดรส ☐ - ผ้าคาดอก หรือ สไบ ☐ - ผ้าขาวม้า ☐ - อื่นๆ.....

3.16 กรุณาระบุ อาหารหรือเครื่องดื่มที่ท่านรับประทานไปเมื่อ ประมาณ 1 ชั่วโมงที่แล้ว ?
อาหาร ☐ ร้อน ☐ เย็น - กรุณาระบุอาหาร
เครื่องดื่ม ☐ ร้อน ☐ เย็น - กรุณาระบุเครื่องดื่ม

Thermal Response of Meditators in Meditation Retreat in Hot and Humid Climate, Case Studies of Khon Kaen , Thailand' Page: 5 /5

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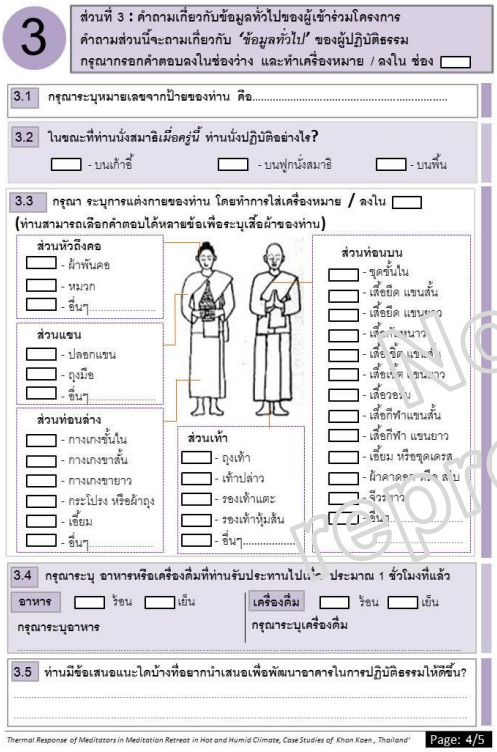
II. Additional pages for the afternoon-version questionnaire:

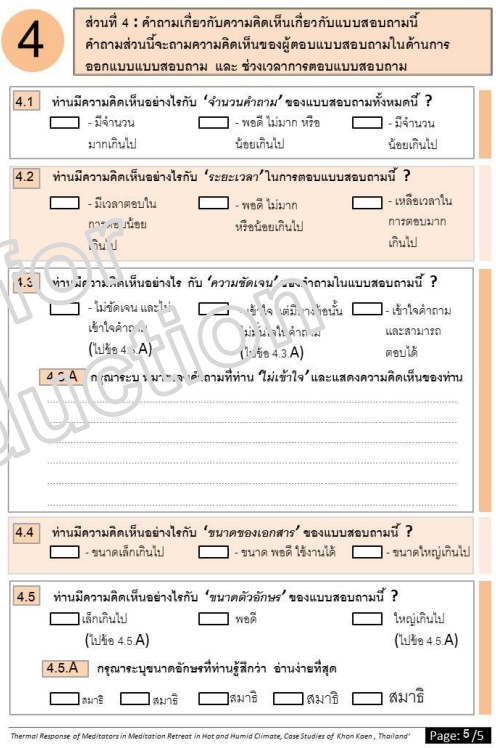
a. Cover pages





b. Questionnaire pages 4/5 and 5/5





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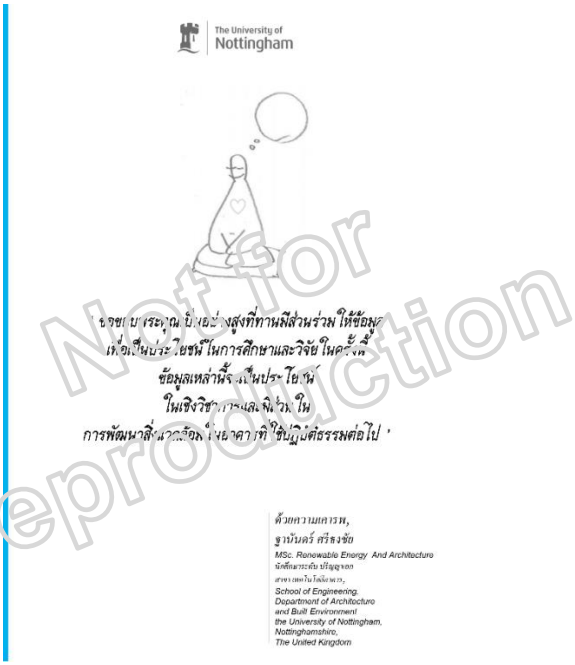
Appendix E: Final Questionnaire

I. Cover pages (Thai)



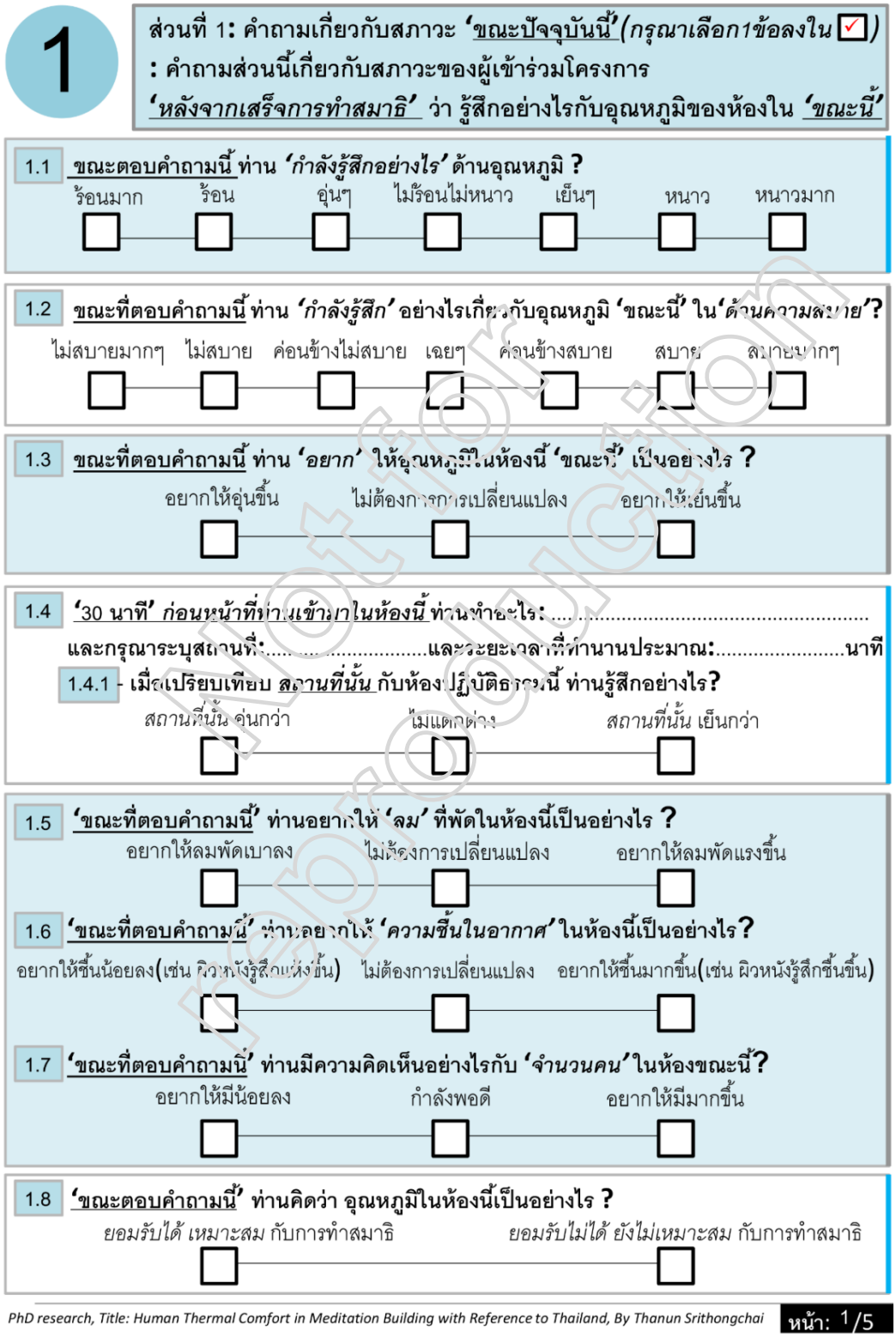


II. Acknowledgement (Thai)



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III. Questionnaire pages 1/5 (Thai)



1

ส่วนที่ 1: คำถามเกี่ยวกับสภาวะ *'ขณะปัจจุบันนี้'* (*กรุณาเลือก1ข้อลงใน* ☑)
: คำถามส่วนนี้เกี่ยวกับสภาวะของผู้เข้าร่วมโครงการ
'หลังจากเสร็จการทำสมาธิ' **ว่า รู้สึกอย่างไรกับอุณหภูมิของห้องใน *'ขณะนี้'***

1.1 ***ขณะตอบคำถามนี้*** ท่าน *'กำลังรู้สึกอย่างไร'* ด้านอุณหภูมิ ?
ร้อนมาก ☐ — ร้อน ☐ — อุ่นๆ ☐ — ไม่ร้อนไม่หนาว ☐ — เย็นๆ ☐ — หนาว ☐ — หนาวมาก ☐

1.2 ***ขณะที่ตอบคำถามนี้*** ท่าน *'กำลังรู้สึก'* อย่างไรเกี่ยวกับอุณหภูมิ 'ขณะนี้' ใน*'ด้านความสบาย'*?
ไม่สบายมากๆ ☐ — ไม่สบาย ☐ — ค่อนข้างไม่สบาย ☐ — เฉยๆ ☐ — ค่อนข้างสบาย ☐ — สบาย ☐ — สบายมากๆ ☐

1.3 ***ขณะที่ตอบคำถามนี้*** ท่าน *'อยาก'* ให้อุณหภูมิในห้องนี้ 'ขณะนี้' เป็นอย่างไร ?
อยากให้อุ่นขึ้น ☐ — ไม่ต้องการการเปลี่ยนแปลง ☐ — อยากให้เย็นขึ้น ☐

1.4 *'30 นาที' ก่อนหน้าที่ท่านเข้ามาในห้องนี้* ท่านทำอะไร: .....
และกรุณาระบุสถานที่: .....และระยะเวลาที่ทำนานประมาณ: .....นาที

1.4.1 - เมื่อเปรียบเทียบ *สถานที่นั้น* กับห้องปฏิบัติธรรมนี้ ท่านรู้สึกอย่างไร?
สถานที่นั้น อุ่นกว่า ☐ — ไม่แตกต่าง ☐ — *สถานที่นั้น* เย็นกว่า ☐

1.5 ***'ขณะที่ตอบคำถามนี้'*** ท่านอยากให้ *'ลม'* ที่พัดในห้องนี้เป็นอย่างไร ?
อยากให้ลมพัดเบาลง ☐ — ไม่ต้องการเปลี่ยนแปลง ☐ — อยากให้ลมพัดแรงขึ้น ☐

1.6 ***'ขณะที่ตอบคำถามนี้'*** ท่านอยากให้ *'ความชื้นในอากาศ'* ในห้องนี้เป็นอย่างไร?
อยากให้ชื้นน้อยลง(เช่น ผิวหนังรู้สึกแห้งขึ้น) ☐ — ไม่ต้องการเปลี่ยนแปลง ☐ — อยากให้ชื้นมากขึ้น(เช่น ผิวหนังรู้สึกชื้นขึ้น) ☐

1.7 ***'ขณะที่ตอบคำถามนี้'*** ท่านมีความคิดเห็นอย่างไรกับ *'จำนวนคน'* ในห้องขณะนี้?
อยากให้มีน้อยลง ☐ — กำลังพอดี ☐ — อยากให้มีมากขึ้น ☐

1.8 ***'ขณะตอบคำถามนี้'*** ท่านคิดว่า อุณหภูมิในห้องนี้เป็นอย่างไร ?
ยอมรับได้ เหมาะสม กับการทำสมาธิ ☐ — *ยอมรับไม่ได้ ยังไม่เหมาะสม* กับการทำสมาธิ ☐

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IV. Questionnaire pages 1/5 (English)

Section 1: This set of questions relate to 'current' states (please select only one option in the box). This section inquire your current thermal experience (after finishing meditation) caused by the current hall thermal stimuli while filling out this questionnaire.

1.1) While you are filling out this questionnaire, 'how do you feel' in terms of thermal sensation?
-3) Hot -2) Slightly hot -1) Warm 0) Neutral 1) Cool 2 Slightly cold 3) Cold

1.2) While you are filling out this questionnaire, 'how do you feel' in terms of thermal comfort?
-3) Very Uncomfortable -2) Uncomfortable -1) Rather uncomfortable
0) Indifferent 1) Rather comfortable 2) Comfortable 3) Very comfortable

1.3) While you are filling out this questionnaire, 'what current temperature of the hall would you prefer in the hall?
-1) Warmer 0) No Change 1) Cooler

1.4) 30 minutes before filling out this questionnaire, what did you do?
..... Where did you do that activity? ..... How long did you did you do that activity? .....(minutes).
1.4.1) When comparing the temperature in the place where you were to that of the current meditation hall, how do you feel?
1) That place was warmer. 2) The same 3) That place was cooler.

1.5) While you were answering this question, how do you prefer current air flow in this hall?
-1) Lower airspeed 0) No change 1) Higher airspeed

1.6) While you were answering this question, how do you prefer current humidity in this hall?
-1) Less humid 0) No change 1) More humid

1.7) While you were answering this question, how do you prefer the number of the meditators in this hall?
-1) Less crowed 0) No change 1) More crowded

1.8) While you were answering this question, is the current temperature of this hall acceptable for the practice?
1) Acceptable for the activity 2) Unacceptable for the activity

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V. Questionnaire pages 2/5 (Thai)

1.9 เมื่อท่านเข้ามาในห้องปฏิบัติธรรมนี้ หากท่านมีความรู้สึกว่าอุณหภูมิในห้องนี้ *'ไม่สบาย'* เนื่องจากความรู้สึกร้อนหรือหนาวไป สิ่งที่ท่าน *'คิดจะทำ'* เป็น ' 3 *อย่างแรก'* คืออะไร (*กรุณาเลือก 3 ข้อ*)

- ☐ 1. - ปรับเปลี่ยนเสื้อผ้าที่สวมใส่ เช่น ใส่หรือถอดถุงเท้า ปรับเสื้อผ้าให้หลวม หรือ เปลี่ยนรูปแบบเสื้อผ้า เช่น ทำให้หนาขึ้น อุ่นขึ้น หรือ บางลง ระบายความร้อนได้ดีขึ้น
- ☐ 2. - การขยับเสื้อผ้า เพื่อลดความร้อน
- ☐ 3. - มัดรวบผม
- ☐ 4. - เปลี่ยนจากการนั่งบนเก้าอี้ หรือนั่งบนฟูกนั่งสมาธิเป็นนั่งบนพื้นห้อง หรือ เปลี่ยนจากการนั่งสัมผัสพื้นห้องเป็นนั่งบนเก้าอี้หรือนั่งบนฟูกนั่งสมาธิ
- ☐ 5. - *'ย้ายที่'* ในการทำสมาธิ ไปที่ ที่ท่านรู้สึกว่า *เย็น* หรือ *อุ่นกว่า*
- ☐ 6. - *'ย้ายที่'* ในการทำสมาธิ ไปที่ ที่ท่านรู้สึกว่า *ลมแรง* หรือ *เบากว่า*
- ☐ 7. - *'ย้ายที่'* ในการทำสมาธิ ไปที่ ที่ *แดดส่องไม่ถึง* หรือ *ส่องถึงตัวท่านโดยตรง*
- ☐ 8. - *'เปลี่ยนท่าทาง'* ในการปฏิบัติเช่น จากเดินจงกรมเป็นนั่งสมาธิ หรือ ยืด ขยับร่างกาย
- ☐ 9. - *'ออกไปพัก'* เข้าห้องน้ำ ล้างหน้า หรืออาบน้ำ
- ☐ 10. - *'นอนหลับ'* นอนพัก
- ☐ 11. - ขยับเข้าใกล้วัตถุที่มีความเย็นกว่า หรือร้อนกว่า เพื่อปรับอุณหภูมิ
- ☐ 12. - ทำจิตใจให้ *'ยอมรับ'* สภาพแวดล้อมที่เป็น และ *'ปล่อยวาง'*
- ☐ 13. - *'เปลี่ยนความสนใจ'* ไปสนใจเรื่องอื่น ที่ไม่ใช่เรื่อง อุณหภูมิ
- ☐ 14. - *'อดทน'* พยายามปรับตัวให้เข้ากับอุณหภูมิ
- ☐ 15. - *รับประทานอาหาร หรือ เครื่องดื่ม* ร้อน หรือ เย็น เพื่อปรับอุณหภูมิร่างกาย
- ☐ 16. - เปิด-ปิด ประตู หน้าต่าง ผ้าม่าน หรือ พัดลม
- ☐ 17 - อื่นๆ (*กรุณาระบุ*):.....

1.10 ***เมื่อท่านเข้ามาในห้องปฏิบัติธรรมนี้ ท่าน *'ได้ทำ'* ตามข้อ 1.9 ด้านบน หรือไม่ ?

- ☐ ไม่ได้ทำ ตามข้อ 1.9 เลย (*** *ข้ามไปข้อ 2.1* ***)
- ☐ ได้ทำ คือ (*** กรุณา *'ลำดับตัวเลข'* ตามข้อ 1.9 ที่ท่านได้ทำ **'3'** อันดับแรก **ด้านล่าง*****)

ลำดับ 1: ..... **(ทำเป็นอย่างแรก)** 2 :..... 3 :.....

2

ส่วนที่ 2 :คำถามเกี่ยวกับสภาวะ ' ในขณะทำสมาธิ ' (*กรุณาเลือก1ข้อลงใน* ☑)

: คำถามส่วนนี้จะถามเกี่ยวกับการรับรู้อุณหภูมิและประสบการณ์ *'ในขณะทำสมาธิ' ของผู้ปฏิบัติธรรม*

2.1 **'ขณะที่นั่งสมาธิ เมื่อครู่นี้' ท่าน *'รู้สึกอย่างไร'* เกี่ยวกับอุณหภูมิในขณะนั้น ?**

ร้อนมาก ☐ — ร้อน ☐ — อุ่นๆ ☐ — ไม่ร้อนไม่หนาว ☐ — เย็นๆ ☐ — หนาว ☐ — หนาวมาก ☐

2.2 **'ขณะที่นั่งสมาธิ เมื่อครู่นี้' ท่าน *'รู้สึกอย่างไร'* เกี่ยวกับอุณหภูมิในด้าน *'ความสบาย'* ในขณะนั้น ?**

ไม่สบายมากๆ ☐ — ไม่สบาย ☐ — ค่อนข้างไม่สบาย ☐ — เฉยๆ ☐ — ค่อนข้างสบาย ☐ — สบาย ☐ — สบายมากๆ ☐

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VI. Questionnaire pages 2/5 (English)

1.9) When you entered into this meditation hall, what three adaptive solutions did you 'want' to do if you felt thermally uncomfortable?
(please select three actions)

1. Modifying clothing
2. Loosening or tightening up clothing
3. Tying hair
4. Changing sitting materials
5. Relocating to a cooler or warmer area
6. Relocating to an area where there is a higher or lower airspeed
7. Avoiding exposure to direct solar radiation
8. Changing activity or posture
9. Taking a short break to toilets or bathrooms
10. Taking a nap
11. Relocating closer to cooler or warmer objects
12. Accepting the current thermal stimuli as it is
13. Deviating focus from dissatisfying stimuli of the current thermal environment to other aspects
14. Resisting dissatisfying stimuli of the current thermal environment
15. Consuming cool or warm drinks or foods
16. Modifying the environmental condition by opening/closing the windows or using curtains and fans
17. Others: (Please specify)

1.10) * Have you performed any actions in the hall as listed in the previous question (1.9)?**

1. No, I have not done anything as the items listed above (*skip to question 2.1).
2. Yes, I have done (*** please order your action below)
   1: (first performed)..... 2.....3: .....

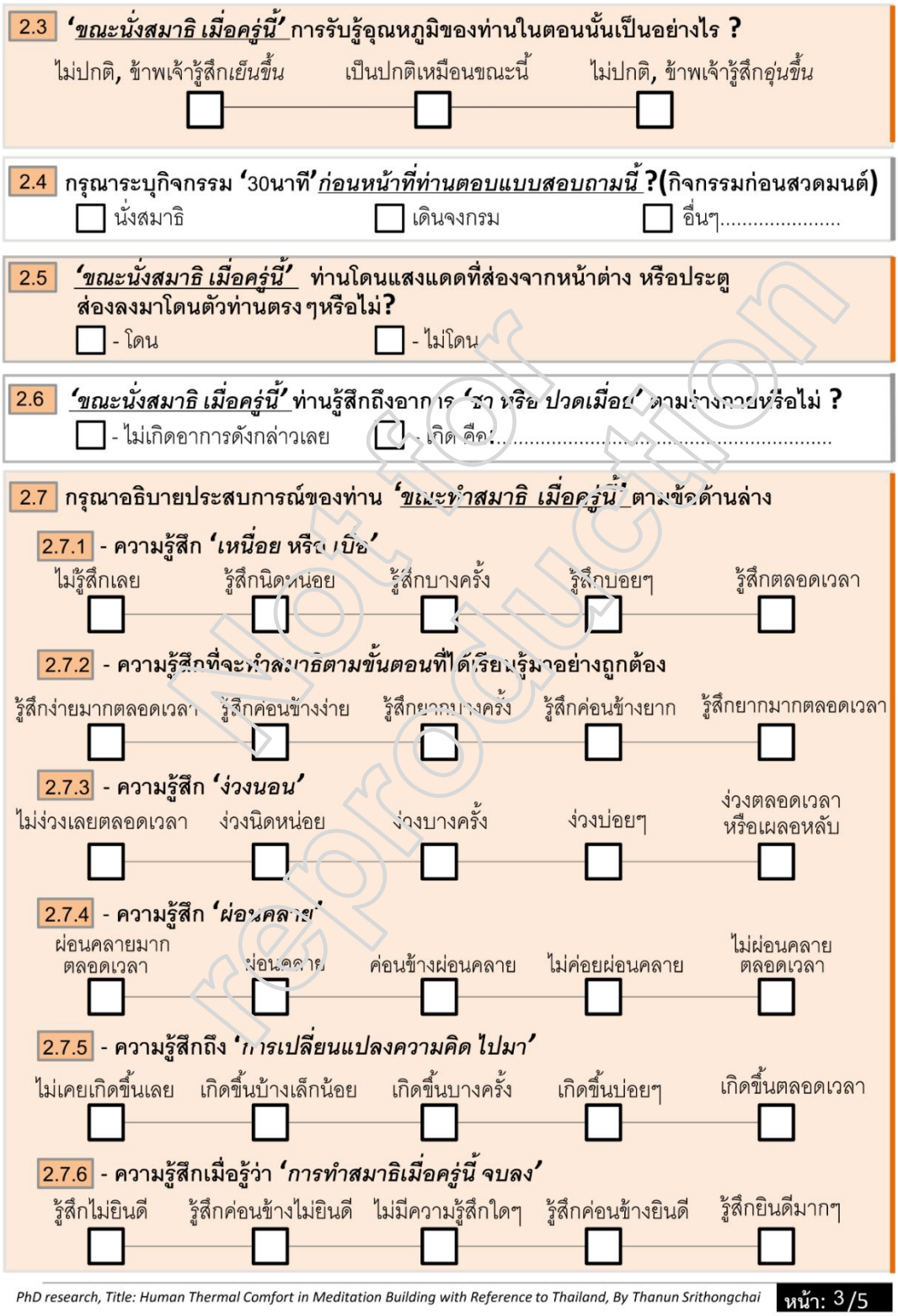
Section 2: This set of questions relate to states during 'meditating' (please select only one option in the box). This section inquire your thermal experience during engaging meditation.

2.1) While you were meditating, 'how did you feel' in terms of thermal sensation?
-3) Hot -2) Slightly hot -1) Warm 0) Neutral 1) Cool 2) Slightly cold 3) Cold

2.2) While you were meditating, 'how did you feel' in terms of thermal comfort?
-3) Very Uncomfortable -2) Uncomfortable -1) Rather uncomfortable
0) Indifferent 1) Rather comfortable 2) Comfortable 3)Very comfortable

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VII. Questionnaire pages 3/5 (Thai)



2.3 ‘ขณะนั่งสมาธิ เมื่อคู่นี้’ การรับรู้อุณหภูมิของท่านในตอนนั้นเป็นอย่างไร ?

ไม่ปกติ, ข้าพเจ้ารู้สึกเย็นขึ้น | เป็นปกติเหมือนขณะนี้ | ไม่ปกติ, ข้าพเจ้ารู้สึกอุ่นขึ้น

2.4 กรุณาระบุกิจกรรม ‘30นาที’ ก่อนหน้าที่ท่านตอบแบบสอบถามนี้ ?(กิจกรรมก่อนสวดมนต์)

☐ นั่งสมาธิ ☐ เดินจงกรม ☐ อื่นๆ.....

2.5 ‘ขณะนั่งสมาธิ เมื่อคู่นี้’ ท่านโดนแสงแดดที่ส่องจากหน้าต่าง หรือประตู ส่องลงมาโดนตัวท่านตรง ๆหรือไม่?

☐ - โดน ☐ - ไม่โดน

2.6 ‘ขณะนั่งสมาธิ เมื่อคู่นี้’ ท่านรู้สึกถึงอาการ ‘ชา หรือ ปวดเมื่อย’ ตามร่างกายหรือไม่ ?

☐ - ไม่เกิดอาการดังกล่าวเลย ☐ - เกิด คือ.....

2.7 กรุณาอธิบายประสบการณ์ของท่าน ‘ขณะทำสมาธิ เมื่อคู่นี้’ ตามข้อด้านล่าง

2.7.1 - ความรู้สึก ‘เหนื่อย หรือ เบื่อ’

ไม่รู้สึกเลย | รู้สึกนิดหน่อย | รู้สึกบางครั้ง | รู้สึกบ่อยๆ | รู้สึกตลอดเวลา

2.7.2 - ความรู้สึกที่จะทำสมาธิตามขั้นตอนที่ได้เรียนรู้มาอย่างถูกต้อง

รู้สึกง่ายมากตลอดเวลา | รู้สึกค่อนข้างง่าย | รู้สึกยากบางครั้ง | รู้สึกค่อนข้างยาก | รู้สึกยากมากตลอดเวลา

2.7.3 - ความรู้สึก ‘ง่วงนอน’

ไม่ง่วงเลยตลอดเวลา | ง่วงนิดหน่อย | ง่วงบางครั้ง | ง่วงบ่อยๆ | ง่วงตลอดเวลา หรือเผลอหลับ

2.7.4 - ความรู้สึก ‘ผ่อนคลาย’

ผ่อนคลายมากตลอดเวลา | ผ่อนคลาย | ค่อนข้างผ่อนคลาย | ไม่ค่อยผ่อนคลาย | ไม่ผ่อนคลายตลอดเวลา

2.7.5 - ความรู้สึกถึง ‘การเปลี่ยนแปลงความคิด ไปมา’

ไม่เคยเกิดขึ้นเลย | เกิดขึ้นบ้างเล็กน้อย | เกิดขึ้นบางครั้ง | เกิดขึ้นบ่อยๆ | เกิดขึ้นตลอดเวลา

2.7.6 - ความรู้สึกเมื่อรู้ว่า ‘การทำสมาธิเมื่อคู่นี้ จบลง’

รู้สึกไม่ยินดี | รู้สึกค่อนข้างไม่ยินดี | ไม่มีความรู้สึกใดๆ | รู้สึกค่อนข้างยินดี | รู้สึกยินดีมากๆ

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VIII. Questionnaire pages 3/5 (English)

2.3) While you were meditating, was your thermal sensation as usual?
-1) No, it was not. I felt cooler. 0) Indifferent 1) No, it was not. I felt warmer.

2.4) Please identify the activity you did '30 minutes before answering this questionnaire? (the activity before praying).
1) Sitting meditation 2) Walking meditation 3) Others:... (please identify)

2.5) While you were meditating, did you expose to direct solar radiation?
1) Yes, I did. 2) No, I did not.

2.6) While you were meditating, did you feel numb or sore on your body?
1) Yes, I did. 2) No, I did not.

2.7) Please describe you meditation experience, while your were practicing according to the meditative qualities below;

2.7.1) Feeling bored or tired.
-2) Never feel it) -1) Almost never feel it 0) Feel it, sometimes
1) Often feel it 2) Always feel it

2.7.2) Feeling of instruction-following ability
-2) Always considerably easy to follow -1) (Moderately east to follow)
0) Slightly difficult to follow 1) Moderately difficult to follow
2) Always considerably difficult to follow

2.7.3) Feeling drowsiness
-2) Never feel it -1) Almost never feel it 0) Feel it, sometimes
1) Often feel it 2) Always fee it

2.7.4) Feeling relaxation
-2) Always considerably relaxed -1) Moderately relaxed
0) Slightly relaxed)
1) Moderately unrelaxed 2) Always considerably unrelaxed

2.7.5) Feeling changing thoughts
-2) Never feel it -1) Almost never feel it
0) Feel it, sometimes 1) Often feel it 2) Always feel it

2.7.6) Feeling when the practice ended
-2) Never feel happy -1) Feel rather unhappy 0) Indifferent
1) Rather happy 2) Very happy

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IX. Questionnaire pages 4/5 (Thai)

3 ส่วนที่ 3 : คำถามเกี่ยวกับข้อมูลทั่วไปของท่าน (กรุณาเลือก 1 ข้อ)
คำถามส่วนนี้จะถามเกี่ยวกับ *'ข้อมูลทั่วไป'* ของผู้ปฏิบัติธรรม
กรุณากรอกคำตอบลงในช่องว่าง และทำเครื่องหมาย / ลงใน ช่อง ☑

3.1 กรุณาระบุ ส่วนสูง : .....ซม. น้ำหนัก: .....กก. ศาสนา.....
ท่านพักอาศัยอยู่ในจังหวัดอะไร:.....
เพศ : ☐ ชาย ☐ หญิง

3.2 ขณะปฏิบัติธรรมอยู่นี้ ท่านกำลังถือ *ศีล* กี่ข้อ?
☐ - ศีล 5 ☐ - ศีล 8 ☐ - อื่นๆ: ....

3.3 เหตุผลใดคือจุดมุ่งหมายหลักในการปฏิบัติธรรมของท่าน (เลือกได้หลายข้อ)
☐ - เพื่อพักผ่อนและคลายเครียด ☐ - อยากทดสอบนั่งสมาธิ
☐ - เพื่อเข้าใจธรรมะ เกิดปัญญา รู้แจ้งเห็นจริง ☐ - เพื่อให้มี สติ มี สมาธิ
☐ - เพื่อชำระล้างจิตใจให้สะอาด ☐ - อื่นๆ.....

3.4 จากการทำสมาธิ *'เมื่อครู่นี้'* ท่านคิดว่า ผล ของการปฏิบัติ ได้ตรงกับที่ท่านตั้งหรือไม่
☐ - ตรงตามที่ตั้งไว้บ้าง ☐ - ตรง ☐ - ไม่ตรง

3.5 กรุณาระบุระดับการศึกษา สูงสุด ของท่าน
☐ - ประถม ☐ - มัธยมต้น / ปลาย ☐ - ปวช. / ปวส. ☐ - อื่นๆ.....
☐ - ปริญญาตรี ☐ - ปริญญาโท ☐ - ปริญญาเอก

3.6 กรุณาระบุช่วงอายุของท่าน :
☐ 10-20 ปี ☐ 31- 40 ปี ☐ 51-60 ปี ☐ 71-80 ปี
☐ 21-30 ปี ☐ 41-50 ปี ☐ 61-70 ปี ☐ 81 ปีขึ้นไป

3.7 ท่านเคยทำแบบสอบถามนี้มาก่อนหรือไม่ ?
☐ เคย เมื่อ..... ☐ ไม่เคย ครั้งนี้ เป็นครั้งแรก

3.8 <u>ในชีวิตประจำวัน</u> ท่านใช้เวลา *'ส่วนใหญ่'* อยู่กับสภาพอากาศแบบไหน <u>*นาน*</u> ที่สุด ?
☐ - อยู่ในห้องที่ *'ไม่มีแอร์'* แต่มีใช้พัดลม หรือลมพัดตามธรรมชาติ
☐ - อยู่ใน *'ห้องแอร์'* ☐ - อยู่ *'กลางแจ้ง'* ภายนอกอาคาร ที่โล่ง

3.9 กรุณาระบุระดับสุขภาพของท่าน
☐ - สุขภาพเป็นปกติ ☐ - ท่านรู้สึกไม่ค่อยสบาย ☐ - ท่านกำลังป่วย คือ.....

3.10 *'การนอนหลับ'* เมื่อคืนที่ผ่านมาของท่านเป็นอย่างไร ?
☐ - นอนไม่พอ ☐ - หลับเป็นปกติ ☐ - อื่นๆ.....

3.11 ท่านมีประสบการณ์การทำสมาธิมานานเท่าไรแล้ว.....ปี.....เดือน

หน้า: 4 /5 *PhD research, Title: Human Thermal Comfort in Meditation Building with Reference to Thailand, By Thanun Srithongchai*

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X. Questionnaire pages 4/5 (English)

Section 3: This set of questions relates to personal information inquiry (please select only one option in the box).

3.1) Please identify: Height:.....cm. Weight:.....kg. Religious:.....
Province of residence:.....
Gender: 1) Male 2) Female

3.2) What precept are you holding?
1) Precept 5 2) Precept 8 3) Others: (Please identify)...

3.3) What is you aims of today's practice? (You can select more than one)
1 (Relaxation and stress relief) 2 (To try to meditate)
3 (To understand the truth of nature) 4 (To cultivate mindfulness)
5 (To purify mind) 6 Others (Please identify)..

3.4) According to the aim/s state in the previous question, did you achieve this/these aim/s?
1) Yes, I partially achieved; 2) Yes, I did. 3) No, I did not)

3.5) Please identify your highest education level.
1) Primary school 2) High school 3) Diploma 4) Others (Please identify) ...
5) Bachelor degree 6) Master degree 7) PhD

3.6) Please identify your age range.
1) 10-20 2) 31-40 3) 51-60 4) 71-80
5) 21-30 6) 41-50 7) 61-70 8) over 81

3.7) Have you ever participate this questionnaire survey before?
1) Yes, I have when..... 2) No, I have not. It is my first time.

3.8) What types of ventilation do you most spend your time on a daily basis?
1) In spaces without an AC system, but employing electric fans or *NV* solutions
2) In *AC* spaces 3) Living outdoors

3.9) Please state your health condition.
1) Healthy 2) Feel not quite ok 3) I am sick.

3.10) Please state you last night's sleep quality.
1) I did not sleep well 2) I slept as usual 3) Others: (please identify) ...

3.11) How long is your experience in meditation: ..... year/s.....month/s

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XI. Questionnaire pages 5/5 (Thai)

3.12 กรุณาระบุความสม่ำเสมอของการปฏิบัติธรรมของท่าน

☐ - ทุกวัน ☐ - ทุกสัปดาห์ ☐ - ทุกเดือน
☐ - ทุกปี ☐ - ทุกวันพระ ☐ - อื่นๆ.....

3.13 จากข้อ 3.12 ท่านใช้เวลาปฏิบัติแต่ละครั้ง นานประมาณเท่าไหร่? .....นาที

3.14 ในกิจกรรมครั้งนี้ ท่านจะเข้าร่วมปฏิบัติธรรมทั้งหมด ..... (ระบุจำนวนวัน)
วันนี้เป็นวันที่เท่าไหร่ของการปฏิบัติ .....

3.15 *'ขณะนี้'* ท่านกำลัง นั่ง อยู่บนอะไร?

☐ บนเก้าอี้ ☐ บนพื้นนั่งสมาธิ ☐ บนพื้นห้อง ไม่มีฟูก

3.16 *'ขณะนี้'* ชุดที่ท่านสวมใส่ คือ ชุดประเภทอะไร ?

☐ ชุดปฏิบัติธรรม ☐ ชุดลำลองทั่วไป ☐ อื่น ๆ.....

3.17 *'ขณะนี้'* เสื้อที่ท่านใส่มีลักษณะอย่างไร ☐ แขนสั้น ☐ แขนยาว ☐ เสื้อกล้าม

3.18 สำหรับท่อนล่าง *ขณะนี้* ท่านใส่

☐ กางเกงขาสั้น ☐ กางเกงขายาว ☐ กางเกงขาสามส่วน
☐ กระโปรงสั้น ☐ กระโปรงยาว ☐ ผ้าถุง

3.19 *'ขณะนี้'* ท่านใส่ เสื้อกันหนาว หรือ เสื้อแจ็คเก็ต หรือไม่?	☐ ใส่	☐ ไม่ใส่
3.20 *'ขณะนี้'* ท่านใส่ หมวก หรือไม่ ?	☐ ใส่	☐ ไม่ใส่
3.21 *'ขณะนี้'* ท่านใส่ ผ้าพันคอ หรือไม่ ?	☐ ใส่	☐ ไม่ใส่
3.22 *'ขณะนี้'* ท่านใส่ ถุงเท้า หรือ รองเท้า หรือไม่?	☐ ใส่	☐ ไม่ใส่
3.23 *'ขณะนี้'* ท่านใส่ ถุงมือ หรือไม่?	☐ ใส่	☐ ไม่ใส่
3.24 *'ขณะนี้'* ท่านใส่ กระโปรงหรือกางเกงซับใน เพื่อความเรียบร้อยหรือไม่?	☐ ใส่	☐ ไม่ใส่
3.25 *'ขณะนี้'* ท่านใส่ เสื้อยืดซับใน เพื่อความเรียบร้อยหรือไม่?	☐ ใส่	☐ ไม่ใส่
3.26 *'ขณะนี้'* ท่านใส่ ผ้าสไบ หรือ ผ้าคาดอกหรือไม่?	☐ ใส่	☐ ไม่ใส่

3.27 กรุณาระบุ อาหารหรือเครื่องดื่มที่ท่านรับประทานไปเมื่อ ประมาณ 2 ชั่วโมงที่แล้ว ?

อาหาร ☐ ร้อน ☐ เย็น

- กรุณาระบุชื่ออาหาร .....

เครื่องดื่ม ☐ ร้อน ☐ เย็น หรือ อุณหภูมิห้อง

- กรุณาระบุชื่อเครื่องดื่ม .....

3.29 ท่านมีข้อเสนอแนะใดบ้างที่อยากนำเสนอเพื่อพัฒนาอาคารในการปฏิบัติธรรมให้ดีขึ้น?

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XII. Questionnaire pages 5/5 (English)

3.12) Please state your frequency of meditative practice
1) Daily 2) Weekly 3) Monthly
4) Annually 5) Every Buddhist holy day 6) Others: (please identify)...

3.13) Based on the question No. 3.12, how long do you spend your time on each practicing session? : ..... minutes

3.14) In this meditation event, how many day do you want to participate?
..... (days). **What is the day of your participation for this event?** .....

3.15) What sitting material are you sitting on?
1) Chair 2) Meditation mat 3) On the meditation hall floor

3.16) What type of outfit are you wearing?
1) Meditation uniform 2) Normal casual outfit 3) Others (please identify) ....
3.17) Please describe your current clothing top.
1) Short sleeves 2) Long sleeves 3) Vest
3.18) Please describe your current clothing bottom.
1) Shorts 2) Trousers 3) Cropped trousers
4) Short skirt 5) Long skirt
3.19) Are you currently wearing a jacket or sweater?
1) Yes, I do 2) No, I do not
3.20) Are you currently wearing a cap or hat?
1) Yes, I do 2) No, I do not.
3.21) Are you currently wearing a scarf?
1) Yes, I do 2) No, I do not.
3.22) Are you currently wearing socks, flippers or shoes?
1) Yes, I do 2) No, I do not.
3.23) Are you currently wearing gloves?
1) Yes, I do 2) No, I do not.
3.24) Are you currently wearing extra layers of pants or shorts for bottom to make your outfit more modest?
1) Yes, I do 2) No, I do not.
3.25) Are you currently wearing extra layers of T-shirt for top to make your outfit more modest?
1) Yes, I do 2) No, I do not.
3.26) Are you currently wearing a pashmina (breast scarf)?
1) Yes, I do 2) No, I do not.

3.27) Please identify what types of foods and drinks you had two hours before filling out this questionnaire.

Foods: 1) Hot 2) Cold	Drinks: 1) Hot 2) Cold
Please name the foods you had:	Please name the foods you had:
.....	.....

3.28) Do you have recommendation to improve this meditation center?
.....

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