Thermal Operating Practice in Mixed-Mode Buildings:

Higher Education Case Study in a Hot-Humid Climate

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DECLARATION

I, Darunee Mongkolsawat, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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ABSTRACT

The rapidly increasing demand for cooling in buildings and the growing evidence of ‘air-conditioning addiction’ concern energy policy makers in hot-humid countries. Despite this concern, many existing mixed-mode non-residential buildings in hot-humid climates are operated as fully air-conditioned. This research applies adaptive thermal comfort theory to address the potential reasons for this design-use mismatch and evaluate how to optimise the use of fan assisted natural ventilation in existing mixed-mode non-residential buildings in hot-humid countries in order to limit impending global climate change, focusing on the interrelationships between: individual thermal adaptability, organisational thermal adaptability and the role of facilities managers, pro-environmental attitudes, and user performance.

This thesis hypothesises that *Acceptance of fan assisted natural ventilation in existing mixed-mode non-residential buildings in hot-humid climates is affected by users’ perceived behavioural adaptive opportunities and psycho-physiological adaptation, as well as by facilities management practice*. Higher education buildings in Thailand were utilised as a case study, and a series of student questionnaires were conducted involving a total 2,825 students in 11 Thai universities across six regions and observing 39 classes, 14 of which were instrumented and monitored during the survey. The study also included semi-structured interviews with 25 facilities managers in four universities.

The findings generally supported the hypothesis and identify not only the criteria for students’ acceptance of assisted natural ventilation, but also the reasons behind the current facilities management operating practice in HE sector. Approximately 76% of students reported a willingness to accept (rather than not) the use of assisted natural ventilation in existing mixed-mode classrooms during the cool season if they perceived

moderate-high opportunities (i.e. effective and probable) for using fans (3.3 times more willing than with perceived low opportunities) and windows (2.8 times more willing than with perceived low opportunities). The perceived opportunity to use fans increased when there was at least one fan per 20 students. During the hot season, 37% of students reported a willingness to accept (rather than not) the use of assisted natural ventilation if they perceived moderate-high opportunities to use fans (2.8 times more willing than with perceived low opportunities), had a high daily exposure to naturally ventilated environments (1.8 times more willing than with full air-conditioning exposure), and a low income (1.5 times more willing than with a high income). Students with high exposure to naturally ventilated environments also tended to have a high level of pro-environmental attitudes, but the direction of causality is not certain. The high level of pro-environmental attitudes could be a new driver of adaptive behaviours and the willingness to reduce air-conditioning use.

Interviews with facilities managers revealed that their preference for a certain thermal operation mode appeared to be dominated by preferences for cool comfort of users with high organisational status and/or students on a high income. Universities participated in this study so far had no explicit targets of monitoring and reporting of energy use. Fans, the most effective adaptive device, had been gradually removed from many mixed-mode buildings, and facilities managers tended to rely on full air-conditioning to avoid user complaints and possible user performance drop. However, the study found that students in assisted naturally ventilated classrooms did not perceive their learning performance to be lower than those in air-conditioned classrooms, as long as they felt thermally comfortable. The risk of performance drop appeared to increase when the room air temperatures reached 31°C, the upper limit of comfort boundary for fan-assisted naturally ventilated spaces.

The findings highlight the gradual obsolescence of mixed-mode operation in the non-residential sector in a hot-humid climate. Air-conditioning reduction policy should target high-ranking people within organisations as their commitment is considered to be a key driver of changes in organisational thermal comfort practice. In this regard, monetary incentives alone for high-ranking and high-income users to reduce energy consumption may not be effective. Organisations should maintain the variability of thermal environments indoors and engage more with end-users to reduce air-conditioning use through practical adaptive behaviours. The key performance indicators of facilities management should not only focus on user satisfaction but also energy reduction achievement in order to encourage and empower the facilities managers to implement the more effective energy policies. Regarding the adaptive behaviours, organisations and building designers should be made aware that not specifying or removing fans could potentially shift mixed-mode buildings to fully air-conditioned operation because window opening alone could not always guarantee thermal comfort for the majority of users even in the cool season.

Further research is needed to evaluate the thermal and energy performance of the existing mixed-mode non-residential building stock and the potential energy saving associated with applying assisted natural ventilation based on climate change scenarios. Practical guidelines in terms of effectiveness and practicality for mixed-mode building design and operation for hot-humid climates could then be developed. The links between pro-environmental attitudes and thermal experience needs further investigation in order to clarify the direction of the relationship. More studies using intervention approaches should be conducted to estimate the potential for user performance risks if using mixed-mode operations.

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GLOSSARY

Acceptable thermal environment: An environment that a substantial majority of the occupants would find thermally acceptable (quoted from ASHRAE, 2004, p. 2).

Adaptive opportunity or **behavioural adaptive opportunity**: The cumulative options of possible thermal adjustments (for example, using doors, windows, and fans, changing clothes, and drinking water) in a building that potentially improve thermal comfort of the building's occupants (quoted from Baker and Standeven, 1996).

Adaptive comfort model: A model that relates indoor design temperatures or acceptable temperature ranges to outdoor meteorological or climatological parameters (quoted from ASHRAE, 2004, p. 2). The model is usually used for assessing the thermal comfort of occupants in free-running (naturally ventilated) buildings or whenever natural ventilation is used within a building.

Air-conditioning addiction: A strong dependence of people's thermal comfort on air-conditioning, where attitudes and use patterns of air-conditioning are comparable to drug addiction (quoted from Brager and de Dear, 2003, the term was invented by Kempton, 1992).

ASHRAE Standard 55: Standard for the thermal environmental conditions for human occupancy which were developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers**.**

Assisted natural ventilation (ANV) (in the context of this thesis)**:** A ventilation strategy that combines manually operated windows (single-sided or cross-sided windows) and electric fans (ceiling, wall, or standing fans).

Behavioural adaptation or **adaptive behaviour:** All modifications a person might consciously or unconsciously make that in turn modify heat and mass fluxes governing the body's thermal balance. Means of behavioural adjustment can be further subcategorised as: personal adjustment (changing clothes, cold food/drink consumption, etc.), technological adjustment (windows, fans, air-conditioners operations, etc.), and cultural adjustment (siesta – to avoid activities during the hottest time of the day, etc.) (quoted from Brager and de Dear, 1998).

Change-over strategy: Mixed-mode operational strategies where the building 'changes-over' between natural ventilation and air-conditioning on a seasonal or even daily basis. The building automation system may determine the mode of operating based on outdoor temperature, an occupancy sensor, a window (open or closed) sensor, or based on operator commands (quoted from Center for the Built Environment, 2005).

Clothing value (clo): A unit used to express the thermal insulation provided by garments and clothing ensembles, where 1 clo = 0.155 m^2°C/W (0.88ft^2·h·°F/Btu) (quoted from ASHRAE, 2004, p. 2).

Concurrent strategy: Mixed-mode operational strategies where the air-conditioning system and operable windows operate in the same space and at the same time. The heating, ventilation and air-conditioning system may serve as supplemental or 'background' ventilation and cooling while occupants are free to open windows based on individual preference (quoted from Center for the Built Environment, 2005).

Daily thermal experience (in the context of this study)**:** Daily thermal experience is used to represent the amount of a student's daily exposure to air-conditioned or naturally ventilated environments based on three situations in daily life: bedroom, university, and transportation. The daily thermal experience of students are then classified into three categories: full air-conditioning (using air-conditioning in all three situations), full natural ventilation (using natural ventilation mainly in all three situations), and mixed-mode (using air-conditioning or natural ventilation in the given three situations).

European Standard EN15251: Standard for specifying indoor environmental input parameters for the design and assessment of energy performance of buildings. These address indoor air quality, the thermal environment, lighting, and acoustics, and were developed by Comité Européen de Normalisation (CEN) or European Committee for Standardization**.**

Environmental behaviour: Action that causes an impact, whether positive or negative, on the natural and built world.

Facilities management: An integrated approach to operating, maintaining, improving and adapting the buildings and infrastructure of an organisation in order to create an environment that strongly supports the primary objectives of that organisation. The breadth and scope of facilities management are not constrained by the physical characteristics of buildings. For many organisations the effectiveness and behaviour patterns of the workforce and the effectiveness of their information technology and communication systems are of considerable importance and the profession of facilities management continues to evolve to reflect this (quoted from Barrett and Baldry, 2003, p. xiii).

Individuals' thermal adaptability (in the context of this thesis)**:** One's self-assessed ability to adapt behaviourally, psychologically, or physiologically to remain in comfort in an observed environment if not using air-conditioning.

Mean monthly outdoor air temperature: The arithmetic average of the mean daily minimum and mean daily maximum outdoor (dry-bulb) temperatures for the month in question (quoted from ASHRAE, 2004, p. 3).

Mean radiant temperature (MRT): The mean temperature of the surrounding surfaces (weighted by the solid angle subtended by each surface) (quoted from Auliciems and Szokolay, 2007, p. 8). The MRT can be calculated as:

$$MRT^4 = T_1^4 * F_{(p-1)} + T_2^4 * F_{(p-2)} + \ldots + T_n^4 * F_{(p-n)}$$

where: MRT = mean radiant temperature (K)

T_n = temperature of surface 'n' (K)

$F_{(p-n)}$ = angle factor between a person and surface 'n'.

The mean radiant temperature can also be approximated by globe thermometer as expressed in the following equation (from Auliciems and Szokolay, 2007, p. 21).

$$MRT = T_g * (1 + 2.35 \sqrt{v}) - 2.35 * DBT \sqrt{v}$$

where: MRT = mean radiant temperature

T_g = globe temperature

v = air velocity

DBT = dry-bulb temperature

In still air mean radiant temperature is equal to globe temperature (Auliciems and Szokolay, 2007, p. 21).

Mechanical ventilation (MV): Forced ventilation using mechanical systems to increase air movement by circulating air in spaces or rooms and/or to control indoor air quality by introducing fresh air to replace stale air in spaces or rooms.

Mixed-mode (MM) building: A building that uses a combination of natural ventilation from operable windows (either manually or automatically controlled), and mechanical systems that provide air distribution and some form of cooling (quoted from Brager et al., 2007).

Mixed-mode (MM) operational strategies: Strategies to switch from one mode to another seamlessly (so far as the occupant is concerned) to maintain thermal comfort and ventilation with minimum energy use (quoted from CIBSE, 2000, pp. 36-37). In this thesis, mixed-mode operational strategies are divided into three main categories: Concurrent, Change-over and Zoned strategies according to the Center for the Built Environment.

Mixed-mode (MM) ventilation: Service strategies that combine natural ventilation with mechanical ventilation and/or cooling in the most effective manner. It involves maximising the use of the building fabric and envelope to achieve indoor environmental conditions, and then supplementing this with degrees of mechanical systems, in all or parts of the building (quoted from CIBSE, 2000, p. 1).

Natural ventilation: The ventilation strategy used in spaces or rooms where the thermal conditions of the space are regulated primarily by opening and closing windows (quoted from ASHRAE, 2004, p. 9).

Operative temperature (T_{op}): This index was produced by Winslow, Herrington and Gagge. It is defined as the temperature of a uniform, isothermal "black" enclosure in which man would exchange heat by radiation and convection at the same rate as in the given non-uniform environment; or as the average of mean radiant temperature (MRT) and dry-bulb temperature (DBT) weighted by their respective transfer coefficients, i.e. the following expression: (quoted from Auliciems and Szokolay, 2007, p.25)

$$T_o = \frac{h_r MRT + h_c DBT}{h_r + h_c}$$

where: h_r = linear radiative heat transfer coefficient

h_c = convective heat transfer coefficient

MRT = mean radiant temperature

DBT = dry-bulb temperature

A simpler version of this formula is stated in ASHRAE Standard 55-2004 (ASHRAE, 2004, p. 20) as shown below.

$$T_o = (A)\,DBT + (1\text{-}A)\,MRT$$

where: A = 0.5 if air velocity is < 0.2 m/s

= 0.6 if air velocity is 0.2 to 0.6 m/s

= 0.7 if air velocity is 0.6 to 1.0 m/s

If occupants engaged in near sedentary activity, not in direct sunlight, and not exposed to air velocities greater than 0.2 m/s, T_o is the average of MRT and DBT (quoted from ASHRAE, 2004, p. 3).

Organisational thermal adaptability (in the context of this thesis)**:** Perceived ability of an organisation (as represented by facilities managers) to adjust their cooling strategies within their existing mixed-mode buildings from current full air-conditioning to three mixed-mode operational strategies (see concurrent, change-over, and zoned strategies).

Physiological adaptation: Changes in the physiological responses that result from exposure to thermal environmental factors and which lead to a gradual diminution in the strain induced by such exposure. Physiological adaptation can be broken down into genetic adaptation (intergenerational) and acclimatisation (within the individual's lifetime) (quoted from Brager and de Dear, 1998).

Post-occupancy evaluation (POE): The act of evaluating buildings and their occupants in a systematic and rigorous manner after they have been built and occupied for some time (quoted from Preiser and Vischer, 2005, p. 8). Post occupancy evaluation focuses on both occupant satisfaction and building performance.

Pre-cooling (in the context of this thesis)**:** A practice in some higher education buildings where facilities management staff are assigned to turn-on (split-type) air-conditioning in classrooms 10-15 minutes before classes begin.

Predicted mean vote (PMV): An index that predicts that mean value of the votes of a large group of persons on the seven-point thermal sensation scale, from -3 cold to +3 hot (quoted from ASHRAE, 2004, p. 3).

Predicted percentage of dissatisfied (PPD): An index that establishes a quantitative prediction of the percentage of thermally dissatisfied people determined from predicted mean vote (quoted from ASHRAE, 2004, p. 3).

Pro-environmental attitudes: A belief that shows a concern for the natural world and a desire to minimise negative impacts on the environment resulting from one's own actions.

Pro-environmental behaviour: Behaviour that consciously seeks to minimise the negative impact of one's actions on the natural and built world (e.g. minimise resource and energy consumption, use of non-toxic substances, reduce waste production) (quoted from Kollmuss and Agyeman, 2002).

Psychological adaptation: An altered perception of, and reaction to, sensory information due to past experience and expectations (quoted from Brager and de Dear, 1998).

Steady-state comfort model or **PMV-PPD model:** A model based on extensive laboratory and field data that uses the predicted mean vote and predicted percentage of dissatisfied to primarily determine the acceptable comfort temperature for occupants in a steady-state space (for example, occupants who are carrying out a sedentary activity in air-conditioned space – cooled or heated). The model includes six primary variables: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity (ASHRAE, 2004, p. 4).

Thermal adaptation: The gradual diminution of the organism's response to repeated environmental stimulation and subsumes all processes which building occupants undergo in order to improve the 'fit' of the indoor climate to their personal or collective requirements (quoted from Brager and de Dear, 1998).

Thermal background (in the context of this thesis)**:** Thermal conditions to which a person has been exposed and acclimatised. In this thesis, climate zone and the amount of air-conditioning use are considered to have influence on the thermal background of a person.

Thermal comfort: That condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation (quoted from ASHRAE, 2004, p. 2).

Thermal operating practice or **thermal operations** (in the context of this thesis)**:** How buildings are thermally operated normally to deliver thermal comfort to occupants. It generally refers to who operates the ventilation systems (natural ventilation and mechanical cooling or ventilation), the normal temperature set point for an air-conditioning system, and the level of user control over these systems.

Thermal sensation: A conscious feeling commonly graded into the categories cold, cool, slightly cool, neutral, slightly warm, warm, and hot; it requires subjective evaluation (quoted from ASHRAE, 2004, p. 3).

User control: Users' authority to operate devices and building service systems (e.g. heating, cooling, ventilation, and lighting) and to set and adjust the system programmes as they need.

Zoned strategy: Mixed-mode operational strategies where different zones within the building have different conditioning strategies. Typical examples include naturally ventilated office buildings with operable windows and a ducted heating/ventilation system, or supplemental mechanical cooling provided only to conference rooms (quoted from Center for the Built Environment, 2005).

List of Abbreviations

AC	Air-Conditioned
AHP	Analytic Hierarchy Process
ANOVA	Analysis of Variance
ANV	Assisted Natural Ventilation
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEH	Adaptive Behaviour at Home
BMS	Building Management System
BSRIA	The Building Services Research and Information Association
BUS	Building Use Studies
CBE	Center for the Built Environment
CEN	Comité Européen de Normalisation
CFQ	Cognitive Failure Questionnaire
CI	Confidential Interval
CIBSE	Chartered Institution of Building Services Engineers
Clo	Clothing Value (see the definition in Glossary, p. 18)
CO_2	Carbon Dioxide
DBT	Dry-Bulb Temperature
DEDE	Department of Alternative Energy Development and Efficiency
Defra	Department for Environment Food and Rural Affairs, UK
EARMTM	The Energy Assessment and Reporting Method's
ECI	Equatorial Comfort Index
EIT	Engineering Institute of Thailand
EPA	Environmental Protection Agency, US
EPPO	Energy Policy and Planning Office of Thailand
ET	Effective Temperature
FM	Facilities Manager
HE	Higher Education
HVAC	Heating, Ventilation and Air-Conditioning
IAQ	Indoor Air Quality
IPCC	Intergovernmental Panel on Climate Change
IQ	Intelligent Quotient
MLiR	Multiple Linear Regression

MLoR	Multinomial Logistic Regression
MM	Mixed-Mode
MOE	Ministry of Energy, Thailand
MOI	Ministry of Interior, Thailand
MRT	Mean Radiant Temperature
MV	Mechanical Ventilation
NEP	New Environmental Paradigm
NIOSH	The National Institute for Occupational Safety and Health, US
NSO	National Statistical Office of Thailand
NV	Naturally Ventilated
OAM	Office Assessment Method
PASW	Predictive Analysis Software
PEA	Pro-Environmental Attitudes
PLP	Perceived Learning Performance
PMV	Predicted Mean Vote
POE	Post-Occupancy Evaluation
POL	Acceptance of Air-Conditioning Reduction Policy at University
PPD	Predicted Percentage of Dissatisfied
PROBE	Post-occupancy Review of Building Engineering
RH	Relative Humidity
RIBA	Royal Institute of British Architects
SBS	Sick Building Syndrome
SET	Standard Effective Temperature
SPSS	Statistical Package for Social Sciences
TBP	Total Building Performance
TMD	Thai Meteorological Department of Thailand
TSV	Thermal Sensation Vote
VBN	Value-Belief-Norm
VOC	Volatile Organic Compound

CHAPTER 1: INTRODUCTION

1.1 RESEARCH BACKGROUND

The context for this research is the increasing emissions of carbon dioxide (CO_2) due to the enhanced demand for air-conditioned (AC) buildings in hot-humid developing countries. A vast number of studies have predicted a significant increase in cooling demand whereas the demand for heating will be reduced across climate zones due to the projected rising air temperature (Yau and Hasbi, 2013, Gupta, 2012, Wan et al., 2012, Lam et al., 2010, to name but a few).

Based on an extensive review of published papers since 1995, Yau and Hasbi (2013) showed variations in the projection of cooling and heating energy consumption in various countries, for example, the US, Switzerland, Hong Kong, Italy, United Arab Emirates and Iran, based on different years and methods. The prediction of cooling load increase in the US was as high as 85% in 2050 and 165% in 2080 whereas the heating load is expected to decrease by 28% in 2050 and 45% in 2080 (Huang, 2006 cited in Yau and Hasbi, 2013). Unfortunately, the relevant studies in hot-humid countries are scarce. In Thailand, it was projected that energy demand in small commercial buildings (offices, hotels, hospitals, retail stores, education institutions and others) would increase 5.69% on average each year from 2006 to 2020 (Chaosuangaroen and Limmeechokchai, 2008), but the projection was not segregated into air-conditioning, lighting and others. According to Sivak (2009), demand for cooling is expected to increase rapidly in the 28 largest metropolitan areas located in hot and hot-humid developing countries,[1] in which more people can now afford air-conditioning. The energy consumption of air-conditioning systems, particularly in hot-

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[1] Developing hot and hot-humid countries are: India, Thailand, Vietnam, the Philippines, Indonesia, Pakistan, Nigeria, Bangladesh, Brazil, Iraq, China, Congo, Egypt and Iran (Sivak, 2009).

humid climates, has received much attention because it accounts for approximately 40-60%, the largest proportion of total consumption within the building sector.[2] Energy policies which focus on air-conditioning consumption in buildings must be developed in order to prevent an energy crisis and to mitigate climate change.

The increasing demand for cooling energy concerns energy policy makers in many hot-humid countries. According to a report by the Building Services Research and Information Association (BSRIA), the Asia Pacific region accounted for approximately 55% of the world's air-conditioning demand in 2011 (BSRIA, 2012). However, it is not only the growth of air-conditioning sales, but also the growing evidence of air-conditioning addiction among people in hot-humid regions, that may place a greater strain on energy supply. The term 'air-conditioning addiction' was used by Prins (1992) and Kempton (1992, cited in Brager and de Dear, 2003, p. 183) to refer to the strong dependence of people's comfort on air-conditioning and their desire for quickly cooled air. A field study by Jitkhajornwanich and Pitts (2002) found that occupants of AC buildings wanted their indoor environment to be cooler even when they felt cool. This finding is supported by de Dear and Brager's explanation (2002) that once people become accustomed to fully AC environments then their perceptions of comfort change resulting in a higher expectation for more air-conditioning. Overconsumption of air-conditioning could pose health risks to users as an epidemiological investigation conducted in China shows that long exposure to AC environments may increase health problems to the nervous system, the digestive system, the respiratory system, and irritation to skin and mucous membranes (Cao et al., 2013). Recent governmental

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[2] For example, energy consumption for space cooling accounts for 40% of total energy consumption in the building sector in India (Tembhekar, 2012), 50% of that in Singapore (National Climate Change Secretariat and National Research Foundation, 2011) and 60% of that in Thailand (Energy Policy and Planning Office: Thailand, 2012a).

actions in some countries, for example the CoolBiz campaign in Japan[3] and a government pledge in Hong Kong,[4] clearly show that thermal comfort practice change in non-residential sector is now needed alongside the development of energy-efficient building design, in order to prevent air-conditioning addiction and consequent health risks resulting in the unnecessary use of air-conditioning.

Mixed-mode (MM) ventilation has been regarded as a way to improve the energy performance of a building by combining the advantages of natural ventilation and air-conditioning (Brager, 2006, Brager and Baker, 2009). Occupants are expected to alter their behaviour to remain comfortable when air-conditioning is not provided. According to the Chartered Institution of Building Services Engineers (CIBSE), UK (2000, p. 1), 'mixed-mode' ventilation is formally defined as *"service strategies that combine natural ventilation with mechanical ventilation and/or cooling*[5] *in the most effective manner. It involves maximising the use of the building fabric and envelope to achieve indoor environmental conditions, and then supplementing this with degrees of mechanical systems, in all or parts of the building."* It should be noted that the types of mechanical ventilation (MV) and natural ventilation strategies[6] stated in this definition vary across regions and cultures. For example, in developed countries the mechanical and natural ventilation used in MM buildings often means advanced ventilation systems integrated into a building's fenestration controlled by a building management system (BMS) that automatically switches between modes to minimise energy consumption (see examples in Brager et al., 2007). In many hot-humid developing

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[3] CoolBiz was a campaign introduced to reduce energy use in buildings by setting air conditioning no lower than 28°C throughout the summer months (Southerton et al., 2011).

[4] The Hong Kong government asked shopping malls to sign a pledge to raise the thermostat temperature from 24°C to 26°C starting from September 2012 to reduce air-conditioning over-consumption (Chen, 2012).

[5] Mechanical cooling can be delivered by various systems, such as unitary air-conditioning systems, displacement ventilation, chilled beams (for further details see CIBSE, 2000, pp. 34-35).

[6] MV could be delivered via, for example, local or central mechanical extraction systems or automatically-controlled trickle ventilators. NV could be delivered via manually or mechanically operated windows, passive stacks, or manually operated trickle ventilators (CIBSE, 2000, pp. 28-29).

countries, particularly in small- to medium-sized conventional buildings, ceiling fans and manually operated windows are probably more common (Jain et al., 2004). Thermal operations and occupant behaviour are the crucial factors dictating the energy and thermal performance of the buildings in the latter case.

In practice, in many non-residential buildings in hot-humid regions, buildings are able to operate in MM, air-conditioning is often set as the default mode all year round (Kim and de Dear, 2012). The mismatch of design and operation is often observed but rarely documented extensively. Based on information from building operators, Kim and de Dear (2012) revealed that many MM buildings in Australia reverted to full AC mode a few years after completion. Thomas and Thomas (2010) pointed out that purposely designed MM commercial buildings may never be operated in the natural ventilation mode if the design intentions are not conveyed to the building's owners and operators. In this regard, facilities managers (FMs) have a vital role in delivering the design intentions to the users. Hodges (2005) emphasised that FMs could be leaders of green building operations that would affect the whole-life performance of a facility. Aune et al. (2009) stated further that the building operators' daily practice could enhance the energy performance of the building service systems, with or without user involvement and advanced technology, depending on how the operators perceive their role as a teacher, housekeeper or manager, for instance.

Focusing on the operational aspect Spindler and Norford (2009) highlighted that building operators in the commercial sector are often reluctant to opt for MM operations due to the high possibility for errors in judgement and the consequent adverse effects, either in terms of energy waste or user dissatisfaction. Accordingly, the rejection of MM operations particularly in hot-humid climates, is not merely a technical problem but also an operational one. The influence of FMs, building operators and their practice on users' energy-related behaviour is rarely mentioned in thermal comfort studies.

Another influential factor that may dominate the constant use of air-conditioning in MM non-residential buildings is the standardisation and definitions of thermal comfort. Many hot-humid countries[7] have adopted a steady-state or predicted mean vote-predicted percentage of dissatisfied (PMV-PPD) comfort model[8] as developed by P.O. Fanger (Fanger, 1970 cited in Shove, 2003, p. 31) and later adopted by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for specifying acceptable thermal environments for human occupancy (Janda and Busch, 1994). Based on the steady-state model, thermal comfort is unachievable in many hot-humid countries without the use of air-conditioning. Moreover, the latest version of ASHRAE Standard 55-2010 (see ASHRAE, 2010, p. 11) still considers MM buildings or spaces as AC environments due to the presence of air-conditioning system(s), regardless of the actual capabilities of MM buildings to operate in non-AC modes (Nicol and Humphreys, 2002, Turner, 2008). Hence, the ASHRAE Standards 55-2004 and 2010 recommend that the PMV-PPD model should be used for specifying acceptable thermal conditions for MM buildings, although higher air-speed when using the PMV-PPD model (depending on clothing and activity) have been accepted later in ASHRAE Standard 55-2010 (see ASHRAE, 2010, p. 7). Thus, air-conditioning remains the main operating mode for non-residential buildings, particularly prior to the 21st century *before the introduction of an alternative comfort model* [my addition], in order to guarantee high levels of user satisfaction (Deuble and de Dear, 2012).

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[7] For example, Australia, China, Hong Kong, Malaysia, Pakistan, the Philippines, Singapore, South Korea and Thailand (Janda and Busch, 1994).

[8] PMV-PPD model is a thermal comfort model based on P.O. Fanger's work that uses the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) to determine an acceptable comfort temperature for occupants in a steady-state space (i.e. air-conditioned or heated space). The model includes six primary variables: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed and humidity (ASHRAE, 2004, p. 4).

Contrary to what it is specified in ASHRAE Standard 55-2010 regarding the acceptable thermal conditions for MM buildings' occupants, a growing number of field studies of occupants' behaviour and comfort in MM buildings that actively use MM operations (for example, Rijal et al., 2009, Deuble and de Dear, 2012) suggest otherwise. Rijal et al. (2009) stated that comfort temperatures of occupants in MM and naturally ventilated (NV) buildings both followed the outdoor air temperature. The results from Deuble and de Dear's study (2012) also confirmed that occupants in MM buildings adjusted themselves and/or the environment in order to remain in a comfortable state when buildings were operated in the NV mode. A number of studies of MM buildings have shown that occupants were more satisfied and could tolerate a wider range of indoor temperatures than those in fully AC buildings as long as user controls were available and accessible (for example, Brager and Baker, 2009, Deuble and de Dear, 2010). However, there are gaps in the notion of how MM non-residential buildings should be operated.

With the embedded AC-led thermal comfort practice in many hot-humid countries and the complications of MM operations in non-residential buildings, it is a challenge for energy policy makers, organisations and building operators to reverse or slow-down the full AC trend in existing and future buildings.

1.2 THE CASE STUDY CONTEXT

The background problem addressed by this study is the tendency for full-time AC operation in MM non-residential buildings in hot-humid climates and the possibilities for changing this trend. As this context is rather broad with a wide variety of settings (e.g. building types and ventilation systems), this study focuses on the Higher Education (HE) sector in Thailand, which is taken as a case study for the wider research problem. The tendency for full-time AC operation in the HE sector in Thailand has not been documented yet, probably because the issue of how air-conditioning systems have not gained a lot of attention before, and Thai FM staff who have this information do not usually have an opportunity to share the information through published works. Based on an informal classroom survey in Silpakorn University (urban and suburban campuses), my workplace, during the cool season in 2009 and conversations with FM staff and teachers in other universities, it would be rare to find any MM classrooms with air-conditioning systems installed being used without it. This section describes the specific context of the case study.

1.2.1 Brief background on climate and energy policy of Thailand

The climate in Thailand is categorised as hot-humid (TMD, 2007), and there are three seasons: the hot season, rainy season and cool season. The yearly average air temperature is 27°C but in summer (March – May) it can rise to almost 40°C or higher in the afternoons (TMD, 2007). Relative humidity (RH) for the whole year across all regions is 73-80% (TMD, 2007).

A higher consumption of energy for cooling is expected in Thailand in the future due to climate change as well as economic and demographic factors. Based on the UK Hadley Centre climate model and the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios in 2007, the average air temperature of Thailand is expected to increase by 1.74-3.43 degrees by 2080 (Parkpoom and Harrison, 2008). Accordingly, Parkpoom and Harrison (2008) have projected that the demand for electricity will rise 1.5-3.1% by the 2020s, 3.7-8.3% by the 2050s, and 6.6-15.3% by the 2080s. They claimed that increasing demand for air-conditioning would be the main reason for such an escalation in electricity consumption in Thailand because the cooling energy demand is directly related to the outdoor climate. In their forecast, Parkpoom and Harrison used 24°C, the recommended design and set-point temperature specified in Standard 3003-50: Air-Conditioning and Ventilation Systems developed by the Engineering Institute of Thailand (EIT) (see EIT, 2008, p. 7), as the reference for calculating the cooling energy demand.

With respect to the long-term national energy conservation plan of the Ministry of Energy (MOE) in Thailand, the Energy Policy and Planning Office (EPPO) has been promoting 25°C as the optimum temperature set point for human occupancy in AC buildings since 1992, regardless of the type of building or occupancy (EPPO, 2002). This policy aims to control and reduce AC consumption in the building sector as an increase of one degree above the EIT's standard would reduce the total energy consumption for cooling by approximately 5-10% (EPPO, 2002). This policy has had considerable success in terms of raising energy awareness within Thai society. Due to the length of this policy promotion, the 25°C level is regarded by most Thais as the only definition of thermal comfort.

1.2.2 Non-residential buildings and the higher education sector

In general, the non-residential sector consists of commercial, industrial, transportation, agriculture and other sub-sectors. With regards to air-conditioning use within buildings, the commercial sector, including shopping complexes, hotels, educational buildings, hospitals, offices and others, is the non-residential building type focused upon in this thesis. In 2011 the electricity consumption in commercial buildings was 34% of the total electricity consumption in non-residential sectors within Thailand; the second largest consuming sector after the industrial sector (43%) (DEDE, 2011). Space cooling accounts for approximately 60% of the total electricity consumption in commercial buildings (Chirarattananon and Taweekun, 2003; Yungchareon and Limmeechokchai, 2003 cited in Atthajariyakul and Lertsatittanakorn, 2008); therefore, in commercial buildings, air-conditioning reduction is considered the first priority for mitigating CO_2 emissions. The selection of the HE sector for the case study as opposed to other commercial building types is based upon three main reasons: 1) growing energy consumption in this sector, 2) high proportion of MM buildings in the current HE building stock and 3), the most important one that makes this sector unique, the importance of young people's energy behaviour and attitudes, which will now be detailed.

Firstly, energy consumption behaviour in the HE sector requires investigation. Under competitive market conditions Thai public universities are in the process of transforming into autonomous public universities and governmental funding for public universities will move towards the demand side (student loans) (Kirtikara, 2002), meaning that HE institutions have to reduce operating costs while maintaining and improving the quality of education. Consequently, electricity consumption in the HE sector is one of the key potential areas to consider. In Thailand, electricity use in educational buildings comprises 15%[9] of the total electricity consumption for the whole commercial sector, and is the third largest consumer after shopping complexes (36%) and hotels (17%) (DEDE, 2008). In 2006 the Thai EPPO (2012) launched an energy conservation scheme aimed at reducing energy consumption by 10-15% within the public sector, which includes public HE institutions. Hitherto, the energy reduction strategies adopted by this sector mainly focused on technical solutions,[10] for instance improving building envelopes and replacing old air-conditioning units with more modern units that are more energy-efficient. These strategies, although improving energy performance, do not integrate end-users the main energy consumers in the process; hence, this approach limits the opportunity for organisational or individual

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[9] Data for 2005.

[10] As shown in 'Energy Conservation Promotion Scheme for Designated Public Buildings' developed by Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand.

user learning. A behavioural approach to energy reduction in this sector should gain more attention.

Secondly, current building design and the use of Thai HE buildings are appropriate for this research topic. HE estates in 76 HE institutes in Thailand are now counted as designated buildings[11] due to their high energy consumption. Accordingly, these institutes have to report whether their building areas are classified as NV or AC space to the Thai Department of Alternative Energy Development and Efficiency (DEDE, 2004) in order to comply with the Royal Decree on Designated Buildings 1995 (B.E.2538) (MOI, 2005). Spaces where air-conditioning systems are present are all classified as AC space (DEDE, 2004). For example, Chulalongkorn University, the first university founded in Thailand,[12] has a vast number of traditional buildings from the early and middle period (1916-1973) which were originally designed as fully NV buildings with ceiling fans but then gradually over time had air-conditioning unit(s) installed (Chulalongkorn University, 2007). Once these buildings or spaces were equipped with air-conditioning systems they become recorded as full AC spaces. Therefore, it is difficult to distinguish between spaces able to operate in MM from those with air-conditioning systems only. Based on a preliminary classroom survey in Silpakorn University conducted by the author, classrooms that could be categorised as MM spaces (based on the presence of air-conditioning units and operable windows, with or without fans) account for as much as 64% and 69% of the total classroom area

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[11] The Royal Decree on Designated Buildings 1995 (B.E.2538) with an effective date of 12th December 1995, determined the building of which its feature is a single building or several buildings registered under one house registration, having energy consumption as stated below, to be a “Designated Building” (Ministry of Interior, Thailand, 2005).

1. Getting approval from power distributor to use the power meter or to install electric transformer of one or several sets in total of 1,000 kW or 1,175 kVA and over.
2. Using electricity from the power distributor system, using heat from steam of the distributor or using other depleted energy from distributor or of self generation, either anyone type of these or the overall, from date 1st January up to 31st December of the previous year, having its total energy consumption equivalent to electrical energy of over 20 million MJ.

[12] Chulalongkorn University founded in 1917, is the first university in Thailand in which the physical development and the influences of air-conditioning on building design can be traced.

in urban (3,615 m^2) and suburban (15,796 m^2) campuses, respectively. Although based on only one university, this gives an indication of the size of MM building stock in the HE sector and the potential to reduce air-conditioning use through better thermal operational strategies; hence, their suitability for use in this study.

Thirdly, it is important to investigate the energy behaviour and thermal perceptions of young people because they will fundamentally influence the future energy situation. This reason highlights the importance of the investigation of energy consumption in the HE sector compared to other sectors. Regarding the social responsibility of the HE sector, this sector has a role to play in educating young people about energy-efficient consumption, environmental impact, and sustainability. An awareness of energy consumption should also be reflected in how HE buildings are designed and operated. Considering that almost a million young people generally spend at least three years in HE institutions (NSO, 2012a), the thermal design and operation of HE buildings are worthy of study.

In addition to these main reasons, the author also has ready access to data in this sector. A major benefit of the selection is that the results from this study in a hot-humid climate can be compared with other studies in cold and temperate climates.

1.3 THE RESEARCH PROBLEM

According to the empirical studies mentioned above (for example, Rijal et al., 2009, Deuble and de Dear, 2012), MM building occupants have the ability to adapt to maintain comfort, in a similar way as those in NV buildings. This initial observation highlights the potential for applying the principle of the adaptive mechanism and the need to investigate why many existing MM non-residential buildings in hot-humid climates, which could be used in MM operation, in reality are mostly operated in full AC mode, and whether this trend can be fully or partially reversed.

The development of the adaptive thermal comfort theory is based on extensive empirical studies conducted in free-running buildings (no use of mechanical cooling or heating systems). De Dear and Brager (1998) state that people can tolerate a wider range of temperature if they can adapt behaviourally (i.e. open windows, change clothes, etc.), psychologically (i.e. change expectations), or physiologically (i.e. acclimatisation or genetic adaptation – long-term processes), to restore their thermal comfort. Brager and de Dear (1998) call this mechanism 'thermal adaptation', which is defined as "*the gradual diminution of the organism's response to repeated environmental stimulation and subsumes all processes which building occupants undergo in order to improve the 'fit' of the indoor climate to their personal or collective requirements.*" Based on this principle, the adaptive comfort model was first established in ASHRAE Standard 55-2004[13] as a method for calculating thermal comfort boundaries for NV buildings or spaces, which may be supplemented with MV of unconditioned air (ASHRAE, 2004, p. 9). When using this adaptive comfort model (ASHRAE, 2004, p. 10) there are no air-speed limits and the opportunities to use less energy-intensive thermal designs and operational strategies increase significantly. Thus this adaptive approach can potentially reduce energy demand for space conditioning (i.e. heating and cooling) whilst not sacrificing comfort (de Dear and Brager, 2001, Shove, 2003, p. 40).

In this thesis the notion of adaptive thermal comfort is primarily considered in its broadest sense of behavioural, psychological and physiological thermal adaptation mechanisms, as opposed to considering the numerical relationships between thermal comfort variables as illustrated for example in the ASHRAE 55-2010 Standard. The relationships between the users' ability to adapt and their response to non-AC environments are the main aspects of adaptive thermal comfort theory focused on in this thesis. It is important to note here that in the context of this study, the users'

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[13] The ASHRAE Standard 55-2004 is superseded by ASHRAE Standard 55-2010.

thermal response refers to the self-reported willingness to accept natural ventilation through operable windows assisted by fans or 'assisted natural ventilation' (ANV). Limitations of the application of adaptive comfort model in hot-humid countries will also be discussed later in Chapter 2 (Subsection 2.4.1, p. 53).

Being positioned in the non-residential domain, the research problem also deals with an organisation's ability to implement ANV operations instead of the existing AC-led operation in their MM buildings. With respect to the concept of adaptive comfort, both the individuals' and organisation's ability to adapt is expected to be associated with the acceptance of ANV mode in MM non-residential buildings in hot-humid climates. Because the main research problem also considers the possibilities of changing from the full AC to ANV operation within MM buildings, two additional issues of concern are also considered in this study: environmental attitudes and user performance. These issues may not be directly related to thermal adaptation, but could have a significant impact on thermal operating practices within an organisation.

Overall, the research problem deals with the interrelationships between four aspects: 1) individual thermal adaptability, 2) organisational thermal adaptability and the role of facilities managers, 3) pro-environmental attitudes, and 4) user performance. The relevant literature and knowledge gaps that need to be studied will be discussed in Chapters 2 (p. 43) and 3 (p. 92).

1.4 RESEARCH AIM AND OBJECTIVES

This thesis aims to understand whether and how it is possible to support building design, operation, and energy policy development for maintaining and/or increasing the possibilities for using ANV to supplement air-conditioning in existing and future MM non-residential buildings in hot-humid climates. In order to achieve this aim, the main factors affecting users' acceptance of ANV mode need to be identified. Based on relevant theories and findings from previous studies, this thesis hypothesises that:

> *Acceptance of fan assisted natural ventilation in existing mixed-mode non-residential buildings in hot-humid climates is affected by users' perceived behavioural adaptive opportunities and psycho-physiological adaptation, as well as by facilities management practice.*

This hypothesis does not only focus on how users adapt to remain comfortable, as already extensively examined in other studies, but also investigates why they prefer one adaptive option to others. Most importantly, the effects of facilities management practice on the use of ANV are investigated in particular, and this factor has been rarely mentioned in other field studies.

According to the aim of the research and the relevant aspects (i.e. environmental attitudes and user performance) concerning the possibilities and limitations of using ANV mode in reality, the following four objectives, corresponding to the four topics listed in the previous section, will be addressed in this study. These will be investigated primarily within the context of the case study, i.e. the HE sector in Thailand.

1) To identify the main factors affecting students' thermal adaptability and their contributions to students' acceptance of the ANV mode in existing MM HE buildings in a hot-humid climate.
2) To compare the pro-environmental attitudes and behaviour of students with different daily thermal experiences (i.e. level of exposure to air-conditioning).
3) To investigate the possibilities and barriers facing the implementation of MM operational strategies (to use more ANV mode) in existing MM HE buildings, based on the viewpoint of facilities managers.

4) To investigate whether students with the same state of self-reported thermal comfort (i.e. uncomfortable, neutral and comfortable), perceive their performance at the same level, regardless of AC or ANV rooms.

The interrelationship between these specific objectives and method design is presented in the research method diagram in Chapter 4 (Figure 4.4, p. 134).

1.5 ORGANISATION OF THE THESIS

This thesis is comprised of eight chapters and the contents of each are summarised as follows.

Chapter 1 provides an overview of the research consisting of the background, problem, hypothesis, aim and objectives and the scope of the study.

Chapter 2 reviews the theories applied to the main contents of the study. Prior to the review, definitions of MM ventilation and operational strategies, and thermal comfort standards used in MM buildings are provided. This is followed by details of the case study context, including climate data, Thai thermal comfort standards and key players. Subsequently, the adaptive thermal comfort theory and findings regarding thermal adaptation from empirical studies based in hot and hot-humid climates are reviewed. Tools for assessing thermal behavioural adaptive opportunities are discussed.

Chapter 3 extends the understanding of thermal perceptions and thermal experiences to other disciplines: productive environment and environmental psychology. This chapter discusses parameters of learning performance and findings about the impact of thermal conditions on user performance. In the field of environmental psychology, pro-environmental attitude-behaviour models and associations with thermal experience are reviewed.

Chapter 4 explains in detail the methodology employed in this research, comprising the research framework, a series of field data collections, sample size, sampling methods and tools (i.e. questionnaires, interview form and relevant equipment). In order to identify the main factors of users' thermal adaptability, a method for measuring perceived behavioural adaptive opportunities is developed.

Chapter 5 identifies potential thermal adaptive behaviours in existing MM classrooms perceived by students for relieving heat discomfort when not using air-conditioning. It then investigates the connections between students' acceptance of ANV mode and contextual factors (i.e. climate and design) mediated by students' perceived behavioural adaptive opportunities. Concurrently, correlations between students' acceptance of ANV mode and personal variables (i.e. economic status and daily thermal experience) are analysed. Following this, the contributions of all relevant factors are quantified. In addition, this chapter also examines the associations between daily thermal experience and pro-environmental attitudes and behaviour, and compares the pro-environmental attitude-behaviour scores of students with different levels of daily exposure to AC environments.

Chapter 6 describes the current FM thermal operating practice in selected HE institutions. It reports the possibilities and barriers faced concerning MM operations in existing HE buildings assessed by FMs. With regards to organisational concerns about user performance when relying on ANV, this chapter compares the perceived learning performance (PLP) of students in AC and ANV classrooms, revealing opportunities and performance risks of using the ANV mode in HE buildings in a hot-humid climate.

Chapter 7 discusses the findings from Chapters 5 and 6 based on theoretical backgrounds and previous findings. Direct and indirect factors of thermal adaptability at individual and organisational levels and their associations are discussed.

Chapter 8 concludes the thesis. The implications of the research for energy policy, building design and thermal operation development with the aim of maintaining and/or increasing the possibilities of ANV mode use to supplement air-conditioning in existing and future MM non-residential buildings in hot-humid climates are presented. Finally, the contributions to knowledge and future research directions are stated.

Appendix A contains the questionnaire, interview and relevant forms used for collecting the data presented within this thesis.

Appendix B describes the concepts behind the statistical tools used for the data analysis and sample size determination.

Appendix C presents the complete results of a pilot study carried out before conducting the Learning and thermal performance survey for testing the practicality of the selected methodology and data collection in the field.

Appendix D shows the normality tests and results conducted prior to the data analysis as employed for choosing the appropriate statistical methods. The tests were performed by Predictive Analytics Software (PASW).

Appendix E presents the complete results of all the statistical outputs from PASW.

CHAPTER 2: THERMAL ADAPTATION IN MIXED-MODE BUILDINGS

2.1 PURPOSE

The main purpose of this chapter is to review adaptive thermal comfort theory, which is used as the main approach in the investigation of thermal perceptions and behaviour of occupants in the observed MM buildings in a hot-humid climate.

2.2 MIXED-MODE VENTILATION

Buildings capable of being operated in MM ventilation are the focus of this research. This section explains the definition and framework of the MM approach.

2.2.1 Definitions

MM ventilation is a broad term covering all buildings that are neither fully AC nor fully NV. In 1999, Bill Bordass used the term 'mixed-mode' to describe a ventilation system that combines mechanical cooling or heating and natural ventilation together at all temperatures (cited in Borgeson and Brager, 2008). The CIBSE (2000, p. 1) formally defines 'mixed mode ventilation' as:

> "...service strategies that combine natural ventilation with mechanical ventilation and/or cooling in the most effective manner. It involves maximising the use of the building fabric and envelope to achieve indoor environmental conditions, and then supplementing this with degrees of mechanical systems, in all or parts of the building."

The Center for the Built Environment (CBE), University of California Berkeley (2005) provides a definition of MM ventilation as:

> "...hybrid approach to space conditioning that uses a combination of natural ventilation from operable windows (either manually or automatically controlled), and mechanical systems that include air distribution equipment and refrigeration equipment for cooling."

Based on both definitions, mechanical air-conditioning and natural ventilation are the two main strategies for MM ventilation. Whereas the CIBSE's definition highlights the integration of the use of building fabric and envelope and mechanical systems, the CBE's definition seems to be based on a simple use of windows and mechanical cooling systems in a building.

2.2.2 Mixed-mode operational strategies

CBE (2005) categorised the MM approach into three main strategies as quoted below. A diagram based on these MM operational strategies is shown in Figure 2.1.

1) Concurrent (same space, same time)

   "The air-conditioning system and operable windows operate in the same space and at the same time. The heating, ventilation and air-conditioning (HVAC) system may serve as supplemental or 'background' ventilation and cooling while occupants are free to open windows based on individual preference."

   However, in some cases this approach may not be energy-efficient (Brager et al., 2000). For example, opening windows and running air-conditioners at the same time will certainly waste energy compared to solely using one other of open windows or air-conditioning.

2) Change-over (same space, different times)

   "The building 'changes-over' between natural ventilation and air-conditioning on a seasonal or even daily basis. The building automation system may determine the mode of operating based on outdoor temperature, an occupancy sensor, a window (open or closed) sensor, or based on operator commands."

3) Zoned (different spaces, same time)

   "Different zones within the building have different conditioning strategies. Typical examples include NV office buildings with operable windows and a ducted heating/ventilation system, or supplemental mechanical cooling provided only to conference rooms."

   This strategy, in fact, can also cover buildings that use different air-conditioning strategies in different spaces and at different time as well.

		Time	
		Same	Different
Space	Same	Strategy 1: Concurrent	Strategy 2: Change-over
	Different	Strategy 3: Zoned	

Figure 2.1 The mixed-mode strategies based on the framework stated by the Center for the Built Environment (2005)

Basically, MM ventilation is the strategy that integrates the advantages of both mechanical air-conditioning and natural ventilation thereby offering more opportunities for energy savings. Brager et al. (2007) stated that the thermal comfort protocols or operational strategies for MM buildings have never been standardised. The degree of air-conditioning versus natural ventilation, as well as personal versus automated controls, also differs from case to case (Brager et al., 2007). In fact, it is impossible to establish rigid thermal comfort standards or operational strategies for MM buildings due to various possible combinations of natural ventilation and mechanical cooling technologies as well as building types and users' requirements.

Each type of ventilation system may also deliver different feelings of comfort and degrees of user control which are difficult to compare to each other.

Thermal operations and thermal comfort standards for MM buildings have been extensively researched in order to develop future building design and operations in a more efficient and sustainable way. Relevant studies will be discussed further in Section 2.5 (p. 68) after detailing the case study context and reviewing existing thermal comfort standards.

2.3 AIR-CONDITIONING AND THERMAL COMFORT STANDARDS FOR THAILAND

This section provides background information about the context of HE buildings in Thailand, the setting for the case study reported in this thesis. It consists of brief introduction to climatic data and trends for Thailand, air-conditioning and its influences on building design and operations, particularly for HE buildings, and the current thermal comfort standards for Thais.

2.3.1 Climatic data for Thailand

There are three seasons in Thailand: hot (mid February – mid May), rainy (mid May – mid October) and cool (mid October – mid February) (TMD, 2007). The hottest month is April and the coolest months are December and January. The lowest RH is experienced during the hot season (64% RH) and highest in the rainy season (84%) (TMD, 2007). Figure 2.2 illustrates the 30-year monthly mean dry-bulb temperature (DBT or air temperature) of Thailand by region. Generally, the central region, where Bangkok, the capital city, is located, has higher air temperatures than the rest of the country, and in contrast the north-eastern and northern parts of Thailand are the coolest. The largest temperature difference between regions is found during the cool season; however, the overall temperature range in Thailand is considered narrow, i.e. less than 10 degrees throughout the year.

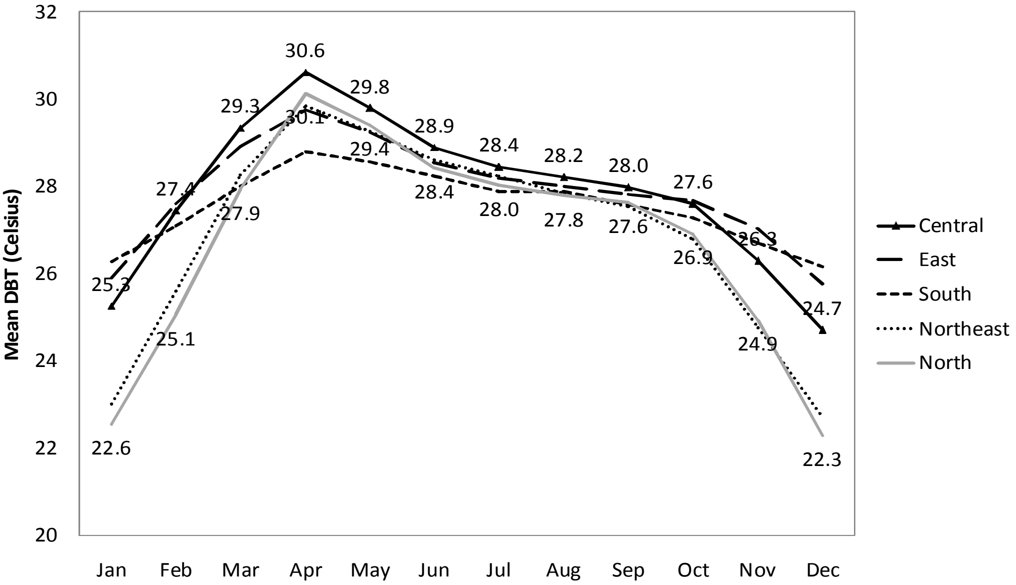

Figure 2.2 Monthly mean dry-bulb temperature by region - average data from 1961-1990, Thailand (TMD, 2008)

Based on historical climatic data (average 30-year data for the central region), the average outdoor temperature during the hot-rainy season is 28.3°C (mean minimum 24.8°C – mean maximum 32.8°C), with 79% RH. During the cool season, the average outdoor air temperature is 26.1°C (mean minimum 21.1°C – mean maximum 31.7°C), with 70% RH (TMD, 2008).

According to the Climatological Center in Thailand (2009), the effects of climate change are noticeable due to the increasing air temperature over recent years. Data from weather stations at 45 locations in Thailand show that in 2009 the average air temperature (27.26°C) was 0.23 degrees significantly higher than the normal (27.03°C, based on 20-year data, 1981-2000) (Climatological Center, 2009). The mean minimum air temperature also increased by 0.49 degrees, from 22.49°C (based on 30-year data, 1971-2000) to 22.98°C (Climatological Center, 2009). Finally, the mean maximum air temperature rose 0.40 degrees, from 32.51°C (based on 30-year data) to 32.91°C (Climatological Center, 2009), and this trend seems to likely to continue in the future.

2.3.2 Thermal comfort standards for Thais

The background for the thermal comfort standards in Thailand is reviewed in this subsection. Here, the thermal comfort standards developed by ASHRAE are mainly referred to since they have been used for developing the thermal comfort standards for Thais (EIT, 2008).

Fanger's model or the steady-state comfort model based on the PMV-PPD indices[14] is used as the reference in the ASHRAE Standard 55-1974, where a comfortable air temperature at 20-60% RH was specified as 23-25°C (Prins, 1992) for people in typical clothes and carrying out sedentary activities. Prins (1992) strongly criticised this extreme standard for making people paid expensively for the cold comfort. Incidentally, the RH lower than 30% is now considered too dry and may cause skin drying, irritation of mucus membranes, dryness of the eyes, and static electricity generation (ASHRAE, 2010, p. 7). Although the latest version of ASHRAE Standard (55-2010) is also aware of this health-related issue, the standard does not specify the lower limits of RH for thermal comfort (ASHRAE, 2010, p. 7). Currently, the acceptable RH levels are 30-60%. Seasonal thermal comfort zones, i.e. winter and summer comfort zones, were stated later in 1981 (EPA and NIOSH, 1991, p. 57) and subsequently revised in 1992, 2004 and 2010. Currently, ASHRAE Standards, which are based on Fanger's work, are cited as a source for thermal comfort standard development in

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[14] Predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) indexes were invented for identifying a thermal comfort zone (ASHRAE, 2004, pp. 4-5). The PMV index is used for estimating the average comfort votes for grouped occupants on the 7-point thermal sensation scale (-3 Cold to +3 Hot) (ASHRAE, 2004, p. 5). The model used for this estimation consists of six variables: metabolic rate (M) of the subjects, clothing insulation (I_{cl}) of the subjects, air temperature (t_a), radiant temperature (t_r), water vapour pressure (p_a) and relative air velocity (v_{ar}) (ASHRAE, 2004, p. 4). The PPD index stands for the predicted percentage dissatisfied, which is used for assessing the percentage of dissatisfied people indicated by the PMV values (ASHRAE, 2004, p. 3).

many countries, including the US, Australia, Canada, China, Hong Kong, Jamaica, Malaysia, New Zealand, Pakistan, the Philippines, Singapore, South Korea and Thailand (Janda and Busch, 1994). However, the standardisation of thermal comfort for Thais did not gain a lot of attention until the 1990s.

According to the EIT Standard 3003-50, the recommended design temperature for residential buildings, hotels, offices and schools is 24°C (EIT, 2008, p. 7). When considering the thermal operation of buildings, the EPPO which falls under the remit of the MOE, has been promoting 25°C, 1 degree above the EIT standard, as the optimum temperature set point for all AC building types since 1992, with the aim of reducing energy for building cooling by approximately 5-10% (EPPO, 2002).

Notwithstanding the attempt to reduce air-conditioning consumption, air-conditioning remains the norm for building design and operation in many hot-humid regions where the outdoor air temperatures exceed the limits of steady-state comfort boundaries most of the time. Based on this review, although it could not be said that the existence of thermal comfort standards accelerate the air-conditioning use, the descriptive steady-state model and definitive meaning of thermal comfort in effect supports the use of air-conditioning in Thailand and possibly other hot-humid countries as early as during the design stage, thereby concurring with Baker's statement: "*the very existence of definable standards for mechanically conditioned building has been the main cause for the proliferation of air-conditioning*" (Baker 1993 cited in Shove, 2003, p. 34). To date, the steady-state comfort model is the only standard used in Thailand and there are no alternative thermal comfort standards published for non-AC buildings.

2.3.3 Key players in shaping thermal operating practice within the Thai higher education sector

This subsection presents the key players at the national and organisational levels who contribute to the shaping of thermal operating practice in the HE sector in Thailand (Figure 2.3). It should also be noted that the names and relationships between key players may differ from case to case.

At the national level, as stated earlier, the EIT recommends 24°C as the standard design temperature for AC buildings (EIT, 2008, p. 7). This standard was adopted from the international thermal comfort standards developed by ASHRAE.

At the university level, HE institutions have adopted the energy policy issued by the MOE and set an energy reduction target and plan according to the EPPO announcement and DEDE recommendations. At this level, the central facilities management division or Physical Resources Management Division, may also develop regulations and detailed action plans for building design, renovation and operations within the university to be more energy-efficient.

At the faculty level, a faculty board of administrators, consisting of the dean and assistants, administrative secretary, representatives of academic staff, etc., generally establish a faculty's energy policy, target and plan, in accordance with the university policy. Faculty FMs and their staff have the role of operating, controlling and fine-tuning the ventilation systems in existing buildings within the potential of the given design and the ventilation systems, in order to suit users' requirements and faculty energy policy. Information on energy consumption is usually recorded and kept by facilities management staff or the financial department. This energy information is regularly reported to the faculty board, the university administrators through the central facilities management division, and the MOE through DEDE or EPPO respectively for improving the energy policy.

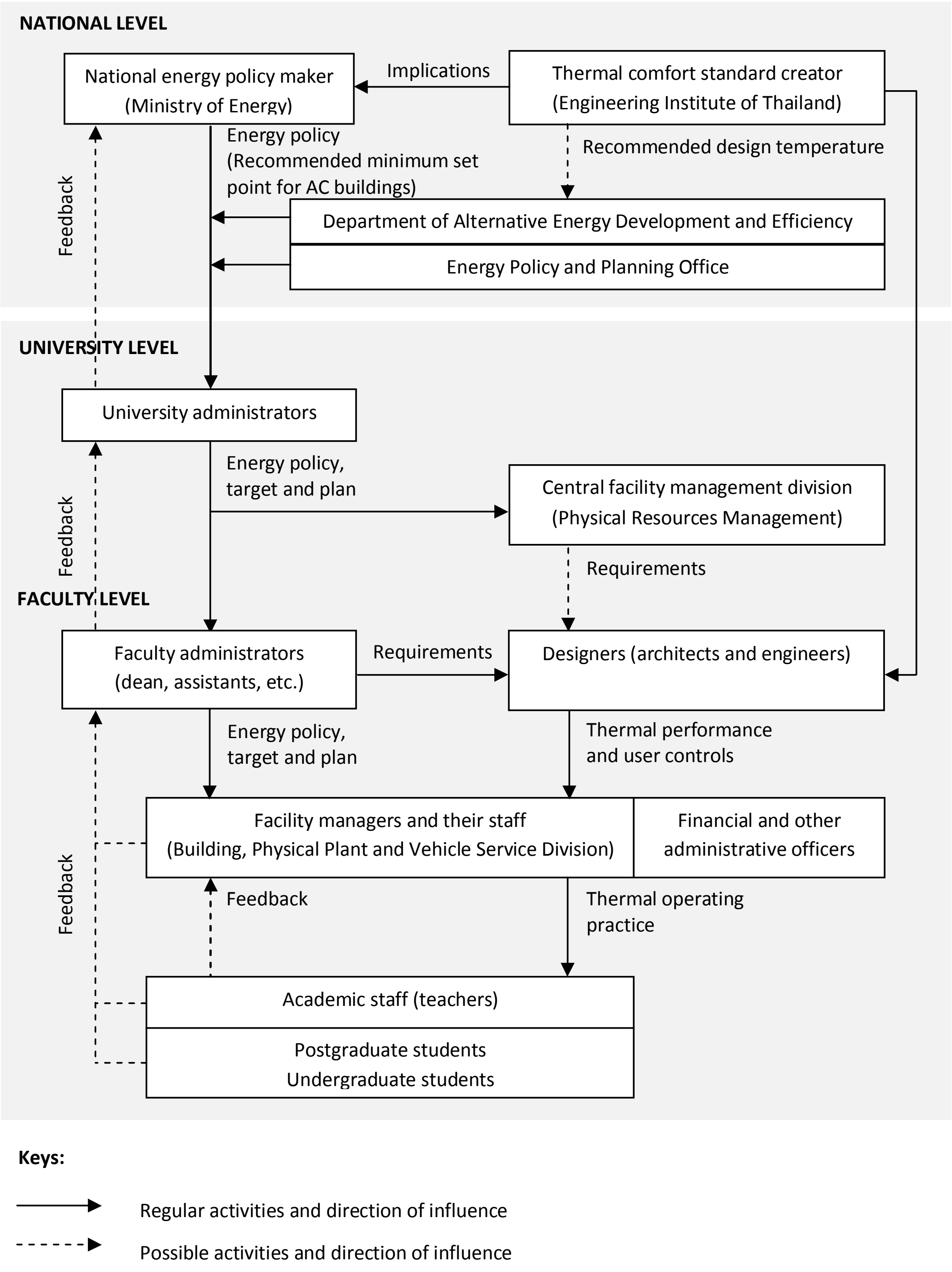

Figure 2.3 Key players in shaping thermal operating practice within the Thai higher education sector

End-users (academic staff or teachers and students) may have a role in feeding back to the faculty board of administrators informally or formally via thermal comfort surveys conducted by facilities management staff. This feedback may then be used to improve the thermal operating practice within the faculty.

2.4 ADAPTIVE THERMAL COMFORT THEORY

As MM ventilation aims to balance thermal and energy performance of a building by combining AC and NV (and MV) modes, occupants are expected to adapt to a diverse range of thermal environments within buildings, particularly when operating in non-AC modes. Therefore, in order to understand the thermal operations and thermal responses of occupants in MM buildings, the principles of adaptive thermal comfort theory are reviewed in this section.

Significant studies that led to the formulation of adaptive thermal comfort theory have been undertaken by a number of researchers, for example Charles Webb, A. Auliciems, J.F. Nicol, M.A. Humphreys, S.V. Szokolay, G. Brager and R. de Dear, to name but a few. Whilst the field studies of Nicol and Humphreys (1973) focused more upon physical actions taken by occupants to remain in comfort, Auliciems (1981) emphasised the influence of psycho-physiological changes on thermal comfort maintenance (Nicol et al., 2012, p. 30). Eventually, the important meta-analysis studies performed by de Dear and Brager (1997, 1998) concluded that not only physiological factors (based on the thermoregulation principle) but also contextual factors and past experiences are all influential in shaping user thermal sensations, expectations, and preferences within a particular environment. They elaborated further and noted that people can maintain their thermal comfort whilst being exposed to thermal conditions outside the steady-state thermal comfort boundaries, through the process of thermal adaptation (de Dear and Brager, 1998). The term ‘thermal adaptation’ in this context is defined as “*the* *gradual diminution of the organism's response to repeated environmental stimulation and subsumes all process which building occupants undergo in order to improve the 'fit' of the indoor climate to their personal or collective requirements*" (Clark and Edholm, 1985; Folk, 1974, 1981; Goldsmith, 1974; Prosser, 1958 cited in Brager and de Dear, 1998).

2.4.1 Adaptive comfort model

The adaptive comfort model was originally established in ASHRAE Standard 55-2004 (revised in 2010) for specifying acceptable thermal environments in fully NV or free-running buildings or spaces, which may be supplemented with MV with unconditioned air (ASHRAE, 2004, p. 9). In contrast, the steady-state model has been mainly applied to buildings in which the occupants have low or no control over their thermal environments (i.e. mechanically cooled or heated buildings) (ASHRAE, 2004, p. 9).

According to the adaptive comfort model, a comfortable temperature is "*the operative temperature*[15] *at which either the average person will be thermally neutral or at which the largest proportion of a group of people will be comfortable*" (Nicol and Humphreys, 2010). The essential criterion for applying the model is that there must be sufficient thermal environmental controls available for occupants to stay in comfort.

The ASHRAE Standard 55-2004 treats the monthly mean outdoor temperature ($T_{\text{out, mm}}$)[16] as the only predictor of comfort or neutral temperature (T_{n}) of occupants in free-running buildings (ASHRAE, 2004, pp. 9-10) (de Dear and Brager, 1998). Based on a meta-analysis of previous empirical surveys (36 NV buildings, mostly in moderate

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[15] Operative temperature (T_{op}): the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat through radiation plus convection as in the actual non uniform environment. T_{op} is a function of dry-bulb temperature, air velocity, and mean radiant temperature (ASHRAE, 2004, p.3).

[16] Mean monthly outdoor temperature ($T_{\text{out, mm}}$): the arithmetic average of the mean daily minimum and mean daily maximum outdoor dry-bulb temperatures (DBT) for the month in question (ASHRAE, 2004, p.3).

climates, using the ASHRAE 7-point thermal sensation vote (TSV)[17] from -3 cold to +3 hot), de Dear and Brager (2002) proposed an equation for adaptive comfort temperature and comfort boundaries for free-running buildings as follows.

$$T_n = 17.8 + 0.31 \times T_{out,\ mm}$$ **Equation 2.1**

where: $10°C \leq T_{out,\ mm} \leq 33°C$

Comfort boundary[18] for 90% acceptable = T_n ±2.5°C (equal to ±0.5 TSV)

Comfort boundary for 80% acceptable = T_n ±3.5°C (equal to ±0.85 TSV)

This adaptive model already takes common adaptive behaviours, e.g. clothing adjustment, fan or window operations, into account; therefore, it is unnecessary to include these variables in the model (ASHRAE, 2004, p. 10). In addition, neither humidity nor air speeds are restricted when applying this model (ASHRAE, 2004, p. 10). In cases where the mean monthly outdoor temperatures are outside the given temperature ranges indicated in the model (i.e. 10-33°C inclusive), then the linear function and its 80% and 90% acceptability limits should flatten out at mean monthly outdoor air temperatures (warmer than 32°C or cooler than 5°C) instead of running the model as usual (de Dear and Brager, 2001). This indicates that the adaptive model should be applied to this temperature range only, and that thermal discomforts occurred within this temperature range could be relieved by the aforementioned simple adjustments.

Based on Equation 2.1, if the outdoor temperature is 33°C, the maximum temperature this model allows, then the comfort temperature would be 28°C. Subsequently, the

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[17] Thermal sensation: a conscious feeling commonly graded into the categories: cold, cool, slightly cool, neutral, slightly warm, warm, and hot; it requires subjective evaluation (ASHRAE, 2004, p.3).

[18] This means that any temperature, not only the neutral temperature, within these boundaries would serve 90% or 80% of occupants well.

comfort boundary for 90% of occupants is 25.5-30.5°C and as wide as 24.5-31.5°C for 80% of occupants if they can adapt freely by opening windows, using fans, and adjusting clothes.

In order to test this model the results from several empirical thermal comfort studies conducted in hot-humid countries are presented in Figure 2.4. The neutral temperatures have been estimated in several indices, for example, operative temperature (T_o), effective temperature (ET)[19], or globe temperature (T_g)[20] (Brager et al., 2004, de Dear and Brager, 1998, Auliciems, 1981). Notably, for hot-humid and subtropical climates, the outdoor air temperatures can be as low as 8.8°C in Chongqing, China (Case 19) and as high as 41.5°C in India (Case 21). The neutral temperatures (T_n) gained from these studies mostly lie between 27-29°C, similar to the results from the ASHRAE adaptive comfort model.

In comparison with the PMV model, the upper limits of the comfort boundaries for NV buildings in hot-humid countries were significantly higher. In studies by Rajasekar and Ramachandraiah (2010) and Wong and Khoo (2002), the neutral temperature found in the field was approximately 3-4 degrees higher than the PMV-T_n. For Thailand, Busch (1992) specified the comfort zone for NV buildings as 26-31°C (ET), and the T_n of 28.5°C was 4 degrees higher than the design temperature recommended in EIT Standard 3003-50 (see Subsection 2.3.2, p. 50).

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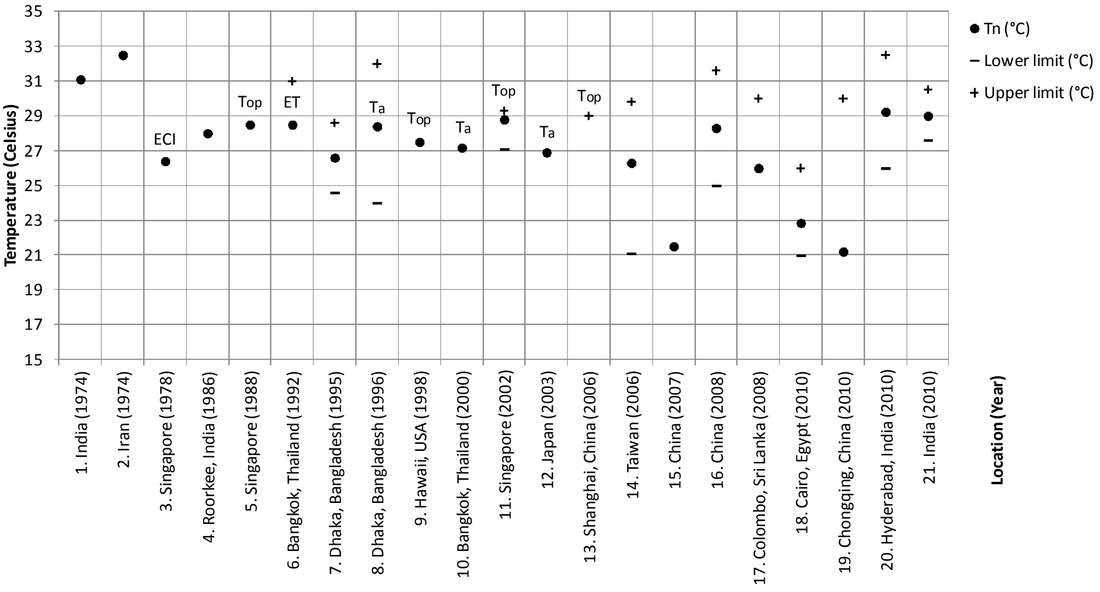
[19] Effective temperature (*ET*): the combination of dry-bulb temperature and humidity in a single index (Feriadi et al., 2003).

[20] Globe temperature (T_g): the uniform surface temperature of an imaginary black enclosure measured using a globe thermometer. By this measure, the globe temperature can take the effect of radiation to or from the surrounding surfaces into account.



Note: The neutral temperatures and comfort bands were reported in various indices which are:

T_a = air temperature, T_{op} = operative temperature, T_g = globe temperature, ET = effective temperature and ECI = equatorial comfort index[21]

Figure 2.4 Thermal comfort studies in hot and hot-humid climates

Sources:

1. Nicol (1974, cited in Busch, 1992)
2. Nicol (1974, cited in Busch, 1992)
3. Rao and Ho (1978 cited in Wong and Khoo, 2002)
4. Charm and Ali (1986 cited in Wong and Khoo, 2002)
5. Leow (1988 cited in Wong and Khoo, 2002)
6. Busch (1992)
7. Ahmed (1995)
8. Mallick (1996)
9. Kwok (1998 cited in Kwok and Chun, 2003)
10. Khedari et al. (2000)
11. Wong and Khoo (2002)
12. Kwok and Chun (2003)
13. Ji et al. (2006)
14. Hwang et al. (2006)
15. Zhang et al. (2007)

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[21] Equatorial comfort index (*ECI*) is based on the parameters of dry and wet bulb temperature and wind speed. However, this index does not consider the activity level and the clothing values as variables (Webb, 1959 cited in Wong and Khoo, 2002).

16. Yang and Zhang (2008)
17. Wijewardane and Jayasinghe (2008)
18. Farghal and Wagner (2010)
19. Yao et al. (2010)
20. Rajasekar and Ramachandraiah (2010)
21. Indraganti (2010b)

Nicol and Roaf (1996 cited in Shove, 2003, p. 37) stated that "*single-temperature standards are costly to the economy, to architecture and to the environment.*" According to Shove (2003, p. 37), the main accomplishment of formulating the adaptive comfort theory is that thermal comfort can be reconsidered as an achievement rather than a description of a set of variables or a single temperature. The implications for building designers and operators are that the provision of adaptive opportunities to buildings occupants can potentially reduce energy consumption for cooling and/or heating.

Still, there are questions about the limitations of the application of the adaptive model in hot-humid countries. The expression 'It's not the heat, it's the humidity' shows the importance of humidity control for thermal comfort provision. However, a number of studies in hot-humid countries have claimed that the effect of humidity on human comfort is insignificant (for example, Chow et al., 2010, Tsutsumi et al., 2007, Givoni et al., 2006, and Teodosiu et al., 2003). Notably, the effect of low humidity is not the main focus of these studies.

Chow et al. (2010) conducted an experimental study with Hong Kong subjects in a laboratory. The laboratory was air-conditioned set at different air temperatures (25-30°C), air speeds (0.5-3 m/s) and relative humidity (50-80% RH). They concluded that the thermal sensation of the subjects varied mainly due to air temperature and speed, not to humidity.

A chamber study by Tsutsumi et al. (2007) also shows similar conclusions. Twelve Japanese participants were required to stay in the first chamber set at 30°C, 70% RH (a typical summer condition in Japan) for 15 minutes then moved to the second chamber set at 25.2°C (a typical set point in an office), but at four different humidity levels, i.e. 30%, 40%, 50% and 70% RH, and stayed there for 180 minutes. Air velocity was still in all conditions. They found that the participants felt more pleasant when they just moved from the first to the second chamber set at 30%, and felt tired when moving to the chamber set at 70%. However, these responses were temporary. The effect of humidity on the participants' thermal and humidity sensations was not significant when they entered the steady state.

Givoni et al. (2006) also tested the effects of humidity on humans' comfort by re-examining five existing thermal comfort studies conducted in Thailand, Singapore, Indonesia (2 studies) and Japan. Two data analyses – taking and not taking humidity into account, were performed. The humidity levels were measured as the ambient humidity ratio in gr/kg. Similarly to the other studies, the thermal sensations of participants in these five studies were not sensitive to the humidity levels.

Teodosiu et al. (2003) used a numerical model for predicting the humidity levels indoors and its influence on the indoor environment. Based on the model, they stated that the effect of humidity seems to be ignorable only when indoor air temperature and speed are at acceptable levels (based on the PMV model for a sedentary activity and thin clothes scenario).

According to these studies, it seems that the impact of humidity on thermal sensation is not independent, but interrelated with air temperature and speed. At comfortable temperatures, the humidity effect cannot be easily detected, only when it is hot, and the body needs to exchange the heat to the surrounding environments through sweating.

That is when the humidity has a role to play. Sweat cannot evaporate properly in high humidity resulting in an uncomfortable feeling. With sufficient air speed, this unpleasant feeling could be relieved. Therefore, it is possible that the effect of humidity within a thermal comfort zone is not noticeable. Outside the comfort zone, the interaction between humidity and air speed, not the humidity alone, should be investigated. Acclimatisation to high humidity is another reason claimed by Givoni et al. (2006) for explaining the insignificant effects of humidity on the thermal sensations of people in hot-humid climates.

In the adaptive model, humidity limits are not required (ASHRAE, 2010, p. 12). It is probably expected that people can adapt to cope with high humidity in hot-humid climates or that high humidity problems could be relieved by increasing air speed.

2.4.2 Means of thermal adaptation

How can thermal comfort be achieved through adaptive processes? Brager and de Dear (1998) classified thermal adaptive processes into three categories: behavioural adjustments, physiological adaptation and psychological adaptation, which will now be explained.

2.4.2.1 Behavioural adjustment

According to Brager and de Dear (1998), behavioural adjustment includes "*all modifications a person might consciously or unconsciously make that in turn modify heat and mass fluxes governing the body's thermal balance.*" Behavioural adjustment can be further subcategorised as: personal adjustment (e.g. changing clothes, cold food/drink consumption), technological adjustment (e.g. windows, fans, air-conditioners operations) and cultural adjustment (e.g. siesta – to avoid activities during the hottest time of the day, changing dress code, etc.).

For NV buildings increasing the air speed through fans or windows is probably the most significant adaptive action for reducing indoor air temperatures which then extend the thermal comfort boundaries for NV buildings' occupants. According to ASHRAE report RP-884, the mean indoor air speed can explain as much as 53% of the variation of the mean indoor air temperature (de Dear and Brager, 1997, p. 100). Khedari et al. (2000) found that at an air velocity of 1 metre per second (m/s) issuing from a desk fan, the T_n of Thai subjects increased to 30-31°C, although an air velocity as high as 3.0 m/s may be required if the ambient air temperature rises to 34°C (Khedari et al., 2000). However, disturbances from fans at this high speed should be considered in practice. A study by Candido et al. (2009) concluded that the majority of NV buildings' occupants generally required air speeds higher than 0.25 m/s and also complementary cooling (i.e. ceiling fans) when the operative temperatures during the observed period were upwards of 28°C. The role of air distribution on thermal comfort is also highlighted by Kosonen and Mustakallio (2010) in their experimental study using a mock-up classroom (with no students). Four different air distribution strategies: a corridor-wall grille, a ceiling diffuser, a perforated-duct diffuser, and a displacement ventilation, were tested. The results show that the displacement ventilation had the most consistent performance and gave the best average thermal comfort conditions in the occupied zone. Compared to the ceiling diffuser, which is similar to ceiling fans, the weakness of this method is that it brought the floating hot air to the perimeter zone. This points out that further development is needed for the air distribution methods in developing hot-humid countries where ceiling fans are common.

Baker and Standeven (1996) assessed the effects of several adaptive behaviours on subjects' thermal perceptions, i.e. PPD. They found that a combination of meaningful behavioural adjustments (for example, using doors, windows and fans, changing clothes and drinking water) can dramatically decrease the PPD by up to 51%. In their later publication (Baker and Standeven, 1997), they estimated that the increments could be extended beyond the upper limit of the non-adapted comfort boundary if the occupants were provided with the following opportunities: use of control devices 2°C, spatial variation (change of position) 1.5°C, temporal variation (increased tolerance of high temperature to harmonise with the outdoor climatic pattern) 0.25°C, clothing and posture 1.7°C and decrease in metabolic rate 2.2°C (Baker and Standeven, 1997). However, this prediction remains inconclusive because it is not based on the actual responses of occupants.

Behavioural adjustments are the immediate responses utilised to extend the upper limit of the thermal comfort zone for people in warm climates. However, users do not always have total freedom to adjust themselves or their environments. Brager and de Dear (1998) stated that the limitations and potential of behavioural adaptation in any environment is due to four main criteria:

1) Climate: Milder climates (as well as good outdoor air quality) can provide greater opportunities for occupants to adapt. In contrast, too hot or too cold climates and polluted air prevent some adaptive opportunities, e.g. window use.
2) Building design: Design features can encourage or restrict adaptive behaviour. Relevant design attributes may include window location and area, availability of control devices, space sharing, interior layout, types of ventilation systems and types of controls (manual or automatic).
3) Organisational customs/social norms: In general, this factor is more related to public spaces and non-residential buildings. The organisational customs or social norms in this context could be thermal practice within an

organisation, organisational dress code or seasonal clothing, and work breaks during the day.

4) Economics: This factor refers to initial and operating costs for the thermal control technology available, facilitated by the building owner *or by occupants themselves* [my addition]. For example, automatic window-opening control could encourage the adaptive behaviour of occupants but the initial cost is high, whilst occupants in manually operated buildings (lower initial cost) may opt for air-conditioning all year round as it is the most convenient option to reduce discomfort, resulting in higher operating costs.

Among these four groups of variables, outdoor air temperature is the only one included in the adaptive model and for which its effects can be quantified. The effects of some other climatic and design factors, particularly air velocity and user controls have also been extensively researched (see further details in Section 2.6, p. 76). In contrast, organisational and economics variables have been rarely investigated. This also limits the possibility to analyse the factors that contribute to occupants' thermal responses in free-running buildings, based on the adaptive comfort model.

2.4.2.2 Physiological and psychological adaptation

Brager and de Dear (1998) described physiological adaptation as "*changes in the physiological responses that result from exposure to thermal environmental factors, and which lead to a gradual diminution in the strain induced by such exposure.*" Physiological adaptation can be broken down into genetic adaptation (intergenerational) and acclimatisation (within the individual's lifetime). Brager and de Dear (1998) claimed that acclimatisation should not be considered as a factor of immediate responses to thermal environments in most buildings, since it is a long-term unconscious process activated by the nervous system. However, a growing number of recent studies (for example, Yamtraipat et al., 2005, Yu et al., 2012, de Vecchi et al., 2012) have claimed that occupants' exposure to AC environments also affects their neutral temperatures and thermal acceptability. Based on these studies, participants who had increased daily exposure to AC rather than NV environments tended to have lower neutral temperatures (Yamtraipat et al., 2005), slower or less effective physical reactions (e.g. skin temperature, sweat rate, heart rate and heat stress protein 70[22]) to cope with the heat (Yu et al., 2012) and higher cooling preferences (de Vecchi et al., 2012). These findings were claimed to be the results of acclimatisation to constant AC environments which then affected participants' thermal expectation.

Regarding psychological adaptation, this is described by Brager and de Dear (1998) as "*repeated or chronic exposure to an environmental stressor leading to a diminution of the evoked sensation's intensity*" and is based on Frisancho's (1981) and Glaser's (1966) explanation. Auliciems (1981) and Brager and de Dear (1998) explain that psychological adaptation is mainly influenced by thermal experience, for example, repeated exposure to a stimulus can diminish the magnitude of the evoked response (Glaser, 1966; Frisancho, 1981 cited in Brager and de Dear, 1998). Additionally, people do not expect the thermal environment in different places (e.g. indoor and outdoor or AC and NV offices) and times (e.g. cool and hot seasons) to be the same, yet still they find it acceptable (for example, Yao et al., 2010) because they know from their direct past experience or from information what the thermal conditions are likely to be.

In contrast, addiction to air-conditioning could be a result of physiological and psychological adaptation to cool environments. In *"I always turn it on super": user decisions about when and how to operate room air conditioners* by Kempton et al.

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[22] Heat stress protein 70 (HSP70) is a highly conserved essential protein for combating stress (Yu et al., 2011).

(1992) shows that the majority of participants did not pay a lot of attention to air temperature or thermostat settings when they used air-conditioners; they just needed quick cool air. A recent study by Parkinson (2012) showed that when a subject's body temperature was elevated and then skin temperature suddenly decreased due to changing ambient temperature the subject would find it pleasurable rather than uncomfortable. This phenomena is considered a form of the 'psychophysics' mechanism stated by Nicol et al. (2012, pp. 11-12) in which the recent thermal history of the subject is key. In hot-humid climates, the immediate AC operation in MM buildings and AC addiction may be initially driven by occupants' desire for 'thermal pleasure', not merely normal comfort, when moving from hot environments outside into the interior of buildings.

Therefore, people's daily thermal experience or recent thermal experience can be counted as a key parameter of psycho-physiological adaptation which then affects their thermal perceptions.

Fanger and Toftum (2002) accepted that thermal expectation was also the missing factor in the PMV model and this explains the discrepancies between the PMV values and the actual comfort temperatures for people in non-AC buildings in warm climates (Bangkok, Brisbane, Athens and Singapore). Notably, they believed that thermal expectation had a greater impact on people's comfort than did behavioural adjustments. They therefore invented the 'expectance factor', formulated from the yearly average for the duration of the warm weather and air-conditioning use in surrounding buildings, in order to correct the PMV model. They found that the inclusion of the expectancy factor into the model significantly improved its accuracy. Later, Nguyen et al. (2012) tested Fanger's corrected PMV model with a large sample size. They found that the calculated PMV values based on the corrected model still weakly correlated with the actual thermal sensation vote of occupants in non-AC buildings in South-East Asia. Nguyen et al. (2012) commented that the expectancy factor only was insufficient to explain the remaining unknown factors, both subjective and objective, of individuals' responses to thermal environments.

Other personal factors that may also explain the individuals' responses to thermal environments are, for example, gender, economic status and education levels.

A vast number of studies concluded that females are more sensitive to thermal environments than males (for example, Schellen et al., 2012, Karjalainen, 2007, Parsons, 2002, to name but a few). Based on an extensive review of both field and laboratory thermal comfort studies, Misha and Ramgopal (2013) concluded that: women are more sensitive to temperature variations, prefer to be warmer, have higher dissatisfaction rates and a narrower comfort zone, but they are also more adaptive to their environment, effectively and frequently. Differences in body morphology have been claimed by many researchers (Young, A. J. and Lee, D. T., 1997; Tikuisis, P., Meunier, P. and Jubenville, C., 2001, cited in Mishra and Ramgopal, 2013, Schellen et al., 2012) as the main reason for these conclusions. That is, females have a higher surface area to volume ratio for body segments, a smaller average body size, and lesser muscle mass, and these physical conditions affect the heat balance and thermoregulation of males and females differently. Parsons (2002) explained further that females have less tolerance of cold discomfort and may not want to compromise with it resulting in more negative responses to cold environments, while males might be more patient. From my opinion, another explanation related to lifestyle could be that women, in general, spend more time indoors, so they are not accustomed to a wide range of temperature.

Indraganti and Rao (2010) show that in the same thermal environment, higher economic groups tended to rate on the warmer side of the thermal sensation scale. In other words, the higher income groups were more sensitive to heat and preferred the environment cooler, compared to the lower income group. As economic status and lifestyle are potentially related, the higher income group may also spend more time in AC environments, hence acclimate to it.

Yamtraipat et al. (2005) found that occupants who had a higher educational level also had a lower neutral temperature than those who had a lower educational background, but the magnitude of this effect was smaller than that of daily exposure to AC environments. Such highly educated individuals also had a higher status within an organisation, i.e. high ranking officers, professors, executive decision makers. Therefore, they claimed that the highly educated group had personal taste [*wanting to control the thermal conditions* – my addition] or dress code (wearing more layers of clothes and suits) that tended to encourage more air-conditioning use. In this case, education level could have both an indirect psychological and physiological effect on people's thermal perceptions.

Other parameters of psychological adaptation, for example, naturalness (of the causes of climatic changes), time of exposure, perceived control and environmental stimulation (thermal variability), were also mentioned by Nikolopoulou and Steemers (2003). However, they particularly focused on people's thermal comfort and activities in outdoor urban spaces. The impact of some of these parameters may be less relevant to indoor thermal comfort.

2.4.3 A comparison of the effects of the three thermal adaptive mechanisms

Of the three thermal adaptation mechanisms, behavioural adjustments and their effects have been the most extensively researched and often claimed as the main reason for explaining the thermal comfort of occupants in non-AC buildings. There are only a few studies comparing the effects of behavioural adjustments and physiological and psychological adaptation available.

Schweiker et al. (2012) conducted a climate chamber study in which adaptive opportunities, thermal experience and expectation of the subjects were manipulated in order to compare their effects on thermal comfort. The experiment was conducted in Germany during summer (but that summer was shorter than expected). The running mean outdoor air temperature was 18.7°C (16-23.6°C). The results show that behavioural adjustments had the most impact on the participants' comfort temperature compared with psychological and physiological adaptation. The authors contended that adaptive behaviour, such as using fans or opening windows, can significantly improve the participants' thermal comfort. The comfort boundary of the participants who had a lower level of these controls was 6 degrees narrower and 3 degrees lower than of those with a high level of control.

Liu and colleagues (2012) used the analytic hierarchy process (AHP) to analyse three methods of thermal adaptation: behavioural, physiological and psychological adjustments using a subjective approach. British and Chinese experts in thermal comfort studies were asked to evaluate the importance of any pair of given parameters for their thermal comfort (ranging from 1-Two factors are equally important to 9-One parameter is absolutely more/less important than the other factor). Using this method, the degree of the importance of two factors was compared at the same time. The results showed that the both British and Chinese experts rated physiological adaptation as the most influential adaptation. Further analysis showed that the combination of indoor environment and physiological/health contributed for about half of the weights of the importance of overall thermal adaptation and the remaining four criteria (i.e. clothing level/activity level, environmental control level, thermal expectation and outdoor environment) accounted for the other half of the weights.

Based on these two studies, the methods for quantifying the influences of behavioural, physiological and psychological adaptation, how these three adaptive categories were represented, and the context of the study may all contribute to the conflicting conclusions reached. When the context of the study is broadly specified, as in Liu et al.'s study (2012), then physiological adaptation can be interpreted based on lifetime thermal history whereas the time scale of the physiological adaptation in Schweiker et al.'s study (2012) is considerably narrower (i.e. seasonal or daily acclimatisation). When comparing the thermal comfort of people of different races and in different climate zones, genetic adaptation is expected to be the most dominant factor. In contrast, when comparing thermal perceptions of people in the same climate during different seasons, behavioural adaptation in a given space may have a higher impact on people's thermal responses. Psychological adaptation is probably the most difficult factor to quantify. A review of both subjective and objective studies concurs that psychological adaptation was not ranked as the most important factor. However, this is also inconclusive depending on the methodology and study context as mentioned previously.

Under these circumstances it remains difficult to conclude the extent of the three adaptive mechanisms on people's thermal perceptions. However, it is possible to say that the weight of the three categories of thermal adaptation is not stable but varies according to context and the temporal scale of adaptation examined.

2.5 THERMAL COMFORT STANDARDS FOR MIXED-MODE BUILDINGS AND OCCUPANT ADAPTIVE BEHAVIOUR

The steady-state and adaptive comfort models are two existing methods for specifying thermal comfort for HVAC and free-running buildings, respectively. For MM buildings there are two main approaches for defining acceptable thermal conditions or comfort set points. One is based on the ASHRAE Standard and the other on a European Standard.

Whereas the latest version of ASHRAE Standard 55 (see ASHRAE, 2010, p. 11) considers MM buildings or spaces as AC environments (Nicol and Humphreys, 2002, Turner, 2008) (mentioned earlier on p. 30), the EN15251 Standard developed by the Comité Européen de Normalisation[23] (CEN), recommends that the adaptive comfort model can be used whenever a building is operated in NV (non-HVAC) mode (Nicol and Pagliano, 2007, Nicol and Humphreys, 2010). This implies that the neutral temperature of the adaptive model could be used as a threshold for switching from non-HVAC to AC mode. By applying this standard, the period of non-HVAC operation can be extended.

There seems to be contradictions regarding the notion of how MM non-residential buildings should be operated due to the dissimilarity between the two thermal comfort standards specified for MM buildings. Basically, the ASHRAE Standard anticipates that users in MM buildings would behave or expect the thermal conditions within the buildings to be similar to those in fully mechanically heated and/or cooled buildings. However, the benefits of using the second approach have been demonstrated by several researchers. De Wilde and Tian (2010) predicted the impact of climate change in the 2020s, 2050s and 2080s on energy consumption in MM office buildings in the UK, and compared PMV and adaptive thermal comfort methods. Without any building improvements, the cooling energy demand when using the PMV model would result in an increase of 500% compared to current energy use by 2080, but this figure was reduced by half when using the adaptive model. In comparison, a 10% heating energy reduction could be added when using the adaptive model rather than the PMV model. The results can be explained by the allowance of a wider range for the thermal comfort zone when the adaptive thermal comfort model was applied.

Borgeson and Brager (2011) demonstrated that using the PMV and adaptive models for calculating exceedance metrics of MM buildings give significantly different results.

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[23] The English term is European Committee for Standardization.

Exceedance criteria are included in the EN15251 thermal comfort standard and refer to the percentage of hours outside the expected occupant comfort range over time. It was thought that this strategy would stimulate much discussion on the trade-off between energy and comfort. According to the results of their study, the exceedance computed from the PMV model was significantly higher than when using the adaptive comfort model since acceptable temperature limits were different. This implies that more mechanical heating and/or cooling is required if using the PMV model as a reference for calculating exceedance metrics. The authors recommended that methods for calculating the exceedance metrics should be developed and clearly stated in future thermal comfort standards, and should take into consideration the energy performance of a building.

Deuble and de Dear (2012) compared the resulting prediction from the PMV model and actual comfort votes (7-point scale) of occupants in a MM office building in Sydney, Australia (moderate subtropical climate). They found that the PMV model alone could not predict the actual votes properly when the building was operated in NV mode. The discrepancies resulted from the exclusion of occupants' thermal adaptability (window and fan use and expectation change) from the PMV model. According to the results, they recommended that the MM buildings should be switched to mechanical air-conditioning mode only when the indoor air temperature reaches the upper limits of adaptive comfort boundary in order to save energy, thereby corresponding with the EN15251 Standard.

When considering the energy performance and occupants' actual comfort within existing MM buildings, the research reviewed here supports the EN15251 Standard which stipulates that the adaptive comfort model, rather than the PMV model, should be applied to MM buildings to specify the temperature set point for switching between

AC and non-AC modes. To support this approach, it must be ensured that the occupants have sufficient adaptive opportunities or assess to controls during the NV mode.

Several empirical studies have shown that behaviour in relation to achieving thermal comfort for the occupants in MM buildings is comparable to those in NV buildings. This initial observation emphasises the potential for applying the principle of the adaptive mechanism to investigate thermal operation and occupants' responses in existing MM buildings. The adaptive behaviour of occupants in both MM and NV buildings in hot and hot-humid regions is reviewed in this section, and residential and non-residential buildings are compared.

Based on large data sets for MM buildings in Europe and Pakistan, Rijal et al. (2009) summarised that the occupants of MM buildings reasonably used controls (windows, fans, and mechanical heating and cooling systems) in an energy-efficient way while not compromising their comfort. They reported, but not concluded, that the availability of air-conditioning in MM buildings did not have any significant effects on fan use. This seems to contradict the tendency of full-time air-conditioning operations in MM non-residential buildings in some hot-humid countries. Furthermore, they claimed that indoor temperature was found to be a good predictive indicator of window, fan and air-conditioning use. Based on their paper, the effects of relative humidity and non-thermal factors such as organisational culture, facilities management practice, and levels of user control on the occupants' adaptive behaviour were not mentioned.

Table 2.1 presents the diversity of adaptive behaviour in MM and NV buildings based on empirical studies in hot and hot-humid countries since 2002. The first group (studies 1-5) is residential buildings, mostly high-rise student dormitories, the second group (studies 6-14) is non-residential buildings consisting of schools, universities and offices, and the last group (studies 15-16) is multi-purpose buildings. In this table, adaptive behaviour is divided into two categories: environmental adaptation (or technological adjustment) and self-adaptation (or personal adjustment). It should be noted that in these studies most thermal discomfort was incurred due to heat and humidity, not cold. Additionally, methods used for collecting data were different, for example, observation, self-reporting and preference vote/ranking.

From the table, adaptive behaviours in residential buildings show more variation than non-residential environments. In the study in India by Indraganti (2010b), for example, participants used all possible ways to relieve heat discomfort in non-AC buildings. The low-income group used low/no cost methods, such as opening doors and windows, turning fans on and self-adaptations. In contrast, high-income families who can afford an air-conditioner tended to use it but only when the indoor temperature reached 28.5°C, which is very close to their neutral temperature based on the adaptive comfort model, demonstrating concerns about costs incurred by air-conditioning use. In the case of commercial buildings, the thermal adaptive behaviour observed was more limited. For this review, adjusting shading devices, reducing activity, and taking showers were not found in any non-residential buildings.

Table 2.1 Adaptive behaviour in hot and hot-humid climates represented in terms of percentage of use [or rank]

No.	Researcher(s)/Year	Location	Building Type[a]	Ventilation System[b]	Environmental Adaptation					Self-adaptation				
					Window	**Door**	**Fan**	**Shading**	**HVAC**	**Clothes**	**Drink**	**Move**	**Activity**	**Shower**
1	Feriadi et al. (2003)	Singapore	R	MM	64.4%		79.6%		42%	50%	50%	11.9%		45%
2	Tablada et al. (2005)	Cuba	R	NV	72%		59%			29%	62%	33%	39%	48%
3	Cheng et al. (2008)	Taiwan	R	NV	[3][c]		[2][c]	[4][c]	[1][c]	[6][c]		[5][c]		[7][c]
4	Rajasekar and Ramachandraiah (2010)	India	R	MM	[1]	[6]	[2]		[5]	[4]		[3]		
5	Indraganti (2010b)	India	R	NV & MM	in use	in use	[6]	in use	high income	[5]	[2]	[1]	[3]	[4]
6	Wong and Khoo (2002)	Singapore	E	NV			Yes							
7	Kwok and Chun (2003)	Japan	E	NV			Yes			Yes				
8	Nuntavicharna (2004)	Thailand	E	NV			Yes			Yes				
9	Hwang et al. (2006)	Taiwan	E	NV						Yes				
10	Bernardi and Kowaltowski (2006)	Brazil	E	NV	Yes	Yes	Yes			Yes	Yes	Yes		
11	Farghal and Wagner (2010)	Egypt	E	NV	Yes	Yes	Yes			Yes	Yes			
12	Yao et al. (2010)	China	E	NV	Yes	Yes				Yes	Yes			
13	Ji et al. (2006)	China	O	NV	Yes		Yes							
14	Rijal (2009)	Pakistan	O	MM	Yes		Yes		Yes					
15	Yang and Zhang (2008)	China	M	NV	Yes	Yes								
16	Matias et al. (2009)	Portugal	M	NV	Yes					Yes	Yes			

Note: a – Building type: R – Residential building, E – Educational building, O – Office and M – Multi-purpose buildings

b – Ventilation system: NV – Natural ventilated, MM – Mixed-mode

c – This ranking was based on participants' preferences, not actual adaptive behaviour.

According to the studies reviewed, people were relatively enthusiastic regarding environmental adaptation rather than self-adaptation, and using fans and windows was the most common choice in all building types. However, window opening was not always possible due to air and noise pollution, bugs, privacy and safety (Mallick, 1996, Rajasekar and Ramachandraiah, 2010). For personal adjustments, changing clothes seemed to be the most common practice in all building types, possibly because it was easy and effective. The second most popular option was drinking cold water. Other self-adaptations, i.e. moving away from heat sources, reducing activities and taking a shower, were more usual in private residences. This obviously illustrates the behavioural restrictions due to some organisational factors in non-residential buildings. Generally, regardless of the building type, actions that induce air movement, especially fan use, are considered the most useful option to relieve thermal discomfort in hot and hot-humid regions.

Fan use is not only useful when MM buildings are operated in NV mode, they can be a supplementary cooling strategy when air-conditioning is in use. The latter function of fans could replace the concurrent MM strategy, i.e. to use air-conditioning and natural ventilation within the same space and at the same time which is unlikely to be energy efficient. Due to the importance of fans in hot-humid climates, studies regarding fan use in AC buildings and the recommended air velocity specified in ASHRAE Standard 55 for AC buildings are reviewed here to show the potential energy savings when using air-conditioning assisted by fans.

Atthajariyakul and Lertsatittanakorn (2008) conducted experimental studies examining the impact of fan use on the comfort temperature of AC office buildings' occupants in Thailand. Based on the PMV model, if air velocity was increased to 1, 1.5, and 2 m/s, the neutral temperatures increased from 25°C to 27.4°C, 28.3°C, and 29.2°C, respectively. Notably, the current standard set point for AC buildings in Thailand is

25°C (EPPO, 2002) (see the background of this setting in Subsection 2.3.2, p. 48). In practice, they suggested that the set point could be raised to 28°C if a small desk fan (15 cm in diameter) is used (placed in front of each subject) to improve local air movement. Kongkiatumpai (1990 cited in Atthajariyakul and Lertsatittanakorn, 2008) and Atthajariyakul and Leephakpreeda (2004 cited in Atthajariyakul and Lertsatittanakorn, 2008) estimated that a decrease of 1°C for the air-conditioning thermostat setting would save approximately 6.14% of normal cooling energy consumption, thus the potential energy savings from air-conditioning assisted with ceiling fans for the office sector could be as high as 1959.51 GWh/Year.

Vipavawanich (2008) experimented with how ceiling fans (40 cm in diameter) placed at a 3-metre height would affect the comfort temperature of subjects in a small AC classroom (36 m^2). The selected ceiling fans consumed approximately 50 Watt-Hour, and the split type air-conditioners (25,800 btu) used approximately 3027.2 Watt-Hour. The fan air speeds were adjusted to level 1 (0.87 m/s) and level 2 (1.03 m/s) during the experiment. The majority of the respondents were wearing normal clothes (the clo value was 0.57) and felt neutral when the air-conditioning thermostat was set at 27-28°C plus the fans were operating at level 1 (the estimated energy saved was 8-12% compared with 24°C) or 27-29°C with ceiling fans operating at level 2 (the estimated energy saved was 10-13%). The most acceptable mode was for the air-conditioning to be set at 27°C with ceiling fans operating at level 1.

In addition, a higher air speed resulting from fan use can reduce the air-conditioning cooling load, and empirical studies also show preferences for higher air movement in warm environments (for example, Fountain, 1991, Fountain et al., 1994, Arens et al., 1998, to name but a few) leading to several amendments in ASHRAE Standard 55 since 1989 (Fountain, 1991). Recently, ASHRAE Standard 55-2010 (ASHRAE, 2010, pp. 7-8) introduced a new thermal comfort index called the Standard Effective Temperature

(SET)[24]. Higher air speed limits, up to 1.2 m/s, can be applied when using the SET method. This extension of the air-speed limits is aimed at encouraging the use of ceiling fans to supplement mechanical cooling (ASHRAE, 2010, p. 2).

Based on the literature review regarding air velocity in both NV (see Subsection 2.4.2.1, p. 59) and AC buildings, fans can potentially reduce air-conditioning consumption through all MM operational strategies.

Past research studies in MM buildings have mainly focused on occupants' adaptive behaviour; however, the factors that encourage adaptive behaviour and why occupants choose one adaptive option over others have not been widely examined. In particular, the role of organisational factors and facilities management practice, which seems to be influential in shaping thermal comfort practice and end-users' adaptive behaviour in non-residential buildings, has not been mentioned explicitly. Therefore, it is difficult to improve adaptive behaviour in MM buildings, particularly those existing MM buildings in hot-humid climates but operated in full AC mode.

2.6 BEHAVIOURAL ADAPTIVE OPPORTUNITY

The influence of factors, i.e. climate, building design, organisational customs/social norms and economics, on behavioural adaptation cannot be identified straightforwardly. For example, the design features of two MM buildings cannot always be simply compared, since it is uncertain which features are meaningful and practical to users in order to restore their comfort in a specific context. Moreover, the actual use of some adaptive options, e.g. operable windows, fans, etc., particularly in non-residential buildings, may be constrained by other factors. Consequently, an

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[24] The Standard Effective Temperature (SET) is the temperature of an imaginary environment at 50% relative humidity, < 0.1 m/s air speed, and radiant temperature equals air temperature, in which the total heat loss from the skin of an imaginary occupant with an activity level of 1.0 met and a clothing level of 0.6 clo is the same as that from a person in the actual environment, with actual clothing and activity are level (ASHRAE, 2010, p.4).

intermediate variable is required to link the contextual factors, i.e. design features, and users' thermal perceptions. Behavioural adaptive opportunity is therefore reviewed in this section as it may serve as the immediate variable to show how users perceive the opportunities to adapt based on the several options available, which in turn may affect their perceptions towards the thermal conditions within a space.

It should be noted that not only behavioural adaptation but also psychological and physiological adaptation are important for thermal comfort maintenance, as discussed earlier (see Subsection 2.4.2.2, p. 62). However, the effects of psycho-physiological adaptation have usually been assessed and interpreted through the thermal history of a person and other socio-demographic variables, e.g. education background and income (see Subsections 2.4.2.2, p. 62). Therefore, this section does not include these topics within the review.

2.6.1 Definitions

'Thermal behavioural adaptive opportunity' was firstly defined by Baker and Standeven (1996) as "*the cumulative options of possible thermal adjustments (for example, using doors, windows, and fans, changing clothes, and drinking water) in a building that potentially improve thermal comfort of the building's occupants.*" Kwok and Rajkovich (2010) then widened the definition of adaptive opportunity as the ability of a building occupant to make adjustments to the local environment (behavioural adaptation) or to one's own status. Accordingly, adaptive opportunity could only be judged by the users themselves.

'Control' is another term described by Bordass and colleagues (1993) as a key that allows service systems to operate efficiently according to need, management and occupiers to intervene as necessary to adjust programmes and settings, and individuals to obtain the services when they require them. The description of control is later widened into a temporal aspect. Leaman (2009) stressed that "*control is not just access to working and effective physical controls for heating, cooling, ventilation and glare, but control over your own time....*" Within the context of thermal comfort, 'control' and 'adaptive opportunity' have quite similar meanings (Leaman and Bordass, 2004, p. 152).

Adaptive opportunity or control affects users' thermal comfort; however, it is difficult to quantify adaptive opportunities and relate them to users' thermal comfort. Nicol and McCartney (1999) showed that the availability of controls, e.g. windows, fans, doors, etc., did not mean they were actively used. This is because the usability of control is restricted by organisational culture, norms, social practice, facilities management rules, building type, etc. In addition, totalling the number of controls does not provide a good indicator of thermal satisfaction (Nicol and Roaf, 2006). Furthermore, the need and usefulness of controls varies greatly depending on spatial and temporal contexts (Nicol and Humphreys, 2002). In practice, from the options available, users may choose only one or a few adaptive methods to mitigate thermal discomfort particularly in non-residential buildings.

Hwang et al. (2009) stated that thermal adaptation habits of occupants in domestic buildings are influenced by three main qualitative aspects: effectiveness, accessibility and cost. Therefore, although a number of thermal adaptation options may be provided, the options that match these three factors are likely to be chosen. Wei et al. (2010) added that the priority of adaptive preference is probably due to the type of buildings and outdoor conditions experienced during the survey and each space provides thermal adaptive opportunities at different levels. This statement is related to both building design and organisational customs or social norms prevailing in a particular place.

Overall, behavioural adaptive opportunities cannot be quantified as the number of controls (e.g. windows, fans, etc.) alone but also depends on qualitative aspects of those controls. The following subsections review tools for quantifying adaptive opportunities or controls based on two main approaches: post-occupancy evaluation (POE) and field studies of thermal comfort. Furthermore, the review shows how existing research studies connect the contextual factors with users' thermal perceptions.

2.6.2 Post-occupancy evaluation studies

POE is a process for assessing the quality of environments, including thermal environments and the control of buildings in use. Bordass and Leaman (2005, p. 72) defined POE as a practice to answer the following four questions:

- How is this building working?
- Is it intended?
- How can it be improved?
- How can future buildings be improved?

In 1980, Zimring and Reizenstein provided a definition of POE as "*examinations of the effectiveness for human users of occupied design environments*" (cited in Turpin-Brooks and Viccars, 2006). Based on this definition, the objective of POE is actually quite broad and covers many aspects of building performance depending on the requirements of the building owner.

POE is now included in Royal Institute of British Architects (RIBA) Plan of Work 2013 – the definitive UK model for the building design and construction process. According to the RIBA (2013), POE should be carried out in the last step as part of the handover strategy in order to give feedback to clients for continuing building performance improvements.

Barrett and Baldry (2003, p. 120) categorised POE methods into two groups, user-based systems and expert-based systems. The former collects data directly from end-users, for instance environmental comfort, whilst for the latter system data is collected by experts who are usually concerned with strategic planning of an organisation, such as changes in staff work style and energy efficiency. The first method type can gather more insights which external experts may not be able to access or fully understand.

There are both standardised POE tools developed by professionals and bespoke tools developed by in-house FMs or academics. Most environmental comfort assessment tools are user-based systems utilising questionnaires, interviews and/or observations in order to collect the data. A number of POE tools have been developed and used as prototypes; however, only two relevant tools which include thermal control as one of the building performance indicators are reviewed here. It should be noted that in POE studies the term ‘control’ is more commonly used than ‘adaptive opportunity’. The issue of control in this context focuses on the availability of control devices and their ease of use.

Post-occupancy Review of Building Engineering

Post-occupancy Review of Building Engineering (PROBE) was developed by Halcrow Gilbert Ltd and William Bordass Associates (WBA), with Building Use Studies Ltd (Bordass and Leaman, 1997). PROBE examines hard and soft issues as explained below.

Hard issues are comprised of technical performance, management perspectives and energy performance as surveyed in general by experts (Bordass and Leaman, 1997). Later, a survey system was developed and named the Energy Assessment and Reporting Method’s (EARMTM) Office Assessment Method (OAM) for energy analysis.

This was then renamed as TM22 and published as guidance for energy survey methods by CIBSE in 1999 (Cohen et al., 2001).

Soft issues focus on physical conditions (lighting, temperature, noise and air movement), personal control, response to complaints, health and overall comfort, productivity, background and the overall quality of the building (Bordass and Leaman, 2005, p. 75). Self-completion questionnaires are used as the data collection method. The whole process of data gathering and analysis is called Building Use Studies (BUS). In considering the issue of control, the objective of the analysis is to investigate whether or not occupants are more satisfied with the environment if more controls (e.g. switches, blinds and opening windows, etc.) are available to them. In PROBE studies a subjective approach is used to quantify the degree of user control over their working environment. Participants are asked how they perceive their level of control over five systems: heating, cooling, lighting, ventilation and noise, using a 7-point rating scale (1-Low Control to 7-High Control) (Leaman and Bordass, 1999). The mean score for control is then calculated by averaging the raw scores of the five variables (Leaman and Bordass, 1999).

PROBE surveys have been conducted, mainly in the UK, for many years allowing a database to be established so that the performance of buildings can be compared against best practice or reference benchmarks (Leaman and Bordass, 1999). Results from PROBE surveys are usually fed back to designers and their clients but not to building operators or users, although the summary reports might be given to building managers (Bordass and Leaman, 2005, p. 75).

Total Building Performance

Total Building Performance (TBP) was developed by Public Works Canada (PWC), Architectural and Building Sciences Directorate between 1981-1985 (Hartkopf and

Loftness, 1999). TBP is a framework that uses a combination of objective and subjective measures in the field to analyse what is needed to guarantee the overall building performance (Wong and Jan, 2003). The objectives of TBP are to reduce energy consumption, pollution and waste in both existing and new constructions and to improve the quality of life within buildings. The contents of TBP covers six mandates, these are: thermal, spatial, visual, acoustic, indoor air quality (IAQ) and building integrity. Basically, the objective measurements of a building, i.e. temperature, illumination, noise and indoor air quality, are undertaken. The results are then compared against local standards or other applicable international standards. The subjective measurements are carried out by an expert walkthrough (to observe any traces of stress or user modification) and occupant questionnaires are analysed to survey the environmental quality, health and productivity (Wong and Jan, 2003).

For the thermal environment, TBP states there are four area of users' needs serving as performance indicators available for data analysis (Hartkopf and Loftness, 1999).

- Physiological needs: no numbness, frostbite, no drowsiness, heat stroke
- Psychological needs: healthy plants, sense of warmth, individual control
- Sociological needs: flexibility to dress according to custom
- Economic needs: energy conservation

According to the goal of TBP as stated above, the issues of individual control and a flexible dress code are those most related to behavioural adaptation. TBP employs correlation and regression analyses to identify the contribution of each environmental factor to the average TBP score (Wong and Jan, 2003).

Both BUS and TBP are user-based surveys supplemented with objective measurements. However, BUS seems to focus more on building improvements to increase user satisfaction, whereas TBP aims at optimising the energy consumption in buildings whilst not compromising user satisfaction. Compared to BUS, TBP includes more aspects of building performance – *spatial, IAQ and building integrity*, in their survey. Focusing on the issue of control, perceived levels of user control is more highlighted in BUS, while TBP considers the user control as one of many other users' needs. Considering the data analysis, BUS gives equal weight to all environmental indicators for producing the mean score, whereas TBP uses regression analysis which gives unequal weight to each of the six environmental indicators. This may increase the validity of TBP assessment. Most importantly, BUS compares the performance of buildings against best practice or reference benchmarks, but TBP uses established standards as the references.

2.6.3 Field study of thermal comfort

In this subsection selected field studies of thermal comfort and adaptive behaviour are reviewed in order to present alternative methods for thermal adaptive opportunity evaluation and its relationship with occupants' thermal perceptions.

Based on an investigation of thermal comfort, control and satisfaction in three MM buildings in northern California, Brager et al. (2000) concluded that ease of access to windows, outdoor air quality (temperature and pollution), organisational culture (FMs speedy response to complaints) and availability of alternative control over HVAC systems, all affected occupants' overall satisfaction with their office. The authors found a significant relationship between degree of control in the office, assessed by the percentage of occupants with easy access to windows and thermostats, and occupants' satisfaction with almost all environmental performance indicators, i.e. air movement, ventilation, air quality and temperature. They concluded further that in MM offices (with operable windows and HVAC systems), users preferred using windows to HVAC.

The main reasons noted for opening windows were related to IAQ (e.g. too warm and air too still) while the outdoor air quality (e.g. noise and air pollution, too cold and disturbing air movement) was the most common reason provided for closing windows.

Brager et al. (2004) used objective measurements to investigate the impact of control on temperatures in participants' workstations and their thermal comfort in a NV building in San Francisco. The data collected included temperature monitoring in participants' workstations, a web-based survey regarding their thermal sensations, and photos recording the use of windows and blinds (adaptive behaviour). In this study, they classified the degree of participants' control into four levels with regards to types of office (space sharing) and distance from windows, these were: Level 1 – Direct Control (private office), 2 – Direct Control (open plan desk adjacent to windows), 3 – Indirect Control (open plan desk, usually one desk away from windows) and 4 – No Control (open plan desk blocked by exterior private office or high partitions). These levels were later merged into two groups, i.e. High (Level 1 and 2) and Low (Level 3 and 4), since most of the samples fell into categories 2 and 3 only. The authors found that the neutral temperature of the High-control group varied more than the operative temperature compared with the Low-control group, particularly in the warm season. They finally concluded that the variations in neutral temperatures could be explained by the degree of control.

Demers et al. (2009) developed a Physical Ambience Rose (PAR) to illustrate the relationships between users' satisfaction of environmental conditions (thermal, luminous, acoustical and olfactory) and level of physiological adaptation of office workers in the CDP Building in Montreal. In this study, the authors created a new variable called the adaptive index which equated to the difference in environmental satisfaction scores rated by participants before and after they took adaptive actions. A questionnaire was designed for collecting the data and consisted of several items regarding environmental satisfaction, for example, the quality of the four environmental conditions mentioned above, ranging from -1 intolerable to +1 very pleasant; spatial scale (part of body affected by the stimulus) ranging from 0 a body part (e.g. hand) to +1 entire body; time scale ranging from 0 short duration to +1 permanent; and effectiveness of an adaptive opportunity ranging from 0 to 1. The results showed that occupants in cellular offices were more satisfied than those in open plan offices in terms of environmental quality and adaptability.

Daghigh et al. (2009) conducted an experimental study at Putra University, Malaysia to investigate the thermal comfort of occupants in AC offices with several states of windows and door opening. They chose a typical AC room with no fans and arranged the door and windows in 14 different ways based on different combinations of one door (closed or opened) and two similar windows (closed, half opened and fully opened) whilst the air-conditioner was running. Volunteers were asked to individually use the room for a period of 30 minutes and then to answer a thermal comfort questionnaire. Before answering the questionnaire, participants were allowed to freely interact with the environment. The questionnaire consisted of demographic information, use of controls, thermal sensations and preferences, and current clothing. At the same time, the indoor environmental conditions (i.e. dry-bulb temperature, globe temperature, RH, air velocity and CO_2) were measured. The authors found that air-conditioner adjustment varied according to the indoor air temperature, whereas the windows and door were opened only when the participants felt that the outdoor air was cooler than indoors. Furthermore, among all the adaptive behaviours, adjusting the air-conditioner was the first choice, followed by window opening and clothes adjustment. Other adaptive behaviours observed were opening/closing the door, drinking water, leaving the room and using the curtains.

2.6.4 A comparison of post-occupancy evaluation and field study of thermal comfort

Differences between POE and field studies of thermal comfort are discussed in this subsection. According to Nicol and Roaf (2006), both field studies of thermal comfort and POE are interested in how and why occupants adapt and control their environments and how this affects the occupants' thermal responses or satisfaction. However, the main purpose and methods used for field studies of thermal comfort and POE are different.

The main purpose of a field study of thermal comfort is to extend the existing knowledge about thermal comfort and adaptation using a science-based approach, whilst POE aims to solve problems in a real-world building and/or improve the quality of a building. Nicol and Roaf (2006) explained that field studies of thermal comfort are more interested in how occupants feel and respond to the environment at a particular time. Such feelings are based on environmental factors and participants' physical conditions that may vary over time (Nicol and Roaf, 2006). POE, in comparison, reveals the long-term relationships between occupants, outdoor climate, and the observed buildings, but is also dependent on the period, i.e. summer or winter, when the survey is undertaken (Nicol and Roaf, 2006). Therefore, timing is important to POE since it requires users to have sufficient experience within the observed building. Basically, occupants answer POE questions based on their memories which might deviate from reality (Nicol and Roaf, 2006). Social, economic and cultural factors are also expected to have an influence on the occupants' answers (Nicol and Roaf, 2006).

Methods for thermal adaptive opportunity or control quantification in POE and field studies of thermal comfort also differ. POE quantifies level of thermal control through user perceptions, i.e. degree of control or satisfaction of control using a rating scale, whereas field studies of thermal comfort use a more objective approach, for example, counting numbers of controls in an observed area, the number of occupants who have access to windows, or measuring the distance from windows or space sharing. This method directly connects the design factors to thermal perceptions. Therefore, the usefulness of these factors is not interpreted by users themselves, but by researchers. In this regard, POE surveys that use user perceptions which contain both quality and quantity of controls may be considerably more successful in revealing the connections with users' thermal perceptions. However, the observation of thermal control when undertaking a POE only identifies how satisfied users are with the controls provided but does not explain why or what the relevant factors are. Therefore, a POE does not contain adequate information for managing or improving existing controls.

As far as this review is concerned, there is no rigid framework or technique for assessing and analysing thermal adaptive opportunity and overall thermal adaptability of both individuals and organisations. At an individual level, only external factors of thermal control have been investigated and most of the tools available measure the existence and use of control only.

At an organisational level, there are BUS and TBP analyses that include some organisational aspects but are limited to the issues of dress code, level of user intervention in the service systems, and speed and efficiency of FMs in responding to occupants' complaints. These organisational issues certainly affect occupants' adaptive opportunities; however, these surveys are mainly based on users' opinions. There are few studies investigating thermal adaptability from service providers' perspective to explain why the buildings are operated as they are. In order to understand the thermal comfort practice held by an organisation, knowledge needs to be obtained from this key group as they are directly responsible for building operations and maintenance in non-residential buildings on a daily basis and have insights into end-users attitudes and behaviours.

2.6.5 The influence of facilities management on users' thermal adaptive opportunities

Hodges (2005) stated that the role of FMs and their leadership are influential in shaping the performance of buildings and facilities for their entire life. Focusing on building energy consumption, there are few studies which mention the influence of facilities management and FMs on user behaviour in relation to energy consumption.

Based on extensive studies of buildings in use, Leaman (2003, pp. 159-160) classified design-operation strategies of service systems into four quadrants based on the degree of contextual dependency and behavioural engagement required to maintain system performance. The strategies are (Leaman, 2003, pp. 159-160):

- Make invisible (fit and forget)
- Make usable (implement and manage)
- Make habitual (implement and internalise)
- Make acceptable (risk and freedom).

The four types of design-operation strategies create as well as reflect different levels of opportunities and constraints for user control and adaptation.

According to Leaman (2003, p. 160), the best buildings always employ all strategies in response to changeable situations over time; however, the modern trend is to move towards the fit and forget strategy which seems to have less capability to deal with changes and variations in demand. Consequently, environmental control is increasingly taken away from occupants, which in turn is likely to adversely affect their comfort

(Leaman and Bordass, 2004, p. 152). For buildings installed with automation systems in particular, occupants seem to be more susceptible to environmental problems and demand speedy responses (Bordass and Leaman, 1997). In contrast, occupants seem to accept or forgive the flaws in other buildings, NV buildings for example, if they have more involvement in the results (Vischer, 2008) or if they know that the flaws are not avoidable (Leaman, 2003, p. 161).

Aune et al. (2009) studied the approach and style of FMs and building operators regarding energy management in non-residential buildings. They argued that an improvement in building energy consumption is not merely an issue of advanced technology, but that the role of building operators in linking such technology to use through their daily work is also important. This study shows the influence of an individual, rather than the design strategies, on user energy consumption behaviour. The daily routine operations of five building operators were analysed and four different roles identified: 1) *the teacher* – dominate the service system settings (such as thermostats) and educate users, 2) *the house keeper* – make the service systems work constantly while users are treated as customers, 3) *the manager* – have a feeling of ownership and resourcefulness and get involved in the building design process while users are required to do simple tasks (such as changing light bulbs) by themselves and 4) *the juggler* – deal with various tasks and people in a complex organisation to satisfy everyone, can accomplish an energy saving target with or without user involvement and advanced technology. The study suggested that the integration of each role, particularly 'hands-on' managers, may be important for delivering a more energy-efficient building.

According to the literature, both facilities management strategies, which are related to building design and technology, and managing styles (based on FMs' background knowledge and enthusiasm), contribute to energy performance as well as user energy consumption behaviour and attitudes. However, these roles are not usually scrutinised or even mentioned within thermal comfort studies in non-residential buildings. Further research is therefore needed to understand the influence of facilities management on user thermal adaptive opportunities.

2.7 SUMMARY

The review of literature on MM ventilation, adaptive comfort model and process, and adaptive opportunity assessment can be summarised as follows:

- MM operational strategies are categorised into three strategies:
    - Concurrent – to use air-conditioning and natural ventilation in the same space at the same time
    - Change-over – to use air-conditioning and natural ventilation in the same space at different times
    - Zoned – to use air-conditioning and natural ventilation in different spaces at the same or different times.
- ASHRAE Standard recommends the use of PMV model for thermal operation in MM buildings, whereas EN15251 Standard and many field studies in existing MM buildings in hot and hot-humid regions suggest that adaptive comfort limits can be used as a thermostat set point for switching between air-conditioning and natural ventilation modes.
- Relative humidity is not included in the adaptive comfort model, which may limit the application of adaptive comfort model in hot-humid climates.
- Apart from the outdoor air temperature, the contributions of other factors – *design, organisational norms and economics*, to user thermal sensation and adaptability, have not been quantified yet.
- Effectiveness, accessibility and cost are suggested as the criteria of behavioural adaptation.

- Thermal experience, thermal expectation, gender and economic status are mostly mentioned as the variables of physiological and psychological adaptability.
- POE is the method used for assessing behavioural adaptive opportunities or user control and effects on user satisfaction through user perception, whereas field studies of thermal comfort mostly focus on researchers' chosen climatic and design variables that affect user thermal sensation, control and adaptive behaviour.
- Methods for investigating the overall adaptation (behavioural, physiological and psychological adaptation) of individuals have not yet been well developed.
- The effects of organisational factors and facilities management practice that support or restrict MM operations have rarely been mentioned in past research studies.

CHAPTER 3: THERMAL EXPERIENCE, ENVIRONMENTAL ATTITUDES AND USER PERFORMANCE

3.1 PURPOSE

Acceptance of non-AC cooling strategies in non-residential buildings in practice could be affected by other factors than those specified within the thermal comfort theories. As stated in Chapter 1 (Section 1.3, p. 36), environmental attitudes and user performance are issues of concern. Therefore, the purposes of this chapter are: 1) to review the relevant theories and field studies in order to understand the drivers and influence of environmental attitudes on energy-efficient behaviour, e.g. acceptance of non-air-conditioning use and 2) to review the evidence of the impact of thermal conditions on user performance. Methods for assessing pro-environmental attitudes and behaviour, as well as learning performance are also reviewed in order to formulate the research methodology.

3.2 THERMAL EXPERIENCE, ENVIRONMENTAL ATTITUDES AND BEHAVIOUR

Some thermal comfort studies have connected thermal perceptions with the environmental attitudes of occupants. Pro-environmental attitudes, possibly developed by giving the information about the contributions of building energy consumption to CO_2 emissions, have been claimed as one of the reasons why users accept the imperfections of thermal conditions in non-fully AC buildings (Deuble and de Dear, 2010, Leaman and Bordass, 2007). Using this assumption, such pro-environmental attitudes could be considered another variable of individuals' psychological adaptation, in addition to thermal expectation.

In the field of thermal comfort studies, Deuble and de Dear (2010) applied a psychological tool to additionally explain the differences in how occupants in different building types responded to their thermal environments. They found that users in green buildings with an NV system had a significantly higher level of pro-environmental attitudes and forgiveness factor[25] than those in MM buildings. Incidentally, the forgiveness factor does not give weight on each environmental factor; therefore, it assumes the importance of all factors is equal. This may slightly limit the validity of the forgiveness factor. The findings concerning forgiveness factor also agreed with Leaman and Bordass's study (2007). Deuble and de Dear (2010) explained that the pro-environmental attitudes among green buildings' occupants changed expectations regarding ideal comfort; therefore, they could accept some minor deficiencies for energy savings in return (Deuble and de Dear, 2010). Thus, the authors suggested that to educate or provide information to users about the contribution of buildings to climate change could potentially raise their pro-environmental attitudes and acceptance of non-AC green buildings. In contrast, some studies in environmental psychology have contended that past or present experiences could also determine pro-environmental attitudes and behaviour. From the latter point of view, thermal design and operations in the built environment that shape users' thermal experiences have a role to play in cultivating people's pro-environmental attitudes, which then possibly contribute to the psychological adaptation of individuals.

Whilst climate change is being discussed, people's pro-environmental attitudes may be gradually shaped through everyday media and its role in psychological thermal adaptation in thermal comfort studies has to be considered. In order to understand more about environmental attitudes, the relevant theories, variables, and associations with behaviour are reviewed in the following subsections.

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[25] Forgiveness factor: the score for overall comfort divided by the mean of six principal comfort variables (i.e. air temperature, humidity, air velocity, lighting, acoustic, and indoor air quality) (Bordass and Leaman, 1997).

3.2.1 Definitions

The topic of pro-environmental attitudes and behaviour has gained a lot of attention in academic research since 1970 (van Liere and Dunlap, 1981) due to increasing concerns regarding environmental degradation, for example, ozone depletion, acid rain, soil erosion and resource consumption by humans (Grob, 1995). There is growing evidence that environmental attitudes are associated with, and to some extent can predict, environmental behaviour.

Kollmuss and Agyeman (2002) stated that pro-environmental behaviour is "*behaviour that consciously seeks to minimise the negative impact of one's actions on the natural and built world (e.g. minimise resource and energy consumption, use of non-toxic substances, reduce waste production).*" Environmental attitudes are a psychological tendency expressed by evaluating the natural environment with some degree of favour or disfavour (Milfont and Duckitt, 2010). Accordingly, pro-environmental attitudes can be defined as a belief that shows a concern for the natural environment and a desire to reduce the environmental impact resulting from one's own actions.

3.2.2 Pro-environmental behaviour models

There are many models proposed for explaining the drivers of pro-environmental behaviour. Kollmuss and Agyeman (2002) reviewed the most influential pro-environmental behaviour models and classified them as ascribing to three concepts: 1) linear model, 2) altruism, empathy, and prosocial behaviour model and 3) sociological model. These models are briefly reviewed below.

Linear model

The linear model considers pro-environmental behaviour to be a result of attitudes, and attitudes are shaped up by knowledge (Figure 3.1) (Burgess et al, 1998 cited in

Kollmuss and Agyeman, 2002). Accordingly, the model assumes that education about environmental impact leads to more environmental conservation behaviour. This model is straightforward, but is restricted to the belief that people behave logically, which is not always true in reality.

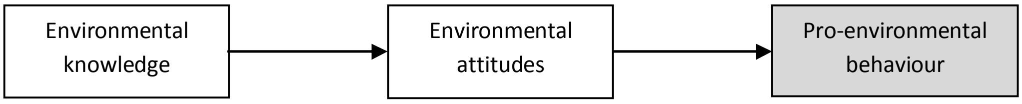

Figure 3.1 Linear model of pro-environmental behaviour (as presented in Kollmuss and Agyeman, 2002)

Altruism, empathy, and prosocial behaviour model

The altruism, empathy, and prosocial behaviour model (Figure 3.2) explains that environmental behaviour is caused by a combination of three factors, which can be ordered from high to low in terms of influence (Stern et al., 1993 cited in Kollmuss and Agyeman, 2002) as:

1) Egoistic orientation – the removal of suffering and harm from oneself
2) Altruistic orientation – the removal of suffering of other people
3) Biospheric orientation – the removal of destruction and suffering from the non-human world.

According to the model, if a person is aware of the negative consequences of his/her own actions on him/herself, other people and other living creatures, then he/she tends to behave more responsibly.

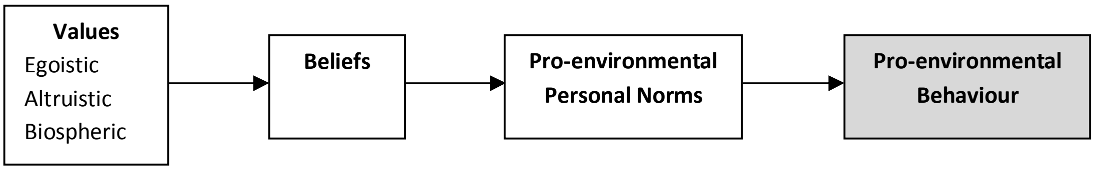

Figure 3.2 A simplified version of value-belief-norm (VBN) theory of pro-environmental behaviour (based on the model from Stern, 2000)

Sociological model

The sociological model states that there are five variables that influence pro-environmental behaviour, either directly or indirectly or both, as shown in Figure 3.3 (Fietkau and Kessel, 1981 cited in Kollmuss and Agyeman, 2002). Notably, the possibility to act pro-environmentally refers to external and economic factors that may support or obstruct pro-environmental behaviour. Incentives for pro-environmental behaviour cover monetary and non-monetary benefits, such as social admiration and self-esteem.

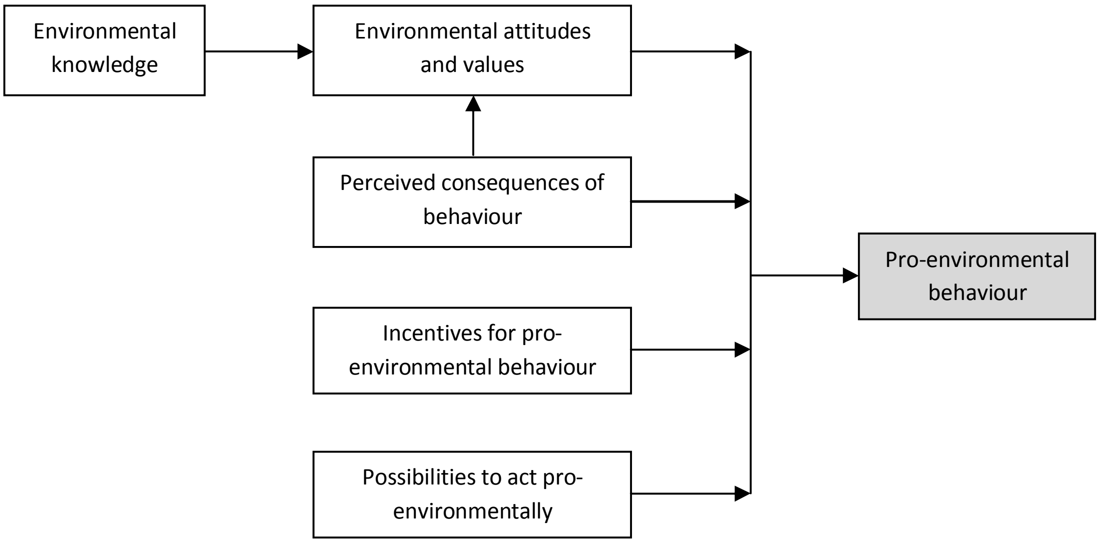

Figure 3.3 Ecological behaviour model by Fietkau and Kessal, 1981 (reproduced from Kollmuss and Agyeman, 2002)

The drivers of pro-environmental behaviour models reviewed here are limited to the internal quality of an individual with environmental attitudes as the main driver. However, these conventional models have been considered inadequate to explain the complicated pro-environmental behaviour observed in reality. Rather than proposing a model, Kollmuss and Agyeman (2002) stated that pro-environmental behaviour can be influenced by various factors which can be categorised into three groups as:

1) Demographic factors (e.g. gender, years of education)
2) External factors (e.g. institutional – infrastructure provided, economic, social and cultural factors)
3) Internal factors (e.g. motivation, environmental knowledge, awareness, values, attitudes, emotion, locus of control, responsibilities and priorities).

Based on these conventional models and Kollmuss and Agyeman's statement, past or present experience is not explicitly mentioned as to whether or not it is a factor of pro-environmental attitudes and behaviour. Nevertheless, Black et al. (1985) stated that the attitude-behaviour model is reversible. That is, behaviour could determine attitudes mediated by past pertinent experiences. This reversed relationship or behaviour-attitude model has been noted in some field studies. Prior to the discussion of those studies, the next subsection reviews methods for pro-environmental attitudes and behaviour measurement.

3.2.3 Measures of pro-environmental attitudes and behaviour

Attitudes are intangible and must be measured through a set of statements in relation to the environment. Some well-known environmental attitudes measuring tools formulated by researchers in the field are: the Ecology Scale (Maloney and Ward, 1973; Maloney, Ward and Braucht, 1975), the Environmental Concern Scale (Weigel and Weigel, 1978) and the New Environmental Paradigm (NEP) Scale (Dunlap and van

Liere, 1978; Dunlap, van Liere, Mertig and Jones, 2000) and so on (cited in Milfont and Duckitt, 2010). Of these, the NEP is probably the most well-known tool since it contains items that are relatively generic, hence it is compatible with a wide range of research topics.

The NEP Scale comprises of several dimensions of pro-environmental attitudes: balance of nature, limits to growth, human domination of nature and ecological catastrophe. Accordingly, 15 items are included in the NEP Scale, using a 5-point rating scale (1-Strongly Disagree to 5-Strongly Agree) to evaluate the level of pro-environmental attitudes of an individual (Dunlap et al., 2000). For example, statements included in the NEP Scale are *We are approaching the limit of the number of people the earth can support* and *Humans have the right to modify the natural environment to suit their needs* (Dunlap et al., 2000).

In the UK, the Department for Environment Food and Rural Affairs (Defra) has also been developing a framework for studying public attitudes and behaviours towards the environment since 1986 (Defra, 2007). Compared to NEP, the recent Defra surveys contain more direct statements concerning climate change, which are considerably more relevant to air-conditioning consumption than general environmental attitudes. The survey focuses on three main aspects: attitudes, behaviour and barriers, for seven topics which are: 1) environment and climate change, 2) transport, 3) energy and water efficiency, 4) recycling, 5) eco-friendly purchasing, 6) biodiversity and animal welfare and 7) wellbeing. Regarding the contents of this thesis, only statements in relation to attitudes towards the environment and climate change in the Defra's survey are focused. For example, statements included in the Defra's survey are *Climate change is beyond control – it is too late to do anything about it* and *I find it hard to change my habits to be more environmentally friendly* (Defra, 2007).

Compared to the Defra's survey, the NEP Scale emphasises much more the relationships between human beings, the world and nature on a global scale, and the balance of the world population and natural resources due to a concern about population growth. These issues are large and perhaps not sufficiently direct to the issue of air-conditioning consumption in daily life. In this regard, the Defra's survey consists of both generic and specific questions related to energy use. Moreover, the issue of climate change is highlighted more within Defra's questionnaire. The use of 'I' in the statements also reminds participants that they are a part of the whole relationship whereas this term does not appear in the NEP Scale.

Compared with environmental attitudes, the measurement of environmental behaviour is more explicit. Stern (2000) classified environmental behaviours into three levels:

1) Private-sector household behaviours
2) Environmental citizenship behaviours
3) Policy support, expressed as willingness to make sacrifices economically to protect the environment.

Normally, an environmental behaviour evaluation focuses upon a specific behaviour of interest, such as air-conditioning use, recycling, travelling, etc., depending on the research objectives. Therefore, there is no standardised tool for this purpose, and researchers can use either a self-report or observation (direct or indirect), or a combination of both, as study methods. However, observing environmental behaviours in the field is almost impossible in several cases. In fact, actual behaviours could also be constrained by other contextual factors that distort original behavioural intentions (Tanner, 1999, Black et al., 1985). Therefore, in order to investigate pure relationships between environmental attitudes and behaviours, many researchers opt for self-reported 'behavioural intentions' as the main approach for field data collection (for example, Stern et al., 1993, Steg et al., 2005, Fujii, 2006, Davis et al., 2009). In this type of research, pro-environmental attitudes and behavioural intentions were found to be significantly correlated. Even though this method does not provide realistic information, for data analysis and explanation it is more practical and more straightforward.

In the following subsection, field studies that tested the factors relating to environmental attitudes are reviewed. Furthermore, the associations between environmental attitudes and behaviour, including problems encountered within field studies, are discussed.

3.2.4 Field studies of environmental attitudes and behaviour

Findings of field studies on environmental attitudes and behaviour are reviewed in this subsection. The first part concentrates on the associations between socio-demographic variables and environmental attitudes before reviewing the relationships between environmental attitudes and behaviour.

As stated earlier by Kollmuss and Agyeman (2002), there are various socio-demographics variables that differentiate individuals' attitudes towards the environment. Focusing on college students, educational backgrounds and majors, gender and political views, have all been claimed as significant variables of students' environmental perceptions. The political views might not be a factor in countries where environment-related policies of political parties are not palpable. Wysor (1983) found that environmental studies students had a higher concern for the environment than business students. This is consistent with a study by Tikka, Kuitunen and Tynys (2000) in which the environmental attitudes, knowledge and activities of biology students and those of technology and economics students were compared. Stern, Dietz and Kalof (1993) and Tikka et al. (2000) found that female students were more aware of the adverse effects of one's actions on overall environment and demonstrated more responsibility towards the environment. This contrasts with the results of a study by Hess-Quimbita and Pavel (1996) who found that liberal male participants were more likely to have higher pro-environmental attitudes than females. Although pro-environmental attitudes have been extensively studied in different countries, it is still difficult to provide conclusive results because there are many other external contextual variables involved.

Regarding the relevant findings about past experience and environmental attitudes, Chawla (1999) stated that experience with nature during childhood was the most frequently mentioned as one of the reasons for becoming an environmentalist (cited in Kollmuss and Agyeman, 2002). In more recent research, Hinds and Sparks (2008) stated that having more experience in natural environments increased people's willingness to engage in environmental projects and campaigns. Moreover, people would perceive themselves as more part of nature and more eager to protect it (Hinds and Sparks, 2008). When considering experiences of outdoor climate, the results of some studies have shown that beliefs in global warming were associated with both the perception of recent local temperature changes (Krosnick, Holbrook, Lowe and Visser, 2006 cited in Joireman et al., 2010) and actual outdoor temperatures (although the association was not significant at higher temperatures) (Joireman et al., 2010). Although these studies did not clearly conclude that thermal experience is a driver of pro-environmental attitudes, they show a tendency for people to be more aware of environmental impact when they spend time in natural environments and perceive some changes.

With regards to household energy use, research studies conducted in the Netherlands confirmed that thermal experience, safety and convenience indicate an awareness of energy consumption (van Raaij and Verhallen, 1980, 1981, 1983; van de Maele-

Vaernewijck et al., 1980; and Ritsema et al., 1982 cited in Heijs and Stringer, 1988). That is, a need for thermal comfort in particular may hinder efforts to reduce HVAC use. These findings show that personal preference for comfort, resulting from previous actions, also determined environmental attitudes, consistent with the behaviour-attitude model. This relationship between past thermal experience and an energy-conscious attitude corresponds very well to thermal comfort theories. However, the comfort theories directly relate thermal experience and thermal responses, and do not mention energy-conscious attitudes as a driver of responses.

Can one's pro-environmental attitude predict one's behaviour? Meinhold and Malkus (2005) and Grob (1995) insisted that pro-environmental behaviour could be explained by pro-environmental attitudes. Black et al. (1985) stated that if constraints were low, then attitudes and behaviours were related as cause and effect. However, in many studies correlation coefficients of environmental attitude-behaviour were fairly low. For example, Thapa (1999) found that most students in his study who showed concern over environmental problems had higher NEP scores, but were seldom engaged in environmental activities other than recycling. Thapa (1999) explained that university students have been well educated regarding environmental value; therefore, they tend to be good at answering questions to match what the society expects. Their actions in practice are not necessary to be corresponding. In addition, weak relationships could result from some methodological problems. For example, discrepancies between attitudes and behaviour are common when the specificity of measures is incompatible, i.e. too general an attitude survey versus too specific a behavioural observation (Rajecki, 1982 cited in Kollmuss and Agyeman, 2002).

Understanding the factors involved in environmental attitudes and their relationships with behaviour is useful for providing additional explanations for why occupants in green NV buildings find the environmental deficiencies acceptable, as shown in Deuble and de Dear's findings (2010). Deuble and de Dear's assumption (2010) is based on the conventional model that education can improve the level of pro-environmental attitudes of occupants. However, their study did not examine whether pro-environmental attitudes could have been strengthened by direct thermal experience within such buildings. That is, when users have direct experience of NV buildings then they may realise the impact of climate change. In turn, this may raise awareness of energy consumption in buildings and gradually change occupants' behaviour to be more environmental friendly.

As thermal experience could drive pro-environmental attitudes, it is questionable that people with different levels of exposure to AC environments would have different levels of pro-environmental attitudes. If true, then pro-environmental attitudes can be considered another parameter of psychological adaptation, referring to a willingness to reduce air-conditioning use in order to mitigate environmental impact. This attitudinal variable is not mentioned in the adaptive thermal comfort theory, but rather is regarded as one of the motivating factors in the behaviour change framework (Dahlbom et al., 2009, p. 14).

Based on the literature review, pro-environmental attitudes and behaviour studies have been extensively conducted in developed countries. Studies concerning the relationships between thermal experiences and pro-environmental attitudes among people in developing hot-humid countries should be explored further. In particular, a comparison of pro-environmental attitudes and behaviour among people with different thermal backgrounds should be carried out as this may provide additional explanations for their acceptance or refusal of the non-AC mode.

3.3 THERMAL ENVIRONMENT AND USER PERFORMANCE

Can natural ventilation assisted with fans provide effective working environments in hot-humid climates, at least during some periods of the year?

The relationships between thermal environments and user performance have been studied from various approaches depending on how thermal conditions and user performance are defined. For thermal environments, these can be defined objectively (i.e. room temperature) or subjectively (i.e. thermal comfort). Likewise, performance or productivity can be identified using several methods. The diversity of the definitions for these two main variables explains why findings from previous research studies are various and sometimes contradictory. Therefore, in order to investigate thermal impact on user performance, it is vital to firstly define the dependent and independent variables of a study and how to measure them. This clarification is also useful when generalising the results to a wider context.

3.3.1 Definitions

Firstly ‘performance’ and ‘productivity’ must be defined. The term ‘performance’ as used in research, has been interpreted in many ways depending on the context and its application. Generally, the definition of performance is rather broad and covers economic and procedural aspects of an activity or task (Tangen, 2005). In contrast, ‘productivity’ has been used more in an industrial context, focusing on output or products compared with input or resources deployed (Kemppilä and Lönnqvist, 2003). According to Parson (2003, p. 327), ‘performance’ is defined as “*the extent to which activities have been carried out to achieve a goal*” while ‘productivity’ is “*the extent to which activities have provided performance in terms of system goals.*” For the definition of productivity, ‘goals’ usually refer to organisational goals, which generally are quantifiable. With regards to these definitions, performance is concerned with processing an individual task, whilst the cumulative achievement of undertaking these tasks contributes to final outcome or productivity.

How should performance or productivity be measured? The assessment of productivity and performance is not universal, rather it is heavily context- and job-dependent (Parsons, 2003, p. 326) and types of tasks must also be considered. Generally, work activities can be divided into manual and cognitive tasks, and most of the time both types of activities are required in order to achieve a task. For the commercial sector, Hedge (2001) classified performance assessments into three levels: individual, group and organisational measures. Specifically for the scope of this thesis, performance of individual students engaged in cognitive tasks within classrooms is of interest. A cognitive task is defined as "[a task] *that critically requires the processing of information – information from the outside world that can be perceived by the individual and placed in some kind of memory, and/or information derived from previous experiences and retrieved from memory*" (Carroll, 1983, p. 3).

Cognitive tasks can be evaluated using two main methods. First it can be directly assessed from what an individual achieves by using objective indicators, for example, speed, accuracy, quantity and quality. Alternatively, it can be estimated by individuals themselves through their own perceptions. According to Clements-Croome (2006, p. 30), speed and accuracy are two basic indicators for evaluating productivity, since they are straightforward, objective and practical for repetitive studies. In many studies, speed and accuracy have also been used for indicating user cognitive performance. A comparison of user performance in different environments can be achieved through observation of a real situation or an experiment in a laboratory (Hedge, 2001). The major limitation of the first approach is difficulties in controlling some irrelevant variables, whilst the second strategy may be time and cost consuming if special equipment is needed and usually only a few participants can attend at a time. A combination of the two methods is also possible in order to obtain the benefits of both.

Since the case study described in this thesis is the higher educational sector, user performance relevant to this context is learning performance. The framework for assessing learning performance of students in universities is described further in the following subsection.

3.3.2 Learning performance assessment

Learning performance can be measured by several methods. This subsection firstly reviews both objective and subjective approaches for cognitive performance assessment and describes their advantages and drawbacks. Appropriate parameters of learning performance with respect to the context of this thesis are then proposed.

Measures of cognitive performance

This subsection focuses on objective and subjective cognitive performance assessments in education and their contexts. Concepts and methods for each approach are elaborated as follows.

An objective learning performance assessment can be undertaken in a number of ways. ‘Attention’ is one of the cognitive performance indicators frequently used in environmental studies since it can reveal short-term effects of environmental conditions, whereas other indicators, e.g. IQ, academic attainment, etc., result more from long-term education and a vast number of non-environmental factors such as motivation, personality, family support, etc. However, attention cannot be observed directly; therefore, it is necessary to measure this cognitive process using several tests and/or monitoring of observable behaviours (Valdez et al., 2005). Basically, an attention test employs a set of designed psychological sub-tests, for example, selective, sustained, or divided attention tests (Cooley and Morris, 1990 cited in Shapiro et al., 1998). In the educational context, the Sustained Attention Test (SAT – or vigilance test) seems to be the most relevant tool for assessing students' performance. This involves continuous maintenance of attention over time with regards to alertness and receptivity for a particular set of stimuli or stimulus changes (Davies et al., 1984; Parasuraman and Davies, 1984; Parasuraman, 1984 cited in Ballard, 1996). Further details and examples of SAT can be found within neurological research (for example, Smith et al., 2002, Ballard, 1996).

Although the objective attention test is robust, it primarily measures an individual's ability to maintain attention on tasks without external interruptions but with random designed distracters, rather than measuring environmental effects on an individual's performance. In the real context, some distracters might be considered positive in maintaining attention, i.e. provide a chance to restore attention or increase the arousal level. In contrast, these distracters seem to cause a negative effect on short-period laboratory tests. However, when applying the attention test in environmental studies it can be difficult to distinguish the effects of physical environments from other possible confounding factors unless the test-retest differences are analysed pair-wise (within-subject analysis). Furthermore, if non-focused variables, such as subject characteristics (e.g. age, gender, etc.), are not controlled for, a comparative study may not be appropriate (Ballard, 1996). Impracticality in relation to the materials used and costs for conducting the tests in a real environment is another disadvantage to the attention test. In addition, Wyon and Wargocki (2013) also comment that the performance of participants in a laboratory study may lessen in a real context due to lower motivation and longer exposures to the environment.

Subjective cognitive performance measurement is based on beliefs, perceptions, or attitudes and participants themselves report on how well they perform a given task or in general (Kemppilä and Lönnqvist, 2003). The advantages of a self-reported performance assessment are its practicality, simplicity, low-cost and ease of sample recruitment (Clements-Croome and Kaluarachchi, 2000 cited in Kemppilä and Lönnqvist, 2003). Questionnaires using an ordinal rating scale and numerical scale are the most commonly utilised evaluation tool. For example, Broadbent, Cooper, Fitzgerald and Parkes (1982 cited in van der Linden et al., 2005) constructed a cognitive failure questionnaire (CFQ) for analysing the relationships between work stress and attentional difficulties. The questionnaire comprises of several questions or statements focusing on different aspects of attentional problems, such as '*Do you find you forget what you came to the shops to buy?*' In Leaman and Bordass's BUS conducted in the UK, a single question was used for estimating the effects of environments on office worker productivity (Leaman and Bordass, 1999). Participants were asked '*How you think your productivity at work is increased or decreased by the environmental conditions in the building?*', which was rated using a 9-point scale where 1 denotes productivity had increased by 40% or more, 9 represents that productivity had decreased by 40% or more and 5 is neutral.

The main problems associated with the subjective approach are its validity and reliability, but this can also be an issue with objective performance measures as stated earlier. Wyon and Wargocki (2013) commented that self-reported performance may not be valid for cognitive performance assessment, but it possibly represents occupants' effort. Their argument could be true if those available cognitive tests can represent overall occupants' activities. For example, the use of basic cognitive tests, e.g. language, maths, etc., for assessing young children's learning performance is reasonable because those tests are similar to what children usually do in a real learning environment. In other environments, for example, an office or university (with various user groups and activities), those objective tests may not represent all aspects of their cognitive activities.

Kemppilä and Lönnqvist (2003) suggested that validity of subjective performance assessment can be improved by careful selection of questions to represent the nature of the tasks they are measuring. The reliability can also be increased by using more than one performance-related question to cover several aspects of performance (Kemppilä and Lönnqvist, 2003), although some researchers prefer to use a single question to cover all dimensions of performance or productivity. The interpretation of self-reported cognitive performance in reality can also be difficult. However, it is possible depending on what questions or parameters are used in the assessment. Despite these drawbacks, the questionnaire for performance evaluation can be tailor-made for a specific task; therefore, it is considered a strength of subjective assessments. Moreover, subjective methods are more practical in field studies with a large sample size and it does not require an expert in psychology to conduct the survey and analyse the data.

Parameters of learning performance

As this thesis focuses on the impact of environmental conditions, particularly thermal conditions, on students' learning performance, the thermal ventilation mode and thermal perceptions are the independent variables of interest, whereas students' performance in class is the main dependent variable. Accordingly, the selection of parameters to represent the pure relationships between environmental quality and learning performance is crucial. In other words, the parameters should not focus on background knowledge, personality, or motivation of the participants, as these variables are not influenced by environmental conditions.

Research on user performance and indoor environment have been reviewed in detail in Parson's *Human Thermal Environments: the effects of hot, moderate and cold environments on human health, comfort and performance* (2003) and Clements-Croome's *Indoor environment and productivity* (2006). Within the learning context, many parameters have been used to indicate learning performance; however, most of these fall under the umbrella of attention as mentioned earlier. Attention and other tentative parameters that could represent learning performance in classrooms are further elaborated below.

1) Attention: Attention is claimed to be the foundation of a productive high-value cognitive workplace (Davenport and Beck, 2001 cited in Heerwagen et al., 2006, p. 136). According to Fried et al. (2001 cited in Heerwagen et al., 2006, p. 136), attention is the '*psychic energy that makes events occur in consciousness*', and this energy is a limited resource (Eysenck, 1982 cited in Heerwagen et al., 2006, p. 136). Based on a literature review by Pashler et al. (2001), attention is more likely to be driven and controlled by an individual's goal rather than external stimuli, which are able to capture visual attention only. Therefore, an individual's goal could be an important confounding factor that limits the investigation of the relationships between environmental conditions and attention. Focusing on the learning environments, distractions, interruptions and discomfort or stressors are potential risks to attention maintenance, whilst maintaining attention levels for a long period of time can adversely affect performance as a result of mental fatigue (Kaplan, 2001; Tafalla and Evans, 1993 cited in Heerwagen et al., 2006, p. 137). In this situation, attention breaks or positive

distractions,[26] such as seeing natural sceneries, can restore attention capacity (Tennessen and Cimprich, 1995 cited in Heerwagen et al., 2006, p. 139).

2) Alertness: Alertness is another factor related to cognitive performance and can be affected by environmental stimulation (i.e. thermal, visual, hearing and olfactory). In reality, there is no perfect steady environment. Users need to adapt and negotiate in order to get the best out of their environments at all times (Joiner and Ellis, 1985). Such interactions make users more active and alert when performing tasks. To some extent, activeness and alertness may compensate for a decrease in performance due to stress (Selye, 1956 cited in Sutherland and Cooper, 2006, pp. 83-84). However, stress may occur if the environmental demands are greater than the person's capabilities, and/or the person's expectations are greater than the environment supplies (Salvendy, 1997 cited in Farshchi and Fisher, 2006, pp. 65-66).
3) Sleepiness: Sleepiness is an obstruction to effective learning and can be a result of environmental problems. Poor IAQ due to a low ventilation rate and its consequent outcome (i.e. lack of fresh air supply, high CO_2 and/or volatile organic compound or VOC concentrations and mould growth) cause sick building syndrome (SBS) (Wargocki et al., 1999, Seppänen et al., 1999). Symptoms of SBS are numerous, for example, headaches, respiratory problems, concentration difficulties, sleepiness and drowsiness (Levin, 1989 cited in Apte et al., 2000). Hedge (1989) found that in AC offices SBS symptoms, including sleepiness, were more widespread than in NV

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[26] Positive distractions are mini mental breaks that shift individuals' attentions which can relieve stress and restore attention capacity. These positive distractions at work can be achieved by inducing environmental stimuli and other phenomena (Ulrich, 1999 cited in Heerwagen et al., 2006, p. 139).

buildings. In addition, Otto et al. (1990) concluded from their study that VOC exposure causes general discomfort and a strong odour, impairs air quality, and increases headaches and sleepiness. Accordingly, sleepiness can be considered another learning performance indicator that is linked to the environmental conditions of classrooms.

4) Environmental tolerance: This is the ability to bear the imperfections of environmental conditions and is considered to be one of the factors for maintaining both manual and cognitive performance. Leaman (2003, p. 156) stated that in general, occupants do not concentrate on taking their time adapting or changing to their working environments unless they perceive them to be intolerable. When this occurs, time is taken off to cope with the discomfort experienced. Parson (2003, p. 338) calls it a 'time off task' and utilises it as an indicator of working performance. In a study by Ito et al. (2006), 'time lost', a similar term with a similar meaning, was also used as one of the indicators for comparing the learning performance of students in different thermal conditions and at varied ventilation rates. Accordingly, a time off task and environmental tolerance are two sides of the same coin. Therefore, both terms can be used as an indicator of learning performance.

These four parameters are considered to be the most relevant in the assessment of the learning performance of students in different thermal environments.

Performance assessment is often applied in research targeting students and office workers. Both objective and subjective methods can be used depending on available time, costs, equipment, labour and sample size required. The interpretation and generalisation of the results is based upon the methods used and this sometimes limits the ability to compare one study with another.

3.3.3 The relationships between user performance and thermal environments

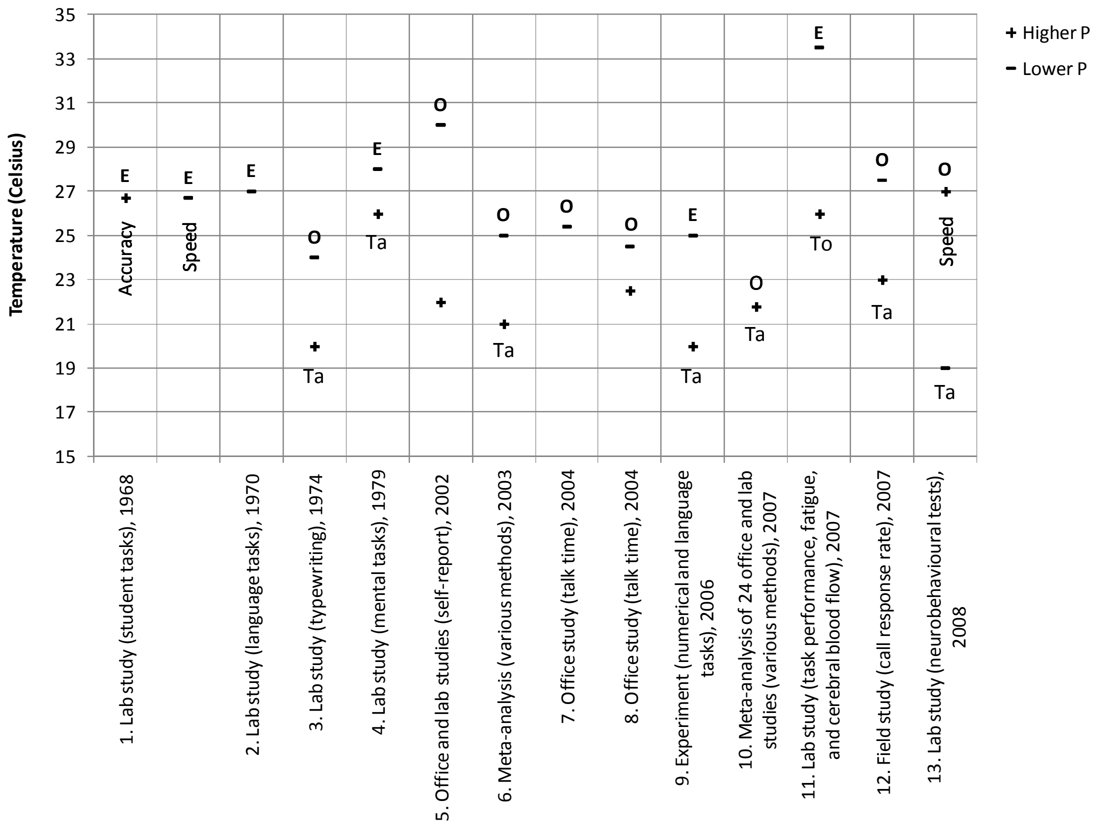
How are user performance and the thermal environment related? As stated earlier in Chapter 1 (Section 1.1, p. 26), FMs and organisations may be reluctant to change the thermal condition from full air-conditioning to MM by utilising more natural ventilation, due to their concern regarding a decrease in performance. Several studies have shown connections between thermal conditions and user performance. In this subsection the findings from relevant studies that focused on cognitive performance within the office and educational sectors are reviewed.

Clements-Croome (2006, p. 45) stated that productivity is influenced by four main groups of factors: personal, social, organisational and environmental. The environmental factors consist of several subordinate parameters, which are thermal comfort, visual comfort, hearing comfort, and indoor air quality. With regards to overall environmental comfort, Vischer (2005) classified this into three levels: physical, functional and psychological comfort. At the physical comfort level, a space is made habitable, whilst functional comfort is ensuring a space is at a standardised quality for a specific task. Finally, psychological comfort is recognised when occupants derive satisfaction and well-being from a space. However, it may be difficult to grade thermal comfort appropriately compared with other environmental factors, since it is very subjective. Many studies in recent years have attempted to stipulate productive temperatures based on two main approaches. The first is to study the relationships between actual temperatures and performance, whilst the second is centred on performance and thermal perceptions.

Actual temperature and user performance

Most researchers who study the associations between actual temperatures and cognitive performance use objective methods for measuring both thermal conditions and performance. These are experimentally based, using climate chambers or mock-up AC rooms set at different air temperatures.

In fact, the relationship between air temperature and learning or working performance was being discussed even before thermal comfort standardisation was proposed. In 1913, Ellsworth Huntington (an American geographer) suggested that the suitable temperature for classrooms should be 15.5°C, with 75% RH (Ackermann, 2002, p. 30), although in 1924 this was adjusted to 20°C or lower (Ackermann, 2002, p. 31). According to a report by the New York State Ventilation Commission, this guidance compelled more than half of the classrooms in the US to use mechanical cooling as this was the only option available to facilitate this temperature (Ackermann, 2002, pp. 30-33). However, productive temperatures have changed over time, similar to comfort temperatures. This is possibly because more studies have been carried out in a wider climate zone. Figure 3.4 shows the findings from studies that have compared user performance at different temperatures.



Key: + indicates temperature that users perform better (higher P)

- indicates temperature that users perform worse (lower P)

Note: O = office (tasks – dealing with customers on phone and typewriting, etc.)

E = education (tasks – doing maths, language, or memory tests, etc.)

T_a = air temperature, T_{op} = operative temperature, no indicator = not specified

Figure 3.4 Investigations into the effects of temperature on occupants' productivity and performance

Sources:

1. Pepler and Warner (1968 cited in Parsons, 2003, p. 331)
2. Ryd and Wyon (1970 cited in Parsons, 2003, p. 331)
3. Wyon (1974)
4. Wyon et al. (1979)
5. Witterseh et al. (2002 cited in Rashid and Zimring, 2008)
6. Seppänen et al. (2003)
7. Federspiel et al. (2004)
8. Tham (2004)
9. Wargocki and Wyon (2006)
10. Fisk and Seppänen (2007)

11. Tanabe et al. (2007)
12. Tanabe et al. (2007)
13. Lan et al. (2008)

Studies in European countries or cold climates (Cases 1-10 except Case 8) have shown that user performance improved for lower temperature categories compared to higher ones. In Schneider's review (2002), he concluded that based on Harner (1974), Wyon, Andersen and Lundqvist (1979), students were likely to perform best when room temperatures were kept within the 20-23°C range. Based on a meta-analysis by Seppänen et al. (2003), every degree rise in temperature above 25°C resulted in a 2% drop in productivity. Wargocki and Wyon (2007a) found that students' performance in numerical and language-based tests was better at 25°C than 20°C. Fisk and Seppänen (2007) summarised that based on their multiple studies with office workers, 21-22°C was the most productive temperature and performance decreased when the temperature exceeded 24°C. For students' performance, they found that students worked faster at 17°C but error rates were higher, whereas at 27°C students performed slowly but more accurately. However, Wyon and Wargocki (2013) stated that raised temperature does not affect accuracy. In fact, the raised temperature alone may not affect accuracy, but since it slows down user working process, it may allow some time for users to think more carefully, which then indirectly increases the accuracy.

Tham (2004) found that the interaction between air temperatures and ventilation rates affected call-centre operators' performance in the tropics. At 24.5°C, increasing the ventilation rate from 5 to 10 litre/second/person (l/s/p) improved the operators' performance. At a low ventilation rate (5 l/s/p), decreasing the air temperature from 24.5°C to 22.5°C also improved operators' performance. A study in a call centre in Japan (the specific location of the call centre was not identified) by Tanabe (2007)

(Case 12) concluded that increasing the air temperature from 25°C to 26°C approximately decreased the performance of operators by 1.9% (the number of calls per hour), a finding consistent with the study by Seppänen et al. (2003). Their laboratory study also suggested that participants in hot environments (short exposure – 1.5 hours) may be able to perform mental tasks as well as those in cool environments, but were likely to suffer higher levels of fatigue due to the increased cerebral blood flow required for maintaining their performance. Wyon and Wargocki (2013) suggested that occupants can possibly maintain their performance in warm or hot environments if they can adapt to reduce the heat from their body. However, the side effect is that the process of adaptation may take time and disturb occupants' activity leading to a decrease in performance and productivity.

A study in Shanghai, China (subtropical climate) (Case 13) showed that office workers performed most tasks involving perception, learning and memory, thinking and executive functions, more accurately at 24°C than at 19°C (Lan et al., 2008). In addition, in some tests the accuracy rate bounced back at 32°C from a decline at 27°C, although speed improved when the temperature increased from 19°C to 32°C (Lan et al., 2008). Lan and colleagues (2008) concluded that the relationship between air temperature and performance was not consistent and depended upon the type of task and performance indicators used. Wyon and Wargocki (2013) suggested that finger temperature could be a more reliable indicator of user performance. Based on the few studies conducted in subtropical and tropical climates, the relationship between air temperature and user performance is inconclusive.

Interestingly, Seppänen et al. (2003) highlighted that the productivity of office workers was not significantly different if the air temperature fluctuated within the comfort zone and it was only when the air temperature exceeded the upper comfort boundary (above 25°C) that performance decreased considerably. This implies that air temperature alone cannot explain all variations in user performance. The issue of comfort and its relevance to individuals' thermal background must also be taken into account.

Thermal perceptions and user performance

Based on subjective approach studies, thermal perceptions have been acclaimed as a more meaningful performance indicator than actual temperatures. In these studies thermal conditions are measured subjectively (i.e. thermal comfort), whereas performance can be estimated by either subjective or objective methods or both.

When both performance and thermal conditions are assessed by self-report, then the correlations between these two variables are relatively strong. Extensive surveys of environmental conditions and perceived productivity have been conducted in the UK by BUS and WBA since 1985 (Leaman, 2003, p. 164). These have concluded that perceptions of overall comfort and perceived productivity are strongly positively correlated. Reports from their earlier surveys confirmed that comfortable users perceived up to 25% higher productivity than uncomfortable groups (Leaman and Bordass, 1999). Remarkably, although the NV spaces were less comfortable than the AC ones according to the standards, it was found that people in many NV buildings felt comfortable and perceived that they had a higher productivity gain than people in AC buildings if explicit controls of their working environments were provided. McCartney and Humphreys (2002) agreed with the findings of Leaman and Bordass but drew slightly different conclusions, stating that productivity can be explained by participants' thermal preference votes. According to their study, which was undertaken in Europe, they noted that the perceived productivity of people who preferred 'No Change' was significantly higher than those who preferred either cooler or warmer temperatures.

For studies where performance is measured objectively, the results are relatively inconclusive. Cold environments have been reported to reduce productivity and speed of manual dexterity (Levin, 1995 cited in US Environmental Protection Agency Indoor Environments Division, 2003), whilst in a study by Kosonen and Tan (2004), it was found that productivity loss in typing and thinking tasks increased when the PMV was raised or deviated from neutral (PMV = 0, at 21°C) to the warmer side (PMV = 1.28, at 27°C) of a PMV index. The productivity reached its peak when PMV was -0.21 (slightly cool). Murakami et al. (2006) conducted a field intervention survey to test the effects of the thermal environment on the learning performance of students in Tokyo, Japan. The results showed that students who were more satisfied with the air temperature scored higher in both subjective and objective learning performance evaluations (Murakami et al., 2006). In addition, the performance of students who gained higher scores was less affected by changes in the environmental conditions, i.e. ventilation rate and air temperature, whereas the effects were significant for students in the lower scoring group (Murakami et al., 2006).

Findings from studies that treated thermal perceptions as an independent variable are fairly similar. That is, people who were satisfied with the thermal conditions often perceived a higher performance than those who felt uncomfortable. However, Wyon (1996) argued that on some occasions when exposed to moderate warmer or cooler than neutral temperatures, performance may be enhanced (cited in Heerwagen et al., 2006, p. 141). For example, people performed tasks that required creativity better in a warmer than a neutral environment. Parsons (2003, p. 348) commented on this issue and noted that it is reasonable to say that non-neutral environments (i.e. hot or cold) are more arousing and may improve the performance of people who are carrying out a boring task. Again, it must be kept in mind that the conclusions vary according to the performance assessment methods, indicators used and types of tasks.

In practice, it seems that using thermal perceptions as a performance indicator is more advantageous than actual temperatures since this integrates the thermal background of participants into the results. Furthermore, by using thermal perceptions as a performance indicator, the results from different studies conducted in different climate zones or thermal modes can be compared.

Indoor air quality and user performance

While the relationships between thermal environment and performance seem to be inconclusive, a number of empirical and chamber-based studies have consistently shown positive associations between IAQ and user performance (for example, Fisk et al., 2013, Bakó-Biró et al., 2012, Wargocki, 2007, Wargocki and Wyon, 2007b, Mendell et al., 2005, Fisk and Seppänen, 2007, Shendell et al., 2004, Coley and Greeves, 2004, Tham, 2004, Wargocki et al., 2002, Seppänen et al., 1999, to name but a few). Ventilation rate, CO_2 concentrations and odour have often been used as IAQ indicators.

A large number of field and chamber studies have shown that occupants' productivity/performance and health increases significantly at lower CO_2 concentrations and at higher ventilation rates. Coley and Greeves (2004) found that the cognitive performance of primary school students, measured using Power of Attention tests, decreased approximately 5% when the CO_2 concentration increased from approximately 690 to 2,909 parts per million (ppm), indicating that students seemed to pay less attention in class when the level of CO_2 was high. The size of the effect was comparable to not having breakfast.

Recently, Fisk et al. (2013) conducted an experimental study with 22 subjects to examine the effects of CO_2 alone on cognitive performance. Each of 22 subjects was required to be exposed to low (600 ppm), medium (1,000 ppm) and high (2,500 ppm) CO_2 concentrations for 2.5 hours while completing decision-making tasks. The results show that at 1,000 ppm CO_2 the participants performed significantly worse than at 600 ppm CO_2, in six out of nine tests of decision-making tasks. The performance of seven tasks was even worse when the participants were exposed to 2,500 ppm CO_2, although the performance of focused activity test was slightly better. Their study revealed that CO_2 is not only an indicator of IAQ, but also the indoor air pollution itself.

Bakó-Biró et al. (2012) carried out an experimental study focusing on the effects of ventilation rates on pupils' computerised performance tasks. The study was held in 16 MV classrooms in eight schools (two classrooms each) in the UK for three weeks. More than 200 pupils participated in this study. The ventilation rates were set from low (1 l/s/p) to high (8 l/s/p) levels while the air temperature was set at an acceptable range. The results show that the pupils' performance increased at the high ventilation rate: Choice reaction (2.2%), Colour word vigilance (2.7%), Picture memory (8%), Word recognition (15%).

Focusing on school environments, Wargocki and Wyon (2006) highlighted that the schoolwork of young children was more likely to be affected by CO_2 levels, ventilation rates and air temperature compared to that of adults. The situation in a university with large and high-density classrooms may be worse still. Recently, Greene et al. (2012) monitored the CO_2 levels in mix-ventilated large lecture theatres in universities in the UK and found that the daily mean maximum CO_2 levels in the sample classrooms was as high as 2,714 ppm, far exceeding the recommended level (1,500 ppm). The calculated ventilation rates were only 0.25 – 0.93 l/s/p, again much lower than the standard level (3 l/s/p). They reported that only 51% of the students scored basic mathematics tasks at higher than 50% when the CO_2 levels reached their peak (2,000 – 3,500 ppm) and the air temperature was high.

Mumovic et al. (2007) compared IAQ and thermal comfort in schools with different ventilation systems: natural ventilation, MM and MV. The average CO_2 levels in one of two NV classrooms exceeded 1,000 ppm, whereas the lowest average CO_2 levels (789 and 733 ppm) were found in both the MV classrooms. The ventilation rates in NV classrooms were the lowest, but were not lower than the standard. The ventilation rates in MM and MV classrooms on occasions exceeded 8 l/s/p. A generalisation of these findings may not be appropriate due to the limited period of measurement and the unexpected use of some classrooms (for example, low occupancy rate and overriding of the system) (Mumovic et al., 2007). A larger survey was later conducted by Mumovic et al. (2008) comprising of 16 cases and two pilot cases with various ventilation types. Here it was found that the daily average CO_2 levels exceeded 1,500 ppm in six NV classrooms, particularly those with single-sided windows and a limited openable area. In comparison, NV classrooms with cross or stack ventilation or a large openable window area had the highest ventilation rates. Despite the better ventilation rates, the noise problem in the MV classrooms became a challenge for effective learning environment design (Mumovic et al., 2008).

While CO_2 and ventilation rates may be less perceptible by occupants, odour may be another meaningful indicator of IAQ, which in contrast occupants can sense, memorise and respond to. Clements-Croome (2008) reviewed the evidence of low IAQ and low work performance, and highlighted that odours can stimulate people's cognitive processes, memories and mood. Particles and chemicals within indoor air can also negatively affect people's concentration (Clements-Croome, 2008).

Currently, user performance studies in developing hot-humid countries are scarce; therefore, it is difficult to make comparisons with findings from cold climates. Comparisons of user performance in different thermal conditions (i.e. AC and non-AC) are necessary in order to identify the limitations of non-AC operations (i.e. NV and MM cooling strategies) in hot-humid environments.

3.4 SUMMARY

Users' thermal experiences and influence on pro-environmental attitudes and learning performance are reviewed in this chapter and summarised in the following:

- Pro-environmental attitudes may increase the willingness to behave environmentally friendly.
- Environmental attitudes can be affected by demographic, external and internal factors, including past experience.
- The attitude-behaviour model is two-way related, in that attitudes can dominate behaviour or behaviour can dominate attitudes through past experience.
- The relationships between thermal experience and the willingness of reducing air-conditioning use have been rarely investigated.
- Defra's public attitudes and behaviours towards the environment survey can be used for assessing pro-environmental attitudes within the context of this study because it is specifically aimed towards the issue of climate change.
- With regards to user performance, attention, alertness, sleepiness and environmental tolerance are considered to be the most relevant parameters and can vary according to environmental conditions.
- Both actual temperature and thermal perceptions have been found to be associated with user performance.
- In temperate and cold climates, most users were likely to perform best at temperatures below 25°C.

- User performance is unlikely to be affected if the temperature fluctuates within the comfort boundaries.
- Thermal comfort was found to be positively correlated with self-reported performance, regardless of thermal mode, i.e. AC or NV, where user performance might reach its peak when PMV is slightly deviated from neutral.
- Evidence from a vast number of studies shows that higher ventilation rates with fresh air supply, i.e. no pollution, and lower CO_2 concentrations consistently contribute to better performance.
- Relevant studies in hot-humid climates are rare and consequently, there are no conclusive results.

CHAPTER 4: RESEARCH METHODOLOGY

4.1 PURPOSE

The main purpose of this chapter is to describe the methods used for collecting and analysing data. The chapter starts by stating the hypothesis of the study which focuses on the thermal adaptability of individual users and organisations in order to explain the self-reported willingness to accept ANV operation in MM buildings in hot-humid climates. The main research framework and sub-frameworks for investigating individual and organisational thermal adaptability are then explained based on the adaptive thermal comfort theory and its connections with pro-environmental attitudes and user performance, as reviewed in Chapters 2 (p. 43) and 3 (p. 92).

4.2 HYPOTHESIS AND RESEARCH FRAMEWORK

In order to understand why many MM HE buildings are currently operated in full AC mode and what factors could be changed to encourage more ANV use within these buildings, the adaptive comfort theory has been applied as the main theoretical framework of the investigation.

Considering that thermal comfort is the main driver of how occupants respond to thermal environments for a specific place and time, an individual's acceptance or rejection of ANV use can be primarily explained by thermal comfort theories. According to the criteria of behavioural thermal adaptation, organisational customs have been stated as one of the factors that affect users' responses to thermal environments. Based on this, the hypothesis stated below considers acceptance of the ANV mode as a result of the thermal adaptability of both individuals and organisations. FMs are selected in this research as representatives of an organisation. They typically interact directly with both end-users and high-ranking people on a regular basis, and can provide insights into how and why buildings are operated as they are. Therefore the hypothesis is:

> *Acceptance of fan assisted natural ventilation in existing mixed-mode non-residential buildings in hot-humid climates is affected by users' perceived behavioural adaptive opportunities and psycho-physiological adaptation, as well as by facilities management practice.*

In accordance with the proposed hypothesis, the thermal adaptation theory and previous relevant research studies, the overall framework of this research is illustrated in Figure 4.1.

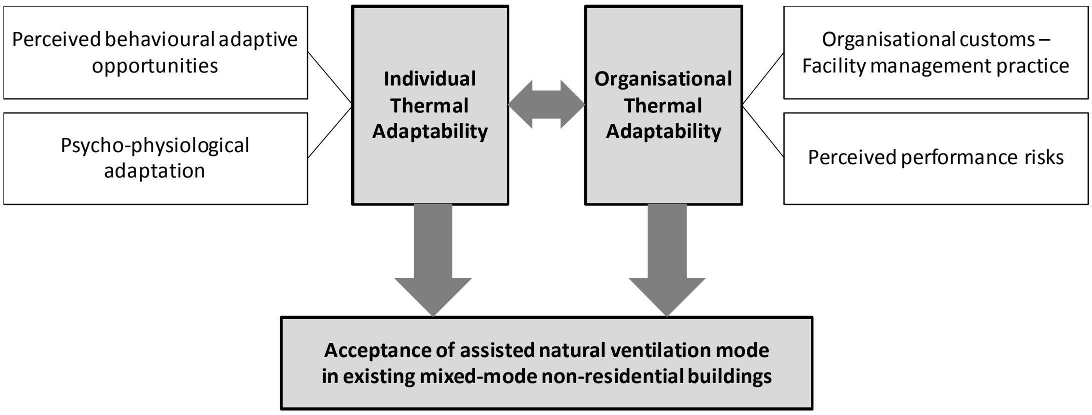


Figure 4.1 Research framework

Within this framework, the acceptance of ANV in existing manually operated MM non-residential buildings is affected by individual and organisational thermal adaptability. According to Brager and de Dear (1998), for individual thermal adaptability, individual users are able to adapt to achieve thermal comfort through behavioural, psychological and physiological adjustment. In this research, users' perceived behavioural adaptive opportunities and psycho-physiological adaptation are the terms used and these will be explained further in the following subsection. Concurrently, organisational thermal adaptability is assessed through two main aspects: facilities management practice and perceived performance risks due to ANV use. Although the perceived performance risks are usually investigated at an individual level, the organisations and FMs possibly see the connections between reduced user performance and poor environmental conditions settings through daily user complaints. In this framework the issue of perceived performance risk is then treated as an aspect of organisational thermal adaptability investigation because an effective learning environment provision is considered a responsibility of HE institutes.

In the following subsections, the sub-frameworks utilised for the investigation of individual and organisational thermal adaptability are elaborated.

4.2.1 Investigation of individual thermal adaptability

The sub-framework for the investigation into individual thermal adaptability is illustrated in Figure 4.2.

According to the empirical findings from thermal comfort studies, the more users have opportunities to adapt, the more they are likely to feel comfortable. Most studies conducted in the field usually observed actual adaptive behaviours of occupants in non-AC environments. However, this thesis postulates that the measurement of behavioural adaptive *opportunities* is also important as it has been noted several times that the more opportunities users have to adapt, the greater the possibility to extend thermal comfort boundaries and consequently reduce cooling energy demand (see examples in Section 2.5, p. 68 and Section 2.6, p. 76). It is also important to investigate the qualitative aspects of adaptive options in order to understand why users demonstrate a preference for one adaptive behaviour over others (as previously studied in residential buildings by Hwang et al., 2009). Such an opportunity not only reflects the availability of adaptive devices, but also their *perceived appropriateness/effectiveness* in a given context. In particular, this thesis mainly focuses on users' *perceptions* of behavioural adaptive opportunities within the context of MM buildings which are operated in full AC mode. According to the review of studies in a similar topic (Subsection 2.6.3, p. 83), the perception of adaptive opportunity is expected to be positively associated with users' acceptance of the ANV mode. The method for quantifying perceived behavioural adaptive opportunities is explained in detail in Subsection 4.4.1.2 (p. 143).

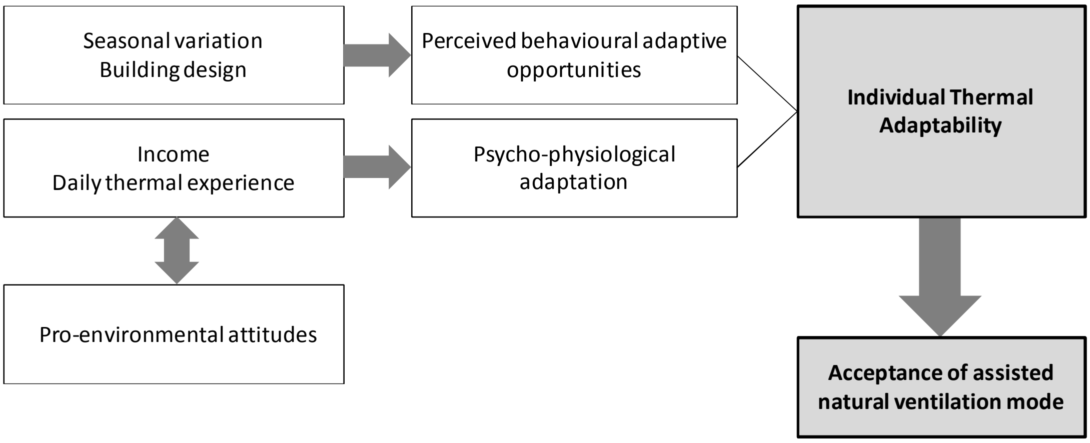


Figure 4.2 Sub-framework for the investigation of individual thermal adaptability

Focusing on behavioural adaptation, perceived behavioural adaptive opportunities are now considered as an intermediate variable that connects users' acceptance of the ANV mode with contextual factors, e.g. climate, building design features and organisational culture. As reviewed in Chapter 2 (Subsection 2.4.2.1, p. 59), behavioural adaptation can be both directly and indirectly affected by various variables (i.e. climate, building design, organisational customs and economics) (Brager and de Dear, 1998). The influence of climate and building design on perceived behavioural adaptive opportunities are examined in the investigation into individuals' thermal adaptability, whilst organisational customs are examined separately in the organisational thermal adaptability investigation (see Subsection 4.2.2, p. 130).

Whilst a potentially large number of psycho-physiological variables, for example, thermal experiences, expectations, economic status, habits and lifestyle, could be considered as relevant to adaptation mechanisms (see Subsection 2.4.2.2, p. 62), in this thesis three main variables have been selected: income, daily thermal experience and pro-environmental attitudes.

Daily thermal experience (i.e. daily exposure to AC environments) was included here since it is directly associated with acclimatisation (physiological adaptation) and thermal expectation (psychological adaptation) (see Subsection 2.4.2.2, p. 62). It should be noted that physiological adaptation in terms of biological responses (e.g. sweat rate, blood flow, etc.) was not measured in this study (it has been studied by Yu et al., 2012 – see Subsection 2.4.2.2, p. 62); only the assumption of acclimatisation based on daily thermal experience was considered.

Income was included as a variable of physio-psychological adaptation because it potentially dominates users' daily thermal experience (i.e. affordability of air-conditioning in daily life), as demonstrated in the study by Indraganti (2010b) (Section 2.5, p. 68). Moreover, income will probably affect users' personal preference for thermal mode according to what suits their social and economic status, similar to the relationships between educational background and comfort temperature found by Yamtraipat (2005) (Subsection 2.4.2.2, p. 62).

Pro-environmental attitudes have recently been claimed as an additional variable to explain occupants' acceptance of non-AC operations or forgiveness for the imperfections of non-AC buildings' thermal environments. Therefore, this is included in this sub-framework. Based on the environmental psychology framework (Subsection 3.2.2, p. 94), pro-environmental attitudes and behaviour exhibit a two-way association (Black et al., 1985). The cultivation of pro-environmental attitudes can also influence users' behaviour. In addition, pro-environmental attitudes can be dominated by past behaviour through experience. An investigation of the relationships between user's daily thermal experience and pro-environmental attitudes may help explain the acceptance or refuse of the ANV mode. Measurements of pro-environmental attitudes and behaviours applied to this study are explained in Subsection 4.4.2 (p. 149).

4.2.2 Investigation of organisational thermal adaptability

An investigation of organisational thermal adaptability requires a slightly different approach. As stated earlier, there is no established framework for evaluating the thermal adaptability of an organisation. A sub-framework for organisational thermal adaptability investigation was therefore developed and is presented in Figure 4.3.

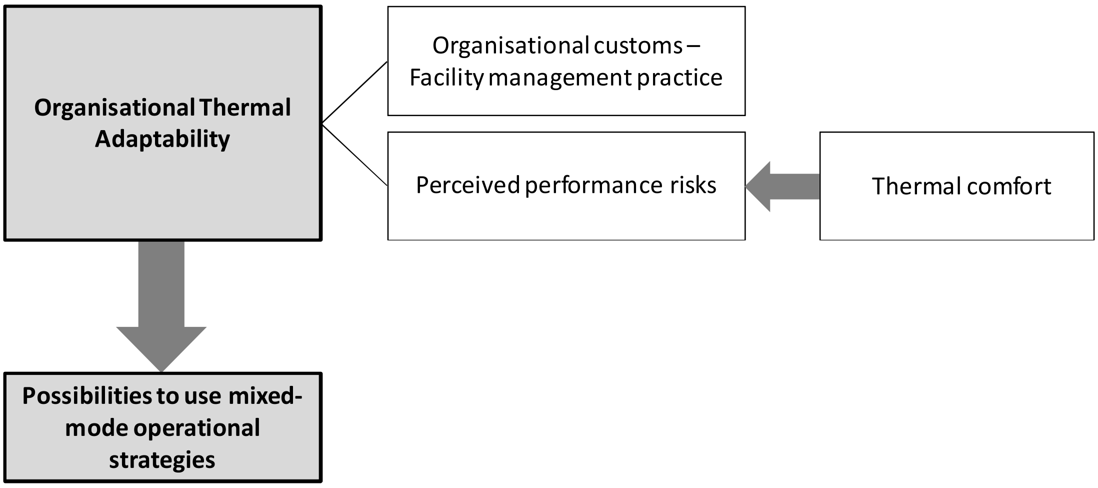


Figure 4.3 Sub-framework for the investigation of organisational thermal adaptability

As can be seen in this sub-framework, rather than simple acceptance of the ANV mode (as in the individuals' case), the possibilities to implement MM operational strategies were used to represent the thermal adaptability of an organisation. This is because MM strategies provide several approaches to increase the use of natural ventilation and fans; therefore, considered more suitable for indicating the thermal adaptability of an organisation that may own buildings with various design strategies. The possibility for implementing MM strategies in this case covers: 1) the practicalities related to building design and facilities management practice and 2) acceptance (or resistance) of users as perceived by FMs. Based on the literature review, there are three principal MM cooling strategies summarised in Subsection 2.2.2 (p. 44) (Center for the Built Environment, 2005) and all combine the use of natural ventilation and air-conditioning and/or mechanical ventilation. FMs' perceptions of the possibilities for implementing these three MM operational strategies will reveal not only the effects of current building or HVAC design, but also the organisational and managerial variables on the thermal adaptability of users within existing HE buildings.

While the previous sub-framework is centred around the effects of relevant factors on individual thermal adaptability based on existing theories, the investigation into the factors that affect organisational thermal adaptability from the point of view of FMs is considered exploratory rather than hypothesis testing.

Regarding the performance risks, concerns about lowered performance due to thermal discomfort may restrict the use of the ANV mode and a reduction in air-conditioning in non-residential organisations. In order to clarify this relationship and estimate the performance risks, the performance of users in existing AC and ANV environments was evaluated and compared, with a focus on university student performance. The method for assessing performance is presented in Subsection 4.4.4 (p. 159).

4.3 METHOD DIAGRAM

This section presents a research method and a data structure diagrams in order to provide an overview of the research methodologies utilised and field data collection.

In Figure 4.4, the diagram starts with the stating of the research problem which leads to two areas of investigation: individuals' and organisational thermal adaptability.

Under these two main areas, four groups of variables that may limit ANV use in reality are addressed: perceived behavioural adaptive opportunities, psycho-physiological adaptation, facilities management practice, and perceived performance risks. Methods were developed to investigate the relationships between these variables and acceptance of ANV with the specific objective of each investigation as stated in the diagram. With respect to these objectives, four field studies were designed.

Study 1: Thermal adaptive opportunity scoring system and acceptance of ANV survey

Study 2: Pro-environmental attitudes, adaptive behaviour, and daily thermal experience survey

Study 3: Facilities manager interviews

Study 4: Learning and thermal performance survey

Theoretically, it would be possible to combine Studies 1 to 4 together; however, the objective of each of the four surveys requires the answering of a specific set of questions that could place a heavy burden on participants. Therefore, it was considered more practical to administer three individual surveys and one interview utilising different cohorts. Data collection and analysis are briefly described. Finally, the diagram ends with the implications for building design, operation, and policy development for existing and future MM non-residential buildings in order to reduce air-conditioning demands within the building sector in hot-humid climates. Details of the data collection methods for each study are explained in the following section. Figure 4.5 presents a data structure diagram of the four studies enumerating faculty names and universities in which students and facility managers participated in the surveys. Some faculties participated in more than one study, but the individual participants were independent. This may limit the integration of the results of the four studies, but it is more practical for obtaining a sample size with specific requirements, for example, sufficient variance in classroom design, a balance between male and female participants, and sufficient variance in participants' daily thermal experience, for each study.

As the objectives of the three surveys and one interview were different, an appropriate statistical technique must be chosen for the data analysis of each study as briefly described below.

Study 1: Regression analysis was used to investigate the relationships between independent variable(s) and dependent variable, and estimate the effects of each independent variable(s) on the dependent variable.

Study 2: Analysis of variance (ANOVA) was used to compare means of three or more individual data sets.

Study 3: Descriptive analysis was used to show the prevalence of answers obtained from an interview.

Study 4: Independent t-test was used to test whether the means of two individual data sets are equal.

Accordingly, the determination of sample size for each of four studies requires different methods depending on the criteria of chosen statistical techniques and the required characteristics of participants.

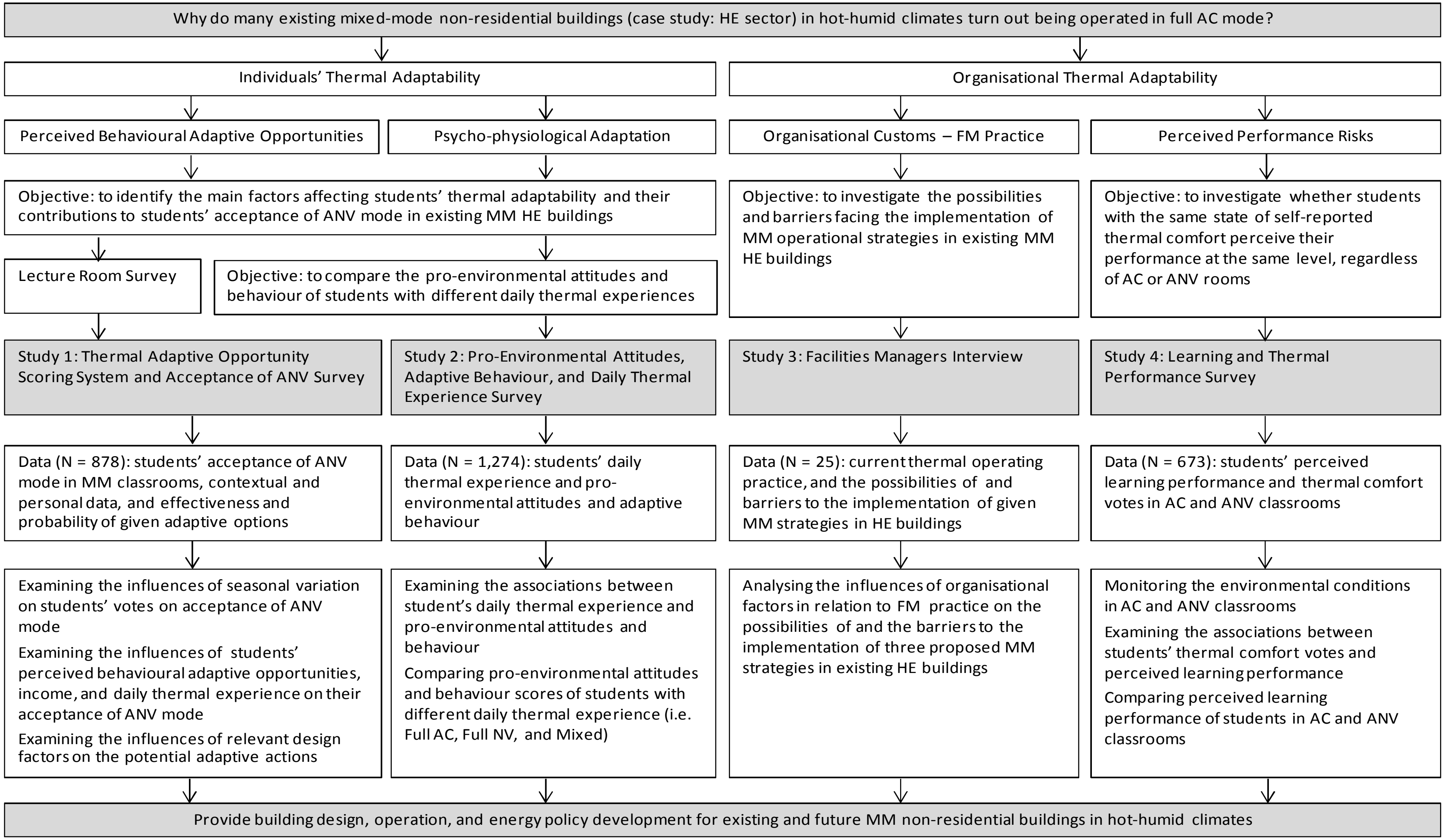


Figure 4.4 Research method diagram

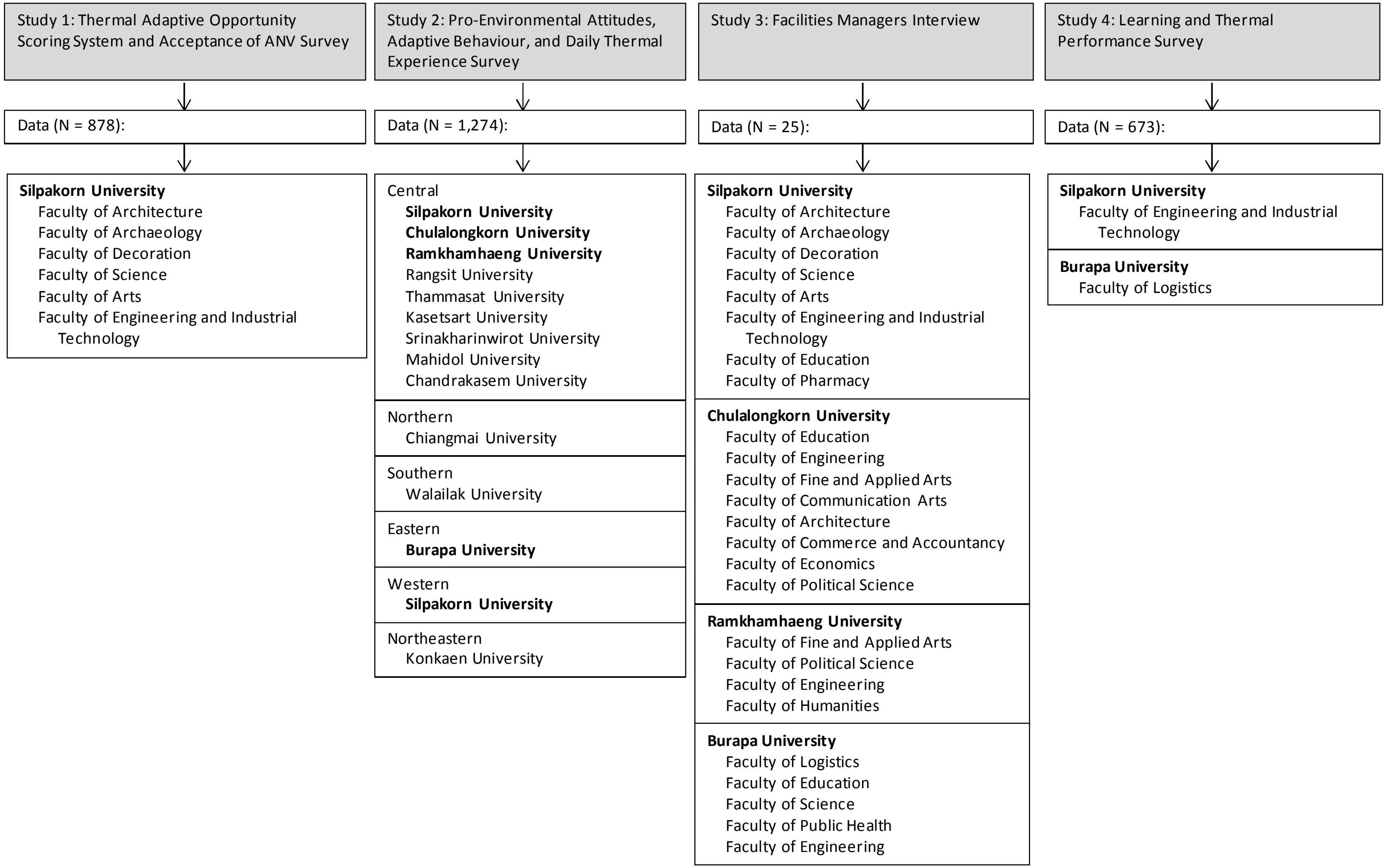


Figure 4.5 Data structure diagram

4.4 SURVEY DEVELOPMENT AND DATA COLLECTION

Following the research framework and sub-frameworks, this section describes the methods utilised for data collection and analysis of the field survey results and interviews. Accordingly, the section is divided into four subsections with each one comprising of the objective, details of data collection (e.g. contents, variables, tools, etc.), sample size and sampling methods used.

4.4.1 Study 1: Thermal adaptive opportunity scoring system and acceptance of assisted natural ventilation survey

This study examined the relationships between users' acceptance of the ANV mode in existing MM lecture rooms (i.e. dependent variable) and contextual and personal variables (i.e. independent variables). Additionally, the magnitude of the effects of contextual and personal variables was estimated.

Generally, HE buildings consist of various types of spaces and functions that provide different levels of thermal adaptive opportunities. MM HE lecture rooms, rather than MM HE buildings, were chosen as the context of this study because the investigation of perceived adaptive opportunity must be site specific for users to relate themselves with rules and organisational culture applied to that site. Lecture rooms were also considered the main function of HE buildings. Based on different physical characteristics, such as, window area, orientation, and availability of electric fans, each lecture room could be considered unique and the adaptive opportunities in each room cannot be simplified.

Prior to the student survey, a lecture room survey was carried out. The objectives and details of both surveys are explained below.

4.4.1.1 Lecture room survey

Objective: To survey the physical characteristics of existing classrooms in HE estates in order to choose representative classrooms for the thermal adaptive opportunity scoring system and the survey on acceptance of ANV

As stated in the Introduction (Section 1.2.2, p. 33), there is no comprehensive dataset of MM spaces in HE buildings in Thailand, as the current data collection method only classifies the ventilation systems of this building type as AC or NV. Spaces where air-conditioning systems are present are all labelled as AC space (DEDE, 2004).

In order to evaluate the potential of existing HE buildings which could be operated as MM, a lecture room survey was conducted. The survey included both design and use-related items, for example, location, window area, cross-ventilation, ventilation system and room capacity (see the Lecture room survey form in Appendix A, p. 354). The physical conditions of the rooms aside from the ventilation system, such as building location, room dimensions and area, room capacity, window type and size, ceiling height, and number of electric fans, were noted in order to use these as criteria for room selection for the Thermal adaptive opportunity scoring system and acceptance of ANV survey, as well as to provide supporting information for further data analysis.

The survey was carried out in May 2009 in Silpakorn University to which the author gained permission for access. The characteristics of some observed MM buildings are shown in Figure 4.6. The oldest building observed dates back to the 1940s and represents the early-period of HE buildings in Thailand (Chulalongkorn University, the first Thai university, founded in 1917). The majority of buildings observed are from the middle period when most buildings were designed as fully NV buildings but then installed with air-conditioning systems. Buildings in the current period are mostly designed with air-conditioning systems and operable windows, whereas electric fans are optional.

(a) Urban area

(b) Urban area

(c) Suburban area

(d) Suburban area

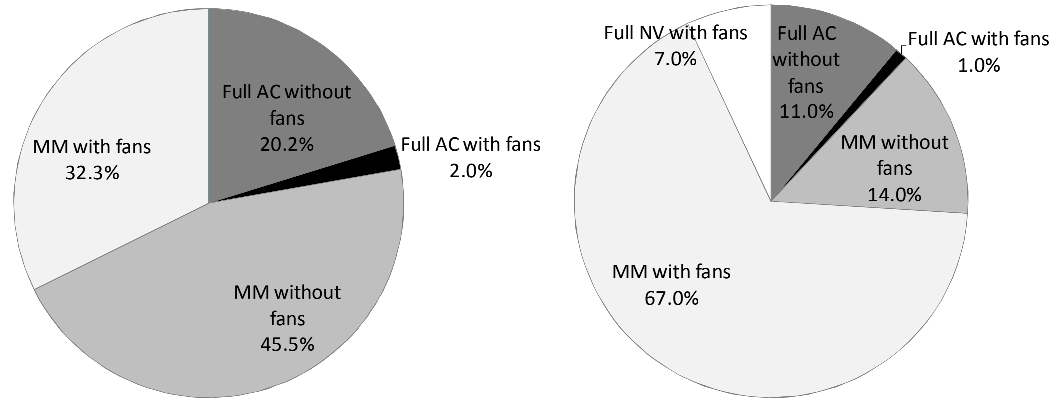
Figure 4.6 Examples of observed higher education buildings

Based on a survey of 206 classrooms in total on the Bangkok (urban area) and Nakhon Pathom (suburban area) campuses, the ventilation systems of the observed classrooms, based on existing design rather than actual thermal operations, could be divided into five categories as shown below. Please note that the term 'fan' used in these categories mean a ceiling or a wall fan, not an internal fan in an air-conditioner. Most of the observed classrooms were operated in full AC mode with no/less use of windows and electric fans in practice.

1) Full AC without fans: central or split type air-conditioner(s), no operable window(s), no ceiling or wall fan(s)
2) Full AC with fans: central or split type air-conditioner(s), ceiling, wall or exhaust fan(s), no operable window(s)
3) MM without fans: operable window(s) and central or split type air-conditioner(s), no ceiling or wall fan(s)
4) MM with fans: operable window(s), central or split type air-conditioner(s) and ceiling or wall fan(s)
5) Full NV with fans: operable window(s) and ceiling or wall fan(s)

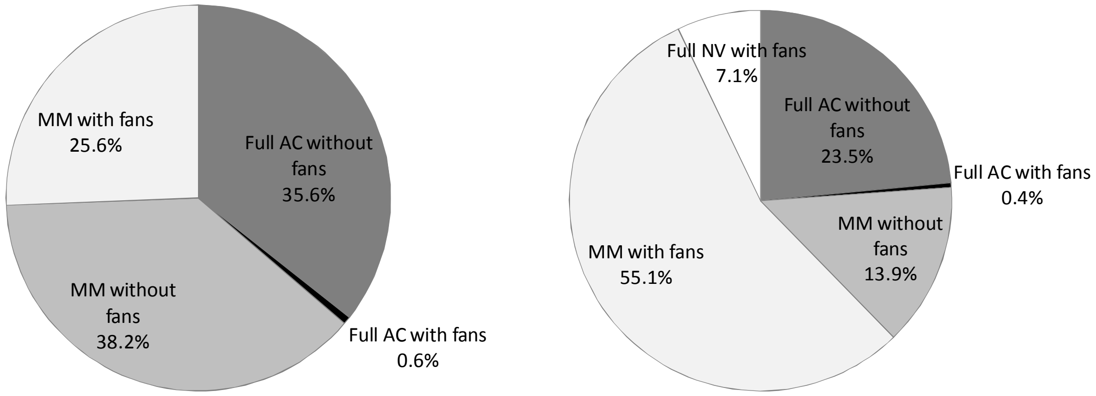
Figure 4.7 shows the number of classrooms and room area in each location and the ventilation systems present.

MM classrooms (based on the presence of air-conditioning units and operable windows, with/without fans) account for more than three quarters of the classrooms but two thirds of the classroom floor area (64% and 69% of the total classroom area in urban [total area is 3,615 m^2] and suburban [total area is 15,796 m^2] campuses, respectively). Notably, larger classrooms are more likely to be air-conditioned. That is why the percentage of AC classroom area is higher than the percentage of AC classroom counts. Although this statistic is crude, it may hint at the size of MM building stocks within the HE sector. MM classrooms (with or without fans) can therefore be considered suitable for this study since there is significant potential for ANV use to reduce air-conditioning consumption in this building type. It should be noted that the MM classrooms without fans were included in the study to investigate how the absence of fans affects users' perceived adaptive opportunity.



(a) Urban campus (room count) (b) Suburban campus (room count)

(Total number of rooms: 44) (Total number of rooms: 162)



(c) Urban campus (room area) (d) Suburban campus (room area)

(Total area: 3,615 m^2) (Total area: 15,796 m^2)

Figure 4.7 Percentage of classroom number (a and b) and area (c and d) in Silpakorn University classified by location and ventilation system

To investigate the perceived behavioural adaptive opportunities in existing MM classrooms and the influence on acceptance of ANV, some existing MM classrooms (with or without fans) were purposively selected for the next survey based upon the following four criteria. These criteria potentially affect the opportunity to use windows and fans as these two adaptive options are considered common in hot-humid climates. They do not intend to cover all possible adaptive behaviours. As well, other common adaptive behaviours, such as changing clothes and drinking cold water (see Table 2.1, p. 73), are less likely to be affected by room design.

- Location (urban or suburban): buildings surroundings can affect the quality of air supply into the buildings and window opening
- Floor level (up to the 4th floor or from the 5th floor upwards): at different floor levels, the possibility to open window(s) could be different due to different outdoor air velocity and other reasons (e.g. personality, security, etc.)
- Ceiling height (up to 3 m or higher than 3 m): the effectiveness and the possibility to use fans could vary according to ceiling height
- Cross-ventilation (No or Yes)[27]: the effectiveness of window opening varies according to cross ventilation

It should be highlighted here that to gain variations in the characteristics of chosen classrooms is important for this study because they are expected to affect adaptive opportunities and the acceptance of the ANV mode. From these four criteria, which have two categorical responses each, the minimum number of classrooms that would need to be observed in the next survey was 16 (= 4^2), although in the event, only 12 types of classroom were included in the survey. The room types that were not available are (also shown in Table 5.1, p. 170):

- Urban area, higher than the 4th floor, ceiling height higher than 3 m, without cross ventilation
- Urban area, higher than the 4th floor, ceiling height higher than 3 m, with cross ventilation

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[27] Rooms with windows on more than one-side were categorised as cross-ventilated rooms. Rooms with windows on a single side were classified as non cross-ventilated rooms.

- Suburban area, higher than the 4th floor, ceiling height lower than 3 m, without cross ventilation
- Suburban area, higher than the 4th floor, ceiling height higher than 3 m, with cross ventilation (most buildings are not high-rise).

The characteristics of participants are also influential in determining their psychological and physiological adaptability. Therefore, to gain participants with various characteristics, at least two classrooms of each type, with 30 or more occupants in each, should be primarily chosen to ensure the sample size required (see Appendix B: Part 1 - Subsection 1.1.5, p. 367). Classrooms from the list of lecture rooms obtained from the Lecture room survey were randomly selected but rooms with typical capacity (30-90 seats) were preferred. In total, 23 classrooms were surveyed and examples of the selected classrooms are shown in Figure 4.8.

With limited time, budget and access, it was difficult and inconvenient to include HE buildings and classrooms in other universities and regions in this lecture room survey. Therefore, the chosen classrooms were not intended to be used as representatives of all HE buildings and classrooms in Thailand. As these 23 classrooms were chosen based on the aforementioned four criteria of MM classroom selection in one university, they represent classrooms with sufficient variations in these four characteristics in that university only. This may result in some limitations of the study.

(a) Room in urban area 1 (b) Room in urban area 2

(c) Room in suburban area 1 (d) Room in suburban area 2

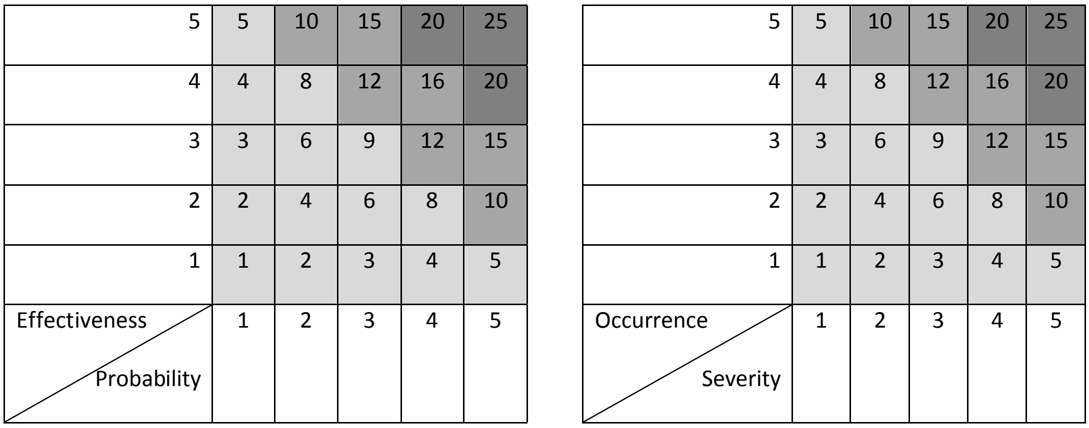
Figure 4.8 Examples of selected classrooms

4.4.1.2 Thermal adaptive opportunity scoring system and acceptance of assisted natural ventilation survey

Objective: To identify the main factors affecting students' thermal adaptability and their contributions to students' acceptance of the ANV mode in existing MM HE buildings in a hot-humid climate

In order to achieve the objective of this study, a questionnaire survey was employed for the data collection. The outcome variable for this study was acceptance of the ANV mode in observed classrooms during the hot and cool seasons, which are the worst and the best case scenarios for using ANV. The explanatory variables according to the thermal adaptive concept were seasonal variation (a climate-related factor), building design attributes, users' income (an economics-related factor) and daily thermal experience. For seasonal variation and building design factors, the impact of these factors on the acceptance of ANV was interpreted through users' perceived behavioural adaptive opportunities.

First of all, a method for quantifying perceived behavioural adaptive opportunities in a classroom was proposed. As detailed in Chapter 2 (Subsection 2.6.4, p. 86), currently available tools merely measure design attributes (e.g. access to windows or distance from windows, space sharing, etc.), the presence of user controls or satisfaction with controls in an environment (Subsection 2.6.2, p. 79 and Subsection 2.6.3, p. 83); these may not represent the actual use of such controls for mitigating users' thermal discomfort. A method for quantifying perceived behavioural adaptive opportunity or to prioritise adaptive behaviour has not yet been properly developed. In this study, the method of risk assessment quantification was borrowed and modified in order to measure opportunities for behavioural adaptations within classrooms. In such an assessment, risk is measured by multiplying the likelihood of risk (occurrence) by the severity of the risk (Shah, 2007, pp. 125-126). A 5-point Likert rating scale was applied to both indicators, with risk scores ranging from 1 to 25, classifiable as Low (1-9), Moderate (10-19) and High (20-25). These cut-off bands were obtained by a graphic method shown in Figure 4.9. For thermal adaptive opportunity quantification, of three criteria (i.e. effectiveness, availability and operating cost) for people's choice of thermal adaptive behaviours as stated by Hwang et al. (2009), 'effectiveness' and 'availability' were chosen to quantify the level of perceived behavioural adaptive opportunities within classrooms, using a 5-point Likert scale (1-Very Low to 5-Very High). Operating cost was not included because most of the adaptive behaviours were no/low-cost to students. The 'availability' opportunity was later altered to 'probability' since this term not only provides a sense of the availability of adaptive options but also the possibility to act accordingly in a given context. The thermal adaptive opportunities estimated by using this technique and ranging from 1 to 25, can be treated as an interval scale or reclassified into three ordinal categories (1-Low, 2-Moderate and 3-High) as mentioned earlier.



5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
Effectiveness Probability	1	2	3	4	5

a) Quantitative thermal adaptive opportunity

5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5
Occurrence Severity	1	2	3	4	5

b) Quantitative risk assessment methodology

(Shah, 2007)

Figure 4.9 Proposed perceived behavioural adaptive opportunity quantification based on the concept of risk assessment method

With regard to empirical studies in different building types (Table 2.1, p. 73), observed adaptive behaviours differ from context to context (for example, Bernardi and Kowaltowski, 2006, Indraganti, 2010a, Rijal et al., 2010). For this study, a list of ten possible thermal adaptive behaviours to relieve heat discomfort in classrooms was included in the survey. Five of these were environmental adaptations and the others were self-adaptations. Participants were required to rate the ‘effectiveness’ and ‘probability’ against these adaptive options. The given adaptive options which students rated are presented in Table 4.1.

Table 4.1 Thermal adaptive behaviours in classrooms included in the Thermal adaptive opportunity scoring system and acceptance of ANV questionnaire survey

Environmental adaptation	**Self-adaptation**
Door operation (open-close)	Clothes adjustment
Window operation (open-close)	Cold drink consumption
Internal shading devices adjustment	Face washing
External shading devices adjustment	Fanning yourself (hand or a hand-held fan)
Electric fan operation (turn-on/off)	Seat moving

The data collection of other variables, i.e. daily thermal experience and income are explained in the questionnaire structure as follows.

The questionnaire structure

The questionnaire was developed to gain data on the variables mentioned above and consisted of five main parts (for the complete questionnaire see Appendix A, p. 355).

Part 1 Personal information

The questionnaire began with a section on participants' background – gender, age, faculty and monthly income (i.e. student's allowance excluding rent). All data were collected using a categorical scale except for students' age.

Part 2 Clothes worn

This part provided a list of garments so that participants could select what they were wearing whilst answering the questionnaire. This information was used to calculate the clothing value (clo) of existing air-conditioning users in order to support the data analysis regarding the adjustment of clothes. A list of clothing value for each type of garment can be found in *ASHRAE Standard 55-2004, Normative Appendix B: Clothing Insulation* (ASHRAE, 2004, p. 19).

Example: The calculation of total clo value

T-shirt (0.08) + Shorts (0.06) + Bra (0.01) + Panties (0.03) + Sandals (0.02) = 0.20

Part 3 Thermal experience

In this part of the survey participants were asked whether they usually use air-conditioning in three different situations: bedroom, transportation and classrooms. Based on these three major daily environments of a student, their overall daily thermal experience was then classified as full AC (all three answers were AC), MM (answers are mixed), or full NV (all three answers were NV).

Part 4 Acceptance of the ANV mode in this classroom

Students were asked to rate whether they agreed with the statement: "*You would still be able to maintain your comfort if using natural ventilation and fans (if available) instead of air-conditioning within this classroom*." The question was divided into two scenarios: the cool and hot seasons, using a 3-point scale (1-Disagree, 2-Uncertain and 3-Agree).

Part 5 Perceived behavioural adaptive opportunities

In this part students were asked to rate the effectiveness and the probability of ten given adaptive behaviours, which could be employed to relieve possible warm discomfort, using a 5-point Likert scale (from 1-Very Low to 5-Very High). If some design features related to the adaptive behaviours were not available, it was suggested to students that they rate the probability as 1. For example, the probability of fan operation in a classroom with no fans would be rated as 1.

Sample size and sampling method

As stated in Subsection 4.4.1.1 (p. 137), 23 MM classrooms qualified for this study and a paper-based questionnaire was administered to students in these classrooms.

In order to identify the main factors affecting students' thermal adaptability and their contributions to students' acceptance of the ANV mode in existing MM HE buildings in a hot-humid climate, logistic regression was employed. Logistic regression is a statistical technique used for building a model to predict the outcome variable that is a categorical scale where the independent variables can be continuous or a categorical scale or both. There are three methods for logistic regression analyses as shown in Figure 4.10.

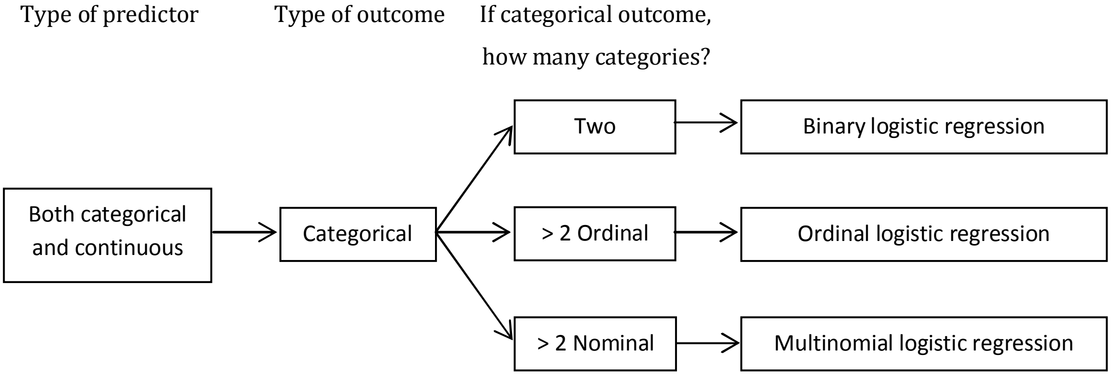


Figure 4.10 Logistic regression

First, if the outcome variable is dichotomous (i.e. a variable with two categories in which respondents can fall into one category only), binary logistic regression should be applied. Second, if the outcome has more than two categories and is an ordinal scale, ordinal logistic regression should be used. Third, if the outcome variable is a nominal scale with more than two categories (unordered), multinomial logistic regression (MLoR) should be applied.

In this study, MLoR was employed because the outcome variable has three possible responses (i.e. Agree, Uncertain and Disagree). Since it was planned to analyse the data using logistic regression, an estimation of appropriate sample size was made.

According to the method of Hosmer and Lemeshow (2000), the total sample size required was 750 students in order to ensure the reliability of the statistical tests (see explanation provided in Appendix B: Part 1 – Subsection 1.1.5, p. 367). Therefore this study aimed to gain at least 30 participants from a single class conducted in each of the 23 classrooms. If this number was not obtained, then the survey was administered to one more class where possible in order to increase the sample size for that particular classroom type. The class selection was made by checking classroom timetables in advance, considering the room type, class size and users. Then introduction letters regarding the study were sent out to the teachers who were responsible for each class before commencing the survey. The survey was conducted during the first term, July-August 2010 (rainy season) and all respondents were independent, i.e. none of the classes or students were replicated. However, in two classes that were visited, the class size was smaller than 30 students. Therefore, these two classrooms were surveyed twice but with different cohorts. In total, the survey was conducted in 25 different classes. The total number of participants who responded was 878 (for further details of each class see Table 5.1, p. 170).

4.4.2 Study 2: Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey

Objective:	To compare the pro-environmental attitudes and behaviour of students with different daily thermal experiences (i.e. level of exposure to air-conditioning)

This survey focuses on the relationships between pro-environmental attitudes and behaviour, and overall students' daily thermal experience. A self-reported questionnaire was chosen as the method for this study.

The pro-environmental attitudes questionnaire developed by Defra (2007) was adopted and modified slightly to suit the objective of this study. Defra's survey was considered appropriate since it included a section that investigated attitudes towards climate change in particular, which is more directly related to the issue of air-conditioning consumption. In addition to pro-environmental attitudes, thermal adaptive behaviour at home and acceptance of a university air-conditioning reduction policy were also measured. These indices represent two types of pro-environmental behaviour, i.e. private-sector household behaviour and policy support, as suggested by Stern (2000). The questionnaire structure is presented below.

The questionnaire structure

The questionnaire was comprised of five parts (see the complete questionnaire in Appendix A, p. 357). Notably, the term 'global warming' is used in this questionnaire because its Thai translation is more well-known than that for 'climate change'.

Part 1 Personal information

This part contains demographic data of the participants: age, gender, faculty and monthly income (i.e. student's allowance excluding rent).

Part 2 Thermal experience (TExp)

In this part, students were asked whether they used air-conditioning in these three situations: bedroom, university and transportation. Based on their responses, daily thermal experiences were then classified as full AC, MM, or full NV.

Part 3 Adaptive behaviour at home (BEH)

Five questions were constructed to investigate how often students behave adaptively in a manner that reduces air-conditioning and energy use at home using 5-point Likert scale (from 1-Never to 5-Always). The questions were: '*When you are at home, how often do you...?*'

1) Use windows and/or fans instead of air-conditioners to save energy
2) Use curtains/blinds to get natural light in order to save energy
3) Set the air-conditioner thermostat higher than 25°C to save energy
4) Adjust the air-conditioner thermostat when you feel cold, rather than wearing more clothes
5) Wear lighter clothes than usual when not using air-conditioners

Part 4 Acceptance of air-conditioning reduction policy in university (POL)

In this part, students were asked to rate how acceptable they would find the five potential university air-conditioning reduction policies using a 5-point rating scale (from 1-Not Acceptable at all to 5-Very Acceptable). The policies are:

1) Set air-conditioner thermostats in lecture rooms/labs/studios 1 or 2 degrees higher than usual to reduce the effect of global warming
2) Use only windows and fans in some lecture rooms when the outdoor climate is pleasant for at least 2 hours per day in order to reduce the effect of global warming
3) Use only windows and fans in some labs/studios when the outdoor climate is pleasant for at least 2 hours per day in order to reduce the effect of global warming

4) Use only windows and fans in some lecture rooms all day in order to reduce the effect of global warming
5) Use only windows and fans in some labs/studios all day in order to reduce the effect of global warming.

Part 5 Pro-environmental attitudes (PEA)

The set of environmental statements given in this part was modified from the *Public Attitudes and Behaviours towards the Environment Survey* devised by Defra (2007). Eight statements from Defra's survey were selected, and a further two statements added that emphasise the issues concerning air-conditioning use and energy consumption within the university in order to increase the specificity of the pro-environmental attitudes scale. Notably, the entire Defra's survey was not used because some statements are more related to home owners, for example, statements about appliance purchasing, which were considered irrelevant to the target group (i.e. students) of this study. The ten statements were as follows:

1) Humans are capable of finding ways to overcome the world's environmental problems
2) Scientists will find a solution to global warming without people having to make big changes to their lifestyles
3) Global warming is beyond control – it is too late to do anything about it
4) I find it hard to change my habits to be more environmentally friendly
5) I do not believe my behaviour and everyday lifestyle contribute to global warming
6) The environment is a low priority for me compared with a lot of other things in my life

7) The effects of global warming are too far in the future to really worry me
8) I believe that air-conditioning use contributes to global warming [additional statement]
9) I do not pay much attention to the amount of electricity I use at home
10) I do not pay much attention to the amount of electricity I use at university [additional statement].

Students were asked to score their level of agreement the statements given based on 5-point rating scale (from 1-Strongly Disagree to 5-Strongly Agree). All answers for negative statements relating to the environment were later recoded in reverse in order to set code 1 as low and code 5 as high pro-environmental attitudes.

Sample size and sampling method

As the objective of this study is to compare means of pro-environmental attitudes and behaviours of students in three different groups of daily thermal experience, it needs a sufficient sample size to be able to detect the differences in the means and to ensure the reliability of the results.

According to Cohen's (1977) method for calculating sample size considering the power of analysis required, a total of 1,212 participants were needed (see further explanation in Appendix B: Part 2 - Subsection 2.1.3, p. 374). With regards to the sampling method, it is important to gain sufficient variation in the daily thermal experiences of participants. Students in the same region or in the same university are likely to have similar thermal experiences in university and transportation. For example, students in suburban area may not usually use AC transportation because it is not available, and that affects the variation of daily thermal experiences of students in the same region. Therefore, it was considered appropriate to conduct this survey in different geographical regions. There are six geographical regions in Thailand: central, northern, north-eastern, southern, eastern and western regions. Since ‘region’ then became a subcategory of population, 202 (1,212/6) participants in each region were required. The main university in each region was therefore the targeted location for conducting the survey. Additionally, to avoid sampling bias, quota sampling was used to balance the number of participants for gender and educational background (i.e. science or non-science major), since these variables could affect environmental attitudes (see Subsection 3.2.4, p. 100). Therefore, in each region, the sample should comprise of 51 (202/4) female and 51 male students in science-based faculties and 51 female and 51 male students in humanity/social science-based faculties.

For this national survey, assistants on site were hired to administer the questionnaire to students on campus and students were asked to complete the paper-based questionnaire by themselves. The survey was conducted in July-August 2010 for the northern, north-eastern, eastern and southern regions and in November 2010 for the central and western regions. The process was monitored regularly by phone and through taking photographs.

At the end of this process, 1,274 valid samples had been obtained, with 628 female respondents and 646 male participants. Almost half of these respondents were studying in science-based faculties (594) and the remainders were in humanities or social-based faculties (680).

4.4.3 Study 3: Facilities managers interviews

Objective:	To investigate the possibilities and barriers facing the implementation of MM operational strategies (to use more ANV mode) in existing MM HE buildings, based on the viewpoint of facilities managers

Since there is no framework for the assessment of organisational thermal adaptability, the possibilities for implementing MM operational strategies (see the concept of the MM strategies – Concurrent, Change-over and Zoned strategies in Subsection 2.2.2, p. 44) were proposed as a primary indicator. This allows relevant organisational customs and facilities management practice that may support or restrict MM operations to be investigated further. Accordingly, this study focuses on the current thermal comfort practice within the HE sector and the possibilities for adopting three MM cooling strategies in their existing MM buildings. The data were obtained through interviews with FMs in Thai universities. There are normally two levels of facilities management units within an academic institution; the central department and the faculty division. In this study, the head FMs of the faculty division were chosen to be interviewed. A semi-structured interview was employed because it can help the interviewer focus on the information of interest, but also provide opportunities to participants to add comment freely. Interviewees were also able to refuse to answer some questions if they were not appropriate for their responsibilities or beyond the scope of their knowledge. This method was also considered suitable for collecting the information from FMs who tend to be busy and may have no interest in answering a questionnaire or phone survey. The interview questions consisted of six main parts as detailed below (see the complete interview questions in Appendix A, p. 359).

The interview structure

Parts 1 to 4 contain background information related to thermal comfort practice within the organisation used in the data analysis of this study. In this study, the term 'thermal operating practice' is used to indicate how buildings are normally thermally operated in order to deliver thermal comfort to their occupants, and it generally refers to who operates the air-conditioning systems, normal temperature set point and level of user control over the systems. Parts 5 and 6 specifically focus on the current thermal operating practice and the possibilities for implementing MM operational strategies (i.e. to increase use of the ANV mode) in existing MM HE buildings.

Part 1 General background of the interviewee and the faculty

The data collected included interviewee's name, faculty, university, position, work experience, number of local facilities management staff and number of buildings under responsibility.

Part 2 Current energy reduction policies

This is to show how aware the faculty was of energy consumption within their buildings.

Part 3 Energy information system

This part addresses the capacity of the faculty to monitor energy consumption within their faculty through sub-metering, electricity costs monitoring and dissemination, energy audits and thermal comfort surveys.

Part 4 Air-conditioning installation

Since most HE buildings have already been transformed from fully NV to AC, this part aims to investigate the introduction of air-conditioning into the buildings and influences on building configurations.

Part 5 Air-conditioning operation and user controls

This part aims to explore how air-conditioning systems in HE buildings were currently operated and to estimate the degree of user controls over the systems. The questions on thermal operating practice particularly focused on classrooms and lecture rooms. Such information can illustrate building-user interactions, particularly the issue of users' expectation for air-conditioning within this building type.

Part 6 The possibilities and barriers to implementing MM strategies within the faculty

In this part, interviewees were asked to express their opinions regarding the possibilities and barriers to implementing the following three MM cooling strategies for reducing air-conditioning use in their faculty (in classrooms and in general – covered labs, offices and social areas, but excluded libraries and student residential accommodation).

Strategy 1 Concurrent: To use air-conditioners and fans together and set the thermostats 1 or 2 degrees higher than usual (from 25°C to 26-27°C) to save energy

This strategy was modified from the original concept since using air-conditioning and ANV together in the same space and at the same time is uncommon and causes increased energy waste under the conditions of existing MM HE buildings. As estimated by Vipavawanich (2008) and Atthajariyakul and Lertsatittanakorn (2008), the potential energy saving from this strategy is 6-12% compared to the usual setting (Section 2.5, p. 68).

Strategy 2 Change-over: To use natural ventilation assisted by fans in the morning and evening classes and/or in the cool season, when the outdoor temperature is not too hot, in existing MM rooms

Strategy 3 Zoned: To conserve and/or extend fully NV spaces (with or without fans) within faculty buildings in the future

Sample size and sampling method

Generally, the sample size of interview-based studies depends on a researcher's judgement, convenience and theoretical models (Marshall, 1996). Alternatively, the sample size may be decided during the data collection process when the information gained from the interviewees has reached saturation and there is sufficient variation (Guest et al., 2006). However, this principle does not aid in the determination of sample size prior to conducting the interviews. According to a post-study analysis by Guest et al. (2006), signs of saturation and variability in the study analysed appeared following the first six interviews. Therefore, in order to gain sufficient variation in the responses, a purposeful sampling method was used for selecting case studies and faculties in different locations with different thermal operating practices were chosen.

The aim was to interview FMs from at least 12 faculties in each urban and suburban area, within the same climate zone. In each location, the plan was to target six faculties with buildings operated in the full AC mode (although the buildings were designed as MM) and six MM faculties (i.e. there were some forms of natural ventilation used in their buildings) in order to compare the reasons behind the current thermal operating practice. Faculties with lecture-based teaching in four universities (two in urban and two in suburban area) to which the author had access were targeted and contacted by phone first to gain preliminary information about thermal operating practice (MM or full AC) in their faculties. Then, invitation letters were sent out to the Division of Building and Physical Plant in 35 qualified faculties in the four universities, and 25 of them accepted the invitation. Ten faculties refused to participate in the interviews mainly due to inconvenience. It should be noted that all faculties used in Study 1 and Study 4 also participated in the interviews. The interviews were carried out in December 2010 – January 2011. Unfortunately, of the 25 faculties which accepted, there were only five and four examples of buildings operated in MM in urban and suburban areas, respectively. This is due to the current limited use of natural ventilation (with or without fans) within this building type. The interviews were recorded on a digital voice recorder and summarised for the data analysis, i.e. the interviews were not word-by-word transcribed.

4.4.4 Study 4: Learning and thermal performance survey

Objective: To investigate whether students with the same state of self-reported thermal comfort (i.e. uncomfortable, neutral and comfortable), perceive their performance at the same level, regardless of AC or ANV rooms

Learning performance and the comfort of students in two thermal conditions, i.e. AC and ANV classrooms, was surveyed. A pilot study was conducted for this survey using an interventional approach and the results are presented in Appendix C. The same cohort of students was surveyed twice, once when using air-conditioning as normal and once when AC was not in use. The main problem encountered during the pilot study was that the sample size in the 'Very Comfortable' ANV and 'Very Uncomfortable' AC groups were too small, thereby reducing the reliability of the results. Additionally, some teachers resisted the turning off of air-conditioners, which made this approach impractical in the field. The results of the pilot study (see Appendix C, p. 378) showed that students who felt uncomfortable in the ANV mode perceived a lower learning performance than students who reported themselves to be uncomfortable in the AC mode. The interventional approach used in the pilot study which changed the usual thermal mode from AC to ANV with the same cohort may have had a negative effect on their thermal expectation and consequent perceived performance. Due to these methodological problems, an observational approach was then chosen for the actual study and different groups of students who were already accustomed to the observed environments in existing AC and ANV classrooms were selected as the samples.

For the learning performance assessment, a subjective approach, i.e. a self-completed questionnaire, was considered to be more suitable as it was more appropriate for students in the HE sector with a variety of background knowledge and did not require psychology expertise to analyse the data obtained. According to the literature (Subsection 3.3.2, p. 106), four parameters of learning performance – *Attention*, *Freshness (as opposed to Sleepiness)*, *Alertness* and *Environmental tolerance* (see Subsection 3.3.2, p. 106), are likely to be affected by environmental comfort, and these were included in the questionnaire. Environmental tolerance was explained to the respondents as 'how well can you tolerate the imperfections in the environmental conditions in this classroom, which may negatively affect your learning performance'. *Overall learning performance* was added as the fifth parameter in order to cover other aspects of learning performance. Environmental comfort data was also collected and used as an independent variable. The questionnaire is described in detail below.

The questionnaire structure

The questionnaire used for this survey contains five main parts (see the complete questionnaire in Appendix A, p. 361).

Part 1 Personal information

This part consisted of the background information of the participants: gender, age and monthly income (i.e. student's allowance excluding rent).

Part 2 Clothes worn

Students were asked to select garments from a given list to show what they were wearing whilst they were answering the questionnaire. The clothing value (clo) was later computed to indicate the level of clothing insulation (explained earlier in Subsection 4.4.1.2, p. 143).

Part 3 Perceived learning performance

Students were asked to rate how the environmental conditions affected their learning performance, so called perceived learning performance (PLP) using a 5-point rating scale (1-Much Lower than Normal, 2-Moderately Lower than Normal, 3-Normal, 4-Moderately Higher than Normal and 5-Much Higher than Normal). The parameters of learning performance consisted of: *Attention*, *Freshness*, *Alertness*, *Environmental tolerance* and *Overall learning performance*. The description provided with the rating scale emphasised that students were rating their learning performance based on their own normal state, not against other students.

Part 4 Indoor environmental comfort

Students were asked to vote how comfortable they perceived the classroom environment to be. They were given five environmental items to score: thermal comfort, visual comfort, hearing comfort, IAQ (perceptions of air freshness and odour) and overall environmental condition. The rating scale ranged from 1-Very Uncomfortable to 5-Very Comfortable.

Part 5 Seating zone

Students were asked to mark their seating zone on a room diagram. This allowed the matching of data obtained from students with the indoor environment within the classroom, which was monitored at the time of the survey.

Environmental condition measurements

Whilst the questionnaire was being completed, the environmental conditions were monitored in order to support the data analysis regarding the relationships between thermal conditions and PLP. The parameters were indoor and outdoor air temperature and RH, indoor globe temperature, and indoor air velocity. Details of measurements follow:

1) Air temperature and RH indoors were measured using a TinyTag Ultra 2, a data logger with internal sensors. The accuracy of the reading is ±0.4°C (resolution 0.01°C) and ±3% RH (resolution 0.3% RH). The instruments were located in nine positions evenly in the occupied area, at 0.60 metre approximately above floor level. The loggers were set to record the averaged data at 3-minute intervals for the whole class period.
2) Air temperature and RH outdoors were measured using a HOBO U12-012, a data logger with internal sensors. The accuracy is ±0.35°C (resolution 0.03°C at 25°C) and ±2.5% RH (resolution 0.03% RH). The instruments were located under shade on roof decks. The HOBO was set to record the averaged data at intervals of 3 minutes for the whole class period.
3) Globe temperature was measured indoors using a modified instrument. A regular 40mm diameter table tennis ball painted matt black was connected with a HOBO H08-003-02 data logger. The accuracy is ±0.7°C at 21°C with a resolution of 0.4°C. Mean radiant temperature, as a basic parameter of comfort temperature, can be calculated as a function of globe temperature, air temperature and air velocity. Globe temperature was measured at a height of approximately 0.80 metre in the centre of the room only due to the limited number of instruments available. The loggers collected average data at 3-minute intervals for the whole class period.
4) Indoor air velocity was measured using a Testo 405-V1, a hot-wire anemometer. The accuracy is ±0.1 m/s or ±5% for each reading (for 0 to ±2 m/s range) and the resolution is 0.01 m/s. Initially, it was planned to

measure the air velocity in nine locations in the room in order to match the air temperature and RH measurements. However, since there was only one instrument available, this would take at least 27 minutes to accomplish. Due to these time and instrument constraints, measurements were carried out in the centre of the room only, at a height of approximately 1 metre. The 3-minute averaged data were recorded.

It is important to note here that the CO_2 concentration was not included in the environmental condition measurements, although it is an important IAQ indicator, because there was no CO_2 monitor available for borrowing at the time of the field survey. However, there is some information about CO_2 concentrations in typical AC and ANV classrooms gained from a pilot study (see Appendix C, p. 378). Based on the pilot study, CO_2 concentrations in AC classrooms (measured at the end of a 2-hour class period) were always higher than 2,500 ppm (see Appendix C, Table C.1, p. 383), thereby exceeding the recordable range of the data logger. In comparison, the concentrations in ANV classrooms ranged from 806 to 2,049 ppm, depending on the number of occupants, opening area and associated ventilation rates. CO_2 concentrations outdoors during the same period were 362-380 ppm. Despite the lower CO_2 concentrations, students rated the IAQ in ANV classrooms significantly lower than those in AC classrooms. Notably, the IAQ was explained to students as ‘perceived indoor air freshness and odour’. In the pilot study, outdoor air pollution (odour and dusty air) might partially explain the lower IAQ rating given for the ANV classrooms. Possibly, for a lower range of air temperatures in AC classrooms, the adverse effects of low ventilation rates became less significant, as shown in the study by Tham (2004) (Subsection 3.3.3, p. 113).

Regarding the use of self-reported IAQ, Wyon and Wargocki (2013) commented that IAQ cannot be assessed by occupants because some contaminants cannot be sensed by humans but still affect their health and performance. Therefore, this potentially limits the self-reported IAQ assessment method and one must be aware of this when analysing the results.

Sample size and sampling method

The objective of this study is to test whether the self-reported learning performance of students in the same thermal comfort group, but in different thermal environments, i.e. AC and ANV classrooms, is different or not. The sample size determination then aims at deriving sufficient samples in each thermal comfort group or sufficient variance in participants' thermal comfort votes. In this regard, an equation proposed by Bartlett, Kotrlik and Higgins (2001) was used for estimating the sample size for this study. According to this a sample size of 308 in each comparative case (i.e. AC and ANV cases) was required for this survey, i.e. a total of 616 participants (see further explanation in Appendix B: Part 3 – Subsection 3.1.2, p. 376).

Four existing AC and three ANV classrooms were selected (see examples in Figure 4.11) and the questionnaire was administered in eight classes in AC rooms and six classes in ANV rooms in order to reach the targeted sample size.

The selected AC classrooms were in the Faculty of Science and Faculty of Engineering and Industrial technology in University A (coded) and ANV classrooms were in the Faculty of Logistics in University B (coded). Both universities were in suburban area to which the author had access. To control for other variables that were not relevant to this study but had potential influences on PLP, classes were carefully chosen for the survey by checking classroom timetables before selecting the classes. That is, no students participated in the survey twice. The teaching style in all classes was deemed to be relatively similar, i.e. lecture-based teaching. The proportions of students in each category for these variables, e.g. class size (<50, >50), participant's gender (female,

male) and class session (morning, afternoon) in AC and ANV cases were kept balanced as much as possible to avoid sampling bias. Introduction letters regarding the study were sent out to the teachers who were responsible for the selected classes before commencing the survey. Once the teachers agreed to participate in the study, equipment was installed in the classrooms in advance for measuring the environmental conditions during the survey.

(a) Air-conditioned room 1 (d) Air-conditioned room 2

(c) Assisted naturally ventilated room 1 (d) Assisted naturally ventilated room 2

Figure 4.11 Examples of selected air-conditioned and assisted naturally ventilated classrooms

Initially it was planned to carry out the survey in existing AC and ANV classes at the same time of the year. Unfortunately, the former selected ANV classrooms were installed with air-conditioners a few months before the commencement of the survey and therefore new ANV classrooms had to be identified. Consequently, the AC case was conducted first during the rainy season (July 2010), while the ANV case was undertaken later in the cool season (January 2011). The seasonal difference was not considered a significant methodological problem since the thermal environment in an AC classroom was relatively stable throughout the year and the independent variable of interest was thermal comfort not air temperature. Additionally, conducting the survey in ANV classrooms in the cool season was considered an advantage for this comparative study because a greater variation in daily outdoor and indoor temperatures could be obtained (low temperature in the morning and high temperature in the afternoon), compared to the hot season, when the daily temperature was always high. Consequently, a sufficient sample size in each thermal comfort category could be obtained. The paper-based questionnaire was administered to all students presented in the selected classes. The students completed the questionnaire by themselves at the end of each lecture. In total, 673 students participated in the survey with 348 respondents for the AC case and 325 respondents for the ANV case.

4.5 SUMMARY

In order to understand the research problem stated in Chapter 1 (Section 1.3, p. 36) concerned with the full-time use of air-conditioning in many MM non-residential buildings in hot-humid climates, the adaptive comfort theory has been mainly applied to formulate a research framework to test the following hypothesis.

> *Acceptance of fan assisted natural ventilation in existing mixed-mode non-residential buildings in hot-humid climates is affected by users' perceived behavioural adaptive opportunities and psycho-physiological adaptation, as well as by facilities management practice.*

The research framework consists of four main aspects concerning the possibilities for using ANV in HE buildings in Thailand, the case study of this thesis. Accordingly, four field studies were designed to achieve the specific research objectives.

Study 1: Thermal adaptive opportunity scoring system and acceptance of ANV survey, aims to identify the main factors of individual thermal adaptability and their contributions to the acceptance of the ANV mode. A questionnaire was developed for quantifying the effects of perceived behavioural adaptive opportunities and psycho-physiological adaptation on students' acceptance of the ANV mode in selected classrooms in two scenarios, the cool and hot seasons.

Study 2: Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey, aims to compare the pro-environmental attitudes and behaviour of students with different daily thermal experiences (i.e. full AC, full NV and mixed). A questionnaire was designed for assessing the levels of pro-environmental attitudes and adaptive behaviour of students.

Study 3: Facilities manager interviews, aims to investigate the possibilities and barriers to the implementation of three MM operational strategies (i.e. Concurrent, Change-over and Zoned) in existing MM HE buildings. Semi-structured interviews were used as the main method for obtaining data from FMs in various faculties in selected universities.

Study 4: Learning and thermal performance survey, aims to compare the perceived learning performance of students in AC and ANV classrooms. The perceived learning performance and thermal comfort were rated by students using a questionnaire.

The results of the field studies are expected to provide understanding about the possibilities for maintaining and/or increasing the use of ANV mode to supplement air-conditioning in existing and future MM non-residential buildings in hot-humid climates.

CHAPTER 5: RESULTS – INDIVIDUAL THERMAL ADAPTABILITY

5.1 FRAMEWORK AND PURPOSE

This chapter focuses on the investigation into individual thermal adaptability, and the framework of the investigation is presented in Figure 5.1 (also shown in Figure 4.2, p. 128). The investigation is divided into two main sections, with the first focusing on perceived behavioural adaptive opportunities and selected psycho-physiological adaptation factors of individual students. In the second section, pro-environmental attitudes of students are analysed in order to supplement the individuals' psychological adaptation investigation. It should be noted that the Predictive Analysis Software (PASW) package was used for the statistical analyses within this chapter.

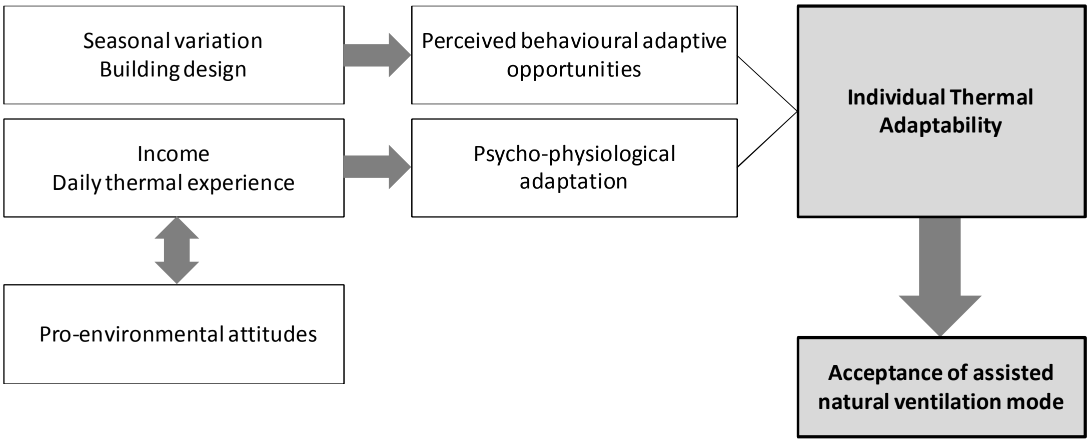


Figure 5.1 Sub-framework for the investigation of individual thermal adaptability

In Section 5.2, the investigation of students' perceived behavioural adaptive opportunities and psycho-physiological adaptation is presented based on the data obtained from Study 1: Thermal adaptive opportunity scoring system and acceptance of assisted natural ventilation survey. Statistical analyses were performed to estimate the contributions of the main factors (i.e. seasonal variation, building design, income and daily thermal experience) on students' acceptance of ANV mode in existing MM classrooms in a hot-humid climate.

In Section 5.3, the data analysis and the results of Study: 2 Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey, are described. This focuses on the relationships between daily thermal experience (i.e. level of exposure to air-conditioning) and pro-environmental attitudes and adaptive behaviour of students. In particular, the pro-environmental attitudes and behaviour of students with different daily thermal experiences are compared.

5.2 PERCEIVED BEHAVIOURAL ADAPTIVE OPPORTUNITIES AND PSYCHO-PHYSIOLOGICAL ADAPTATION

5.2.1 Case studies

Prior to conducting the Thermal adaptive opportunity scoring system and acceptance of ANV survey, a lecture room survey was conducted in May 2009 in order to obtain background information about the ventilation systems used in existing HE classrooms and to select appropriate classrooms for the survey.

Silpakorn university located in the central region of Thailand to which the author had access was selected for the lecture room survey. A total of 206 classrooms (almost all the classrooms available) were investigated; 162 classrooms were on suburban campus and 44 classrooms on urban campus.

As stated in the methodology chapter (Subsection 4.4.1.1, p. 137), based on four criteria, location, floor level, ceiling height and cross-ventilation, 25 classes conducted in 23 MM classrooms were visited for the Thermal adaptive opportunity scoring system and acceptance of ANV survey. The sample size obtained for each class and room type is shown in Table 5.1. As can be seen in the table, the sample sizes were quite different across the room typologies, which was dependent on the class size and rooms available.

Table 5.1 Sample collected classified by room type and class

Room Type				**Class**	**Room Name**	**Sample Collected**	**Subtotal**
Location	**Floor**	**Ceiling Height**	**Cross-ventilation**				
Urban	1-4	≤ 3.00 m	No	1[a]	ARCHAE-217	19	96
				13	ARCH-412	47	
				21[a]	ARCHAE-217	30	
			Yes	12	LC3306-7	19	110
				18	DEC-303	25	
				20	DEC-405	36	
				23	DEC-308	30	
		> 3.00 m	No	2	ARCHAE-406	36	36
			Yes	10[a]	ARCHAE-413	20	86
				16[a]	ARCHAE-413	29	
				25	CHULA-219	37	
	> 4	≤ 3.00 m	No	3	ARCHAE-506	38	66
				22	DEC-506	28	
			Yes	24	DEC-508	35	35
		> 3.00 m	No	-	-	-	-
			Yes	-	-	-	-
Suburban	1-4	≤ 3.00 m	No	14	SCI-1238	82	82
			Yes	7	EDU-1406	53	84
				11	EDU-1407	31	
		> 3.00 m	No	15	EDU-2124	18	104
				17	EDU-3402	32	
				19	EDU-3308	54	
			Yes	6	EDU-3416	27	59
				9	EDU-3316	32	
	> 4	≤ 3.00 m	No	-	-	-	-
			Yes	5	ENG-513	47	47
		> 3.00 m	No	4	BDG50-617	42	73
				8	BDG50-604	31	
			Yes	-	-	-	-
						Total	**878**

Note: a – These rooms had a low occupancy level during the first round of the survey; hence were surveyed twice but for different classes. However, not all rooms with a low capacity were surveyed twice due to some inconveniences in the field data collection.

The paper-based questionnaire was administered to all students presented in the chosen classes. In total, 878 students completed the survey and the respondent profiles are presented in Table 5.2.

Table 5.2 Personal data of the respondents

Characteristics		**Count (Respondent)**	**% of Valid**
Gender	Female	651	74.1%
	Male	227	25.9%
	Total	**878**	**100%**
Age (year)	Mean (min.-max.)	20.4 (18-30)	
	Valid	877	
	Missing	1	
	Total	**878**	
Faculty	Architecture	47	5.4%
	Archaeology	191	21.8%
	Decoration	154	17.5%
	Education	248	28.2%
	Science	106	12.1%
	Engineering	50	5.7%
	Arts	73	8.3%
	N/A	9	1%
	Total	**878**	**100%**
Clothing value (clo)	Mean (min.-max.)	0.39 (0.18-0.78)	
	Std. Deviation	0.105	
	Std. Error Mean	0.004	
	Valid	821	
	Missing	57	
	Total	**878**	
Income (Baht/Month)[b]	≤ 2,500	71	8.1%
	2,501-5,000	456	52.2%
	5,001-7,500	211	24.2%
	7,501-10,000	114	13.1%
	> 10,000	21	2.4%
	Valid	873	100%
	Missing	5	
	Total	**878**	
Thermal experience: Bedroom	AC	596	67.9%
	NV	282	32.1%
	Valid	878	100%
	Missing	0	
	Total	**878**	

Table 5.2 Personal data of the respondents (continued)

Characteristics		Count (Respondent)	% of Valid
Thermal experience: University	AC	723	83.1%
	MM[a]	147	16.9%
	Valid	870	100%
	Missing	8	
	Total	**878**	
Thermal experience: Transportation	AC	352	40.4%
	NV	519	59.6%
	Valid	871	100%
	Missing	7	
	Total	**878**	
Overall daily thermal experience (bedroom, university and transportation)	Full AC experience	236	27.3%
	Mixed experience	597	69.1%
	Full NV experience	31	3.6%
	Valid	864	100%
	Missing	14	
	Total	**878**	

Note: a – Fully NV university buildings are rare as well as students who use fully NV classrooms whole day; therefore, mixed-mode was used as a choice of thermal experience at university instead NV.

b – Approximately 50 Thai Baht is equal to 1 British Pound Sterling (GBP).

The number of female respondents was nearly triple that of male respondents (651: 227) and the average age was 20 years old. Regarding the imbalance between male and female students, the faculties surveyed had many more females than males enrolled. According to the national statistics for 2008 (the most recent data available), the number of female and male students (aged 18-24) within the HE sector in Thailand were 409,245 and 292,695 respectively (NSO, 2012a). Therefore, the proportion of female students was considerably higher than male students in general.

The educational backgrounds (faculty) of the respondents were mixed. The average clothing insulation value was 0.39, which is fairly low but normal for hot-humid countries. Notably, the majority of participants were wearing a student uniform whilst completing the survey (see an example of student uniform in Figure 5.2). The clothing values for a female and male student wearing a uniform were 0.29[28] and 0.48[29] respectively. Approximately 60% of the participants had low to moderately low incomes (≤ 5,000 Baht/Month) and almost 70% of respondents reported they had a mixed daily thermal experience (i.e. mix of air-conditioning and natural ventilation thermal experiences in daily life – bedroom, university and transportation).

Note: Male students can also wear a short-sleeve shirt and leave the tie. Some female students also wear a thin jacket in air-conditioned classrooms.

Figure 5.2 Silpakorn University uniform

Source: Student Affairs Division of Silpakorn University (2013)

The mean outdoor air temperature and RH during the observed period (July-August 2010 – rainy season) was 32.4°C (mean min. 25.9°C – mean max. 38°C) and 61% RH (mean min. 46% RH – mean max. 80% RH). All classrooms were operated in air-

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[28] Clothing value of a female uniform: short-sleeve shirt (0.09) + knee-length skirt (0.14) + thin-soled shoes (0.02) + bra and panties (0.04) = 0.29. If wearing a thin jacket, the clothing value would be 0.54.

[29] Clothing value of a male uniform: long-sleeve shirt (0.20) + trousers (0.15) + men's briefs (0.04) + thick ankle socks (0.05) + thick-soled shoes (0.04) = 0.48.

conditioning mode during the survey; therefore, the indoor climatic conditions were relatively stable (i.e. indoor air temperature was 25±3°C, 48±13% RH).

5.2.2 Factors affecting users' acceptance of assisted natural ventilation and effects

In this subsection the data collected from the Study 1: Thermal adaptive opportunity scoring system and acceptance of ANV survey were analysed using relevant statistical techniques. The process consisted of the five main steps shown below. Once the data analysis had been performed the factors affecting users' acceptance of the ANV mode in existing MM classrooms in a hot-humid climate and their contribution could be identified.

Step 1: Acceptance of assisted natural ventilation mode in MM classrooms

Step 2: Thermal adaptive opportunity – effectiveness and probability of given adaptive options

Step 3: Correlations tests

Step 4: Influences of thermal adaptive opportunity and personal variables on acceptance of assisted natural ventilation (multinomial logistic regression)

Step 5: Influences of design factors on thermal adaptive opportunity

The purpose of each step, the statistical techniques used and the results are explained in Subsections 5.2.2.1 to 5.2.2.5.

5.2.2.1 Step 1: Acceptance of assisted natural ventilation mode in mixed-mode classrooms

The frequencies and percentages of students' votes on acceptance of the ANV mode in the cool (ANVcool) and hot (ANVhot) seasons are presented in Table 5.3.

Table 5.3 Acceptance of assisted natural ventilation mode in the cool and hot seasons

	Acceptance of ANV			
	Cool season		**Hot season**	
	Frequency	Valid Percent	Frequency	Valid Percent
Disagree	62	7.1%	292	33.5%
Uncertain	263	30.1%	347	39.8%
Agree	550	62.9%	233	26.7%
Total	875	100%	872	100%
Missing value	3		6	
Total	**878**		**878**	

For ANVcool, the majority of participants (62.9%) agreed that they can maintain thermal comfort by using the ANV mode in MM classrooms. For ANVhot, many students (39.8%) were uncertain, which was slightly higher than those who disagreed (33.5%), about using the ANV mode in the hot season. The three most common reasons given by students (total number of responses was 318) who did not accept the use of ANV mode in either the cool or hot season were: too hot and/or humid air (45%), poor ventilation rates in the observed rooms (18%) and expected performance drop (17%). These reasons may also explain why a significant number of students were uncertain about the use of ANV. For the cool season, if the thermal condition is not the factor, then organisational and/or personal factors (for example, perceived low control over the thermal environments in classrooms and preference for constant AC comfort) may influence students' perceptions of ANV use. Factors that affected the students' acceptance of ANV are analysed further in the following parts.

5.2.2.2 Step 2: Thermal adaptive opportunity – effectiveness and probability of given adaptive options

The purpose of this subsection is to provide primary information about how students perceived the effectiveness and the probability of using ten adaptive options suggested for relieving heat discomfort in their existing MM classrooms. The raw scores for effectiveness and the probability of using the adaptive options were transformed into adaptive opportunity scores by multiplying them together.

First of all, the mean values for effectiveness and probability of each adaptive action rated by individual students were determined (1-Very Low to 5-Very High). It should be noted that the students were asked to rate the effectiveness of the given adaptive options in general, whilst the probability of those options was dependent on the classroom context. For example, if there was no ceiling fan in the room then the probability of using a fan was rated as 1 - Very Low.

Figure 5.3 shows a scatter plot of the mean scores for effectiveness against the probability of the given thermal adaptive options. For most adaptive options, the probability votes were higher than the effectiveness votes (i.e. the mean probability scores were above the diagonal line) except for the probability scores for fan operation, changing clothes and adjusting external shading devices. The absence of fans in some classrooms and non-adjustable shading devices were the main reasons for the low probability scores observed.

Considering the clothes adjustment, this finding is quite different from studies reviewed in Chapter 2 (Table 2.1, p. 73) where removing some clothes is considered one of the most common personal reactions when feeling hot. Liu and Yao (2012) state that in extreme climatic condition (very hot or very cold), clothing adjustment is not influential in restoring thermal comfort because the clothing values have already reached its maximum or minimum limit. The average clothing value of Thai students in this research was already low 0.39 clo (Table 5.2, p. 171). In this case, to take-off some more clothes is probably impractical. For a male student, it is possible to reduce the clothing value of a normal uniform from 0.48 to 0.28 if wearing a short-sleeve shirt and shorts instead. However, shorts might be considered impolite in Thai culture, particularly in education buildings. Therefore, the merit of clothing adjustment is restricted by the thresholds of clothing value associated with the degree of thermal discomfort and the strict dress code required in the classroom context.

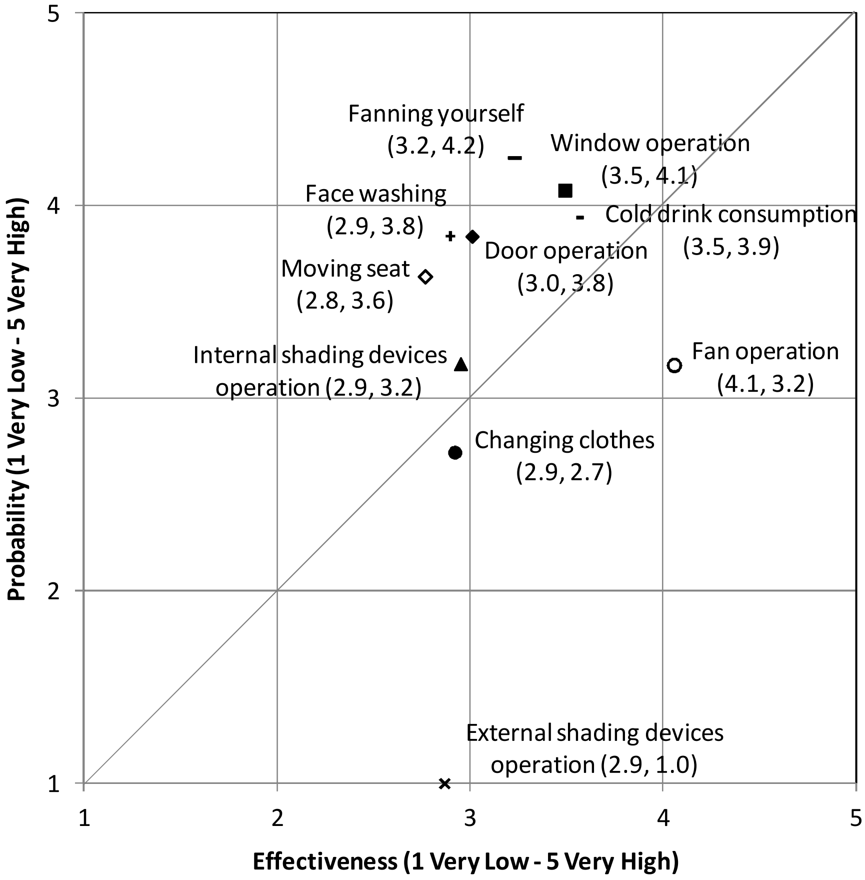
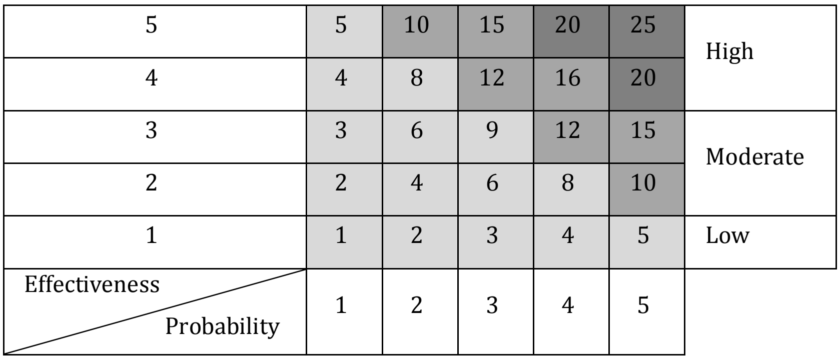


Figure 5.1 Scatter plot of the mean scores for 'effectiveness' against the 'probability' for the ten thermal adaptive options suggested

Based on the method proposed for adaptive opportunity quantification as presented in Figure 5.4 and shown earlier in Figure 4.9 (p. 145), thermal adaptive opportunity scores were calculated. The effectiveness score (5-point scale) was multiplied by the probability score (5-point scale) to produce the adaptive opportunity score which ranged from 1 to 25.



5	5	10	15	20	25	High
4	4	8	12	16	20	
3	3	6	9	12	15	Moderate
2	2	4	6	8	10	
1	1	2	3	4	5	Low
Effectiveness Probability	1	2	3	4	5	

Figure 5.4 Thermal adaptive opportunity quantification

The average opportunity scores, standard deviation and variance of the ten adaptive options are presented in Table 5.4. When considering both the perceived effectiveness and probability of the adaptive options in context, window operation (14.80) was ranked first followed by cold drink consumption (14.38) and fanning yourself (14.12).

Table 5.4 Mean scores, standard deviations and variances of adaptive opportunity scores of ten thermal adaptive options

Rank	**Thermal Adaptations**	**Opportunity Score (1 Low – 25 High)**			
		N	**Average**	**Standard Deviation**	**Variance**
1	Window operation	874	14.80	6.89	47.46
2	Cold drink consumption	874	14.38	6.15	37.77
3	Fanning yourself	874	14.12	6.35	40.31
4	Fan operation	873	13.06	8.49	72.00
5	Door operation	874	12.08	6.88	47.29
6	Face washing	871	11.56	6.13	37.53
7	Moving seat	874	10.33	6.09	37.11
8	Internal shading devices operation	872	9.68	6.53	42.70
9	Changing clothes	866	8.41	5.78	33.44
10	External shading devices operation	868	2.87	1.06	1.12

At this stage, the results only show the effectiveness, the probability and calculated adaptive opportunity scores of the given adaptive options in the observed MM classrooms. In order to examine the influences of these perceived behavioural adaptive opportunities as well as other contextual and personal variables on students' acceptance of ANV mode in the selected classrooms, the correlations between these variables were then tested.

5.2.2.3 Step 3: Correlation tests

In step 3, the dependent variables (i.e. acceptance of ANV mode in the cool and hot seasons – ANVcool and ANVhot) were tested as to whether they were directly correlated with the adaptive opportunity scores for the ten adaptive actions and personal variables (i.e. monthly income and daily thermal experience). The purpose of these correlation tests is to identify potential independent variables (the variables that can explain the students' acceptance of ANV mode) which will be used in multinomial logistic regression in Step 4 (Subsection 5.2.2.4, p. 183).

Prior to the correlation analysis, the original adaptive opportunity scores (1-25) of the ten adaptive options were transformed into a 3-level ordinal scale (i.e. 1-9 = Low, 10-19 = Moderate and 20-25 = High) following the diagram in Figure 5.4 (p. 178). The reason for transforming the adaptive score from interval into an ordinal scale is the sparseness of the score itself. Although the original score ranges from 1 to 25, a number of scores are missing (i.e. 7, 11, 13, 14, 17, 18, 19, 21, 22, 23 and 24) due to the nature of the quantification method used. Therefore, it was considered more suitable to treat the adaptive opportunity scores as an ordinal scale in this analysis. The transformed adaptive opportunity scores for the ten adaptive options, participant's daily thermal experience, and income were used in a bivariate analysis to test their correlations with ANVcool and ANVhot. Since ANVcool and ANVhot were a nominal scale and adaptive opportunity levels were an ordinal data, the Pearson chi-square (χ^2) test was chosen for the correlation analysis.

Table 5.5 shows the results of the χ^2 tests between acceptance of the ANV mode (i.e. ANVcool and ANVhot) and the opportunity levels for the ten adaptive options. Cramer's V values (φ_c) express the strength of the association between two nominal variables that have more than two categories (Field, 2009, p. 695). The φ_c ranges from 0 (no association) to 1 (complete association), but does not indicate the direction of any association (i.e. positively or negatively correlated) (Field, 2009, p. 698).

Considering the ρ-values, the opportunity to use fans (OPPfan), windows (OPPwindow) and door(s) (OPPdoor) were statistically correlated with ANVcool and ANVhot, although the strengths of the relationship were weak (i.e. φ_c is lower than 0.30).

Table 5.6 shows the results of the correlation tests between acceptance of ANV mode, ANVcool and ANVhot, and participant's personal variables. As can be seen, all personal variables except for thermal experience at university (EXuni) were statistically correlated with ANVhot only, with ρ-values < 0.05, but the relationships were weak (i.e. φ_c is lower than 0.30).

Table 5.5 Correlations between acceptance of assisted natural ventilation (in the cool or hot season) and adaptive opportunity levels (low, moderate and high) of ten adaptive options

No.	Variables	Statistics	ANVcool	ANVhot
1	Door operation (OPPdoor)	Sig. (2-tailed)	0.042	0.033
		Cramer's V	**0.075***	**0.078***
2	Window operation (OPPwindow)	Sig. (2-tailed)	0.000	0.024
		Cramer's V	**0.167****	**0.080***
3	Internal shading devices operation (OPPint)	Sig. (2-tailed)	0.133	0.406
		Cramer's V	0.064	0.048
4	External shading devices operation[a] (OPPext)	Sig. (2-tailed)	-	-
		Cramer's V	-	-
5	Fan operation (OPPfan)	Sig. (2-tailed)	0.000	0.000
		Cramer's V	**0.190****	**0.157****
6	Changing clothes (OPPclo)	Sig. (2-tailed)	0.054	0.612
		Cramer's V	0.073	0.039
7	Face washing (OPPface)	Sig. (2-tailed)	0.538	0.838
		Cramer's V	0.042	0.029
8	Cold drink consumption (OPPdrink)	Sig. (2-tailed)	0.384	0.473
		Cramer's V	0.049	0.045
9	Fanning yourself (OPPself-fan)	Sig. (2-tailed)	0.503	0.487
		Cramer's V	0.044	0.045
10	Moving seat (OPPseat)	Sig. (2-tailed)	0.923	0.428
		Cramer's V	0.023	0.047

Note: ** Correlation was significant at the ρ = 0.01 level (2-tailed).

* Correlation was significant at the ρ = 0.05 level (2-tailed).

a. No statistics were computed because the opportunity for external shading devices operation (ordinal scale) was a constant.

Table 5.6 Correlations between acceptance of assisted natural ventilation (in the cool or hot season) and participant's personal variables

No.	Variables	Statistics	ANVcool	ANVhot
1	Thermal experience_Bedroom (EXbed) (1-AC, 2-NV)	Sig. (2-tailed)	0.055	0.005
		Cramer's V	0.081	**0.109****
2	Thermal experience_University (EXuni) (1-AC, 2-Mixed-mode)[a]	Sig. (2-tailed)	0.656	0.220
		Cramer's V	0.031	0.059
3	Thermal experience_Transportation (EXtrn) (1-AC, 2-NV)	Sig. (2-tailed)	0.270	0.000
		Cramer's V	0.055	**0.166****
4	Daily thermal experience (TExp) (1-Full AC, 2-Mixed-mode, 3-Full NV)	Sig. (2-tailed)	0.568	0.001
		Cramer's V	0.041	**0.104****
5	Income (Baht/Month) (1 = ≤ 2,500, 2 = 2,501-5,000, 3 = 5,001-7,500, 4 = 7,501-10,000, 5 = > 10,000)	Sig. (2-tailed)	0.168	0.001
		Cramer's V	0.082	**0.126****

Note: a – Fully NV university buildings are rare; therefore, mixed-mode was used as a choice of thermal experience at university instead NV.

** Correlation was significant at the ρ = 0.01 level (2-tailed).

* Correlation was significant at the ρ = 0.05 level (2-tailed).

One observation resulting from this correlation analysis and the previous assessment of the effectiveness and probability of the ten adaptive options, is that although some adaptive options were highly effective and probable, such as drinking cold water and fanning yourself, they were not found to be correlated with acceptance of the ANV mode for both seasons. This could possibly be explained by the limitation of the variances in the adaptive opportunity scores of these adaptive options. According to Table 5.4 (p. 178), the variances of adaptive opportunities for some adaptive actions across all selected classrooms were low compared to others. When the variation in an independent variable is limited, then its correlation with a dependent variable may not be found. This can be a weakness of field data collection when only one type of building is surveyed. Therefore, insignificant correlations between ANVcool/ANVhot and some adaptive options do not always mean that the adaptive actions are not important for users to accept or refuse the use of the ANV mode within the observed MM classrooms.

5.2.2.4 Step 4: Influence of thermal adaptive opportunity and personal variables on acceptance of assisted natural ventilation (multinomial logistic regression)

In the previous step, the correlation tests only revealed whether students' acceptance of the ANV mode was associated with the levels of adaptive opportunity and personal variables, i.e. daily thermal experience and income; however, the direction of the associations and the contribution of each independent variable on the dependent variable were not clarified. Therefore, in this step the influence (direction and contribution) of those independent variables found to be statistically correlated with the acceptance of the ANV mode in the cool or hot seasons, based on the results of the correlation tests in Subsection 5.2.2.3 are examined.

Multinomial logistic regression (MLoR) was employed for this analysis since the dependent variables, i.e. ANVcool and ANVhot, are a nominal scale. MLoR is a statistical tool which is equivalent to a multiple linear regression (MLiR), but is used for categorical dependent variables with more than two categories. Further information concerning MLoR is provided in Appendix B: Part 1 – Section 1.1 (p. 363).

Generally, MLoR is used to construct logit model(s) to predict the probabilities of an outcome in one category against a reference category (Agresti, 2007, pp. 173-174), and the form of a logit model is presented in Equation 5.1. From the model, J denotes the number of categories for the outcome variable, π_1, ...π_J denotes the response probabilities, R is the reference category, and x is an independent variable, which can be a categorical or interval scale. A logit model for predicting 'log odds' that the outcome is j rather than R is given as:

$$\text{Log}\,(\pi_j/\pi_R) \quad = \quad \alpha_j + B_j\,x, \qquad j = 1, \ldots, J - 1 \qquad \textbf{Equation 5.1}$$

where: π_j/π_R = the probability of the outcome being *j* rather than *R*

α = intercept

B = parameter estimates

A MLoR will generate $J - 1$ equations with separate sets of parameters for each. For example, if $J = 3$ and j_3 is the reference category, a MLoR will produce two equations ($J - 1$); the first equation contrasts π_{j1} and π_{j3} and the second equation contrasts π_{j2} and π_{j3} (as contrasts of π_{j3} and π_{j3} will always equal 1). Parameter estimates (B) show the increase or decrease in the predicted probability of the event of interest resulting from a unit change in the independent variables, where α is a constant value (Koutoumanou and Wade, 2010, p. 6). As the output of a logit model is expressed in terms of 'log odds', the odds of the outcome being π_1 or π_2 rather than π_3 (i.e. π_1/π_3 and π_2/π_3) can be identified using by an anti-logarithm using an exponential function. Finally, the actual probabilities of an event (i.e. π_1, π_2 and π_3) can be estimated by applying Equations 5.2 – 5.4 based on the rule that the sum of the probabilities of all three possible outcomes is equal to 1 (i.e. $\pi_1 + \pi_2 + \pi_3 = 1$).

$$\pi_1 = \frac{(\pi_1/\pi_3)}{(\pi_1/\pi_3) + (\pi_2/\pi_3) + 1} \qquad \textbf{Equation 5.2}$$

$$\pi_2 = \frac{(\pi_2/\pi_3)}{(\pi_1/\pi_3) + (\pi_1/\pi_3) + 1} \qquad \textbf{Equation 5.3}$$

Thus, $\pi_3 = 1 - \pi_1 - \pi_2$ **Equation 5.4**

Apart from the probability of an event, the results can be reported in terms of an 'odds ratio'. An odds ratio is the odds of an event in situation A divided by the odds of the same event in situation B (Koutoumanou and Wade, 2010, p. 12), as expressed in

Equation 5.5. In the MLoR output from the PASW package, an odds ratio is expressed as $Exp(B)$. By considering the odds ratio, the effects of independent variables on the event of interest or outcome can be measured.

$$\text{Odds ratio} = \frac{\text{Odds of an event given situation A}}{\text{Odds of an event given situation B}} \qquad \textbf{Equation 5.5}$$

The MLoR analysis for this step was divided into three parts: Part 1 Acceptance of assisted natural ventilation in the cool season, Part 2 Acceptance of assisted natural ventilation in the hot season, and Part 3 Acceptance of assisted natural ventilation between seasons, as follows.

Part 1: Acceptance of assisted natural ventilation in the cool season

Three independent variables were included in this analysis: opportunity to use doors, windows and fans, as these were statistically correlated to the dependent variable according to the results of the correlation tests (Subsection 5.2.2.3, p. 179). These variables are on an ordinal scale with three categories: Low, Moderate and High. The acceptance of the ANV mode in the cool season was the dependent variable with three outcome categories: Disagree, Uncertain and Agree.

The MLoR analysis of how the opportunity for door, window, and fan operations affected students' acceptance of the ANV mode in the cool season was performed for three trials by PASW. 'Disagree' was selected as the reference category and only the main effects of the independent variables were considered, i.e. there was no interaction between the independent variables. Problems encountered in each trial and the improvements made are summarised in Table 5.7. In the last trial, most statistical problems have been solved and the MLoR model obtained was considered reliable. Only the results of the last trial are presented here. The completed results from MLoR

Trials 1 – 3 can be found in Appendix E: Part 1 – Section 1.1, Tables E.1 - E.21 (pp. 412 - 420).

Table 5.7 Summary of multinomial logistic regression trials for ANVcool analysis

Trial	Dependent Variable	Independent Variables	Observations
Trial 1	ANVcool	1. OPPdoor 2. OPPwindow 3. OPPfan	There were 16 (20.5%) cells (i.e. dependent variable levels by valid subpopulations[30]) with zero frequencies. Ideally, all cells must have at least 1 count, and the number of cells with less than 5 counts must not exceed 20% of the total cells.
Trial 2	ANVcool	1. OPPwindow 2. OPPfan	The weakest predictor, i.e. OPPdoor, was removed to improve the cell counts. According to the parameter estimate (B), the probabilities of students voting 'Uncertain' and 'Agree' against 'Disagree' between those who perceived moderate and high OPPwindow and between moderate and high OPPfan were not significantly different in all cases.
Trial 3	ANVcool	1. OPPwindow 2. OPPfan (moderate and high categories of each variable were combined)	The moderate and high OPPwindow categories were combined. Similarly, the moderate and high OPPfan categories were merged.

In the last trial, the opportunity to use the door was excluded due to its insignificance. Furthermore, the level of adaptive opportunity for window opening and fan operation were reduced from three to two in order to improve the significance of the variables. All variables were then recoded and renamed as presented in Table 5.8.

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[30] The number of subpopulations is calculated by multiplying the number of all categories of independent variables together. In this case, the number of subpopulations should be (3×3×3) = 27. The number of cells is calculated by multiplying the number of subpopulations by the number of categories of dependent variable. The total number of cells should be 27×3 = 81. However, a subpopulation with zero frequencies was considered invalid. For Trial 1, there was one invalid subpopulation. Therefore, there were only 26 valid subpopulations and 78 (26×3) valid cells.

Table 5.8 Code sheet for the variables in the multinomial logistic regression analysis, ANVcool – Trial 3

Variable	Description (scale)	Codes/Values	Name
1. DV	Do you agree that you would still be able to maintain your comfort if using natural ventilation and fans (if available) instead of air-conditioning within this classroom in the cool season? (nominal)	1 = Disagree (ref.) 2 = Uncertain 3 = Agree	ANVcool
2. IV	Adaptive opportunity for window operation (dichotomous)[a]	1 = Low 0 = Moderate-High	OPPwindow
3. IV	Adaptive opportunity for fan operation (dichotomous)	1 = Low 0 = Moderate-High	OPPfan

Note: a – A dichotomous variable is a variable with two categories and respondents can fall into one category only.

Of the total number of 878 cases, 868 cases were valid and used in the MLoR analysis (Table 5.9). There were no empty cells detected by PASW.

Table 5.9 Case processing summary for the multinomial logistic regression analysis, ANVcool – Trial 3

Variables		N	Marginal Percentage
Acceptance of ANV in the cool season	Disagree	61	7.0%
	Uncertain	259	29.8%
	Agree	548	63.1%
Opportunity for window operation	Low	218	25.1%
	Moderate-High	650	74.9%
Opportunity for fan operation	Low	380	43.8%
	Moderate-High	488	56.2%
Valid		868	100%
Missing		10	
Total		878	
Subpopulation		4	

The final results of the MLoR analysis regarding the effects of adaptive opportunity for window and fan operations on the probability of respondents voting 'Agree' or

'Uncertain' against 'Disagree' to the ANV mode in the observed MM classrooms in the cool season are presented in Table 5.10.

Table 5.10 Multinomial logistic regression output from PASW, ANVcool – Trial 3

Acceptance of ANV in Cool Season	**B (SE)**	**95% Confidence Interval for Exp(B)**		
		Exp(B)	**Lower Bound**	**Upper Bound**
Uncertain vs. Disagree				
Intercept	1.839 (0.260)***			
[OPPwindow =1]	-0.348 (0.298)	0.706	0.394	1.267
[OPPfan =1]	-0.398 (0.314)	0.672	0.363	1.244
Agree vs. Disagree				
Intercept	3.128 (0.248)***			
[OPPwindow =1]	-1.022 (0.292)***	0.360	0.203	0.637
[OPPfan =1]	-1.196 (0.301)***	0.303	0.168	0.546

Note: R^2 = 0.08 (Cox and Snell), 0.10 (Nagelkerke), 0.05 (McFadden). Model $\chi^2(4) = 75.78$, $\rho < 0.001$. * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.

From Table 5.10, the statistics shows that the opportunities to use windows and fans significantly contributed to students' acceptance of the ANV mode during the cool season. The contributions of these two independent variables are described as follows (based on the $Exp(B)$ values from Table 5.10).

The odds of 'Agree' versus 'Disagree' vote (cool season)

1) Students are 2.8 (1/0.360) times more likely to vote 'Agree' rather than 'Disagree', if the opportunity to use windows increased from a low to moderate-high level, the 95%CI for these odds is 1.6 to 4.9 times, $\rho < 0.001$.
2) Students are 3.3 (1/0.303) times more likely to vote 'Agree' rather than 'Disagree', if the opportunity to use fans increased from a low to moderate-high level, the 95%CI for these odds is 1.8 to 6 times, $\rho < 0.001$.

Based on Equation 5.1 and the MLoR output, two logit models were generated to estimate the percentages of ANV votes for the cool season based on the levels of adaptive opportunity for window and fan operations. The equations for these are:

1) The log odds of voting Agree versus Disagree (π_A/π_D) for ANVcool

$$\text{Log}\,(\pi_A/\pi_D) = 3.128 + (1.022)(LowOPPwindow) + (1.196)(LowOPPfan) \qquad \textbf{Equation 5.6}$$

2) The log odds of voting Uncertain versus Disagree (π_U/π_D) for ANVcool

$$\text{Log}\,(\pi_U/\pi_D) = 1.839 + (-0.348)(LowOPPwindow) + (-0.398)(LowOPPfan) \qquad \textbf{Equation 5.7}$$

Figure 5.5 shows the overall predicted percentages for votes in different situations (i.e. the levels of opportunities to use windows and fans).

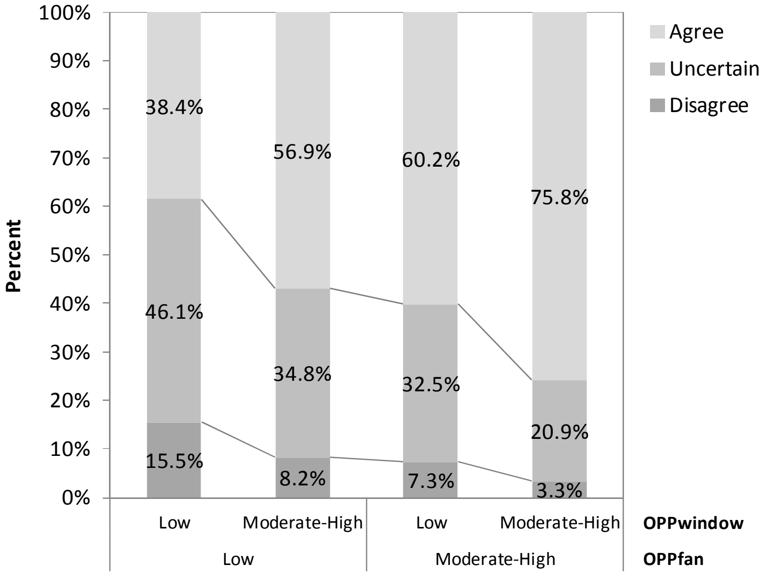

Figure 5.5 Predicted percentages of students' votes on the agreement to use assisted natural ventilation in the cool season categorised by the level of opportunities to use windows (OPPwindow) and fans (OPPfan)

In summary, students were more likely to vote 'Agree' for the use of ANV in the cool season if they perceived high opportunities to use windows and/or fans. In comparison, the ρ-values (from Table 5.10) indicate that changes in perceived opportunities for window and fan operations did not predict the 'Uncertain' (against 'Disagree') vote.

Part 2: Acceptance of assisted natural ventilation in the hot season

The MLoR analysis in this part focuses on the factors affecting students' acceptance of the ANV mode during the hot season. The relevant independent variables were obtained from the correlation tests conducted in Subsection 5.2.2.3 (p. 179); opportunity for door opening (OPPdoor), window opening (OPPwindow), fan operation (OPPfan), participant's daily thermal experience (TExp) and participant's monthly income (Income). All the independent variables were on a categorical scale. The dependent variable was acceptance of the ANV mode in the hot season with three categories: Disagree, Uncertain and Agree.

The analysis for ANVhot was also conducted three times using PASW and all of the significant independent variables were input into the first trial. Only the main effects of the independent variables were examined, i.e. no interactions between the independent variables. 'Disagree' was chosen as the reference category and Table 5.11 gives a summary of the statistical trials for the ANVhot analysis and the problems encountered. Only the results of the third trial are reported here; the full results of all the trials are presented in Appendix E: Part 1 - Section 1.1, Tables E.22 - E.42 (pp. 421 - 431).

Table 5.11 Summary of the multinomial logistic regression trials for the ANVhot analysis

Trial	Dependent Variable	Independent Variables	Observations
Trial 1	ANVhot	1. OPPdoor 2. OPPwindow 3. OPPfan 4. Daily thermal experience 5. Monthly income	There were 208 (39%) cells (i.e. dependent variable levels by subpopulations) with zero frequencies. This potentially caused problems with the chi-square tests. According to the likelihood ratio chi-square tests, OPPdoor and OPPwindow were not significant.
Trial 2	ANVhot	1. OPPfan 2. Daily thermal experience 3. Monthly income	The insignificant independent variables were removed. There were still 15 (13.2%) cells (i.e. dependent variable levels by subpopulations) with zero frequencies. Based on parameter estimates, the effect of having a mixed thermal experience was not significantly different from having a full NV experience. Also, the effects of having an income higher than 2,500 Baht/Month were not significantly different from having an income higher than 10,000 Baht/Month.
Trial 3	ANVhot	1. OPPfan 2. Daily thermal experience 3. Monthly income (levels of OPPfan, daily thermal experience, and monthly income were collapsed from three levels into two levels)	Moderate and high OPPfan levels were combined. For the daily thermal experience, the mixed-mode and full NV categories were grouped together. For participant's income, the variable was re-categorised into two groups: low (≤ 5,000 Baht/Month) and high (> 5,000 Baht/Month).

In Trial 3, the opportunities to use door(s) and windows were removed from the analysis due to their insignificance. The remaining independent variables, i.e. adaptive opportunity for fan operation, participant's daily thermal experience and monthly income, were reclassified in order to improve the cell counts and the significance of the parameter estimates of the final model. Names and codes for all the variables are shown in Table 5.12.

Table 5.12 Code sheet for the variables employed in the multinomial logistic regression analysis, ANVhot – Trial 3

Variable	Description (scale)	Codes/Values	Name
1. DV	Do you agree that you would still be able to maintain your comfort when using natural ventilation and fans (if available) instead of air-conditioning within this classroom during the hot season? (nominal)	1 = Disagree (ref.) 2 = Uncertain 3 = Agree	ANVhot
2. IV	Adaptive opportunity for fan operation (dichotomous)	1 = Low 0 = Moderate-High	OPPfan
3. IV	Participant's daily thermal experience (dichotomous)	1 = Full AC 0 = Non-full AC	TExp
4. IV	Participant's income (Baht/Month) (dichotomous)	1 = ≤ 5,000 0 = > 5,000	Income

Table 5.13 shows the number of cases categorised by the dependent and independent variables. A total number of 851 valid cases were analysed. At this stage, there were no cells with a zero frequency; therefore, the distribution of the data was sufficient for the MLoR analysis.

Table 5.13 Case processing summary for the multinomial logistic regression analysis, ANVhot – Trial 3

Variables		N	Marginal Percentage
Acceptance of ANV in the hot season	Disagree	284	33.4%
	Uncertain	339	39.8%
	Agree	228	26.8%
Opportunity for fan operation	Low	373	43.8%
	Moderate-High	478	56.2%
Daily thermal experience	Full AC	232	27.3%
	Non-full AC	619	72.7%
Participant's income (Baht/Month)	</=5,000	512	60.2%
	>5,000	339	39.8%
Valid		851	100%
Missing		27	
Total		878	
Subpopulation		8	

The output of the MLoR analysis performed by using PASW is presented in Table 5.14.

Table 5.14 Multinomial logistic regression output from PASW, ANVhot – Trial 3

Acceptance of ANV in Hot Season	B (SE)	95% Confidence Interval for Exp(B)		
		Exp(B)	Lower Bound	Upper Bound
Uncertain vs. Disagree				
Intercept	0.157 (0.160)			
[OPPfan=1]	-0.625 (0.168)***	0.535	0.385	0.744
[TExp=1]	0.039 (0.181)	1.039	0.728	1.483
[Income=1]	0.547 (0.167)***	1.729	1.247	2.396
Agree vs. Disagree				
Intercept	0.120 (0.171)			
[OPPfan=1]	-1.038 (0.193)***	0.354	0.243	0.517
[TExp=1]	-0.581 (0.225)**	0.559	0.360	0.869
[Income=1]	0.437 (0.187)*	1.548	1.072	2.236

Note: R^2 = 0.07 (Cox and Snell), 0.08 (Nagelkerke), 0.03 (McFadden). Model $\chi^2(6) = 63.09$, $\rho < 0.001$. * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.

From Table 5.14, the statistics shows that all three variables, i.e. OPPfan, TExp and Income, significantly contributed to the final models. The revisions of the OPPfan levels from three to two categories (Low and Moderate-High OPPfan), TExp levels from three to two categories (Full AC and Non-full AC) and Income levels from five to two categories (≤5,000 and >5,000 Baht/Month) improved the significance of the parameters. That is, this made the effects of these independent variables on the probabilities of students' votes more apparent.

According to the $Exp(B)$ values shown in Table 5.14, the contributions of the independent variables on the probability of students' vote on the ANV mode for the hot season can be concluded as follows:

The odds of 'Agree' versus 'Disagree' vote (hot season)

1) Students are 2.8 (1/0.354) times more likely to vote 'Agree' rather than 'Disagree', if the opportunity to use fans is increased from low to a moderate-high level, the 95%CI of the odds is 1.9 to 4.1 times, $\rho < 0.001$.
2) Students are 1.8 (1/0.559) times more likely to vote 'Agree' rather than 'Disagree', if students have had more daily exposure to NV environments rather than full AC, the 95%CI of the odds is 1.2 to 2.8 times, $\rho < 0.01$.
3) Students are 1.5 times more likely to vote 'Agree' rather than 'Disagree', if the students have a low income rather than a high income, the 95%CI of the odds is 1.1 to 2.2 times, $\rho < 0.05$.

The odds of 'Uncertain' versus 'Disagree' vote (hot season)

1) Students are 1.9 (1/0.535) times more likely to vote 'Uncertain' rather than 'Disagree', if the opportunity to use fans is increased from low to moderate-high level, the 95%CI of the odds is 1.3 to 2.6 times, $\rho < 0.001$.

2) Students are 1.7 times more likely to vote ‘Uncertain’ rather than ‘Disagree’, if the students have a low income rather than a high income, the 95%CI of the odds is 1.2 to 2.4 times, $\rho < 0.001$.

Following the final statistical output, two equations for predicting the probabilities of the outcomes, i.e. students’ vote on the use of the ANV mode during the hot season could be established.

1) The log odds of voting Agree versus Disagree (π_A/π_D) for ANVhot

$$\text{Log}\ (\pi_A/\pi_D) = 0.120 + (-1.038)(LowOPPfan) + (-0.581)(FullAC) + (0.437)(Income \leq 5{,}000) \qquad \textbf{Equation 5.8}$$

2) The log odds of voting Uncertain versus Disagree (π_U/π_D) for ANVhot

$$\text{Log}\ (\pi_U/\pi_D) = 0.157 + (-0.625)(LowOPPfan) + (0.039)(FullAC) + (0.547)(Income \leq 5{,}000) \qquad \textbf{Equation 5.9}$$

Figure 5.6 illustrates the predicted percentages of students’ votes by levels of OPPfan, TExp and Income.

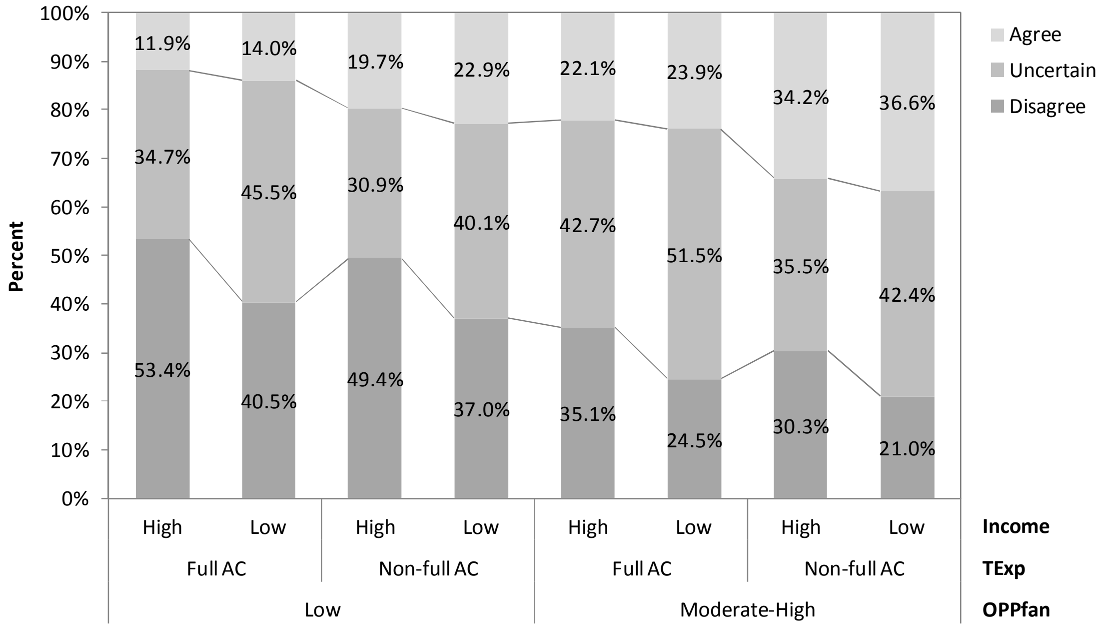

Figure 5.6 Predicted percentages of votes on the agreement to use assisted natural ventilation in the hot season categorised by the level of opportunities to use fans (OPPfan), daily thermal experience (TExp) and income

In summary, the MLoR analysis suggests that students were more likely to agree that the ANV mode can maintain thermal comfort in the observed MM classrooms in the hot season if they had a lower income (i.e. lower than 5,000 Baht/Month), less daily exposure to air-conditioning, and a perceived moderate to high opportunity to use fans. The higher opportunity to use fans and a low income also increased the likelihood of voting 'Uncertain' as opposed to 'Disagree'. In contrast, a change in daily thermal experience did not predict the likelihood of choosing 'Uncertain' over 'Disagree' regarding the use of ANV.

Part 3: Acceptance of assisted natural ventilation between seasons

The effect of seasonal variation on students' acceptance of the ANV mode is investigated in this part as it has not been analysed in either Part 1 or 2. Odds ratios for students' voting 'Agree' against 'Disagree' and 'Uncertain' against 'Disagree' for use of the ANV mode during the cool and hot season were calculated. Table 5.15 shows the frequencies of the votes in a cross-tabular form. Equation 5.5 (p. 185) was used for the odds ratio calculation.

Table 5.15 Cross table for assisted natural ventilation votes by season (count)

		ANV votes for the hot season			Total
		Disagree	**Uncertain**	**Agree**	
ANV votes for the cool season	**Disagree**	36	20	6	62
	Uncertain	116	120	26	262
	Agree	140	207	201	548
Total		292	347	233	872

Firstly, odds ratio for students voting 'Agree' rather than 'Disagree' in the cool and hot seasons was calculated based on the data in the 3×3 table of cell frequencies above.

$$\text{Odds ratio} = \frac{\text{Odds of 'Agree' vs 'Disagree' in cool season}}{\text{Odds of 'Agree' vs 'Disagree' in hot season}} \qquad \textbf{Equation 5.10}$$

$$= (548/62) \ / \ (233/292)$$

$$= 11.08$$

The result shows that the odds of students voting 'Agree' for ANV use during the cool season compared with 'Disagree' were 11.1 times (95%CI of the odds ratio is 8.1 to 15 times) more than for the hot season (for the calculation of 95%CI see Appendix E: Part 1 – Section 1.1, after Table E.43, p. 431).

Secondly, odds ratio for students voting 'Uncertain' rather than 'Disagree' during the cool and hot seasons was calculated based on the data in Table 5.15 (p. 197).

$$\text{Odds ratio} = \frac{\text{Odds of 'Uncertain' vs 'Disagree' in cool season}}{\text{Odds of 'Uncertain' vs 'Disagree' in hot season}} \qquad \textbf{Equation 5.11}$$

$$= (262/62) \ / \ (347/292)$$

$$= 3.55$$

The odds of students voting ‘Uncertain’ for ANV use during the cool season compared with ‘Disagree’ were 3.6 times (95%CI of the odds ratio is 2.6 to 4.9 times) more than for the hot season (for the calculation of 95%CI see Appendix E: Part 1 – Section 1.1, after Table E.43, p. 431).

The perception of the outdoor climate in different seasons was likely to be the most influential factor in predicting students’ acceptance of the ANV mode in the observed MM classrooms. This finding is consistent with the reasons given by students as to why they disagreed with using the ANV mode in the existing MM classrooms (see Subsection 5.2.2.1, p. 175).

5.2.2.5 Step 5: Influences of design factors on thermal adaptive opportunity

In the last step, the design factors affecting the opportunity for fan and window operations were investigated as the evidence from the correlation tests and the MLoR analysis showed that fan and window operations were the two most important adaptive options that predicted students’ acceptance of the ANV mode in MM classrooms. The data analysis in this step focused on what design variables were influential in increasing the level of opportunity to use fans and windows and to what degree. Notably, the opportunity scores used in this analysis were treated as an interval rather than ordinal scale, although the data were sparse, because the author needed to retain the original information of the dependent variable as much as possible. The opportunity scores can be reported in terms of an ordinal scale later. Caveats applied to the findings resultant from this data treatment are also addressed. The statistical analysis of this subsection is divided into two parts: the opportunity to use fans and windows.

Part 1: Opportunity for fan operation

The relevant factor for the opportunity to use fans was the number of fans per student (Nfan), which combined the availability of fans and how they were shared by students. The number of fans was obtained from the lecture room survey, and the fan sharing ratio was based on total number of seats. In order to examine changes in the OPPfan score when the number of fans per student changes, the original OPPfan scores (1-25) and Nfan were regressed via Linear Regression. OPPfan was treated as the dependent variable and Nfan the independent variable. Figure 5.7 shows the distribution of the data on fan sharing. From the chart, there were 319 students occupying the MM classrooms with no fans.

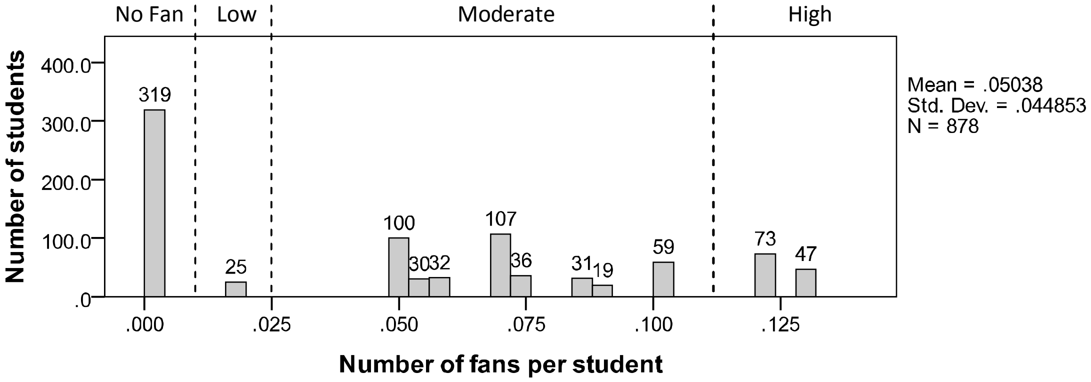

Figure 5.7 The distribution of the data of fan sharing (number of fans per student)

From Figure 5.7 it can be seen that the number of fans across all the observed classrooms were limited and sparse. Therefore, it was more suitable to treat Nfan as a categorical variable and subsequently, Nfan was classified into four categories as shown in Table 5.16.

Table 5.16 Number of cases categorised by number of fan per student

Category	**Number of Fan/Student**	**OPPfan**	
		N	**Mean**
1	No Fan	316	4
2	Low (0.02 fan/student OR 50 students/fan)	25	14
3	Moderate (0.05-0.10 fan/student OR 10-20 students/fan)	412	18
4	High (0.12-0.20 fan/student OR 5-8 students/fan)	120	18
	Total	**873**	

Since the Nfan was already transformed from an interval to categorical scale, to include categorical data with more than two categories, i.e. four categories, as an independent variable in the linear regression, the categorical predictor must be recoded. Dummy coding was used for generating a new set of Nfan variables (see further explanation in Appendix B: Part 1 – Subsection 1.2.2, p. 369). As can be seen in Table 5.17, three new dummy variables were created. The first category (No Fan) was treated as a baseline group (coded as 0 for all of the dummy variables created) and the remaining Nfan categories were coded as shown in the table.

Table 5.17 Dummy coding for the number of fans per student variable

Category	**Number of Fan/Student (Categorical)**	**Dummy Var 1**	**Dummy Var 2**	**Dummy Var 3**
1	No Fan (baseline category)	0	0	0
2	Low	1	0	0
3	Moderate	0	1	0
4	High	0	0	1

Since there are now more than one independent variable, i.e. three dummy variables, MLiR was performed in order to examine the mean differences in the OPPfan scores between the four Nfan groups. Table 5.18 shows the variables input into the MLiR analysis for estimating changes in the opportunity scores of fan operation when the number of fans changed.

Table 5.18 Code sheet for the variables used in the multiple linear regression analysis for the opportunity scores of fan operation

Variable	Description (scale)	Codes/Values	Name
1. DV	Opportunity scores of fan operation (interval)	1-25	ANVhot
2. IV	Number of fan/student: dummy variable 1 (dichotomous)	1 = Low Nfan 0 = Otherwise	Low Nfan
3. IV	Number of fan/student: dummy variable 2 (dichotomous)	1 = Moderate Nfan 0 = Otherwise	Moderate Nfan
4. IV	Number of fan/student: dummy variable 3 (dichotomous)	1 = High Nfan 0 = Otherwise	High Nfan

The main PASW output of the MLiR is presented in Table 5.19 (see Appendix E: Part 1 - Subsection 1.2.1, Tables E.44 - E.48, p. 434 for the complete results). In total, there were 873 valid cases included in the analysis. From the table, it can be seen that inputting the three dummy variables into the model can explain 67% (Adjusted R^2) of the variance observed in the OPPfan scores.

Table 5.19 Multiple linear regression output from PASW for OPPfan analysis

Model	B	Std. Error	Beta
(Constant)	3.889	0.274	
Low Nfan	10.071	1.013	0.198***
Moderate Nfan	14.574	0.365	0.858***
High Nfan	14.577	0.523	0.592***

Note: Adjusted R^2 = 0.67 ($\rho < 0.001$), * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.
Dependent variable is the opportunity for fan operation.

Based on the coefficients (B) given, changing from ‘No Fan’ to all other levels of Nfan increased the opportunities to use fans significantly, all B values are positive and ρ-values < 0.001. The model for estimating OPPfan scores for different Nfan groups was constructed as shown below (Equation 5.12). It should be noted that the purpose of presenting the model is not to predict the OPPfan in general, rather, it aims to compare the effects of fan allocation (i.e. number of students per fan) on students’ perceived opportunities to use fans in the observed classrooms.

$$\begin{aligned} OPPfan \quad = \quad & 3.889 + 10.071\,(LowNfan) + \\ & 14.574\,(\text{ModerateNfan}) + 14.577\,(\text{HighNfan}) \end{aligned} \qquad \textbf{Equation 5.12}$$

Following the model, mean OPPfan scores for classrooms with different levels of Nfan were obtained (Table 5.20).

Table 5.20 Predicted mean scores for the opportunity to use fans in classrooms with different numbers of fans available

Category	Number of Fan/Student (Categorical)	Predicted OPPfan Scores	95%CI for Predicted OPPfan Scores
1	No Fan	3.89 (Low)	3.35 – 4.43
2	Low Nfan (1 fan/50 students)	13.96 (Moderate)	11.43 – 16.48
3	Moderate Nfan (1 fan/10-20 students)	18.46 (Moderate-High)	16.94 – 19.72
4	High Nfan (1 fan/5-8 students)	18.47 (Moderate-High)	16.90 – 21.03

Note: Score 1-9 = Low, 10-19 = Moderate and 20-25 = High

From the results, having even only as few as one fan per 50 students significantly changed the perceived opportunity for fan use from very low (OPPfan score = 3.35 – 4.43 out of 25) to moderate (11.43 – 16.48). Furthermore, students were likely to perceive a moderate-high level of adaptive opportunity for fan operation (OPPfan score = 16.90 – 19.72) when the number of fans was escalated to one fan per 10-20 students or better. However, having 5-8 students/fan did not further improve the OPPfan scores, as the 95%CI of OPPfan scores of categories 3 and 4 overlapped. It should be noted that the generalisation of this finding may not be appropriate because the variation in the fan dataset is limited and the opportunity scores are bounded to 1 and 25.

Part 2: Opportunity for window operation

Similarly to the OPPfan case, a linear regression was performed for analysing the influences of relevant design variables on the opportunity for window operation scores. With regards to the relevant design variables, OPPwindow is expected to greatly vary according to the surroundings and the configuration of the windows.

In this study, building location (i.e. Suburban or Urban), cross ventilation (i.e. Yes or No) and view (i.e. Yes or No) were used as the explanatory variables, whilst OPPwindow (1-25) was the outcome variable. The building location was selected because it could more or less indicate the air quality in the surroundings which is important with regards to window opening. Cross ventilation is also important to the effectiveness of window ventilation. The view through windows indicates whether users have a connection with the outdoor climate which may stimulate window opening. It should be noted that the two other factors, ceiling height and floor level, mentioned earlier in Subsection 5.2.1 (p. 169) as the criteria for room selection for the Study 1: Thermal adaptive opportunity scoring system and acceptance of ANV Survey, were not included as independent variables in this analysis because they were found to be not significantly correlated with OPPwindow (ceiling height versus OPPwindow, $r = -0.014$, floor level versus OPPwindow, $r = -0.038$, all ρ-values > 0.05). Codes and values for all the variables used in the MLiR are presented in Table 5.21.

Table 5.21 Code sheet for the variables used in the multiple linear regression analysis of the opportunity scores for window operation

Variable	Description (scale)	Codes/Values	Name
1. DV	Opportunity scores of window operation (interval)	1-25	OPPwindow
2. IV	Building location (dichotomous)	1 = Suburban 0 = Urban	Loc
3. IV	Cross ventilation (dichotomous)	1 = Yes 0 = No	Vent
4. IV	Current view (dichotomous)	1 = Built/Natural environments 0 = No view/Unseen	View

MLiR was performed since there was more than one independent variable. The main PASW output of the MLiR is presented in Table 5.22 (see Appendix E: Part 1 - Subsection 1.2.2, Tables E.49 - E.53, pp. 435 - 436, for the complete results). In total, there were 874 valid cases included in the analysis. It can be seen from the regression analysis that all three variables only explain 5% (Adjusted R^2) of the variance observed in the OPPwindow scores.

Table 5.22 Multiple linear regression output from PASW for OPPwindow analysis

Model	B	Std. Error	Beta
(Constant)	12.633	0.428	
Building location (Suburban)	2.178	0.510	0.158***
Current view (Built/Natural environments)	1.279	0.520	0.093*
Cross ventilation (Yes)	0.968	0.470	0.070*

Note: Adjusted $R^2 = 0.05$ ($\rho < 0.001$), * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.
Dependent variable is opportunity for window operation.

Since all the coefficients (B) were positive, it can be interpreted that classrooms in suburban areas with cross ventilation and where occupants can view natural or built environments (as opposed to no view) were statistically associated with an increase in OPPwindow scores, all ρ-values < 0.05. The model for estimating OPPwindow scores is shown below (Equation 5.13) and aims to compare the OPPwindow scores of classrooms with different attributes (i.e. building location, view and cross-ventilation).

$$OPPwindow = 12.633 + 2.178\ (Suburban) + 1.279\ (View) + 0.968\ (\text{Crossvent}) \qquad \textbf{Equation 5.13}$$

Table 5.23 presents the OPPwindow scores for classrooms with different inputs.

Table 5.23 Predicted mean scores for the opportunity to use windows in classrooms in different contexts

Location	View	Cross Vent.	Predicted OPPwindow Scores	95%CI for Predicted OPPwindow Scores
Urban	**No**	**No**	12.63 (Moderate)	11.79 – 13.47
		Yes	13.60 (Moderate)	11.84 – 15.36
	Yes	**No**	13.91 (Moderate)	12.05 – 15.77
		Yes	14.88 (Moderate)	12.10 – 17.66
Suburban	**No**	**No**	14.81 (Moderate)	12.97 – 16.7
		Yes	15.78 (Moderate)	13.02 – 18.5
	Yes	**No**	16.09 (Moderate)	13.23 – 18.95
		Yes	17.06 (Moderate-High)	13.27 – 20.84

Note: Score 1-9 = Low, 10-19 = Moderate and 20-25 = High

According to these results, it seems that change in the independent variables can slightly improve the OPPwindow scores (based on *B* values). The 95%CI for the predicted OPPwindow scores also overlapped greatly, which implies that these three variables, i.e. location, view and cross ventilation, are inadequate to explain the variance in OPPwindow scores. Therefore, this model (Equation 5.13) is ineffective as a predicting tool. The overall analysis only showed that the OPPwindow scores were statistically associated with building location, view and cross ventilation, but the effect sizes were small and insignificant.

According to the results reported in Section 5.2, the acceptance of ANV in the cool and hot seasons varied according to different variables. Students were more likely to accept the use ANV during the cool season when they perceived high opportunities to use both fans and windows. In comparison, potential acceptance of the ANV mode during the hot season was influenced the most by perceived opportunity to use fans. Moreover, having a low daily exposure to AC environments and a low income also increased the probability of accepting ANV use during the hot season. Further data analysis showed that the opportunity to use fans increased significantly when the number of fans per students increased.

5.3 PRO-ENVIRONMENTAL ATTITUDES AND DAILY THERMAL EXPERIENCE

The data analysis and results from Study 2: Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey are presented in this section. The objective of this study was to compare the pro-environmental attitudes and behaviour of users with different daily thermal experiences (i.e. level of exposure to air-conditioning). The analysis first investigated the association between daily thermal experience (i.e. full AC, MM and full NV) and pro-environmental attitudes and behaviour of HE students, before comparing the level of pro-environmental attitudes and behaviour of the students with different daily thermal experiences. The results supplement the findings about psycho-physiological adaptation presented in Subsection 5.2 (p. 183). To be more precise, it is expected that the results will prove that, apart from thermal tolerance and expectation – which are directly related to participant's thermal experience – pro-environmental attitudes also contribute to the acceptance of ANV use among students who have had low exposure to AC environments.

5.3.1 Respondents

The Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey was carried out nationally in order to obtain variations in respondents' daily thermal experience. Six universities were chosen to represent the six regions of

Thailand (Northern, Southern, Eastern, Western, North-eastern and Central regions). These six geographical regions fall into four sub-climatic zones according to the study of Khedari et al. (2002).

1) Zone T1H1 (12-38°C, 30-100% RH) – Northern region
2) Zone T2H1 (16-38°C, 30-100% RH) – North-eastern region
3) Zone T3H2 (20-38°C, 41-100% RH) – Central, Western and Eastern region
4) Zone T3H3 (20-38°C, 50-100% RH) – Southern region

In general, the attributes of these sub-climatic zones are not very different; all regions have similar mean maximum air temperatures but have different mean minimum air temperatures and RH.

Apart from the climatic conditions, these regions also differ in terms of economic status. According to the data available for 2009, the Central region[31] has the highest average monthly income per household (Bangkok and perimeters 37,732 Baht and other Central areas 20,952 Baht) followed by the Southern region (22,926 Baht) (NSO, 2012b); both regions are in the warmest area of the country. The North-eastern region has the lowest household average monthly income (15,358 Baht) but this is not much lower than that of the Northern region (15,727 Baht) (NSO, 2012b). However, in all regions the average monthly expenditure per household is similar, ranging from 75-80% of monthly income (NSO, 2012b).

Research assistants administered the questionnaire to 1,681 students. Incomplete questionnaires were removed, and only 1,274 questionnaires (76% of the total) were valid for further data analysis. The characteristics of the respondents are described in Table 5.24.

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[31] The Central region in the context of the national economy also includes the Western and Eastern regions.

Table 5.24 Personal data of the respondents

	Characteristics	Frequency (respondent)	% of Valid
Region	Central	331	26%
	East	212	16.6%
	North	212	16.6%
	North-eastern	211	16.6%
	South	208	16.3%
	West	100	7.8%
	Total	**1,274**	**100%**
Climate Zone	T1H1 (Northern)	212	16.6%
	T2H1 (North-eastern)	211	16.6%
	T3H2 (Central, Eastern, Western)	643	50.5%
	T3H3 (Southern)	208	16.3%
	Total	**1,274**	**100%**
Gender	Female	628	49.3%
	Male	646	50.7%
	Total	**1,274**	**100%**
Age (Year)	Mean (min.-max.)	20.3 (16-30)	
	Total	**1,274**	
Faculty group	Science-based	594	46.6%
	Humanities/Social-based	680	53.4%
	Total	**1,274**	**100%**
Income (Baht/Month)	≤ 2,500	79	6.2%
	2,501-5,000	624	49%
	5,001-7,500	295	23.2%
	7,501-10,000	198	15.5%
	> 10,000	78	6.1%
	Total	**1,274**	**100%**
Thermal experience_Bedroom	AC	873	68.5%
	NV	401	31.5%
	Total	**1,274**	**100%**
Thermal experience_University	AC	772	60.6%
	MM[a]	502	39.4%
	Total	**1,274**	**100%**
Thermal experience_Transportation	AC	476	37.4%
	NV	798	62.6%
	Total	**1,274**	**100%**

Note: a – Fully NV university buildings are rare; therefore, mixed-mode was used as a choice of thermal experience at university instead NV.

Table 5.24 Personal data of the respondents (continued)

	Characteristics	Frequency (respondent)	% of Valid
Overall daily thermal experience (bedroom, university and transportation)	Full air-conditioning	269	21.1%
	Mixed-mode	893	70.1%
	Full natural ventilation	112	8.8%
	Total	**1,274**	**100%**

Approximately 50% of the respondents were from the T3H2 climate zone where the temperature ranges from 20-38°C. The proportion of male to female participants was almost equal and the average age of the students was 20 years old. The number of science-based students (47%) was not significantly different from that of humanities or social-based students (53%). Most students (49%) had a moderately low monthly income (2,501-5,000 Baht/Month), and monthly income is the only variable used to indicate the economic status of students. Although this may not represent the actual economic status of students as some may receive a low monthly allowance whilst living with wealthy parents, it is the most convenient data set to collect from this target group. In addition, the students were asked to estimate their income after the deduction of rent to minimise any inaccuracy in the data obtained.

It should be noted that the categorisation of students' overall daily thermal experience was based on their thermal experiences in three situations - bedroom, university and transportation:

1) Full AC group: thermal experiences in all 3 situations were AC
2) MM group: thermal experiences in 3 situations were mixed
3) Full NV group: thermal experiences in all 3 situations were NV.

5.3.2 Comparison of pro-environmental attitudes and adaptive behaviour of students with different daily thermal experiences

The data obtained from Study 2 are analysed in this subsection in order to compare the pro-environmental attitudes and adaptive behaviour scores of students with different daily thermal experiences, i.e. full air-conditioning, mixed and full natural ventilation. The process is divided into three steps as shown below.

> Step 1: Reliability tests of Adaptive behaviour at home (BEH), Acceptance of air-conditioning reduction policy in university (POL) and Pro-environmental attitudes (PEA) scores
>
> Step 2: Correlation tests
>
> Step 3: A comparison of BEH, POL and PEA scores between students with different daily thermal experiences

5.3.2.1 Step 1: Reliability tests of Adaptive behaviour at home (BEH), Acceptance of air-conditioning reduction policy in university (POL) and Pro-environmental attitudes (PEA) scores

As the questionnaire used three sets of statements with a 5-point rating scale to assess students' environmental attitudes and behaviour, the consistency of these statements must be firstly be examined. For the PEA score 10 items were input into the reliability test.[32] It should be noted that the ratings for some of the negative statements were inverted prior to the test. For environmental behaviour, the study centred on self-reported behaviour and behavioural intentions relating to air-conditioning reduction at home and university. There were five statements related to adaptive behaviour at

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[32] Reliability test: a test for indicating whether an instrument can produce consistent results when the same entities are measured under different conditions (Field, 2009, p. 793).

home and another five statements about acceptance of an air-conditioning reduction policy in university, resulting in the BEH and POL scores, respectively.

According to the reliability tests, Cronbach's Alpha[33] values for BEH and POL items were 0.82 and 0.80, respectively, which are acceptable (not lower than 0.70). Therefore, the mean scores of all five items for BEH and POL could be used for further analysis. In contrast, Cronbach's Alpha value for the ten PEA items was low; 0.59. This is possibly due to the inclusion of some statements that are inconsistent with the others or maybe too specific into the PEA scale. Therefore, the two statements, *I do not believe my behaviour and everyday lifestyle contribute to climate change,* and *I believe that the increase of air-conditioning significantly contributes to climate change*, were removed in order to improve the internal consistency of the scale, as recommended by PASW. The second run showed that the reliability improved to 0.71; therefore, the average score for the remaining eight PEA items was used for further statistical analysis. The average score for all three environmental attitudes and behaviour indicators ranged from 1 to 5, where the lower score indicated lower pro-environmental attitudes and behaviour.

5.3.2.2 Step 2: Correlation tests

In order to test whether daily thermal experience and pro-environmental attitudes and behaviour were associated, bivariate correlation tests were performed. The personal data of respondents were also included to examine the relevance of these variables to respondent's pro-environmental attitudes and behaviour. Since all the variables were different in terms of scale (nominal, ordinal and interval scales), different methods were used for investigating the correlations. As a result of using different methods, the

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[33] Cronbach's Alpha: a measure of the reliability of a scale (Field, 2009, p. 784). In this case, it was used to test the reliability of the self-reported pro-environmental attitudes and adaptive behaviour scales.

correlation coefficients (the strength of the relationships) cannot be directly compared. All variables included in the bivariate tests are listed in Table 5.25.

Table 5.25 Variables input into the bivariate correlation tests

Variable	Description (scale)	Codes/Values	Name
1.	Thermal experience in bedroom (dichotomous)	0 = Air-conditioned 1 = Naturally-ventilated	EXbed
2.	Thermal experience in university (dichotomous)	0 = Air-conditioned 1 = Mixed	EXuni
3.	Thermal experience in transportation (dichotomous)	0 = Air-conditioned 1 = Naturally-ventilated	EXtrn
4.	Participant's daily thermal experience (nominal)	1 = Full AC 2 = Mixed-mode 3 = Full NV	TExp
5.	Climate zone (nominal)	1 = T1H1 (12-38°C, 30-100% RH) 2 = T2H1 (16-38°C, 30-100% RH) 3 = T3H2 (20-38°C, 41-100% RH) 4 = T3H3 (20-38°C, 50-100% RH)	Clim
6.	Participant's income (Baht/Month) (ordinal)	1 = ≤ 2,500 2 = 2,501-5,000 3 = 5,001-7,500 4 = 7,501-10,000 5 = > 10,000	Income
7.	Participant's faculty (dichotomous)	0 = Humanities/social-based 1 = Science-based	Fac
8.	Participant's gender (dichotomous)	0 = Male 1 = Female	Gen
9.	Adaptive Behaviour at Home score (interval)	1 – 5	BEH
10.	AC Reduction Policy Acceptance score (interval)	1 – 5	POL
11.	Pro-Environmental Attitudes score (interval)	1 – 5	PEA

The correlation coefficients of two variables are presented in Tables 5.26 and 5.27. Methods used for the correlation tests for different types of data are explained underneath the table. It is important to note that in psychological studies, the correlation coefficients may be interpreted differently from studies in other fields. According to Hemphill (2003), a perfect relationship between two variables in applied psychological studies is extremely rare. Based on Hemphill's suggestion, the interpretation of correlation coefficients for empirical studies should be: < 0.20 as a small effect, 0.20 to 0.30 as a medium-sized effect and > 0.30 as a large effect.

Table 5.26 Correlation tests (part 1)

No.	Variable (scale)	Statistics	1	2	3	4	5
			EXbed	EXuni	EXtrn	TExp	Clim
1	Thermal exp. bedroom (dichotomous)	Corr. Coefficient	1.000				
		Sig. (2-tailed)	-				
2	Thermal exp. university (dichotomous)	Corr. Coefficient	-0.090**	1.000			
		Sig. (2-tailed)	0.001	-			
3	Thermal exp. transport (dichotomous)	Corr. Coefficient	0.314**	0.068*	1.000		
		Sig. (2-tailed)	0.000	0.015	-		
4	Daily thermal experience (nominal)	Corr. Coefficient	0.537**	0.527**	0.683**	1.000	
		Sig. (2-tailed)	0.000	0.000	0.000	-	
5	Climate zone (nominal)	Corr. Coefficient	0.447**	0.245**	0.307**	0.272**	1.000
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	-
6	Income (ordinal)	Corr. Coefficient	0.337**	0.155**	0.168**	0.245**	0.343**
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000
7	Faculty group (dichotomous)	Corr. Coefficient	0.041	-0.209**	0.045	0.051	0.066
		Sig. (2-tailed)	0.146	0.000	0.106	0.190	0.139
8	Gender (dichotomous)	Corr. Coefficient	0.089**	-0.001	0.012	0.061	0.027
		Sig. (2-tailed)	0.001	0.959	0.674	0.091	0.825
9	BEH (interval)	Corr. Coefficient	0.635**	-0.084**	0.321**	0.374**	0.516**
		Sig. (2-tailed)	0.000	0.003	0.000	0.000	0.000
10	POL (interval)	Corr. Coefficient	0.045	0.209**	0.053	0.164**	0.417**
		Sig. (2-tailed)	0.109	0.000	0.059	0.000	0.000
11	PEA (interval)	Corr. Coefficient	0.104**	0.169**	0.152**	0.245**	0.393**
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000

** Correlation is significant at the $\rho < 0.01$ level (2-tailed).

* Correlation is significant at the $\rho < 0.05$ level (2-tailed).

__ Correlation coefficient is high (the absolute value is > 0.3).

Correlation coefficient for nominal by nominal scale: Chi-square correlation – the coefficient values: Phi (φ) for 2x2 categories or Cramer's V (φ_c) for more than 2 categories (no negative value)

Correlation coefficient for dichotomous scale by interval scale: Point-biserial correlation (r_{pb})

Correlation coefficient for nominal (more than 2 categories) by interval scale: Eta correlation (η)

Correlation coefficient for ordinal by interval scale: Spearman's rho correlation (r_S)

Correlation coefficient for interval by interval scale: Pearson's r correlation (r)

The correlations between BEH, POL and PEA scores and other variables were focused. From Table 5.26, participant's thermal experiences in bedroom (EXbed), university (EXuni) and transportation (EXtrn) environments were all statistically correlated with PEA scores, all ρ-values < 0.001. The correlations between BEH scores and EXbed (r_{pb} = 0.64, strong relationship) and between POL scores and EXuni (r_{pb} = 0.21, moderate relationship) were also statistically significant, all ρ-values < 0.001. Focusing on overall daily thermal experience (TExp), this was statistically correlated with all BEH, POL and PEA scores, all ρ-values < 0.001. Climate zone was associated with BEH, POL and PEA scores with moderate-high correlation coefficients (Clim and BEH, η = 0.52, Clim and POL, η = 0.42, Clim and POL, η = 0.39).

Table 5.27 Correlation tests (part 2)

No.	**Variable (scale)**	**Statistics**	**6**	**7**	**8**	**9**	**10**	**11**
			Income	**Fac**	**Gen**	**BEH**	**POL**	**PEA**
6	Income (ordinal)	Corr. Coefficient	1.000					
		Sig. (2-tailed)	-					
7	Faculty group (dichotomous)	Corr. Coefficient	**0.103****	1.000				
		Sig. (2-tailed)	0.009	-				
8	Gender (dichotomous)	Corr. Coefficient	**0.114****	0.004	1.000			
		Sig. (2-tailed)	0.002	0.893	-			
9	BEH (interval)	Corr. Coefficient	**-0.142****	**0.078****	0.042	1.000		
		Sig. (2-tailed)	0.000	0.005	0.130	-		
10	POL (interval)	Pearson's r	**-0.166****	**0.077****	-0.008	**0.182****	1.000	
		Sig. (2-tailed)	0.000	0.006	0.771	0.000	-	
11	PEA (interval)	Pearson's r	**-0.321****	-0.010	**0.084****	**-0.071***	**0.135****	1.000
		Sig. (2-tailed)	0.000	0.721	0.003	0.012	0.000	-

** Correlation is significant at the $\rho < 0.01$ level (2-tailed).

* Correlation is significant at the $\rho < 0.05$ level (2-tailed).

__ Correlation coefficient is high (the absolute value is > 0.3).

Correlation coefficient for nominal by nominal scale: Chi-square correlation – the coefficient values: Phi (φ) for 2x2 categories or Cramer's V (φ_c) for more than 2 categories (no negative value)

Correlation coefficient for dichotomous scale by interval scale: Point-biserial correlation (r_{pb})

Correlation coefficient for nominal (more than 2 categories) by interval scale: Eta correlation (η)

Correlation coefficient for ordinal by interval scale: Spearman's rho correlation (r_s)

Correlation coefficient for interval by interval scale: Pearson's r correlation (r)

From Table 5.27, monthly income was negatively correlated to BEH and POL with low correlation coefficients, but to PEA scores with a relatively high correlation coefficient (Income and PEA, $r_s = 0.32$). Participant's faculty (Fac) was statistically correlated with BEH and POL scores, all ρ-values < 0.01, but the relationship was weak ($r_{pb} < 0.20$). Likewise, participant's gender (Gen) was statistically correlated with PEA scores only, ρ-values < 0.01, but the relationship was weak ($r_{pb} < 0.20$). Therefore, the pro-environmental attitudes and behaviour levels did not differ greatly between humanities/social-based and science-based students and between male and female students.

As some correlation coefficients in Table 5.26 (p. 213) and Table 5.27 (p. 214) do not indicate the direction of the correlation, Figures 5.8 – 5.10 illustrate the direction of the relationships between each of pro-environmental attitudes and adaptive behaviour indicators (BEH, POL and PEA scores) and contextual and personal variables of interest, i.e. daily thermal experience, climate zone and income.

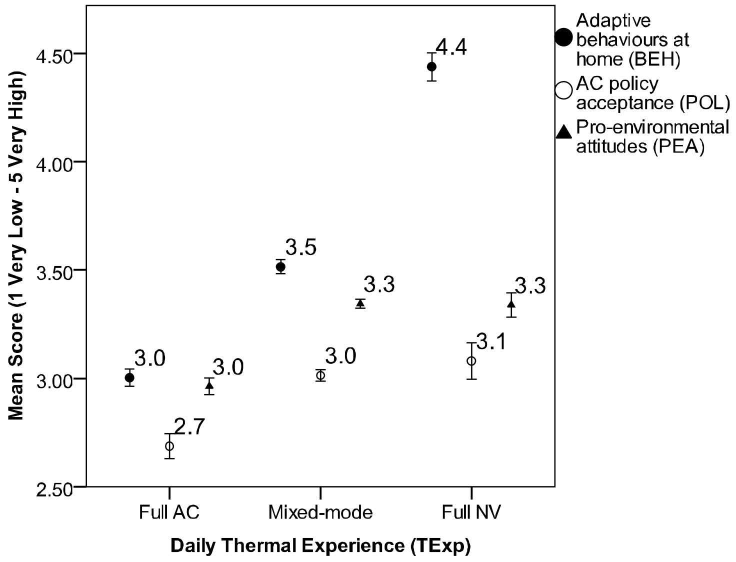

Figure 5.8 Mean environmental attitudes and adaptive behaviour scores (BEH, POL and PEA) by participant's daily thermal experience (TExp) (error bars represent standard error of mean)

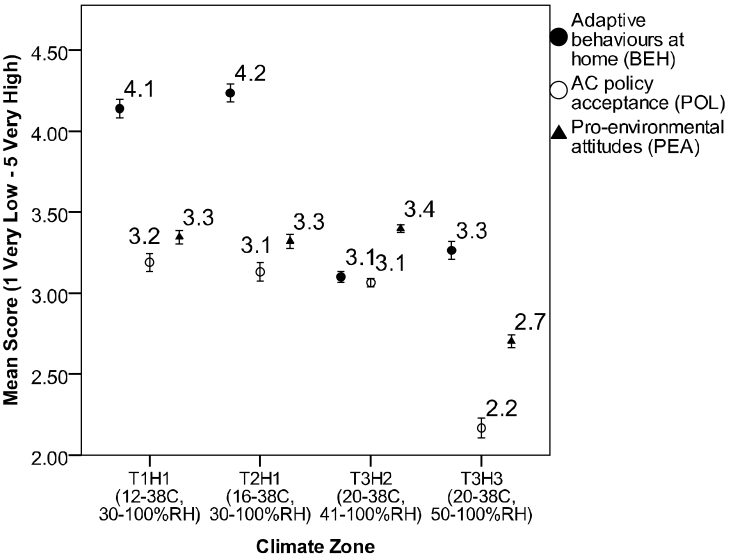

Figure 5.9 Mean environmental attitudes and adaptive behaviour scores (BEH, POL and PEA) by climate zone (error bars represent standard error of mean)

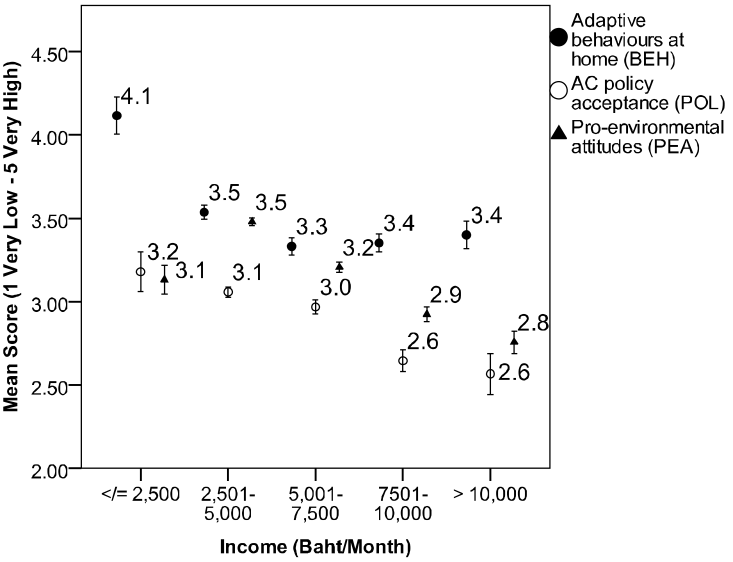

Figure 5.10 Mean environmental attitudes and adaptive behaviour scores (BEH, POL and PEA) by participant's income (error bars represent standard error of mean)

Further scrutiny of Table 5.26 (p. 213) also shows that climate zone, student's income and thermal experience were all correlated to each other. As stated in Subsection 5.3.1 (p. 206), climate zone and household economic status may be related due to the national economic structure, i.e. the capital city is situated within the warmer climate zone, and higher-income people, particularly in warm climate zones (Central, Eastern, Western and Southern), are able to afford air-conditioning and tend to use it more. Therefore, it is possible that BEH, POL and PEA scores may be more influenced by climate and income, rather than merely daily thermal experience alone. Then, partial correlation tests were performed and it was found that the correlations between BEH and daily thermal experience existed even when the climate zone was controlled for (Table 5.28). However, POL and PEA scores were statistically associated with daily thermal experience in the case of warm climate zones only. The variations in daily thermal experiences (in bedroom, university and transportation) of students in milder climate zones (Northern and North-eastern) were possibly influenced by other contextual factors, such as the availability of AC transportation, i.e. most students used a bicycle or motorcycle on university campus regardless of their pro-environmental attitudes level. Then, the correlations between daily thermal experience and POL and PEA scores of students in the milder climate zones cannot be detected.

Table 5.28 Correlation tests

No.	**Climate Zone**	**Variable (scale)**	**Statistics**	**1**	**2**	**3**
				BEH	**POL**	**PEA**
1	T1H1 (12-38°C, 30-100% RH) Northern region	Daily thermal experience (nominal)	Eta[a]	**0.432****	0.055	0.109
			Sig. (2-tailed)	0.000	0.643	0.986
2	T2H1 (16-38°C, 30-100% RH) North-eastern region	Daily thermal experience (nominal)	Eta[a]	**0.350****	0.038	0.048
			Sig. (2-tailed)	0.000	0.478	0.670
3	T3H2 (20-38°C, 41-100% RH) Central, Western and Eastern region	Daily thermal experience (nominal)	Eta[a]	**0.239****	**0.153****	**0.226****
			Sig. (2-tailed)	0.000	0.000	0.000
4	T3H3 (20-38°C, 50-100% RH) Southern region	Daily thermal experience (nominal)	Eta[a]	**0.330****	**0.484****	**0.333****
			Sig. (2-tailed)	0.000	0.000	0.000

Note: ** Correlation was significant at the ρ = 0.01 level (2-tailed).

* Correlation was significant at the ρ = 0.05 level (2-tailed).

a. BEH, POL and PEA scores were treated as the dependent variable.

Considering the attitude-behaviour relationship (see Table 5.27, p. 214), the PEA score was positively correlated with the POL score, r = 0.14, $\rho < 0.001$, but negatively associated with the BEH score, r = -0.07, $\rho < 0.05$. The negative correlation of the PEA-BEH scores was possibly caused by other confounding variables, for example, habits or house conditions (design) and surroundings (pollution) that constrained adaptive behaviour whilst at home.

In summary, students' overall daily thermal performance was associated with their pro-environmental attitudes and adaptive behaviour. At the same time, pro-environmental attitudes and adaptive behaviour were also likely to be affected by the climate zone and student's income. Students in a warmer climate zone or students who had a higher income seemed to have lower pro-environmental attitudes and behaviour score.

5.3.2.3 Step 3: A comparison of BEH, POL and PEA scores between students with different daily thermal experiences

In this step, pro-environmental attitudes and behaviour scores for students with different daily thermal experiences were compared, and the mean differences in the scores between groups quantified. All the comparative groups are listed in Table 5.29.

Table 5.29 Comparative groups

	Dependent Variables	**Comparative Groups**		
1st comparison	Adaptive Behaviour at Home (BEH)	Full AC	Mixed-mode	Full NV
2nd comparison	Acceptance of AC Reduction Policy(POL)	Full AC	Mixed-mode	Full NV
3rd comparison	Pro-Environmental Attitudes (PEA)	Full AC	Mixed-mode	Full NV

Since there were more than two groups to compare, an ANOVA was the appropriate statistical tool if the data were normally distributed. According to the results of normality tests, all the sub-groups had normal distributed scores (see analysis in

Appendix D: Part 2 - Section 2.2, p. 395). Therefore, an ANOVA test was employed for all three comparisons. Another assumption of ANOVA is the homogeneity of variances. This assumption was also tested during the ANOVA procedures. If this assumption was violated then other robust tests were used instead. The complete results of this subsection are presented in Appendix E: Part 2 – Section 2.1, Tables E.54 - E.77 (pp. 436 - 442). The main findings from the ANOVA tests are reported below.

Part 1: Adaptive behaviour at home (BEH)

Means for the BEH scores for the three thermal experience groups, i.e. Full AC, MM and Full NV, were compared and Table 5.30 shows the means and other basic data for each sub-group.

Table 5.30 Descriptive statistics for the BEH scores categorised by daily thermal experience groups

Daily Thermal Experience	N	Mean BEH Score	Std. Deviation	Std. Error
Full AC	269	3.0030	0.66624	0.04062
Mixed-mode	893	3.5153	0.97489	0.03262
Full NV	112	4.4393	0.68856	0.06506
Total	1,274	3.4884	0.96467	0.02703

Welch and Brown-Forsythe statistics[34] show that there was at least one pair of groups with a significant difference in BEH mean scores, $F(2,\ 308) = 177.61,\ \rho < 0.001$. Additionally, a further ANOVA test showed that there was a significant linear trend,

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[34] A Levene statistic was first run to test the homogeneity of the variances among the three comparative groups. The test was significant, indicating that variances in daily thermal experience groups were not similar which violated the assumption of an ANOVA test (Field, 2009, p. 384). Hence, the results from Welch and Brown-Forsythe were considered instead.
Welch's F: a version of the F-ratio designed to be accurate when the assumption of homogeneity of variance has been violated (Field, 2009, p. 796).
Brown-Forsythe F: a version of the F-ratio designed to be accurate when the assumption of homogeneity of variance has been violated (Field, 2009, p. 782).

$F(1, 1271) = 193.78$, $\rho < 0.001$, which means that as the daily thermal experience changed from full AC to MM to full NV, the BEH scores increased proportionately.

In order to explore further where the differences were among these three groups of students, a post-hoc test[35] was performed. Games-Howell[36] was chosen as a post-hoc test as it is suitable for data whose group variances are not equal. The results of multiple comparisons by the Games-Howell test are presented in Table 5.31.

Table 5.31 Games-Howell test for comparing the BEH scores between the three different daily thermal experience groups

(I) Daily Thermal Experience	**(J) Daily Thermal Experience**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% CI**	
					Lower Bound	**Upper Bound**
Mixed-mode	**Full AC**	**0.51237***	**0.05210**	**0.000**	**0.3900**	**0.6348**
	Full NV	-0.92394*	0.07278	0.000	-1.0960	-0.7519
Full NV	**Full AC**	**1.43631***	**0.07670**	**0.000**	**1.2552**	**1.6174**
	Mixed-mode	**0.92394***	**0.07278**	**0.000**	**0.7519**	**1.0960**
* The mean difference is significant at the $\rho = 0.05$ level.						

The results show that:

- The MM group had significant higher BEH scores than the Full AC group, $\rho < 0.001$, $r = 0.36$ (moderate effect). The r value was computed from the t-statistic based on Equation B.5 in Appendix B: Part 3 - Subsection 3.1.1 (p. 375).
- The Full NV group scored significantly higher than the Full AC group, $\rho < 0.001$, $r = 0.70$ (large effect).

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[35] Post-hoc tests: a set of comparisons between group means that are not thought of before data are collected. Typically, these tests involve comparing the means of all combinations of pairs of groups (Field, 2009, pp. 791-792).

[36] Games-Howell: a post-hoc test that is used when there is doubt that the group variances are equal (Field, 2009, p. 375).

- The BEH score of the Full NV group was also higher than the MM group, $\rho < 0.01$, $r = 0.69$ (large effect).

Overall, students who had more daily experience with natural environments were likely to behave adaptively in a manner which reduced energy consumption at home. Alternatively, this can be interpreted as students who used energy efficiently at home were more likely to use air-conditioning only when necessary, hence had more daily experience with natural ventilation.

Part 2: Acceptance of an air-conditioning reduction policy in university (POL)

In this comparison, means of the POL scores of students in three different daily thermal experience groups were compared. Table 5.32 presents sample size, mean and standard deviation, for the data in each sub-group.

Table 5.32 Descriptive statistics of the (POL) scores categorised by daily thermal experience groups

Daily Thermal Experience	N	Mean POL Score	Std. Deviation	Std. Error
Full AC	269	2.6870	0.92592	0.05645
Mixed-mode	893	3.0137	0.78451	0.02625
Full NV	112	3.0804	0.90063	0.08510
Total	1,274	2.9505	0.83752	0.02346

According to the Welch and Brown-Forsythe test, there was at least one pair of groups which had a significant difference in POL mean scores, $F(2, 256) = 14.72$, $\rho < 0.001$. Moreover, the results from the test of the linear term was also significant, $F(1, 1271) = 29.53$, $\rho < 0.001$. This means that as the daily thermal experience changed from full AC to MM to full NV, the POL scores increased proportionately.

In order to detect where the differences were among the three groups, multiple comparisons were conducted by employing the Games-Howell test. The results are presented in Table 5.33.

Table 5.33 Games-Howell test for comparing the POL scores between the three different daily thermal experience groups

(I) Daily Thermal Experience	(J) Daily Thermal Experience	Mean Difference (I-J)	Std. Error	Sig.	95% CI	
					Lower Bound	Upper Bound
Mixed-mode	**Full AC**	**0.32667***	**0.06226**	**0.000**	**0.1802**	**0.4732**
	Full NV	-0.06670	0.08906	0.735	-0.2778	0.1444
Full NV	**Full AC**	**0.39337***	**0.10212**	**0.000**	**0.1523**	**0.6344**
	Mixed-mode	0.06670	0.08906	0.735	-0.1444	0.2778
* The mean difference is significant at the 0.05 level.						

The results suggest that:

- The MM group had significantly higher POL scores than the Full AC group, $\rho < 0.001$, $r = 0.26$ (small effect).
- The Full NV group also scored significantly higher than the Full AC group, $\rho < 0.001$, $r = 0.19$ (small effect).
- The POL scores for the Full NV group and the MM group were not significantly different, $\rho > 0.05$, $r = 0.06$ (insignificant).

Consequently, it can be concluded that students who spent more time in NV environments found the policy to reduce air-conditioning in classrooms more acceptable. Alternatively, the results could be interpreted as students who found full air-conditioning in classrooms unnecessary tended to spend more time in NV environments in their daily life.

Part 3: Pro-environmental attitudes (PEA)

In this part, the results from an ANOVA test to examine whether the PEA scores of students with full AC backgrounds significantly differed from of those with non-full AC experiences are presented. Table 5.34 shows the descriptive statistics for the PEA scores of students with different daily thermal backgrounds.

Table 5.34 Descriptive statistics for the PEA scores categorised by daily thermal experience groups

Daily Thermal Experience	N	Mean PEA Score	Std. Deviation	Std. Error
Full AC	269	2.9628	0.61561	0.03753
Mixed-mode	893	3.3445	0.62127	0.02079
Full NV	112	3.3382	0.58549	0.05532
Total	1,274	3.2633	0.63587	0.01781

According to the ANOVA statistics, among the three groups for PEA, mean scores of at least one pair of groups were statistically different, $F(2, 1271) = 40.45$, $\rho < 0.001$. Moreover, as the test for linear term was significant, this means that the PEA scores increased proportionately when the daily thermal experience changed from full AC to MM to full NV, respectively, $F(1, 1271) = 57.81$, $\rho < 0.001$.

Following the ANOVA test, a post-hoc test was run in order to investigate where the differences were among the three groups of students. In this case, Hochberg's GT2[37] was employed as it is better suited to data where the sample sizes differ greatly. The results are presented in Table 5.35.

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[37] Hochberg's GT2: one of the post-hoc tests used when sample sizes are very different (Field, 2009, p. 375).

Table 5.35 Hochberg's GT2 test for comparing the PEA scores between the three different daily thermal experience groups

(I) Daily Thermal Experience	(J) Daily Thermal Experience	Mean Difference (I-J)	Std. Error	Sig.	95% CI	
					Lower Bound	Upper Bound
Mixed-mode	**Full AC**	**0.38166***	**0.04292**	**0.000**	**0.2791**	**0.4843**
	Full NV	0.00632	0.06185	0.999	-0.1416	0.1542
Full NV	**Full AC**	**0.37534***	**0.06939**	**0.000**	**0.2095**	**0.5412**
	Mixed-mode	-0.00632	0.06185	0.999	-0.1542	0.1416
* The mean difference is significant at the 0.05 level.						

The results of Hochberg's GT2 test indicated that:

- The MM group had significantly higher PEA scores than the Full AC group, $\rho < 0.001$, $r = 0.25$ (moderate effect).
- The Full NV group also had significantly higher scores than the Full AC group, $\rho < 0.001$, $r = 0.27$ (moderate effect).
- The PEA scores of the Full NV group and the MM group were not significantly different, $\rho > 0.05$, $r = 0$ (insignificant).

The results could be interpreted as indicating that when students were connected more with the natural climate then they were likely to be more concerned about environmental problems, particularly climate change and vice versa.

5.4 SUMMARY

This chapter has investigated the factors affecting users' perceived behavioural adaptations and psycho-physiological adaptation that contribute to their acceptance of the ANV mode in the observed MM classrooms. Based on the results of MLoR and MLiR the contributions of contextual and personal variables on students' acceptance of ANV are summarised as follows:

- Changing from the hot to the cool season scenario, students are 4.6 times more likely to vote ‘Agree’ rather than ‘Disagree’ to ANV use in their classrooms.
- Within the cool season scenario, students are 3.3 times more likely to vote ‘Agree’ rather than ‘Disagree’ if the opportunity to use fans is increased from low to moderate-high.
- Within the cool season scenario, students are 2.8 times more likely to vote ‘Agree’ rather than ‘Disagree’ if the opportunity to use windows is increased from low to moderate-high.
- Within the hot season scenario, students are 2.8 times more likely to vote ‘Agree’ rather than ‘Disagree’ if the opportunity to use fans is increased from low to moderate-high.
- Within the hot season scenario, students are 1.8 times more likely to vote ‘Agree’ rather than ‘Disagree’ if they had more variety in their daily thermal experience rather than full daily use of air-conditioning.
- Within the hot season scenario, students are 1.5 times more likely to vote ‘Agree’ rather than ‘Disagree’ if they had a low rather than high income.
- When increasing the number of ceiling fans per students from 1: 50 to 1: 20, the perceived opportunity for fan use increased from moderate to moderate-high level.
- The perceived opportunity for window opening was statistically affected by building location, cross-ventilation and view; however, the effects were too small and insignificant.

Regarding the relationships between daily thermal experience and the willingness to reduce air-conditioning use, the results showed that:

- The daily thermal experience of students was statistically associated with their adaptive behaviour at home, acceptance of a university air-conditioning reduction policy, and pro-environmental attitudes.
- Students who had full NV or mixed daily thermal experience had higher levels of pro-environmental attitudes and behaviour than those who had a full AC background, particularly in warmer climate zones.
- The causation effect between participants' pro-environmental attitudes and daily thermal experience cannot be stated with certainty.

CHAPTER 6: RESULTS – ORGANISATIONAL THERMAL ADAPTABILITY

6.1 FRAMEWORK AND PURPOSE

Continuing on from Chapter 5, the investigation of organisational thermal adaptability is presented in this chapter. The contents are based on the sub-framework shown in Figure 6.1 (previously presented in Figure 4.3, p. 130). According to the framework, organisational thermal adaptability is assessed through the possibilities for using MM operational strategies in existing MM HE buildings in a hot-humid climate. Two main issues that may support or constrain MM operations are: 1) organisational customs related to facilities management thermal operating practices, and 2) perceived performance risks due to a reduction in air-conditioning.

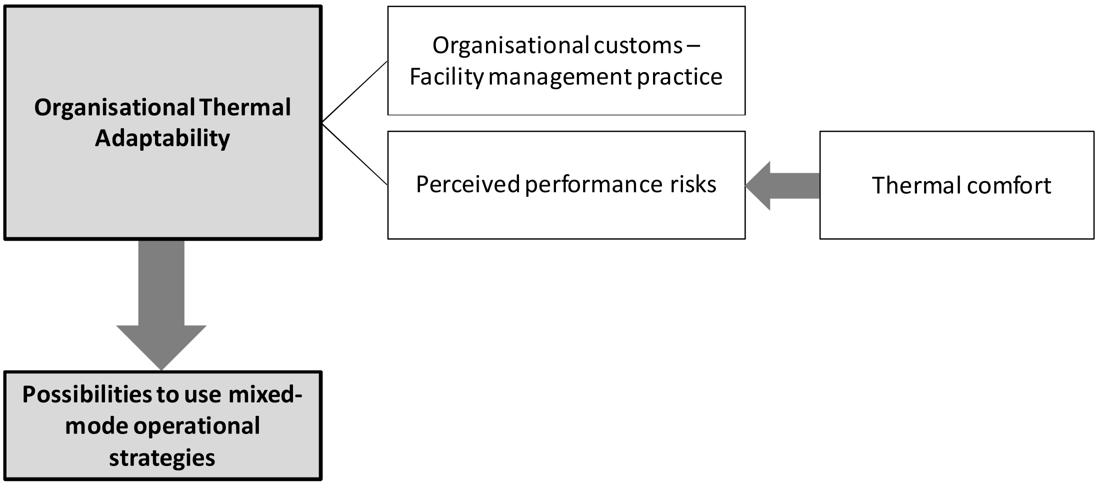

Figure 6.1 Sub-framework for the investigation of organisational thermal adaptability

This chapter is divided into two sections in line with the sub-framework for the investigation into organisational thermal adaptability.

Section 6.2 focuses on facilities management practice affecting the implementation of MM operational strategies in existing MM HE buildings. The data gathered from FMs who participated in Study 3: Facilities manager interviews, were analysed and presented.

Section 6.3 focuses on the organisational concern regarding a decrease in user performance due to a reduction in air-conditioning. The data obtained from Study 4: Learning and thermal performance survey, were analysed using the PASW package. The relationship between thermal comfort and the PLP of students in AC and ANV classrooms is focused upon. The objective of this study is to investigate whether users at the same state of self-reported thermal comfort (i.e. Uncomfortable, Neutral and Comfortable), either in AC or ANV rooms, perceive their performance to be at the same level.

6.2 ORGANISATIONAL CUSTOMS – FACILITIES MANAGEMENT PRACTICE

While Studies 1 and 2 examined the factors of individual thermal adaptability within a specific context, MM classrooms, the interviews explored FMs' views of the organisational factors that constrain (or support) the implementation of the three proposed MM cooling strategies, i.e. Concurrent, Change-over and Zoned, in existing HE buildings. In addition, common attributes of those faculties in which the FMs perceived the possibilities to implement one or more MM strategies were analysed. Descriptive statistics were employed to report the interview results.

6.2.1 Facilities manager interviews

This subsection briefly describes the profile of the FMs and the facilities management division in which they were based. It should be noted that the term 'facilities management' is not well recognised within the HE sector in Thailand as the department responsible for building operation and maintenance in this sector is normally called the Division of Building and Physical Plant (translated from the Thai term). From this point onwards, the term facilities management department or division as used in this chapter refers to the Division of Building and Physical Plant for the participating faculties in Thai universities. This is because the term facilities management, which is more common UK parlance, most clearly expresses the responsibilities of the divisions.

Out of the 35 heads of facilities management divisions invited, 25 heads or representatives from the division from 25 faculties in four universities participated in the interviews: a response rate of 71%. All faculties own buildings with the ability to use some form of MM (i.e. the buildings have operable windows and air-conditioning systems with or without fans), but not all of them are operating in MM. Incidentally, every faculty was located on a university campus rather than as a stand-alone organisation. As mentioned in Chapter 4 (Subsection 4.4.3, p. 154), faculty location (urban or suburban) and facilities management thermal operating practice (fully AC or MM) were the two basic criteria for FMs invitation to participate in the interviews, with the aim of gaining variability in the thermal operating practices and FMs' opinions on the three MM operational strategies. The FMs participated in the interviews can be primarily clustered into four groups by their faculty location and current thermal operating practice as shown in Table 6.1. The number of faculties in MM categories obtained in the event was slightly lower than expected. This was because even though the buildings have the ability to be used in the manually-operated MM, most are operated in the AC mode.

Table 6.1 FM respondents classified by their faculty location and current thermal operating practice

Location / Thermal operating practice[a]	Urban	Suburban	Subtotal
Fully air-conditioned	10	6	16
Mixed-mode	5	4	9
Subtotal	15	10	**Total 25**

Note: a – The thermal operating practice was reported by the facilities managers.

Table 6.2 shows the profile of the FM respondents who were interviewed. For most, the facilities management division in a faculty was positioned within an administrative office. The scope of facilities management responsibility covered building operations (e.g. lighting, air-conditioning, plumbing, elevators and more), maintenance and repair, cleaning, health and security, gardening, vehicle services and parking, and the preparation of audio-visual devices. Therefore, the facilities management division was comprised of administrators, mechanical engineers, computer engineers, technicians, housekeepers, gardeners, janitors, security guards and drivers. In large-size faculties or universities, some common facilities management duties were the responsibility of a central facilities management department or were outsourced, e.g. cleaning, security, gardening, vehicle services and parking, and so on, although the building operations remained the principle day-to-day tasks of local facilities management staff. The number of buildings under a local facilities management division in this interview ranged from one to 22 properties, and the number of staff from one to approximately 50. The work experience of the interviewees in their current position was from as little as a couple of months to as long as nearly 40 years.

Table 6.2 Profile of the FM respondents

Case	Faculty (University Code)	Position	Work Experience in the Position (Year)	Number of Local FM Staff in the Faculty	Number of Buildings in Responsibility
1	Faculty of Architecture (A)	Vice-Dean for Special Affairs and Quality Assurance[a]	4	5-6	1
2	Faculty of Archaeology (A)	Operator in Building, Physical Plant and Vehicle Service Division	>10	5	1
3	Faculty of Decorative Arts (A)	Head of Building, Physical Plant and Vehicle Service Division	20 approx.	6	1
4	Faculty of Arts (A)	Head of Building, Physical Plant and Vehicle Service Division	31	3 (for 1 main education bdg.)	8 (office, conference hall and education)
5	Faculty of Education (A)	Head of Building, Physical Plant and Vehicle Service Division	15	10 (outsourced cleaning)	4 (education and canteen)
6	Faculty of Fine and Applied Arts (B)	Head of Administrative Office	3	No specific facilities management division	3 floors (rent from the university)
7	Faculty of Political Science (B)	Head of Building, Physical Plant and Vehicle Service Division	20	20 (including drivers)	1
8	Faculty of Education (C)	Head of Building, Physical Plant and Vehicle Service Division	6	30 (including cleaners and janitors)	6
9	Faculty of Science (A)	Head of Administrative Office	NA	5 (outsourced cleaning)	4
10	Faculty of Engineering (C)	Head of Building, Physical Plant and Vehicle Service Division	4	43	22 (including shops and canteen)
11	Faculty of Logistics (D)	Administrative Officer	4	No specific facilities management division	1
12	Faculty of Education (D)	Electrical Technician	7	2-3 (technicians)	1
13	Faculty of Science (D)	Audio-Visual Technical Officer	3	2	1 floor (common lecture rooms)

Table 6.2 Profile of the FM respondents (continued)

Case	Faculty (University Code)	Position	Work Experience in the Position (Year)	Number of Local FM Staff in the Faculty	Number of Buildings in Responsibility
14	Faculty of Fine and Applied Arts (C)	Administrative Officer	3 months	9	4
15	Faculty of Communication Arts (C)	Head of Administrative Office	3 months	None (just retired – no position filled)	1
16	Faculty of Architecture (C)	Head of Building, Physical Plant and Vehicle Service Division	5	2 (electrical technicians)	5
17	Faculty of Public Health (D)	Head of Building, Physical Plant and Vehicle Service Division	15	3	1
18	Faculty of Engineering (D)	Vice-Dean for Administrative Affairs	7	3	1 (main buildings – excluding shops)
19	Faculty of Commerce and Accountancy (C)	Head of Building, Physical Plant and Vehicle Service Division	2	50	5
20	Faculty of Economics (C)	Administrative Officer	>30	20 approx.	1
21	Faculty of Engineering (B)	Head of Building, Physical Plant and Vehicle Service Division	11	4 (excluding local workers)	1
22	Faculty of Humanities (B)	Head of Building, Physical Plant and Vehicle Service Division	38	24	2
23	Faculty of Political Science (C)	Head of Administrative Office	38	25	3
24	Faculty of Engineering and Industrial Technology (A)	Head of Administrative Office	12	1 (responsible for main building only)	5 (including shops and chemical stores)
25	Faculty of Pharmacy (A)	Head of Building, Physical Plant and Vehicle Service Division	20	28	6

Note: a – This interviewee was formerly responsible for the faculty's building improvement and had insights into the building operations before being appointed as the Vice Dean for Special Affairs and Quality Assurance.

6.2.2 Current energy reduction policies

This subsection focuses on air-conditioning related energy reduction policies and practices currently held in the observed faculties. The objective of this investigation is to demonstrate how aware HE institutions were of energy consumption within their buildings.

The FMs were asked to describe the energy reduction policy(ies) currently implemented in their faculty. There were three major energy reduction policies currently adopted by the faculties that participated in the interviews (Figure 6.2). The most common was a behaviour and attitude change campaign, which used posters and stickers to raise users' awareness of energy consumption. Purchasing energy-efficient air-conditioners (label no.5) was the second common energy policy. As stated in Subsection 2.3.2 (p. 50), this policy is obligatory for all public organisations in Thailand as announced by the MOE. However, a number of faculties stated that this policy had not yet been implemented since existing air-conditioning systems were still working properly; hence, there was no need to purchase new ones. The third most common energy policy was scheduling air-conditioning operation, i.e. delaying the turning-on time, advancing the turning-off time, and turning-off air-conditioners during lunch break. Nevertheless, this policy was considered suitable for administrative offices only because their working hours were more continuous and consistent than that of classrooms. The remainder of the policies were building improvements and research on thermostat control. Air-conditioning system maintenance, usually carried out every semester or at least once a year, was considered by the FMs as a routine job for maintaining or repairing the systems rather than to reduce energy consumption. There was only one case where this form of proactive maintenance was specifically claimed for an energy saving purpose.

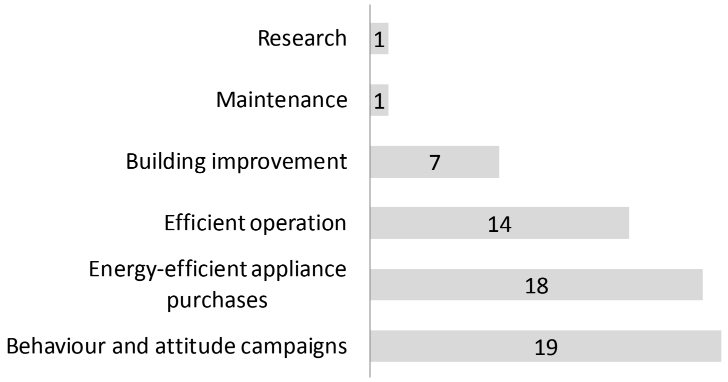

Figure 6.2 Energy reduction policies deployed by 25 facilities managers interviewed

Focusing on the behaviour and attitude campaigns, these seem to be taken as the initial step for all faculties where local facilities management staff are capable of commencing this straight away. However, many interviewees admitted that the success of these campaigns lasted only for a short period, and it was difficult to evaluate the direct energy savings resulting from these campaigns. Both passive and active approaches were employed to reach the end-energy consumers. Hands-on facilities management staff often confronted end-users (teachers and students) face-to-face, inspecting energy waste and making them aware of their energy behaviour. This sometimes led to a misperception among students that facilities management staff were not supporting learning-teaching activities by forcing them to use less energy (based on Cases 3 and 5).

> "Our problem now is that students come and use electrical outlets (to connect to laptops and printers) in the opened hall in the building at night. The electricity cost is considerably increasing. We have to control this by reducing the number of the outlets. We try to compromise, avoiding a quarrel with students, because we do not want them to hate the faculty or feel like we are not supporting their learning."

Faculty of Education, Case 5

Considering capital investment in energy projects, some faculties had obtained financial and technical support from the central facilities management department of the university. Basically, this central department worked in accordance with the MOE policy and had more power than local departments to instigate energy movements within the university. This is because the EPPO and DEDE launched the building improvement scheme for energy conservation in the public sector and this included public universities (DEDE, 2009). According to this scheme, a one-off injection of money into governmental buildings to support energy-efficiency projects, such as the replacement of low-efficiency appliances or building insulation improvements could be offered to governmental organisations. Almost all FMs who took part in the interviews said that their faculties were receiving this financial support from the government through the central facilities management department.

Faculties with more capacity, both in terms of knowledge and technology, seemed to be more advanced in implementing energy reduction policies. For example, energy programmes conducted in the Faculty of Engineering and Architecture (Cases 1, 10, 16, 18, 21 and 24) were better integrated into core academic activities, such as building research and the curriculum and consequently strategic and operational staff in these organisations were sharing the same vision. Technological advancement to assist air-conditioning remote control systems, particularly sensors for split type air-conditioners, was mentioned as part of their ongoing research. Aside from knowledge support from academic staff, commitment on the part of the faculty dean to energy reduction policies and programmes also motivated facilities management staff, teachers and students to behave in a more energy-efficient way (Cases 1, 4, 9, 10, 11, 12, 16, 17, 18, 21 and 24).

Evidence showed that most academic institutions were aware of increasing energy consumption, at least at the policy level. Energy reduction policies and their implementation in the HE sector were generally dominated and initiated by governmental organisations. The local facilities management department was responsible for very few radical changes or innovation with regards to energy policy making.

6.2.3 Energy information systems

This part presents the current energy information systems as these provide real data for the initiation of energy-related policies in the observed faculties. It centres on how energy information, i.e. electricity costs, the amount of energy use and thermal performance, is obtained and disseminated within an organisation. The topic covers metering, electricity costs monitoring and dissemination, energy audits and thermal comfort surveys.

Sub-metering is regarded as an initial step to obtaining meaningful data to assist in decision making on energy policies and actions. The FMs were asked whether there is(are) electricity sub-meter(s) installed in their building(s). As can be seen in Figure 6.3, nine out of 25 faculties had sub-meters installed in their buildings, another nine faculties had a single meter for each building, whilst no electricity meter was installed in six faculties. These six faculties were from the same university in which a central meter was installed and the central facilities management division was responsible for all utility costs. For those faculties in which sub-meters were located, three of them which were multi-departmental organisations not only used sub-metering for monitoring detailed energy use, but also (and mainly) for enumerating energy costs by the organisational department. Therefore, sub-meters were not always installed based on a physical plan or function but instead for organisational structure and budget allocation.

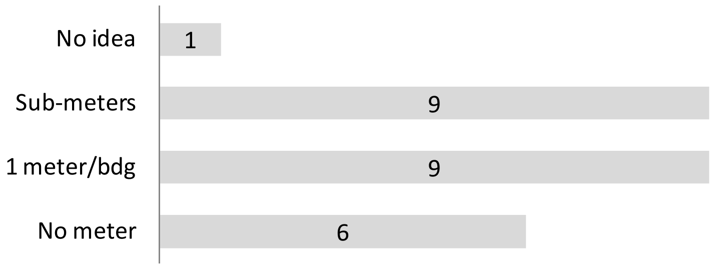

Figure 6.3 Electricity meter installation in buildings in 25 faculties

The second issue is electricity costs monitoring and dissemination. The FMs were asked whether they have the information about electricity consumption and costs, and whether the information is disseminated to the faculty members. From Figure 6.4, it can be seen that most facilities management divisions were able to monitor electricity costs directly (11 cases) or indirectly (eight cases). For the latter, generally the information was kept within the financial division. There were six faculties in the same university that did not usually possess the figures for energy costs since the central facilities management department paid them.

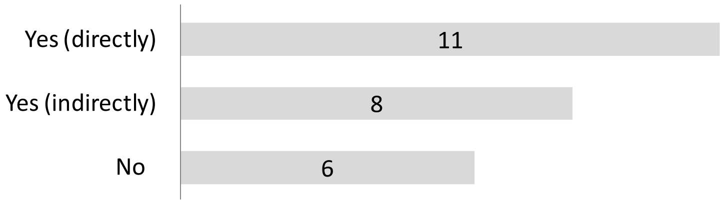

Figure 6.4 Facilities managers who can monitor the information about electricity consumption and costs in their faculty

For energy information dissemination (Figure 6.5), 14 FMs said they reported or used to report energy information regularly to the faculty board of administrators. One of these also publicised the data to end-users in the form of summary charts displayed on the faculty's news board. Three of these FMs stated that they used to circulate the data up and down within the organisation, but did not do so now because they were too busy. In the remaining 11 faculties, the interviewees did not know for certain whether the energy information was sent to the faculty board of administrators and end-users as they did not possess this data themselves.

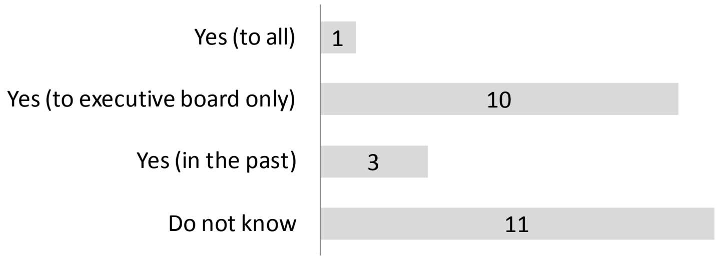

Figure 6.5 Facilities managers who had disseminated the information about electricity consumption and costs to the faculty members

With regards to this issue, as stated in Chapter 1 (Subsection 1.2.2, p. 33), all public universities in Thailand have to abide by the governmental policy to reduce energy use by 10-15% and are responsible for reporting their energy use to the EPPO annually (EPPO, 2012, DEDE, 2009). Concurrently, all HE institutions are required to report their energy consumption data to the DEDE every six-months (DEDE, 2004) in order to comply with the Royal Decree on Designated Buildings 1995 (B.E.2538) (MOI, 2005). Therefore, all universities have to comply with either or both of these regulations to report their energy data to the government, so it is expected that at the university level energy data is available and more accessible.

The third issue is an energy audit. The FMs were asked whether they have ever conducted an energy audit in their faculty. For the 25 responses, energy audits had only been formally carried out in ten faculties, another ten faculties had not yet been audited and five interviewees did not know whether an audit had been conducted or not (Figure 6.6). In general, the decision to undertake an energy audit within faculty buildings was taken at the university level as part of complying with the EPPO and DEDE policies mentioned earlier and the local facilities management division did not usually get involved at the decision-making stage. Nonetheless, the majority of interviewees claimed that an energy audit was one of their responsibilities, at least on an ad-hoc basis, if not fully scheduled, either when service systems failed or when energy costs soared suspiciously. Based on the interviews, many faculties were not capable of conducting a full energy audit by in-house staff. Despite this, with support from the university's central organisation and external accredited auditors, a proper energy audit had been administered in many subordinate organisations.

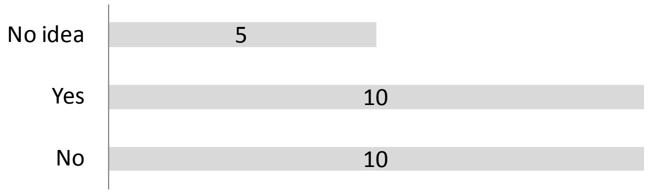

Figure 6.6 Facilities managers who had conducted an energy audit in their faculty

The last issue to be focused in this subsection is a thermal comfort survey. The FMs were asked whether they have ever conducted a thermal comfort survey in their faculty. Such a survey is considered to be the only means of obtaining direct information from end-users which may be useful for making energy policies. It was found that conducting a thermal comfort survey within the HE sector in Thailand was relatively rare. For all 25 responses, only three stated that they had conducted a formal thermal comfort survey (Figure 6.7). However, the topic of thermal comfort was usually included in the section entitled 'user satisfaction with building services' within an annual evaluation form, normally using a 5-point rating scale (1-Very Unsatisfying to 5-Very Satisfying). In contrast, the majority of faculties (21 cases) did not include thermal comfort in their building service performance assessment, if they had an assessment at all. Some claimed that they already received day-to-day feedback and complaints from staff and students about thermal discomfort; hence, they did not see the necessity of administering a formal survey (based on Cases 16 and 20). During the interviews, there were a few occasions when some interviewees showed reluctance to the idea of conducting a thermal comfort survey. From their view, the survey results were regarded as an indicator of facilities management performance. Some facilities management staff commented that it might not serve as a fair judgement because thermal comfort was rather subjective.

> "Results from the thermal comfort survey are based on users' opinions only. Sometimes, it is not fair with us because users judge the quality of facilities based on their own demand for cool comfort without the understanding of the purpose of efficient air-conditioning operation."

Faculty of Architecture, Case 16

However, where thermal comfort survey results were used for promoting rather than blaming facilities management staff, they felt they had support for improving the service standards to be higher than the minimum requirement (based on Case 9).

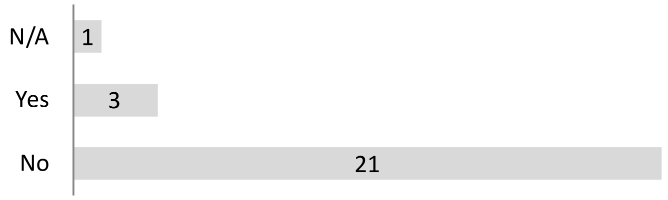

Figure 6.7 Facilities managers who had conducted a thermal comfort survey in their faculty

In summary, energy information within HE institutions was recorded and stored in administrative offices. The information was mainly circulated up to university administrators and governmental organisations for allocating annual budget and making energy policies. End-users, despite being the people who use the energy or benefit from its use, were rarely consulted about the energy situation in their organisation.

6.2.4 Air-conditioning installation

This part describes how air-conditioning systems were introduced into HE buildings, including their influence on building modification. These issues were investigated from an organisational rather than a technical aspect in order to observe the influence of human subjects on air-conditioning in non-residential buildings.

Within the interviews, FMs were briefly asked about where and how air-conditioning systems were firstly introduced into their organisation. From Figure 6.8, teachers' offices were mentioned the most frequently (nine cases) as being the first place to be installed with air-conditioners, four FMs said that the air-conditioning systems came with the buildings, three FMs claimed that the air-conditioning systems were installed in administrative offices first and only in one case were lecture rooms the first place to receive air-conditioning. In addition, it was mentioned several times that teachers were those who first requested air-conditioning. In contrast, students had the least power to make such request. According to the information obtained, user organisational status and air-conditioning seem to be related. However, the amount of time spent in a particular space could also be another reason for prioritising air-conditioning; an office-type space was likely to be the first priority since it is permanently occupied each day by the same group of people, whereas a lecture room is used in a more temporary manner and has no real owner.

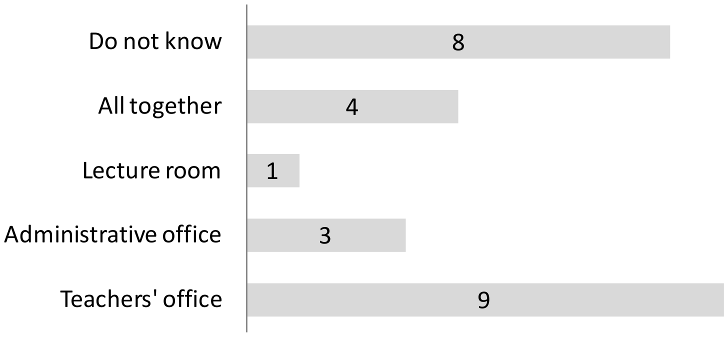

Figure 6.8 First room type installed with air-conditioning system in 25 faculties

The second issue is room improvements or changes made to the buildings before or after the installation of air-conditioning. The FMs were asked whether and how the rooms have been improved or changed before or after the air-conditioning installation. The FMs can give more than one answers. As shown in Figure 6.9, of total 47 responses, fan removal and curtain/blind fitting were the top two modifications made to AC rooms, with 16 and 11 counts, respectively. Alterations made to improve the insulation level of building envelopes were undertaken in nine cases and consisted of seven examples of window insulation, one of roof insulation and one of fitting shading devices. In general, minor alterations rather than major ones were obviously preferable. Reducing the ceiling height was undertaken in five faculties in order to reduce the cooling load in the rooms, and in some cases this caused the ceiling fan to be removed.

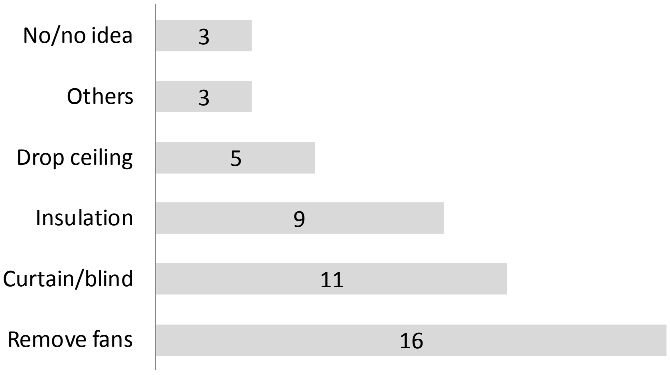

Figure 6.9 Room changes before/after installing air-conditioning systems (47 responses)

The transformation from full natural ventilation to an air-conditioning system is not unusual for existing HE buildings in a hot-humid country. In terms of energy consumption, a room alteration is a significant process that could affect long-term energy use. However, from the interviews it was clear that a room evaluation in relation to energy consumption before and after the alteration process was not often carried out.

6.2.5 Air-conditioning operation and user controls

This subsection explores how the air-conditioning systems in selected HE buildings are currently operated, including the issues of user controls and service standards held in this building type. This is to provide background information about the level of control given to end-users, as it is directly related to their thermal adaptive opportunities in this context.

The FMs were asked who are responsible for operating air-conditioners and setting thermostats (mainly in classrooms). Regarding thermal operation, interestingly, the majority of faculties (14 cases) formally assigned local facilities management staff (e.g. housekeepers, janitors or technicians) the responsibility for turning air-conditioners on and off as part of their daily routine. In these faculties, air-conditioners (mostly the split type) were turned-on approximately 5-15 minutes before classes began (nine cases), although where there was a central air-conditioning system this pre-cooling period could be up to 30 minutes (three cases). There were nine faculties which gave total air-conditioning control to the end-users, i.e. users turned the thermostats on and off by themselves and there were only two faculties where both staff and end-users were co-responsible for the operation for the system.

Almost all facilities management divisions set the standard temperature at 25°C (21 cases), although there was one where it is set at 23°C and another at 24°C. Two FMs said they did not specify the standard temperature set point. In all 25 faculties, end-users in 13 faculties were free to adjust the temperature, except where central air-conditioning was in use. The remaining 12 faculties did not allow users to adjust the thermostats. The prevention of end-users adjusting the thermostats was achieved by installing the thermostats high up on the wall, hiding the thermostat in a box, or removing the remote controls from the rooms. If teachers or students felt uncomfortably cool they would turn-off one or more air-conditioners instead of raising the temperatures, but this was rare (Case 3). Facilities management staff said students seemed to adapt very well to cool air by wearing more clothes and they usually complained more about warmth discomfort.

> "In practice, we do not want users to adjust the thermostats by themselves because they do not understand how the remote controls work and how the air-conditioning system works."

Faculty of Education, Case 12

From the experiences and perceptions of most interviewees, students were likely to use air-conditioners improperly to serve their extreme demand for air-conditioning. For example, when they came in from outside, they would set the temperature unacceptably low at 12°C, because they felt they needed quick cool air (Case 13). According to the interviewees, this frequently caused a premature system break down and high maintenance costs. Therefore, based on the viewpoints of the FMs, preventing students from adjusting thermostats would be more beneficial to their organisation than giving users total freedom with the controls for the air-conditioning system.

> "Users have high expectation for facilities operations. The rooms must be already cooled when entering to the rooms. Problems with the air-conditioning system are mostly about thermostat adjustment. Air-conditioners work properly at optimal temperatures, but students often adjust it too low causing a premature system breakdown. So, we would like to take the remote controls out of the rooms so students cannot

> adjust the temperature freely. However, we are also afraid that this would cause user dissatisfaction.”

Faculty of Education, Case 8

To categorise the cases by level of user controls, two attributes, thermal operational practice and temperature adjustment, were combined. Following this, cases were reclassified into three levels as described below, and the number of cases in each level is shown in Figure 6.10.

- High control: Staff and users can operate the system, and users can adjust the temperature freely. Usually, the thermostats were set at 23-25°C.
- Moderate control: Users operate the system by themselves (i.e. no pre-cooling) but have no control over the temperatures. Usually, the thermostats were set at 23-25°C.
- No/Low control: Staff run the system and set the temperatures beforehand (i.e. pre-cooling), and users are not permitted to adjust thermostats. Usually, the thermostats were set as 25°C.

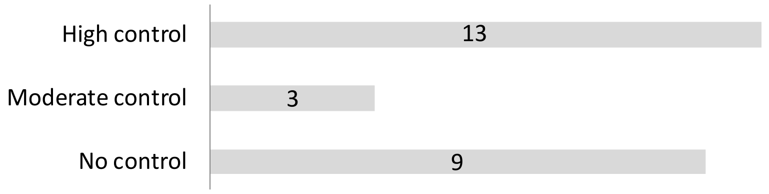

Figure 6.10 Levels of user control over air-conditioning system in 25 faculties

According to FMs’ opinions, total freedom of control could potentially result in a fundamental problem regarding the air-conditioning system maintenance in their buildings. Likewise, assigning local facilities management staff to operate the air-conditioners is not seen as the best solution because it is labour and time intensive. At the time of conducting the interviews there was only one faculty (the Faculty of

Engineering, Case 10) applying software to centrally control their air-conditioning system and this controlled the on-off time and the temperature set point. This faculty owned 22 buildings; however, according to the FM, the current system was still not sufficiently flexible to detect and eliminate thermal discomfort and respond to uncertain patterns of room utilisation. With regards to this issue, a few faculties (the Faculty of Architecture, Case 16 and the Faculty of Engineering, Case 18) were experimenting with software that could automatically adjust the thermostats to suit real-time user requirements. It is expected that this technology could reduce the staff burden and user discomfort.

Although some FMs have taken over control of the air-conditioning from end-users, in many cases facilities management officers provided a higher level of service standard to satisfy the users. This was demonstrated by the pre-cooling process seen in more than half of the observed faculties. Here, facilities management staff acted similarly to an automated system, whereby user intervention was not required to provide thermal adjustment and users were prevented from heat discomfort by all means possible.

6.2.6 The possibilities and barriers to mixed-mode operational strategies in existing higher education buildings

In the final part of the interviews, FMs were asked about the possibilities and barriers to the implementation of MM cooling strategies in their buildings. The proposed strategies were explained to the interviewees as follows.

> Strategy 1: Concurrent - To use air-conditioners and fans together and set the thermostats 1 or 2 degrees higher than usual (from 25°C to 26-27°C) to save energy

Strategy 2: Change-over - To use natural ventilation assisted by fans in the morning and evening classes and/or in the cool season when the outdoor temperature is not too hot, in existing MM rooms

Strategy 3: Zoned - To conserve and/or extend fully NV spaces (with or without fans) within faculty buildings in the future

Only 24 respondents were included in this analysis as one faculty was excluded since it was established only a few years ago and hired a three-floor space in a common university building where they had no direct control over the building and its service systems. In this part of the interview, interviewees were also free not to answer the questions if they thought the issues were out of their authority.

In general, FMs were not convinced that the proposed MM strategies would be practical in reality and the overall responses are illustrated in Figure 6.11.

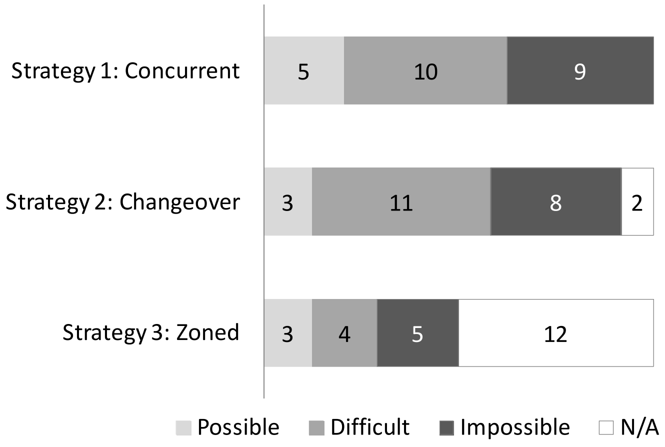

Figure 6.11 The possibilities of mixed-mode cooling strategies reported by 24 facilities managers

Comparing all three strategies, to use air-conditioners in an economic mode assisted with ceiling/wall fans (Strategy 1) was voted the most possible given the condition of existing HE buildings. Using only natural ventilation and fans when the outdoor temperature is not too hot (Strategy 2), was not well perceived and the third strategy, to preserve or increase NV spaces also had low positive responses from the interviewees. Two faculties (Cases 9 and 25) in which a central air-conditioning system had been installed did not think the MM strategies would be practical. In comparison, the rest of the 22 FMs that had a split-type air-conditioning system installed in their buildings had various opinions on the proposed MM strategies. Therefore, types of air-conditioning systems seem to have little influence on how FMs responded to the proposed MM strategies. Further explanations for each strategy are provided in the following subsections.

6.2.6.1 Strategy 1: Concurrent

For the 24 interviewees from different faculties, five indicated that the Concurrent strategy was possible within their faculties, which were:

1) Faculty of Engineering, University C (Case 10)
2) Faculty of Education, University D (Case 12)
3) Faculty of Architecture, University C (Case 16)
4) Faculty of Public Health, University D (Case 17)
5) Faculty of Engineering and Industrial Technology, University A (Case 24)

All of these faculties had both NV classrooms assisted with ceiling/wall fans and AC classrooms with ceiling/wall fans. However, none of these normally used both fans and air-conditioners together. The FMs said that this strategy would be accepted as long as the air-conditioning was on so that students would not complain (based on Cases 10 and 24). The interviewee in Case 1 suggested that a fake thermostat might help to reduce student resistance caused by a change in their expectation of the air-conditioning temperature set point.

> "Using fans and air-conditioners together is possible because there are ceiling fans in every room and as long as thermal comfort is maintained. Students will not bother checking what the temperature set point is."

Faculty of Engineering and Industrial Technology, Case 24

> "If we want to encourage users to use fans and raise air-conditioner temperatures, we might have to install a fake thermostat which is set at standard temperature, *i.e. 25℃* [my addition]. Actually, users do not really care much about the temperature set they just turn the air-conditioners on and off."

Faculty of Architecture, Case 1

From the quotations above, even though the FMs thought that the Concurrent strategy was probable, they revealed that there was some degree of user addiction to air-conditioning and a lack of user-environment interactions within classrooms.

According to 37 responses from 19 participants who disagreed with the Concurrent strategy or felt it would be difficult in practice, room design and user habits were claimed to be the two most important barriers to the strategy, with 13 and 12 responses, respectively. Other barriers are displayed in Figure 6.12.

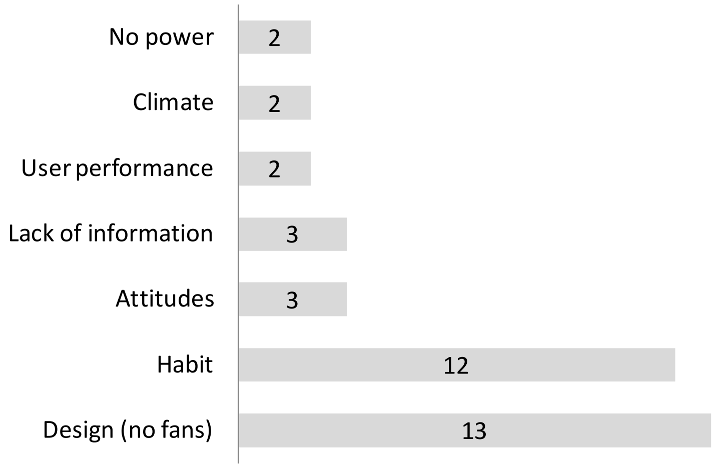

Figure 6.12 Barriers to the Concurrent strategy reported by 19 facilities managers (37 responses)

In terms of design, the absence of fans in most existing classrooms was clearly the most important design constraint. However, even in rooms in which fans were available, a number of FMs stated that concurrent operation of electric fans and air-conditioners was not the norm for Thai users, particularly in non-residential buildings. Fans were occasionally used to relieve heat during air-conditioner start-up time before being turned-off (Cases 5, 12 and 13), or to assist air-conditioning when the room density was high (Case 12). Consequently, users might find the Concurrent strategy contradictory to their habitual air-conditioning use. Lack of user interest and lack of power and motivation by facilities management staff to change occupant habits were also noticeable during the interviews.

> "Even if we had ceiling fans, it will not guarantee that users would use them, and we have no power to ask them to use fans. Users are used to and addicted to air-conditioning. They use air-conditioning all day. Improving physical environments to reduce air-conditioning use is easier than changing users' behaviour."

Faculty of Archaeology, Case 2

> "Normally Thai people use either fans or air-conditioners, not both of them at the same time. Since our building is designed to be centrally air-conditioned, not every room has fans installed. Besides, users in our faculty do not have involvement in room operation at all. Therefore, they are not active in operating fans or anything else. They are very used to air-conditioning."
>
> Faculty of Science, Case 9

Apart from these two main barriers (i.e. design and habit), other associated problems were personal attitudes, lack of energy-saving information, concerns regarding a reduction in productivity, climate, and the limited power of the facilities management department and personnel, which would obstruct the Concurrent strategy. According to some FMs, students did not pay any attention to energy saving whatsoever. Moreover, students apparently complained that strong air movements resulting from fans disturbed their concentration (Case 3). Some FMs themselves believed that fans were not effective and no longer necessary if air-conditioners were available. While air-conditioning was valued as a vital service to support teaching activities (Case 19), fans were perceived as merely a subsidiary cooling device. A lack of information about how energy can be saved by using electric fans to assist air-conditioners, partially because some interviewees did not have the energy data to hand, was also of concern to some FMs (Cases 8, 11 and 22) and therefore, they were reluctant to support this strategy. This lack of data and knowledge might be why fans are gradually disappearing in this building type, when renovations are made as shown earlier in Figure 6.9 (p. 242).

6.2.6.2 Strategy 2: Change-over

Of the 22 interviewees who provided an opinion about the possibilities of changing over from full AC mode to ANV in classrooms when the outdoor climate allows, only three supported the strategy. They were:

1) Faculty of Logistics, University D (Case 11)
2) Faculty of Public Health, University D (Case 17)
3) Faculty of Engineering, University B (Case 21).

The first two faculties currently used only natural ventilation and fans in classrooms all year round and the engineering faculty only used air-conditioning in the engineering workshops. Therefore, these faculties agreed to the Change-over strategy because they were using even more natural ventilation than this strategy proposed, i.e. to use ANV mode during morning or evening classes and during the cool season. In these faculties, extra standing fans were usually put in place in addition to the ceiling fans (Cases 11 and 17). When asking whether students would prefer air-conditioning to ANV, the FMs said they would, although if the air-conditioning would result in an increase in their tuition fees then students might reconsider (Case 11).

In contrast, for the faculties that operated full air-conditioning the strategy was viewed from the opposite angle. That is, this strategy was asking users to sacrifice their constant comfort for energy savings and this would be extremely hard to achieve according to the FMs' responses. There were 11 participants who thought that the strategy would be difficult to put into action and another eight FMs stated it would be impossible. These eight faculties did not have fans installed in most classrooms and a central air-conditioning system was used in two of them. However, students in the faculties of science or engineering did not complain when using existing NV laboratories, studios or workshops, if it was for health and safety reasons, although they would refuse to use ANV mode in existing MM classrooms if air-conditioners were available.

Barriers to the Change-over strategy are presented in Figure 6.13. Being accustomed to AC environments was the most important barrier with nine responses. Since most occupants spent a lot of time in AC environments they did not notice the diurnal or seasonal differences in outdoor climate and therefore, it would be hard to expect them to act responsively to the outdoor climate. The second noteworthy barrier was personal attitudes towards the right to air-conditioning use. From the interviewees' experiences, students thought air-conditioning use was strongly related to the fees they paid. It was mentioned several times that reducing air-conditioning use in evening or night classes was difficult because most of these classes were usually organised for postgraduate students who paid high tuition fees (Cases 5, 7 and 11) and expected high standards of the facilities and services. Consequently, the use of air-conditioning in evening and night classes was not based on necessity but instead on the perception of user as education customers in the organisation and their power.

> "To reduce air-conditioning use in evening classes is difficult because the user group is different. They are executive people wearing suits in classes and pay tuition fees at higher rates. They have higher expectation for services and facilities including the air-conditioning."

Faculty of Education, Case 5

Unlike the residential sector, the costs of energy consumption in HE institutions are not obvious to end-users, and more importantly, the service is considered to be pre-paid (i.e. included in the tuition fees). Consequently, there is no cost constraint on users regarding the use of air-conditioning. Based on this observation, the misconception about energy costs being paid for and the right to use energy is a considerable attitudinal barrier to implementing MM operational strategies.

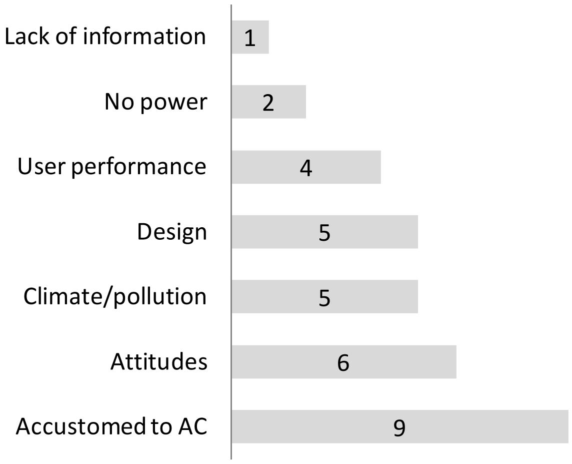

Figure 6.13 Barriers to the Change-over strategy reported by 19 facilities managers (32 responses)

In a hierarchical organisation, the status of users in the organisation or in a specific context also affects the thermal operating practice, as FMs claimed that teachers had the most power to dominate the thermal operations and settings within the classroom context. FMs also admitted that convincing teachers to use less air-conditioning was more difficult. The author also had direct experience of this during the pilot study for Study 4, which aimed to compare the performance of students when using and not using air-conditioning within classrooms. Some teachers resisted turning-off the air-conditioners in classrooms for this experiment despite prior agreement by the FMs indicating the influence of organisational status of users and their power regarding thermal operations within an organisation.

Climate or pollution and poor design were mentioned as the next barriers, with equal counts. For climate, the unpredictability and the realisation of rising outdoor temperatures, associated with air and noise pollution, were claimed as being key to not using ANV, especially for urban campuses (Cases 1 and 9). For design quality, the repetition of building refurbishment, which is normal for HE buildings, probably causes poor ventilation. Most existing HE building stock was originally designed for full natural ventilation and fans; however, due to the increasing space requirement, building spaces had been exploited until they could not maintain the quality of natural ventilation (for example, Cases 14, 18 and 22). There were not many buildings purpose-built to suit their current use and vice versa. The following quotation is an example of how buildings in this sector were typically designed and modified.

> "This building was not initially designed for air-conditioning system. We gradually assemble partitions to suit our functional requirements and install air-conditioners in rooms. Natural ventilation *assisted with fans* [my addition] is then no longer appropriate in some rooms. It is quite common that many education buildings are not designed with a specific air-conditioning system at the first place. Our building, in particular, was built without a specific design requirement. The drawings were made as for a typical engineering faculty building without the air-conditioning system. Then split type air-conditioners were installed as they are the most appropriate choice under these circumstances although the maintenance costs for this system is very high."

Faculty of Engineering, Case 18

Other barriers were risks of performance drop, lack of facilities management power and the lack of information. ANV was claimed to be no longer suitable given the way teachers teach today (i.e. PowerPoint-based materials) which requires a cinema-like teaching environment (Case 16). Facilities management power constraints were emphasised as limiting the ability to make the Change-over strategy practical for existing HE buildings. FMs repeatedly stated that they had no authority to force teachers and students to use the ANV mode, this entirely depended on the faculty board of administrators or the teachers (Case 14).

6.2.6.3 Strategy 3: Zoned

The last strategy, to conserve and increase fully NV spaces, is the one which most FMs felt reluctant to provide an opinion on and there were only 12 responses to this proposed strategy. Of these, only three interviewees said the strategy was partially possible in order to conserve existing NV areas. They were from:

1) Faculty of Education, University D (Case 12)
2) Faculty of Public Health, University D (Case 17)
3) Faculty of Engineering, University D (Case 18).

The main reason given was that it was not worth investing in air-conditioning systems in existing NV spaces, as most existing non-AC spaces were transitional spaces (i.e. halls and circulations), workshops, canteens and toilets. Fully NV classrooms were very rare. Some common attributes of these non-AC spaces are that they were for casual use with relatively low density compared to classrooms. In contrast, increasing fully NV areas sounded impossible. Based on current construction projects in the observed faculties, the current trend for new HE buildings, especially in the urban area, was shifting away from traditional design, i.e. medium-rise with open-air hall or court on the ground floor and open-air circulation, to a high-rise building with full air-conditioning systems installed (Cases 4, 7, 8, 11, 12, 15 and 23).

FMs from four faculties said that the strategy would be difficult and five said with certainty that the strategy was not possible. Four out of these nine faculties did not have fans installed and one of them had a central air-conditioning system. Moreover, three out of these nine faculties had plans to install more air-conditioners in existing NV spaces, with or without fans (Cases 3, 9 and 18), in existing halls and classrooms.

The remaining 12 interviewees provided no response because they had no strategic role to make a decision on this.

> "We are now renovating existing naturally ventilated ground hall to be an air-conditioned multipurpose room because we do not have enough space. Therefore, it is sometimes difficult to preserve naturally ventilated space when the function of space becomes an issue."

Faculty of Science, Case 9

For this last strategy, only three FMs explained why the strategy was impossible. Most FMs had little opportunity to get involved in current building design or refurbishment at a strategic level. From the information available, the barriers to the Zoned strategy were scattered across four topics: facilities management power, climate or pollution, being accustomed to air-conditioning and attitudes (Figure 6.14).

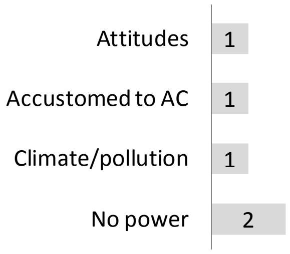

Figure 6.14 Barriers to the Zoned strategy reported by 3 facilities managers (5 responses)

Based on the results of the interviews about the possibilities of MM operational strategies, the following section discusses the organisational attributes that may be related to FMs' perceived possibilities to implement MM strategies in their buildings.

6.2.7 Attributes of the mixed-mode strategy supportive group

In this subsection, the common attributes of those faculties in which the FMs perceived the possibility to implement at least one out of the three MM strategies were analysed. FMs from eight of the 24 faculties stated that at least one of the MM strategies suggested was possible, but only one interviewee, Case 17, stated that all the strategies were possible and were currently implemented in their faculty. Case 17 was therefore considered a champion case regarding the ANV use. All eight faculties, university code (A-D), and the strategies they accepted are listed below.

1) Case 10 (Faculty of Engineering, University C), Strategy 1
2) Case 16 (Faculty of Architecture, University C), Strategy 1
3) Case 24 (Faculty of Engineering and Industrial Technology, University A), Strategy 1
4) Case 12 (Faculty of Education, University D), Strategy 1 and 3
5) Case 11 (Faculty of Logistics, University D), Strategy 2
6) Case 21 (Faculty of Engineering, University B), Strategy 2
7) Case 18 (Faculty of Engineering, University D), Strategy 3
8) Case 17 (Faculty of Public Health, University D), Strategy 1, 2 and 3

Several physical and organisational attributes for the faculties that supported – named the *supportive group* (eight faculties), and those that did not – named the *non-supportive group* (16 faculties), were compared. The common attributes found in the supportive group are presented and Table 6.3 shows the ratios for cases that matched each attribute to the total number of cases in each group.

For the supportive group, of the eight faculties, five were located in a suburban area and five were the faculties of engineering or architecture. Five faculties had sub-metering and were able to monitor electricity costs directly. Remarkably, all eight faculties had faculty administrators, notably the dean or academic staff involved in energy policy implementation. Finally, the proportion of faculties that provided moderate user control over the air-conditioning system between the two groups was equal; therefore, this attribute might be significant. Except for the level of user control, the proportions of these attributes in the non-supportive group were all significantly lower. These six physical and organisational elements may then possibly contribute to the possibilities of MM thermal operations as perceived by FMs.

Table 6.3 The number of faculties in the supportive and the non-supportive groups based on the given attributes

Attributes	Supportive Group Count: Group Total	Non-supportive Group Count: Group Total
Located in suburban area	5: 8	5: 16
Faculty of engineering or architecture	5: 8	1: 16
Sub-metering was installed	5: 8	4: 16
FMs were able to monitor electricity costs directly	5: 8	6: 16
Faculty administrators or academic staff showed commitment to energy reduction	8: 8	3: 16
Provided moderate user control	1 (Case 17): 8	2: 16

It seems that FMs' years of experience, number of local FM staff, and number of buildings under responsibility (see Table 6.2, p. 231) were not clearly related to how FMs responded to the proposed MM strategies.

6.2.8 Summary of findings from facilities manager interviews

The interviews with FMs revealed organisational aspects of thermal operating practice in HE buildings other than the technical aspects of thermal comfort provision. The proposed MM operational strategies were perceived as difficult or impossible to implement in most faculties, based on the views of FMs. Although most faculties and FMs were aware of the increasing energy consumption within their buildings, they were reluctant to address changes in their practice that involved user behaviour change, particularly users with high organisational status (i.e. teachers and postgraduate students). Currently, they can only minimise energy waste by preventing end-users from controlling the air-conditioning systems. With the aim of maintaining or increasing user satisfaction, FMs tend to rely on air-conditioning, especially due to the absence of an explicit energy policy and action plans.

However, when considering the reason behind a building refurbishment within the education sector, the main barrier to the preservation of existing NV spaces is the growing population and rising price of land. The enlargement of undergraduate classes and the proliferation of postgraduate courses have resulted in HE campuses and buildings being more densely populated, and for the latter group of students, air-conditioning is expected. Overall, it could be said that from the education sector side air-conditioning is an economic-led development, and from the user side there is high user expectation for air-conditioning, therefore taken in combination, this minimises the chance to propose an ANV strategy at the design stage.

6.3 PERCEIVED PERFORMANCE RISKS AND THERMAL COMFORT

As stated at the beginning of this chapter, the section focuses on perceived performance risks due to a reduction in air-conditioning which may prohibit MM operations in some existing HE buildings. To assess this perception, this section analyses the data obtained from Study 4: Learning and thermal performance survey, and compares the self-reported performance of students in ANV and AC classrooms. The analysis initially focuses on how students in ANV environments rate their own learning performance compared to those in AC classrooms, given that they were in the same thermal comfort state. Next, the analysis of the relationships between air temperature and performance is presented. The survey form appears in the Appendix A (p. 361).

6.3.1 Case studies

The Learning and thermal performance survey was conducted with a sample of students in existing AC and ANV classrooms. Characteristics of the observed classes and sample size are shown in Table 6.4.

Table 6.4 Characteristics of observed classes and sample size by case

Case No.	Thermal Mode	Room No.	Class Period	Teaching Method	Class Size (Samples Obtained)
1	AC	136	13:00-15:40	Teacher-led	35 (35)
2	AC	137	10:20-12:05	Teacher-led	63 (61)
3	AC	137	13:00-16:20	Teacher-led	81 (79)
4	AC	137	13:00-15:40	Teacher-led	42 (41)
5	AC	4105	8:30-10:15	Teacher-led	26 (26)
6	AC	4104	10:20-11:10	Teacher-led	20 (20)
7	AC	4104	11:15-12:05	Teacher-led	38 (31)
8	AC	4105	13:00-14:50	Teacher-led	57 (55)
	Total AC Samples Obtained				**362 (348 = 96% of full capacity)**
9	ANV	104	9:30-12:00	Teacher-led	27 (27)
10	ANV	102	13:00-15:00	Teacher-led	66 (65)
11	ANV	102	9:00-10:45	Teacher-led	47 (46)
12	ANV	102	9:00-12:30	Teacher-led	64 (62)
13	ANV	101	13:30-15:45	Teacher-led	46 (46)
14	ANV	101	9:00-12:00	Teacher-led	92 (79)
	Total ANV Samples Obtained				**342 (325 = 95% of full capacity)**
	Grand Total				**704 (673 = 96% of full capacity)**

There were 14 classes observed; eight classes in the Faculty of Science and Faculty of Engineering and Industrial Technology in University A (coded) were using air-conditioning, and six classes in the Faculty of Logistics in University B (coded) were using ANV. Both universities were located in suburban areas in the central region of Thailand. Some classes were conducted in the same lecture rooms; however, all respondents were independent (i.e. the same person did not complete the questionnaire twice). There were a total of 673 students who participated in the survey, with 348 respondents for the air-conditioning case and 325 students for the ANV case. The class sizes ranged from 20 to 92 students and the teaching methods used in all classes were based on the teacher standing up front talking to the students who in turn were passive recipients of knowledge on which they could reflect – then named 'teacher-led' method. Class size and teaching method between comparative cases are of concern here because they may affect the learning performance (Schneider, 2002).

In Table 6.5 the personal data of the respondents are described following grouping by thermal mode (i.e. AC and ANV). It can be seen that the majority of participants were female (approximately 64%) in both the AC and ANV cases, and the average age of the participants in both groups was similar, 20 years old. Most students (71%) had low to moderately low incomes (≤ 5,000 Baht/Month) with a slightly higher percentage than that in Study 1 (60%, see Table 5.2, p. 171) probably because this study was carried out in suburban area whereas the Study 1 was carried out in both urban and suburban area. Average clothing values of the students in this study, albeit in different thermal conditions, were similar (AC, 0.42 clo and ANV, 0.41 clo). These clothing values were slightly higher than those of students participated in Study 1 (0.39 clo, see Table 5.2, p. 171) possibly because the percentage of male students (Study 4 = 37: 63, Study 1 = 26: 74), who were more likely to have a higher clothing value, was higher in this study. Also, the ANV case in Study 4 was conducted in the cool season. The proportions of students in morning and afternoon classes using air-conditioning were slightly different with the afternoon classes surveyed slightly more often than ANV.

Table 6.5 Personal data of the respondents

Characteristics		AC		ANV	
		Count (respondent)	**% of Valid**	**Count (respondent)**	**% of Valid**
Gender	Female	222	63.8%	206	63.4%
	Male	126	36.2%	119	36.6%
	Total	**348**	**100%**	**325**	**100%**
Age (year)	Mean (min.-max.)	20 (18-24)		20 (18-22)	
	Total	**348**		**325**	
Income (Baht/month)	≤ 2,500	26	7.5%	24	7.4%
	2,501-5,000	212	60.9%	208	64.0%
	5,001-7,500	81	23.3%	64	19.7%
	7,501-10,000	24	6.9%	27	8.3%
	> 10,000	5	1.4%	2	0.6%
	Total	**348**	**100%**	**325**	**100%**
Clothing value (clo)	Mean (min.-max.)	0.42 (0.21-0.86)		0.41 (0.24-0.80)	
	Std. Deviation	0.12		0.12	
	Variance	.01		.01	
	Valid	332		312	
	Missing	16		13	
	Total	**348**		**325**	
Class session	Morning class	138	39.7%	152	46.8%
	Afternoon class	210	60.3%	173	53.2%
	Total	**348**	**100%**	**325**	**100%**

The indoor and outdoor environmental conditions were also recorded during the survey. As mentioned in Chapter 4 (p. 148), surveying the AC case commenced in the hot-rainy season (July 2010), while that for the ANV case was conducted during the cool season (January 2011). The survey for the ANV case was specifically conducted during the cool season in order to gain an adequate sample size for each thermal comfort group. In contrast, the survey for the AC case could be administered in any season as the indoor air temperature did not vary according to the outdoor air temperature. Conducting the surveys of the two cases in different seasons might affect students' thermal perception and/or expectation. A high percentage of students might feel more comfortable when using AC classrooms during the hot season, compared to the cool season. A high percentage of comfortable students is certainly expected when using ANV classrooms during the cool season, compared to the hot season. Therefore, this methodological limitation potentially affected the proportion of comfortable to uncomfortable students, but it should not cause any major drawbacks in the comparison of student learning performance between thermal comfort groups as thermal comfort is the independent variable not air temperature.

Table 6.6 shows the environmental conditions during the observed period following grouping by thermal mode. In the AC case, air-conditioners in the observed classrooms were on but fans and windows were not in use. In the ANV case, electric fans and windows were operated to reduce the heat experienced within the classrooms. Comparing these two cases, the mean indoor air temperature of the observed AC classrooms was approximately 3 degrees lower than that of ANV classrooms. Although the average RH between the two environments was not significantly different, the range of RH in the observed AC classrooms was slightly wider. The average air velocity in ANV classrooms was almost two times higher than in AC classrooms, but both were considered low.

Globe temperatures were collected in order to calculate the mean radiant temperatures and associated operative temperatures. Based on ASHRAE Standard 55-2004, the operative temperature was the index used for defining the comfort zone which was calculated from the indoor air temperature and mean radiant temperature (ASHRAE, 2004, p. 4). However, based on the data obtained, the indoor air temperatures and operative temperatures were very close. Dependent t-tests[38] showed that the mean

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[38] Dependent t-test: a test using the t-statistic that establishes whether two means collected from the same sample (or related observations) differ significantly (Field, 2004, p. 784).

differences between air temperatures and operative temperatures in the observed classrooms were 0.72°C and 0.05°C for the AC and ANV cases, respectively. The air temperatures in nine locations in the classrooms were recorded to represent conditions experienced by students seated in different parts of the room, while globe temperatures were measured only in the central zone due to the limited availability of equipment. Therefore, the air temperature was mainly used as the index of comfort temperature in further analysis since the data on air temperature was more complete than the operative temperature.

Table 6.6 Environmental conditions during the observed period

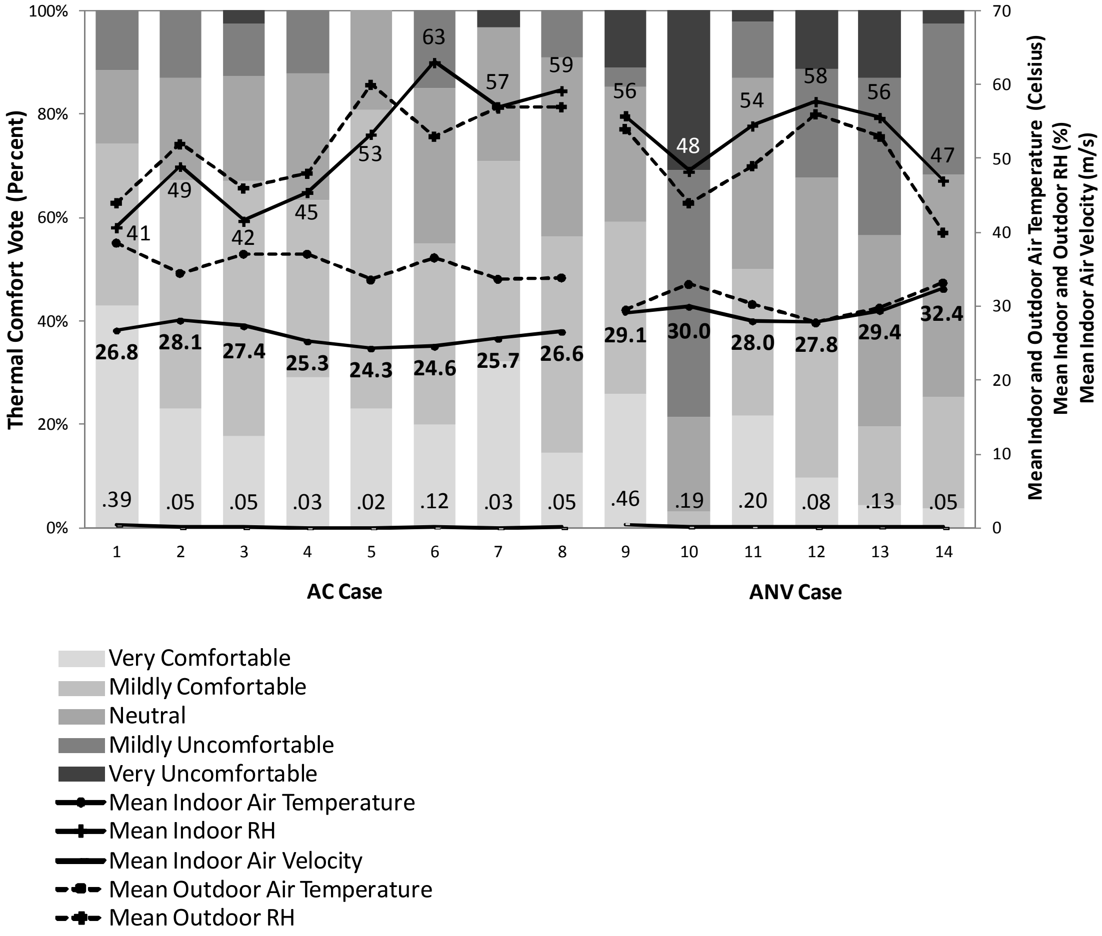
AC Case	**N**	**Mean**	**Min.**	**Max.**	**Range**	**Std. Deviation**	**Var.**
Indoor air temperature (°C)	348	26.5	23.3	30.0	6.7	1.57	2.46
Indoor relative humidity (% RH)	348	50	37	65	28	7.94	63.06
Globe temperature (°C)	45	25.1	23.8	26.5	2.7	0.98	0.95
Mean radiant temperature (°C)	45	24.8	23.8	25.9	2.1	0.74	0.55
Operative temperature (°C)	45	25.3	23.7	26.6	2.9	1.16	1.35
Air velocity (m/s)	348	0.08	0	0.39	0.39	0.12	0.01
Outdoor air temperature (°C)	348	35.7	33.6	38.6	5.0	1.74	3.04
Outdoor relative humidity (% RH)	348	51	44	60	16	5.19	26.91
ANV Case	**N**	**Mean**	**Min.**	**Max.**	**Range**	**Std. Deviation**	**Var.**
Indoor air temperature (°C)	325	29.7	26.2	34.2	8.0	1.85	3.42
Indoor relative humidity (% RH)	325	52	45	61	17	4.60	21.12
Globe temperature (°C)	28	28.8	26.6	31.1	4.5	1.90	3.61
Mean radiant temperature (°C)	28	28.7	26.3	32.0	5.7	2.50	6.26
Operative temperature (°C)	28	28.8	26.7	31.1	4.4	1.89	3.56
Air velocity (m/s)	325	0.15	0.05	0.46	0.41	0.11	0.01
Outdoor air temperature (°C)	325	30.9	27.8	33.2	5.5	2.13	4.52
Outdoor relative humidity (% RH)	325	48	40	56	16	6.23	38.87

As thermal comfort was the main variable of this study, Table 6.7 shows the distribution of thermal comfort votes classified by case and associated mean indoor air temperature. Cases 1 – 8 were AC classrooms and Cases 9 – 14 were ANV classrooms.

Table 6.7 Frequencies of thermal comfort votes and associated mean indoor air temperature categorised by case

Case	Thermal Comfort Vote - N (%)						Mean Indoor Air Temperature (°C)	
	Very Uncomfortable	Mildly Uncomfortable	Neutral	Mildly Comfortable	Very Comfortable	Total	Mean	Std. Deviation
AC Case								
1	0	4 (11.4%)	5 (14.3%)	11 (31.4%)	15 (42.9%)	35	26.8	0.7
2	0	8 (13.1%)	12 (19.7%)	27 (44.3%)	14 (23.0%)	61	28.1	1.2
3	2 (2.5%)	8 (10.1%)	16 (20.3%)	39 (49.4%)	14 (17.7%)	79	27.4	1.2
4	0	5 (12.2%)	10 (24.4%)	14 (34.1%)	12 (29.3%)	41	25.3	0.7
5	0	0	5 (19.2%)	15 (57.7%)	6 (23.1%)	26	24.3	0.7
6	0	3 (15.0%)	6 (30.0%)	7 (35.0%)	4 (20.0%)	20	24.6	0.4
7	1 (3.2%)	0	8 (25.8%)	12 (38.7%)	10 (32.3%)	31	25.7	0.3
8	0	5 (9.1%)	19 (34.5%)	23 (41.8%)	8 (14.5%)	55	26.6	1.4
Total	3 (0.8%)	33 (9.5%)	81 (23.3%)	148 (42.5%)	83 (23.9%)	348		
ANV Case								
9	3 (11.1%)	1 (3.7%)	7 (25.9%)	9 (33.3%)	7 (25.9%)	27	29.1	0.5
10	20 (30.8%)	31 (47.7%)	12 (18.5%)	2 (3.1%)	0	65	30.0	0.3
11	1 (2.2%)	5 (10.9%)	17 (37.0%)	13 (28.3%)	10 (21.7%)	46	28.0	0.4
12	7 (11.3%)	13 (21.0%)	17 (27.4%)	19 (30.6%)	6 (9.7%)	62	27.8	1.1
13	6 (13.0%)	14 (30.4%)	17 (37.0%)	7 (15.2%)	2 (4.3%)	46	29.4	0.2
14	12 (2.5%)	23 (29.1%)	34 (43.0%)	17 (21.5%)	3 (3.8%)	79	32.4	0.9
Total	39 (12.0%)	87 (26.8%)	104 (32.0%)	67 (20.6%)	28 (8.9%)	325		

The data presented in Table 6.6 (p. 265) and Table 6.7 (p. 266) are also illustrated in Figure 6.15. This figure aims to primarily investigate the thermal performance of the selected HE classroom samples, particularly those that were operating in ANV mode.



Note: AC Case = 1 – 8, ANV Case = 9 – 14

Only labels of indoor air temperature, relative humidity and air velocity are shown.

Figure 6.15 Thermal comfort vote (bar chart) against observed mean indoor and outdoor air temperatures and relative humidity and air velocity in air-conditioned and assisted naturally ventilated classrooms

While the thermal performance of AC classrooms was slightly more stable, the potential for conventional ANV classrooms to provide thermal comfort for the majority of occupants could not be neglected. There was only one case (Case 10) where the overall thermal comfort votes were exceptionally low, i.e. only 21% of students felt neutral to comfortable. Notably, the selected ANV classrooms were located in a university campus where most other buildings on the same premises operated full-time air-conditioning which may have influenced student perceptions and willingness to use air-conditioning.

6.3.2 The relationships between thermal perceptions and perceived learning performance

The relationships between thermal perceptions and the PLP of students were analysed, focusing on the comparison of student performance in AC and ANV classrooms as stated in the objective of the study. The data analysis is divided into three main steps:

Step 1: Reliability test of PLP indicators

Step 2: Correlation tests

Step 3: A comparison of perceived learning performance within thermal comfort group between AC and ANV classrooms

6.3.2.1 Step 1: Reliability test of perceived learning performance indicators

As described in Chapter 4 (Subsection 4.4.4, p. 159), PLP was measured through five indicators: *Attention*, *Freshness*, *Alertness, Environmental tolerance*[39] and *Overall learning performance*. Ratings for each indicator, from 1-Much Lower than Normal to 5-Much Higher than Normal, were then averaged to compute a single mean PLP score (ranging from 1-Low to 5-High). In order to do this, the reliability of the five indicators must be first tested in order to confirm the internal consistency of the indicators selected. Based on a reliability test run using PASW, a value of 0.85 for Cronbach's Alpha was obtained which is acceptable according to Nunnaly (1978), i.e. not lower

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[39] Environmental tolerance was verbally explained to the respondents as 'how well you can tolerate the imperfections of the environmental conditions in this classroom, which may negatively affect your learning performance'.

than 0.70, indicating that the internal consistency of these five indicators is satisfactory. Therefore, from this point onwards the mean of the original ratings for the five learning performance indicators (ordinal scale) was transformed into an overall PLP score (interval scale) and used in further analyses.

6.3.2.2 Step 2: Correlation tests

The analysis of the thermal perceptions and PLP relationships was continued by examining bivariate correlations between five individual environmental factors, i.e. thermal comfort, visual comfort, hearing comfort, IAQ (focusing on perceptions of air freshness and odour) and overall environmental comfort, with the PLP score. This was to primarily observe the associations between thermal perceptions and PLP. The PLP score was an interval scale (1-5) whereas the environmental comforts were on an ordinal scale (1-5) but can also be treated as an interval for this analysis. Since the data were not normally distributed (see the normality test in Appendix D: Part 3 - Section 3.1, p. 402), Spearman's rho correlation test was the most appropriate test since it does not require any assumptions about data distribution. Mean comfort votes for the five environmental factors as categorised by thermal mode are presented in Figure 6.16. Overall, the comfort votes for all the environmental factors in ANV classrooms were significantly lower than those in AC classrooms. This could be explained by the fact that the selected ANV classrooms were close to sources of noise and air pollution (construction sites and open sewers) and this might have adversely affected both hearing comfort and IAQ in the chosen ANV classrooms. Visual discomfort was possibly due to sun glare in some rooms and these implications on the results are discussed further in Chapter 7 (p. 300).

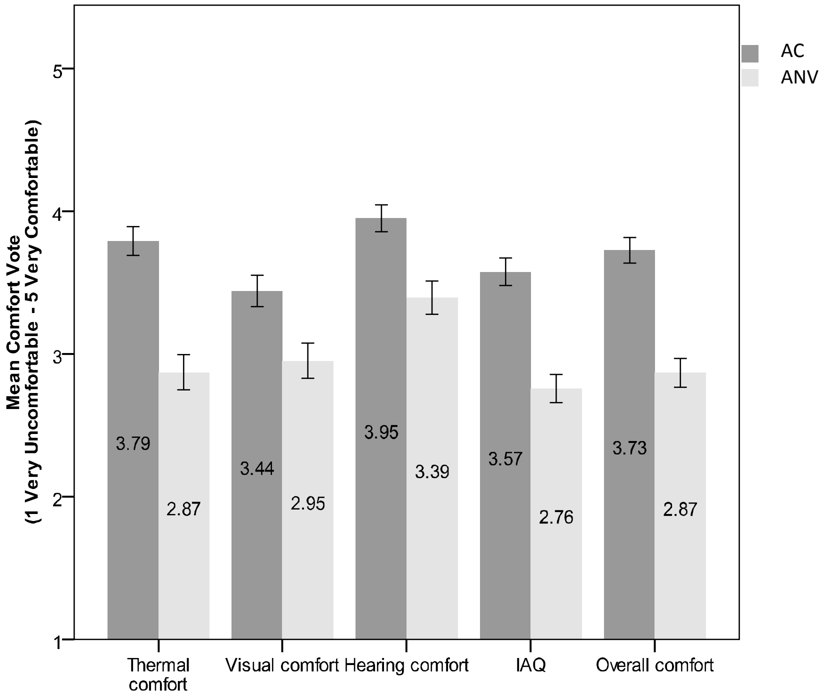

Figure 6.16 Mean comfort votes for five environmental factors categorised by thermal mode, error bars represent 95%CI of mean

The results of the bivariate correlation analyses performed by PASW are shown in Table 6.8.

Table 6.8 Spearman's rho correlation test

Variables	**AC Case**			**ANV Case**		
	Value (r_s)	**N**	**Sig. (2-tailed)**	**Value (r_s)**	**N**	**Sig. (2-tailed)**
Thermal Comfort * PLP Score	0.227	348	0.000	0.394	325	0.000
Visual Comfort * PLP Score	0.217	348	0.000	0.271	325	0.000
Hearing Comfort * PLP Score	0.176	348	0.001	0.259	325	0.000
IAQ * PLP Score	0.152	348	0.004	0.342	325	0.000
Overall Environmental Comfort * PLP Score	0.283	348	0.000	0.366	325	0.000

All environmental comfort dimensions were correlated with the PLP score, with all ρ-values < 0.01. The Spearman's correlation coefficient (r_s) indicates the magnitude and direction of the correlation, ranging from -1 (perfect negative correlation) to 1 (perfect positive correlation) (Field, 2009, p. 192). In the ANV case, the PLP score varied the most with thermal comfort (r_s = 0.39, moderate effect, ρ < 0.001) followed by overall environmental comfort (r_s = 0.37, moderate effect, ρ < 0.001). In the AC case, the effect of overall environmental comfort on PLP was highest (r_s = 0.28, small effect, ρ < 0.001) followed by that of thermal comfort (r_s = 0.23, small effect, ρ < 0.001). Primarily, it can be concluded that thermal perceptions and students' PLP were associated, particularly in the case of ANV classrooms, although the magnitudes of the correlation were not high. The correlation coefficients between thermal comfort and PLP in both the AC and ANV cases were positive. That is, the more students felt comfortable, the more they perceived that they performed better. A further observation showed that the correlation strengths in the ANV case were slightly higher than those for the AC case for all comparisons. Possibly, the associations became stronger when these environmental conditions were uncomfortable and more disturbing to students. When the conditions were neutral or comfortable then the environmental effects disappeared.

6.3.2.3 Step 3: A comparison of perceived learning performance within the same thermal comfort group between students in air-conditioned and assisted naturally ventilated classrooms

In this step, the PLP scores of students within the same thermal comfort group between thermal modes (i.e. AC and ANV) were compared. The thermal comfort, rather than the actual indoor air temperature, was used as the criterion for this comparison since the thermal background[40] of the students needed to be taken into account. Please

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[40] In the context of this thesis, thermal background refers to thermal conditions to which a person has been exposed and acclimatised. Climate zone and the amount of air-conditioning use are considered to have influence on the thermal background of a person.

note that students in both AC and ANV classrooms were already accustomed to the thermal conditions in their classrooms.

Students were initially divided into five groups according to their thermal comfort, and frequencies and percentages of students in each group are illustrated in Figure 6.17. For the AC case, the majority of students (43%) fell into the Mildly Comfortable group, whereas most students (32%) in the ANV case fell into the Neutral group. In comparison, AC classrooms were set to be at 25°C, so the majority of students felt comfortable. Notably, the survey for the ANV case was conducted throughout the day; therefore, the distribution of thermal comfort votes was more spread across the thermal comfort scale. ANV Case 10 had an exceptionally low thermal comfort vote (see Figure 6.15, p. 267) and this affected the overall comfort vote for the ANV case.

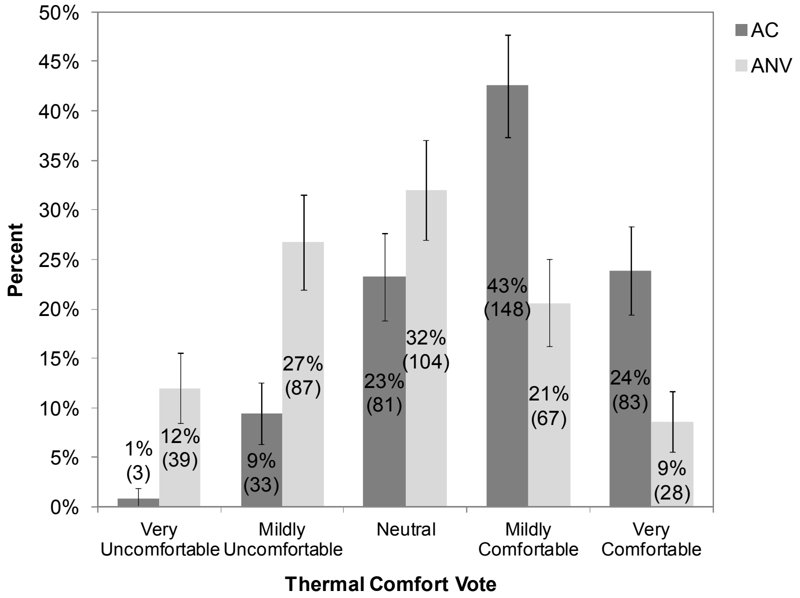

Figure 6.17 Percentage and frequency of respondents categorised by thermal mode and their thermal comfort vote, error bars represent 95%CI of proportion

The corresponding mean indoor air temperatures for each thermal comfort category are presented in Figure 6.18. A preliminary visual inspection shows there is no significant temperature difference between the AC comfort groups as all the error bars overlap. In contrast, students in the observed ANV classrooms felt most comfortable at around 28.5°C and were likely to feel more uncomfortable when the indoor air temperatures reached 30°C. However, because the error bars of the mean indoor air temperature in some comfort groups overlap, the relationships between indoor air temperature and respondents' thermal comfort votes in the ANV case cannot be clearly stated. This is probably due to the limited indoor air temperature ranges during the observation period for both the AC and ANV cases.

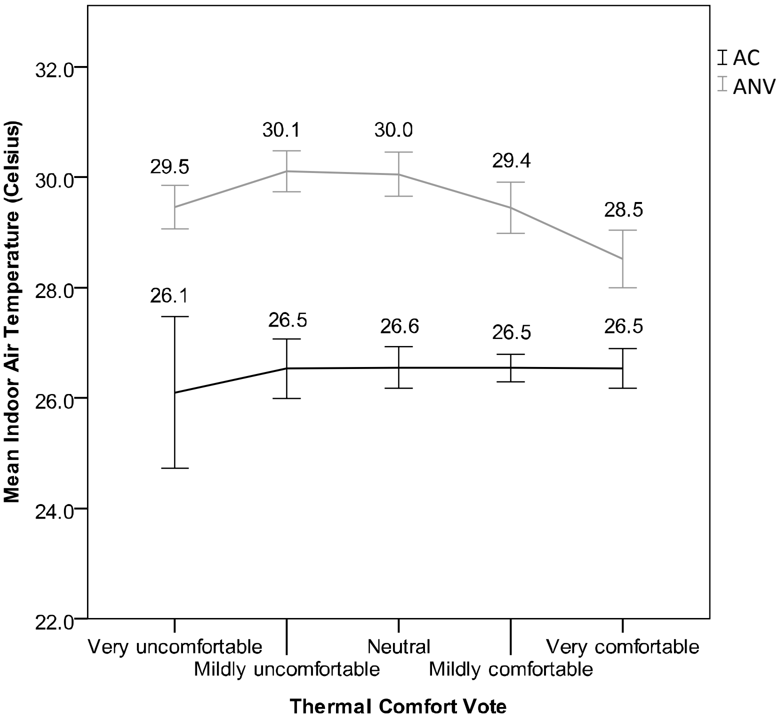

Figure 6.18 Observed mean indoor air temperatures categorised by thermal comfort vote, error bars represent 95%CI of mean

After classifying the respondents by their thermal comfort level, their PLP scores were compared. Initially, a comparison of the PLP scores of students from the five paired comfort groups (e.g. Very Uncomfortable AC versus Very Uncomfortable ANV) was planned. However, there were only a few respondents (three subjects) in the 'Very Uncomfortable' AC group, as can be seen in Figure 6.17 (p. 272). Therefore, to gain sufficient samples for the comparisons, the five thermal comfort categories were collapsed into three groups: Uncomfortable, Neutral and Comfortable. A list of the comparative groups and the numbers of valid respondents in each group are presented in Table 6.9.

Table 6.9 Frequencies and percentages of respondents in three comparisons of PLP scores

	Thermal Comfort Vote	Thermal Mode				Row Total	
		AC		ANV			
		Count	N %	Count	N %	Count	N %
1st Comparison	Uncomfortable (students who voted 1 or 2)	36	22.2%	126	77.8%	162	100%
2nd Comparison	Neutral (students who voted 3)	81	43.8%	104	56.2%	185	100%
3rd Comparison	Comfortable (students who voted 4 or 5)	231	70.9%	95	29.1%	326	100%

Figure 6.19 illustrates the mean PLP scores and associated standard errors categorised by thermal comfort group in both AC and ANV cases and the associated frequencies and percentages of students in each category are shown in Figure 6.20. Preliminary observations show that the thermal perceptions and self-reported learning performance relationships were relatively linear, particularly in the ANV case. This means that students who were satisfied with their thermal environments believed that they were able to maintain their learning performance at their own normal state or above. However, it seemed that the PLP scores of students in ANV classrooms reduced significantly if they felt uncomfortable whilst the scores of AC students were less affected by their perceived thermal discomfort. The PLP scores of Neutral as well as Comfortable AC and ANV students seemed not to be significantly different as the error bars overlapped. However, uncomfortable ANV students were likely to have significantly lower PLP scores than uncomfortable AC students.

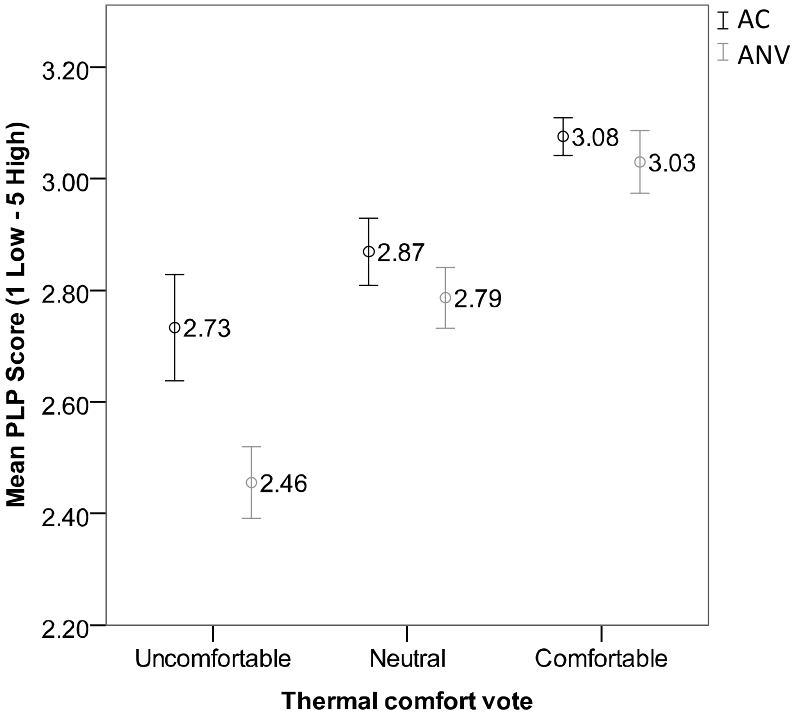

Figure 6.19 Mean perceived learning performance scores of students categorised by thermal mode and their thermal comfort vote, error bars represent standard error of mean

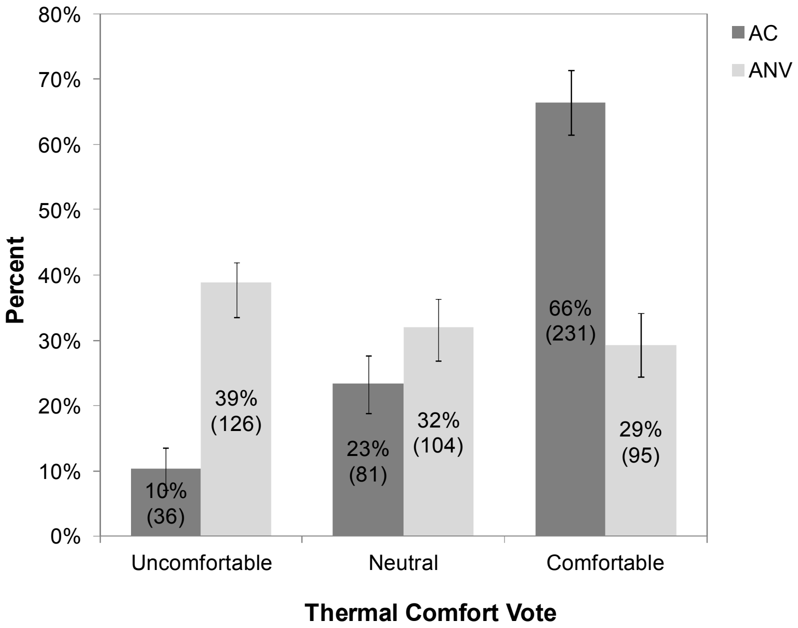

Figure 6.20 Percentage and frequency of respondents categorised by thermal mode and their thermal comfort vote, error bars represent 95%CI of proportion

To confirm the results of the visual investigation, an independent t-test was employed to compare the means of the two independent groups if the data were normally distributed, or the Mann-Whitney U test[41], the equivalent non-parametric test for data that are not normally distributed. The data distributions in all sub-groups were tested first and then the appropriate test performed. The results of the normality tests for this analysis can be found in Appendix D: Part 3 - Section 3.2 (p. 407). The results of the comparisons of PLP means are summarised below. The complete output of the independent t-tests and Mann-Whitney U tests performed by PASW can be found in Appendix E: Part 3 – Section 3.1 (p. 402).

Part 1: Uncomfortable AC versus uncomfortable ANV group

Mean PLP scores of students in the Uncomfortable AC and ANV cases were compared first. According to the normality test conducted beforehand, data in all sub-groups were normally distributed; therefore, the parametric independent t-test was used. Table 6.10 shows the number of uncomfortable respondents included in the analysis and their mean PLP scores.

Table 6.10 Descriptive statistics of the PLP scores of students in the Uncomfortable group categorised by thermal mode

Thermal Mode	N	Mean	Std. Deviation	Std. Error Mean
AC	36	2.7333	0.56971	0.09495
ANV	126	2.4556	0.72427	0.06452

Based on the independent t-test, the PLP score of students in AC classrooms (*Mean* = 2.73, *SE* = 0.09) was statistically higher than those in ANV classrooms (*Mean* = 2.46, *SE*

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[41] Mann-Whitney test: a non-parametric test that looks for differences between two independent samples. That is, it tests whether the populations from which two samples are drawn have the same location. It is a non-parametric equivalent of the independent t-test (Field, 2009, p. 789).

= 0.06), *t*(160) = 2.12, $\rho < 0.05$. The mean difference was 0.28 (95%CI is 0.02 to 0.54); however, the effect size (*r*) was small, *r* = 0.17.

Part 2: Neutral AC versus neutral ANV group

For the second comparison, the PLP scores of students in Neutral AC and ANV groups were compared. As shown in Table 6.11, the number of participants in the Neutral group was 81 and 104 for the AC and ANV cases, respectively.

Table 6.11 Descriptive statistics of the PLP scores of students in the Neutral group categorised by thermal mode

Thermal mode	N	Mean	Std. Deviation	Std. Error Mean
AC	81	2.8691	0.54237	0.06026
ANV	104	2.7865	0.55478	0.05440

Because the data distribution in the AC sub-group was not normal, a Mann-Whitney U test was performed. The results show that the sum ranks of PLP scores of students in the ANV (*Median* = 2.80) and AC (*Median* = 3.00) Neutral groups were not significantly different, *U* = 3845, *z* = -1.03, $\rho > 0.05$, *r* = -0.08 (insignificant).

Part 3: Comfortable AC versus comfortable ANV group

For the last comparison between Comfortable AC and ANV cases, the data were drawn from normally distributed populations; therefore, an independent t-test was performed. The sample size obtained for the AC group was 231 and 95 for the ANV group (Table 6.12).

Table 6.12 Descriptive statistics of the PLP scores of students in the Comfortable group categorised by thermal mode

Thermal Mode	N	Mean	Std. Deviation	Std. Error Mean
AC	231	3.0753	0.51147	0.03365
ANV	95	3.0295	0.54653	0.05607

According to the t-test statistics, within the Comfortable group, the overall PLP scores of students in AC (*Mean* = 3.08, *SE* = 0.03) and ANV environments (*Mean* = 3.03, *SE* = 0.06) were not significantly different, $t(324) = 0.721$, $\rho > 0.05$, $r = 0.04$ (insignificant).

Figure 6.21 shows mean PLP scores of students against their overall environmental comfort votes comparing AC and ANV cases.

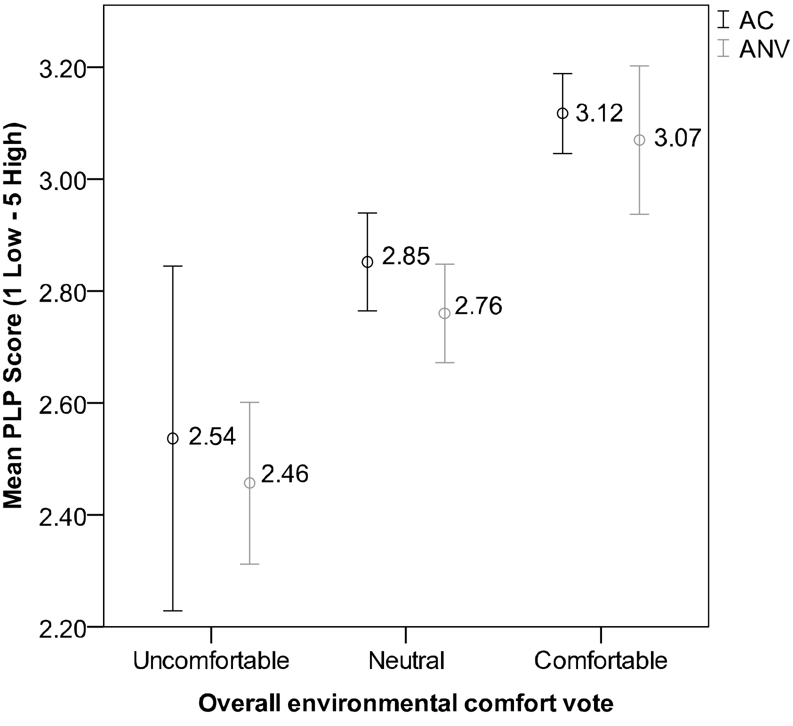

Figure 6.21 Mean perceived learning performance scores of students categorised by thermal mode and their overall environmental comfort vote, error bars represent standard error of mean

The relationships between overall environmental comfort and PLP are similar to those between thermal comfort and PLP. This implies that PLP of students, particularly ANV students, also varied according to their perceptions of non-thermal conditions, i.e. visual comfort, hearing comfort and IAQ.

6.3.3 Thermal comfort as a learning performance indicator

This section investigates whether thermal perception is a more meaningful learning performance indicator than actual temperature. It also provides the objective data with which to explain the findings reported in Subsection 6.3.2.3 (p. 271).

With the aim of investigating whether PLP was also influenced by actual indoor air temperature, students were reclassified into three groups based on their average PLP score as follows.

1) Low (average PLP score was 1 to 2.4 inclusive)
2) Medium (average PLP score was 2.5 to 3.4 inclusive)
3) High (average PLP score was 3.5 to 5 inclusive)

The author used these cut-offs in order to maintain the meaning of original PLP rating scale (i.e. 1-Much Lower than Normal, 2-Moderately Lower than Normal, 3-Normal, 4-Moderately Higher than Normal and 5-Much Higher than Normal).

Figure 6.22 shows the indoor air temperature ranges against the PLP score groups. In addition, the temperature set point recommended for AC buildings in Thailand (25°C), the neutral or comfort temperature line for air-conditioning (26°C), based on empirical thermal comfort studies in Thailand (for example, Nuntavicharna, 2004, Busch, 1995, Yamtraipat et al., 2005), and the calculated neutral temperature line for NV environments (27.4°C)[42] are also indicated in order to provide objective data to support further analysis.

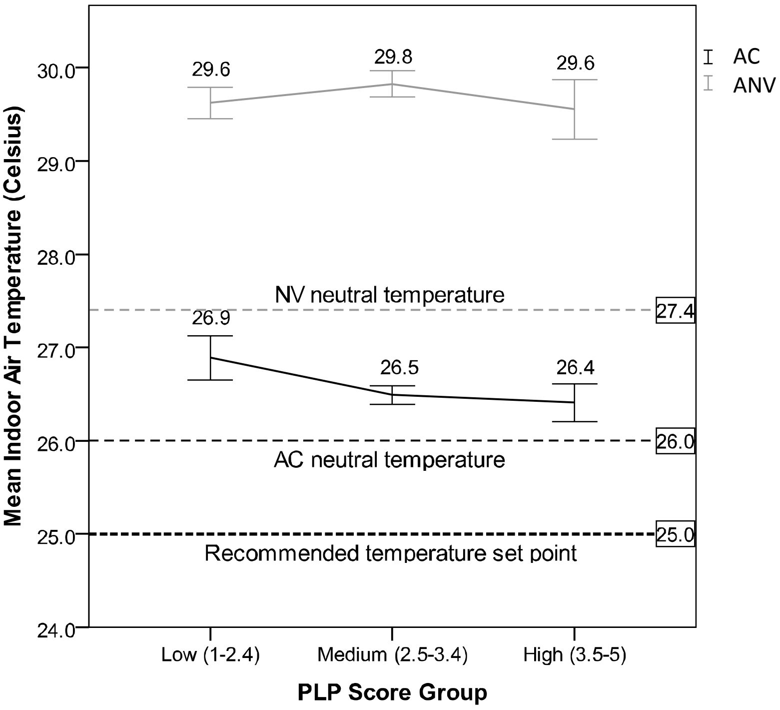

Figure 6.22 Observed mean indoor air temperature categorised by thermal mode and students' perceived learning performance group, error bars represent standard error of mean

Figure 6.23 shows the associated frequencies and percentages of respondents in each group. The majority of students were in the Medium PLP group in both AC (66%) and ANV (59%) conditions.

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[42] The calculation of the neutral temperature for NV environments was based on the adaptive comfort model (Equation 2.1, Chapter 2), using 30.9°C as the mean outdoor air temperature during the survey period.

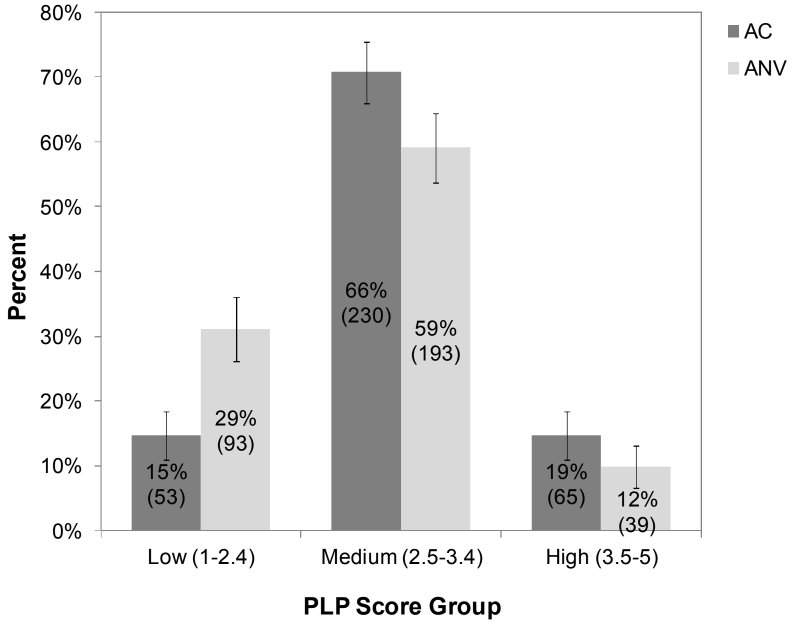

Figure 6.23 Percentage and frequency of respondents categorised by thermal mode and perceived learning performance score group, error bars represent 95%CI of proportion

A visual analysis of the graph in Figure 6.22 showed no direct association between the PLP group and ambient temperatures, particularly in the ANV case, because the temperatures and standard errors of mean of all three performance groups overlap. A Pearson correlation test between indoor air temperatures and PLP scores also confirmed this; ρ-values for both AC ($\rho = 0.35$) and ANV ($\rho = 0.68$) cases were non-significant (see Appendix E: Part 3 – Section 3.2, Tables E.85 - E.86, p. 444, for the complete results). However, this is possibly due to the limited variance in indoor air temperature ranges during the observation period. Therefore, the associations might not be detected. It should also be noted that the results of this study were based on subjective measurements (i.e. thermal perceptions and PLP), so they cannot be applied when learning performance is assessed by objective methods.

Considering the gaps between the temperature observed and the neutral temperatures, the majority of students in ANV conditions, regardless of their PLP group, were exposed to high temperatures just 1 degree under the upper limit of the NV comfort boundary[43] (i.e. 27.4+3.5 = 30.9°C), whereas most of students in the AC mode were experiencing temperatures approximately 1-2 degrees under the upper limit of the air-conditioning temperature comfort boundary[44] (i.e. 26+2°C). The significant differences in the degree of thermal discomfort in the two thermal conditions may explain why uncomfortable ANV students had significantly lower PLP scores than AC students. This issue will be discussed further in Chapter 7 (p. 300).

Another observation can be drawn when considering the proportions of students in the PLP and thermal comfort groups exhibited in Figure 6.20 (p. 275) and Figure 6.23 (p. 281). Even though 39% of students in ANV classrooms felt uncomfortable, only 29% of total participants in ANV classrooms reported that they perceived a lower PLP than usual. This was due to the degree of PLP decrease among some students in the Uncomfortable group not being sufficiently high to demote their PLP score class from 'Medium' to 'Low', although the difference in PLP means was statistically significant. At the same time, when considering that 66% of AC students were comfortable, only 19% of all AC students were in the high PLP score group. Likewise, more comfortable than neutral thermal environments did not significantly promote AC students' PLP class from 'Medium' to 'High'. For a cross table of the proportions of students classified by thermal comfort group and PLP score group see Appendix E: Part 3 - Section 3.3, Table E.87 (p. 445).

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[43] The NV comfort boundary is designed to satisfy 80% of occupants and is based on the adaptive comfort model in which air speed as well as fan use is not limited.

[44] The air-conditioning comfort boundary is generally narrower than the NV comfort boundary.

6.4 SUMMARY

This chapter focuses on how FMs perceived the potential for using MM operations (increased ANV use) in existing HE buildings and related factors, as well as perceived performance risks due to ANV use. The results can be summarised as follows:

- Most FMs did not believe that the proposed three MM operational strategies (i.e. Concurrent, Change-over and Zoned) were possible.
- The long standing promotion of 25°C as the standard temperature set-point has limited means of thermal comfort delivery to air-conditioning only, resulting in the growing disappearance of fans in this building type.
- Main barriers to the implementation of the MM strategies were: the absence of fan(s), users being accustomed to AC environments, and the absence of monetary incentives to reduce air-conditioning use (the operating costs were already paid).
- Students who paid higher tuition fees (postgraduate students) or high-status people (faculty administrators and teachers) within the organisation usually expected air-conditioning.
- FMs had no/low motivation to address changes in the current AC-led thermal comfort practice as long as user satisfaction remained the key indicator of their performance.

Regarding the risks of performance drop due to air-conditioning reduction, the comparisons of self-reported learning performance of students in AC and ANV classrooms showed that:

- Thermal comfort was positively correlated with PLP scores, particularly in the case of ANV classrooms

- Students in the same state of thermal comfort perceived their performance to be at the same level except for those in the Uncomfortable groups
- Students' perceived learning performance was also affected by the perceptions of non-thermal environments, i.e. visual comfort, hearing comfort and IAQ (air freshness and odour)
- The adverse effect of thermal discomfort in ANV classrooms was significant, whilst the PLP scores of students in AC classrooms were not considerably affected by warm discomfort
- The risk of reduced performance due to thermal discomfort in ANV environments should be noted; however, opportunities to provide a productive learning environment using ANV do exist.

CHAPTER 7: DISCUSSION

7.1 PURPOSE

This chapter discusses the findings concerning individual and organisational thermal adaptability, and influences on the acceptance of ANV. The purpose of this chapter is to provide possible explanations for the findings based on past relevant research studies. Problems encountered that may limit the generalisation of the findings are also discussed. The first section focuses on factors affecting individual thermal adaptability and the second centres on organisational thermal adaptability. In the third section, gaps between perceived individual and organisational thermal adaptability are discussed.

7.2 INDIVIDUAL THERMAL ADAPTABILITY

The results showed that students in the observed MM classrooms believed they had the ability to adapt to non-AC environments, although they were now more accustomed to AC classrooms. This perception was not merely behavioural adaptability, as psychological and physiological adaptability in combination, also contributed to their acceptance of the ANV mode. The factors that contribute to students' acceptance of the ANV mode in MM classrooms are discussed in the following subsections.

7.2.1 Perceived behavioural adaptive opportunities

In a given context, i.e. MM classrooms, behavioural adaptation seemed to be the most effective process to cope with thermal discomfort. As expected, users' acceptance of ANV and perceived behavioural adaptive opportunities were mostly influenced by the perceived outdoor climate during different seasons, followed by building design.

Seasonal variation

According to the questionnaire survey results, the percentage of respondents who accepted the ANV mode during the cool season (38-76%) was approximately double that for the hot season (12-37%) (see Figure 5.5, p. 189 and Figure 5.6, p. 196). In terms of the odds ratio, the odds of students voting 'Agree' rather than 'Disagree' to use the ANV mode in the cool season were 11.1 times higher than for the hot season (see Subsection 5.2.2.4, Part 3, p. 196). Objectively, the mean temperatures during the hot season in the Central region of Thailand (where the survey was conducted) can be up to 4 degrees higher than during the cool season (see Figure 2.2, p. 47). This temperature difference is not large but is sufficient to allow a distinction to be made between students' attitudes towards ANV during these two seasons.

When considering the air temperature and humidity, it seems that outdoor air with a mean temperature above 28°C from mid-February to mid-May (the hot season) and relatively high RH (64%) even in the hot season (see Figure 2.2, p. 47), and continuing until September (the rainy season), was not perceived by most respondents as good air conditions for enhancing thermal comfort in the observed MM classrooms. The perception of outdoor air being warmer than indoor air could inhibit window opening. This explanation is supported by the findings of Daghigh and colleagues' study in Malaysia (2009) which reported that users would only open the windows when the outdoor air temperature was lower than the indoor air. It is difficult to comment on the relationships between relative humidity and adaptive behaviours because, to the best of the author's knowledge, there is no study of this particular topic. This is possibly because field and laboratory studies so far (see Subsection 2.4.1, p. 53) have not found significant effects of humidity on occupants' thermal comfort.

In Thailand, the ANV mode was better accepted during the cool season (October – January) when the mean air temperature in the observed region ranged from 24.7°C to 28.0°C (see Figure 2.2, p. 47). Based on Busch's empirical study conducted in Thailand (1995), these temperatures are well below the upper comfort boundary for occupants in NV buildings. Despite the evidence of higher acceptance of the ANV mode during the cool season, the estimated percentage of positive votes for ANV was still just under 80%, even when the opportunities to use fans and windows were high (see Figure 5.5, p. 189). Without any building improvements (e.g. insulation, shading devices, etc.) to existing typical HE buildings in Thailand, this suggests that the ANV mode is probably satisfactory in the cool season only.

The degree of warm discomfort in different seasons also determines the choice of adaptive behaviour; an adaptive action that was meaningful in one season might be of no use in another season. Based on the results, using fans was considered useful in both seasons, whilst window opening had a significant effect in the cool season only. This is probably because a significant number of respondents believed that the effectiveness of fans could overcome warm discomfort in both seasons and that fans are more controllable. Consequently, the level of opportunities to use fans affected the acceptance of the ANV mode in both seasons. In comparison, the data showed that the majority of students believed that opening windows, particularly single-sided windows, could potentially reduce the temperature only in the cool season, but its effectiveness may not be sufficient for the hot season. This finding is consistent with the review by Borgeson and Brager (2008) that window usage significantly varies according to season. These findings confirm that thermal adaptive opportunities are temporally dependent as stated by Nicol and Humphreys (2002).

However, if students perceived a low/no opportunity to use fans, then there was a 56.9% chance that students would accept natural ventilation (no fan assistance) even during the cool season (Figure 5.5, p. 189) and this was reduced to a 22.9% chance during the hot season (Figure 5.6, p. 196). These findings rule out the potential for providing thermal comfort by full natural ventilation in HE classrooms based on students' opinions.

Building design

Of the ten adaptive options suggested, users' acceptance of the ANV mode in existing MM classrooms in a hot-humid climate only varied according to opportunities to use fans and windows. However, this does not mean that other adaptive options were ineffective. It is possible that the variations in the adaptive opportunities for some options in the real context were limited (see Table 5.4, p. 178) and therefore, their effects were undetectable.

An increase in the opportunities to use fans from a low to moderate-high level improved the odds for 'Agree' versus 'Disagree' votes on use of the ANV mode during the cool and hot seasons approximately 3.3 and 2.8 times, respectively (see Chapter 5, Subsection 5.2.2.4, Part 1, p. 185 and Part 2, p. 190). It was not only the existence of fans but also the number of fans shared by occupants that affected the perceived opportunity for fan use. This finding adds the qualitative aspect of fan use into the existing findings from other studies. Based on this study, the chance to have a moderate-high opportunity to use fans increased by having a smaller number of occupants sharing one fan (i.e. 5-20 people per fan) (see Table 5.20, p. 202).

According to the ASHRAE Standard 55-2010 for buildings with the presence of mechanical cooling systems, at least one control is recommended for multi-occupant spaces (e.g. classrooms and conference rooms) regardless of the room size (ASHRAE, 2010, p. 9). If local air-speed control is not available, then the maximum air speed should be 0.8 m/s for operative temperatures higher than 25.5°C where occupants have sedentary activities (ASHRAE, 2010, p. 9). In the observed classrooms there was at least one control for all electric fans, if not one control for each fan. Ceiling fans used at fixed positions (no swing) can produce a minimum air speed at 0.87 m/s (Vipavawanich, 2008, p. 4). However, in the observed ANV classrooms with swinging ceiling fans, the air velocity was only 0.05-0.46 m/s (average 0.15 m/s), insufficient for the room air temperature of 28°C and higher according to Khedari et al. (2000), Nuntavicharna (2004) and Candido et al. (2009). Thus, the control of local ceiling fans in all observed classrooms satisfied the ASHRAE Standard, but the air speeds generated did not. Consequently, students may require more fans to reach the desired air speed.

Within the classroom context, another major benefit of having more fans, in addition to air speeds and control, could be better air distribution. If this is true, then, the number of fans per occupants may be considered as a crude indicator of air distribution, which in turn affected the overall air speed of the whole room. However, the data on fan sharing in the observed classrooms is sparse, and the opportunity scores for fan use are bound within the range of 1 to 25. Therefore, a generalisation of this finding is not appropriate if different adaptive opportunity quantification methods are used. Notably, the number of fans cannot indicate the quality of air (hot air) blown from ceiling fans, as stated by Kosonen and Mustakallio (2010), which also potentially limits the effectiveness of ceiling fans. According to these limitations, air distribution, air speeds and locations of fans should both be investigated in future studies in order to evaluate the effectiveness of fan design and use in multi-occupancy spaces in more detail.

Focusing next on window operation, improving the opportunities to use windows from a low to moderate-high level increased the odds of students voting ‘Agree’ versus ‘Disagree’ on ANV use in the cool season by 2.8 times (see Subsection 5.2.2.4, Part 1, p. 185).

The level of opportunity to use windows did not significantly depend on building location, cross ventilation, or view, as the inclusion of these design factors into the regression analysis did not explain the variance in window opportunity scores (see Table 5.22, p. 204). Another observation was that only the presence of windows, regardless of other physical variables, could raise the window opportunity from a low to moderate level. This field study did not reveal which factors would help increase the window opportunity to a higher level. Based on the literature review on window use in NV buildings (for example, Raja et al., 2001, Rijal et al., 2007, Hellwig et al., 2008, Yin et al., 2010), it is possible to contend that the influence of air temperatures outweighs the effects of those design variables used in this analysis. That is, window opening/closing is basically indicated by actual or perceived outdoor and associated indoor air temperatures and pollution (for example, Mallick, 1996, Brager et al., 2000, Rajasekar and Ramachandraiah, 2010), rather than the attributes of the windows or buildings.

Limited variations in classroom design were observed in the field as only one building type was surveyed and the sample classrooms were chosen from one university which may result in some limitations of the study. Consequently, only fans and windows were found to be significant in relieving thermal discomfort. A survey conducted in different building or room types could improve the variations observed within the data; however, this is not within the scope of this thesis.

7.2.2 Psycho-physiological adaptation

Psycho-physiological adaptability was found to be beneficial only when extreme thermal conditions in the hot season were expected, or probably when the effectiveness of behavioural adaptation reaches its limits. The effects of daily thermal experience, income and pro-environmental attitudes on users' acceptance of the ANV mode are discussed below.

Daily thermal experience

Based on the results, the odds of ANV votes ('Agree' versus 'Disagree' votes) in the hot season for students who had a mixed or full NV daily experience, was 1.8 times higher than for full AC users, but the daily thermal experience did not significantly affect the ANV votes during the cool season (see Subsection 5.2.2.4, Part 2, p. 190).

These results are consistent with those from similar studies. For example, Yamtraipat et al. (2005) found that the neutral temperature of AC office occupants who did not use air-conditioning at home (26.3°C) was 0.9 degrees higher than those who did (25.4°C). Yu et al. (2012) found that people who lived or worked in AC environments for a long time had difficulties in coping with heat shock (36°C and 45% RH) as experienced in a climate chamber. These findings confirm the process of physiological adaptation through acclimatisation and explain why non full-time air-conditioning users believe that they can better tolerate the heat or feel less uncomfortable during the hot season than full-time air-conditioning users. This belief in their thermal tolerance could be considered as a quality of a person that can be retrieved when needed. This ability may then become unnecessary during the cool season when the degree of thermal discomfort is not high.

Compared to life-time thermal experience, daily thermal experience seems to be more manageable through thermal design and building space-time utilisation, for example, providing more variability of thermal environments indoors that suit various activities throughout the day. Some activities or spaces, such as leisure activities, dining area, common rooms and circulation, may not require constant thermal comfort (25°C). Therefore, it is possible to improve an individual's thermal adaptability by providing users with more opportunities to spend their time in non-AC environments.

Income

The odds for low-income students voting ‘Agree’ compared to ‘Disagree’ for using the ANV mode during the hot season was 1.5 times more than for the high-income group (see Subsection 5.2.2.4, Part 2, p. 190).

The effect of income is in agreement with the findings of Indraganti and Rao (2010) who reported that the comfort temperature for low-income people was approximately 2 degrees higher than for high-income people. Notably, their study focused on domestic buildings and so the effect of income may be more obvious than in this study. Another comparable demographic variable was also examined by Yamtraipat et al. (2005). They found that the neutral temperature of office workers who had a post-graduate degree (25.3°C) was 0.7 degrees lower than those who had a lower educational background (26°C). Presumably, people with higher educational levels are likely to earn more and be able to afford air-conditioning; hence, they are accustomed to AC environments. However, this explanation may not be fully applicable to the results of this thesis because the participants do not differ in their educational level. Despite this, the assumption that people with a high-income spend more time in AC environments still can be made by considering the association between participant’s income and daily thermal experience (see Table 5.26, p. 213). In some cases, family income may be more influential in shaping students’ daily thermal experience if they stay with parents, but the family income was not investigated in this study. In this regard, the participant’s income seems to have an impact on physiological adaptation (i.e. acclimatisation), which then shaped personal preferences for AC comfort, an aspect of psychological adaptation.

Participant’s income cannot be manipulated to improve users’ acceptance of ANV. However, determining the relationship between income and personal thermal adaptability is beneficial and allows the target group for thermal adaptability improvement to be identified.

Pro-environmental attitudes

Students with increased daily experience of natural ventilation clearly had higher scores than full-time air-conditioning users for all pro-environmental indices, i.e. Adaptive behaviour at home (BEH), Acceptance of an air-conditioning reduction policy in university (POL) and Pro-environmental attitudes (PEA) (see Figure 5.8, p. 215).

Daily thermal experience and all pro-environmental attitude and behaviour indicators were correlated and two possible interpretations can be drawn from this finding. According to the attitude-behaviour model, it could be assumed that pro-environmental attitudes dominate student's choices of thermal experience in everyday life. In contrast, the finding could follow the behaviour-attitude model, that is behaviour could dominate attitudes via direct experience as stated by Black et al. (1985). In this case, students who spent more time in NV environments for whatever reason may realise that the effect of climate change is real. Having realised this effect, their pro-environmental attitudes and a willingness to mitigate the effect may have developed. However, the current evidence obtained from this study is insufficient to conclude the cause-effect relationship between these two variables. In this regard, pre-/post-tests may be used, for example, the pro-environmental attitudes of NV buildings' occupants before and after moving to fully AC buildings could be assessed and compared. This approach is time-consuming and it is difficult to find an opportunity to study this phenomenon but it could be pursued in further research.

Another argument which can be made from the findings is that non full-time air-conditioning users behave in a more environmentally friendly manner at home or find an air-conditioning reduction policy in university more acceptable because they have a greater physical tolerance of NV environments, not because of a higher awareness of environmental problems. In other words, the impact of changing the thermostat 1-2 degrees higher may be unimportant to non full-time air-conditioning users but significant to those who use it full-time. This argument follows the concept of physiological adaptation and can explain why non full-time air-conditioning users had higher BEH and POL scores than full-time users because these two indices directly focus on adaptive behaviour and air-conditioning use. However, the argument cannot explain the significantly higher pro-environmental attitudes of full NV and MM groups because the pro-environmental attitudes scale did not contain statements related to thermal tolerance or acclimatisation to AC or non-AC environments. Therefore, the associations between thermal experience and pro-environmental attitudes can be explained by the environmental psychology framework, i.e. experience of NV environments may raise students' environmental awareness or vice versa, as stated earlier – which is considered a psychological effect.

When considering the association between pro-environmental attitudes and acceptance of an air-conditioning reduction policy (to use ANV mode more) (see Table 5.27, p. 214), the higher pro-environmental attitudes among non full-time air-conditioning users may be regarded as a motivating factor that provides an additional explanation for the higher acceptance of the ANV mode in the non full-time user group. Possibly, the non full-time users are aware that the ANV environments may on occasions be uncomfortable but they are still willing to compromise their comfort for energy savings. However, pro-environmental attitude is unlikely to be considered as a dominant factor because the correlation coefficient obtained was low (see Table 5.27, p. 214). According to Tanner (1999) and Black et al. (1985), the deviation between attitudes and behaviour is possibly due to the effects of contextual barriers. Based on Study 1, seasonal climate and building design can be considered the major contextual constraints that weaken the strength of the attitude-behaviour relationship. For example, the intention to reduce air-conditioning use may be diminished because of outdoor air pollution or the absence of ceiling fans in classrooms. In addition, the statements included in the Pro-Environmental Attitudes scale (adopted and modified from the Defra's survey) used in this study, may be too generic compared to the specific statements included in the Adaptive Behaviour at Home and Air-Conditioning Reduction Policy in University scales. The incompatibility of the specificity of two measures may result in a low correlation coefficient between them (Rajecki, 1982 cited in Kollmuss and Agyeman, 2002).

7.3 ORGANISATIONAL THERMAL ADAPTABILITY

While individuals show some levels of self-reported thermal adaptability if using ANV, the possibility of reversing the current full-AC thermal operation in existing MM HE buildings was limited according to the opinions of FMs. Factors related to facilities management practice that caused barriers to the implementation of MM operational strategies in existing HE buildings and the impact of thermal perceptions on user performance if using the ANV mode are discussed below.

7.3.1 Facilities management practice

The influence of specifying 25°C as the standard temperature set point on facilities management thermal comfort practice is noteworthy (Subsection 2.3.3, p. 50). Whilst no alternative thermal comfort standards are available, most FMs relied on air-conditioning to maintain the indoor air temperature at this level, aiming to provide constant comfort and reduce energy waste caused by occupants setting the thermostat too low. Organisational goals, facilities management performance indicators, user controls, users' organisational status, and facilities management tools and technology are discussed in relation to how they contribute to the current trend of full-AC operation.

Organisational goals and facilities management performance indicator

Thermal operating practice in existing MM HE buildings (in the same climatic conditions) depends heavily on the organisational goals and the commitment of the faculty managers or leaders, particularly the faculty dean, to reducing energy consumption within their buildings. If the commitment of faculty was not expressed as an explicit goal and subsequent plans and targets, facilities management thermal operating practice was likely to be dominated solely by user preferences (e.g. demand for quick constant cool air). In comparison, in the few faculties that showed positive responses to the possibilities of ANV operation in their existing MM buildings, energy reduction targets and action plans were more clearly stated by the university or faculty board of administrators (see Table 6.3, p. 259), which then shaped the organisational customs in relation to air-conditioning use. It appears, therefore, in this type of organisation, that a top-down approach is probably more effective than a bottom-up approach in order to change facilities management practice and user energy consumption behaviour.

For FMs, user satisfaction was regarded as one of the most important key performance indicators of day-to-day thermal operation service. Failure to respond to users' requirements had a direct impact on facilities management performance and adversely affected the relationships between facilities management staff and end-users (Subsection 6.2.2, Case 5, p. 234). In contrast, the achievements of FMs or failure to save energy may be less recognisable if the energy data were not known to the facilities management service operators themselves nor reported to administrators, particularly when energy policies and targets were not established. Due to the fear of complaints, most FMs were reluctant to ask users to change their behaviour dramatically or do anything to risk user satisfaction and comfort. Air-conditioning is therefore usually run as the default mode in almost all faculties because it guarantees higher rates of user thermal satisfaction. As a result, attempts to increase user satisfaction have reduced FMs' motivation to change the current full-time AC operation to MM operations.

User control

Based on FMs' experience, it is not always true that MM building occupants will use all adaptive devices in an energy-efficient way as stated by Rijal et al. (2009). FMs in the observed faculties claimed that if users had total freedom of control over the AC systems, they were likely to adjust them in the way that would increase their comfort (i.e. setting thermostats even lower to get quick cool air) rather than saving energy (Subsection 6.2.5, p. 243). Importantly, those faculties that operated pre-cooling to serve this demand for quick cool air should be aware that their thermal operating practice is being dominated by users' need for thermal pleasure when moving from hot outdoor environments into the buildings, not by normal thermal comfort in a steady state. Air-conditioning is always preferable to other options as it is the most convenient, although it costs more. In addition, the FMs were tacitly aware that the users were probably already addicted to air-conditioning (Subsection 6.2.6, p. 246) and this is why FMs thought they should control the air-conditioners by themselves (i.e. users cannot operate or adjust the air-conditioning systems).

Once control has been taken from end-users and behavioural adaptation has not been encouraged, the sole responsibility for providing thermal comfort lies in the hands of facilities management staff. End-users then become less active and tend to be more sensitive to changes. This practice and its consequent effects corresponds to the 'fit and forget' design strategy described by Leaman (2003, pp. 159-162) and under such circumstances it is even more difficult to ask users to adapt. This could explain why the three MM strategies seemed to be less feasible within the faculties that provided no user control over the thermal environment (see Table 6.3, p. 259).

Organisational status and power

Users with a higher status in the organisation had more power to access air-conditioning. For hierarchical organisations like the selected universities, facilities management officers, whose position is usually perceived as lower than academic staff and even students, can hardly compromise users' demands for air-conditioning. In many cases, although FMs have taken over the control of air-conditioning from users to minimise energy waste, they still have to respond to teachers' demands for quick cool air by pre-cooling (Subsection 6.2.5, p. 243). In addition, FMs were reluctant to ask postgraduate students, who paid higher tuition fees than undergraduates, to reduce air-conditioning use in evening classes (Subsection 6.2.6.2, p. 252). These examples clearly echo how FMs' power to save energy may be restricted by the organisational status of users.

The role of most FMs in the interviews could be considered as that of a 'housekeeper', according to Aune et al. (2009), where users are treated as customers and have no involvement in energy reduction. The 'teacher' role, i.e. to educate users on how to use energy efficiently, is not obvious in this type of organisation, which is probably because the FMs' power and status is considered lower than academic staff, or even students, in the HE institutions. The 'manager' role (having a feeling of ownership, resourcefulness and the ability to get involved in the building design process while users are required to do simple tasks by themselves) of many local FMs is also weak as they stated that they had no involvement in building design and refurbishment (see Subsection 6.2.6.3, p. 256). However, if FMs gained support from their faculty, especially the dean, or academic staff, then the chance of taking action on energy policy increased (Subsection 6.2.2, p. 233). This status and power interpretation is rarely mentioned in the literature on thermal operating practice, but it seems to significantly affect how non-residential buildings are operated.

Facilities management tools and technology

Many FMs had limited tools and technology with which to monitor the energy and thermal performance of their buildings, which hampered their decision-making on energy policy and facilities management practice development. The energy and thermal performance of the buildings were unknown to FMs in many faculties for three main reasons: first, in the majority of observed faculties, sub-meters were not installed (Subsection 6.2.3, p. 236); second, the energy costs were known only by the financial department and were not routinely passed to the facilities management department (Subsection 6.2.3, p. 236); and third, there was no POE that linked the technical and behaviour side of energy consumption. This last reason is will be discussed further in the following paragraph.

According to the interviews with FMs, there were only two forms of building evaluation conducted in HE buildings, i.e. an energy audit by outsourced experts and a thermal comfort survey by in-house staff (Subsection 6.2.3, p. 236), with the purpose of the energy audit clearly segregated from the thermal comfort survey. Basically, an energy audit concentrates on the technical side of energy supply and aims to reduce energy waste by improving building envelopes and mechanical equipment. Results from energy audits were mainly reported to the faculty board of administrators in order to support decision making on energy policy planning and targeting. In contrast, thermal comfort surveys, both formal and informal, were devised to gain feedback from end-users and report back to service providers in order to improve user satisfaction.

There was no explicit POE tool or analysis process integrating the feedback from both operators and end-users. Moreover, the data resulting from energy audits and thermal comfort surveys were usually analysed based on the air-conditioning mode scenario. Therefore, the true potential of buildings to perform in ANV and full NV modes was not currently systematically inspected. Similarly, the thermal adaptability of end-users was not recognised. As a result, the current building performance evaluation only helps to improve the building envelope and air-conditioning systems so that users can continue to use air-conditioning with less energy waste.

Perceived performance risks

The comparisons of PLP of students in AC and ANV classrooms provided evidence that demonstrates the concern about reduced performance when using ANV in non-residential buildings (see Figure 6.12, p. 250 and Figure 6.13, p. 254). Based on the results, the following concluding points are discussed as follows.

Comfortable students in classrooms operated in AC and ANV, as well as the neutral group, were not significantly different in their PLP, but uncomfortable ANV students perceived a lower performance than uncomfortable AC students (see Figure 6.19, p. 275). This finding is consistent with Leaman's study (2003, p. 164) where people in NV buildings could perform as well as those in AC offices if they felt comfortable and had access to thermal controls. For the 'Uncomfortable' group, the lower PLP of ANV students could be explained by the evidence of a higher degree of thermal discomfort in ANV classrooms compared to the neutral temperature in AC ones (see Figure 6.22, p. 280).

The air temperatures observed in ANV classrooms ranged from 26.2°C to 34.2°C and the average air velocity was 0.15 m/s (see Table 6.6, p. 265). In the AC case, the air temperature ranged from 23.3°C to 30°C with an average air velocity of 0.08 m/s (see

Table 6.6, p. 265). According to several empirical comfort studies that have been conducted in Thailand (for example, Nuntavicharna, 2004, Busch, 1995, Yamtraipat et al., 2005) and the adaptive model for NV buildings, comfortable temperatures for AC and ANV conditions were approximately 26°C and 27.4°C, respectively. Consequently, the ANV comfort boundary for 80% acceptability is 23.9-30.9°C (27.4°C ± 3.5) and the maximum temperature in the ANV classrooms was 3.3 degrees higher than the upper comfort limit (see Figure 6.22, p. 280).

In contrast, the minimum temperature observed in AC classrooms was just 0.7 degrees below the lower limit, and the maximum temperature was 2 degrees higher than the upper comfort limit (26°C ± 2 = 24-28°C) (see Figure 6.22, p. 280). Consequently, the higher degree of warm discomfort associated with insufficient air velocity in the ANV classrooms could potentially result in a greater adverse effect on the PLP of uncomfortable ANV students. Another possible explanation is that the non-thermal factors, i.e. visual comfort, hearing comfort and IAQ within the ANV classrooms were also perceived to be less comfortable compared with AC classrooms (see Figure 6.16, p. 270). These factors, particularly the IAQ, potentially also cause a performance decrease among ANV students. It should be noted however, that this research did not conclude that these non-thermal aspects of the environment in ANV classrooms would always be less comfortable than in AC classrooms. It is suggested that air pollution from outside and other non-thermal factors (i.e. lighting and acoustics) are as important as thermal factors and should be carefully considered during ANV building design and operation.

Students who felt more comfortable perceived a higher performance than those who felt uncomfortable, particularly in the ANV case (see Figure 6.19, p. 275). This finding is consistent with previous studies in Japan where participants who gave a PMV of close to 0 (neutral or comfortable) had a higher perceived performance than other groups (Ito et al., 2006, Murakami et al., 2006). However, there was one case in which the PLP scores of uncomfortable and neutral AC students were not significantly different (see Figure 6.19, p. 275). Considering the objective data, the air temperature range to which the uncomfortable AC students were exposed was on average 27°C, which is still within the comfort boundary. Therefore, the degree of discomfort among uncomfortable air-conditioning users was low. This is a possible reason for why the performance drop among uncomfortable AC students was not significant, thereby corresponding to Seppänen et al.'s statement (2003) that thermal fluctuations within the comfort zone did not affect user performance.

Aside, the uncomfortable AC group actually consisted of 3 and 33 respondents who felt 'Very Uncomfortable' and 'Mildly Uncomfortable', respectively (see Figure 6.17, p. 272). Apparently, the proportion of very uncomfortable students in the AC classrooms was very small, thus the degree of discomfort of the combined group, i.e. Very Uncomfortable and Mildly Uncomfortable, was not high enough to diminish the average PLP scores of the group. Similarly, the imbalance in sample sizes of the subgroups also explains why uncomfortable ANV students (consisting of 39 very uncomfortable and 87 mildly uncomfortable students) had lower PLP scores than the uncomfortable AC students. Therefore, the generalisation of this finding should be made with caveats because the magnitude of discomfort experienced by students in the uncomfortable AC and ANV classrooms was significantly different.

When considering the percentage of uncomfortable students, the finding also highlighted that at 27°C only 10% of students in AC classrooms felt uncomfortable. Therefore, there is a possibility of raising the temperature set point in AC classrooms slightly higher than 25°C and not causing the majority of students to be uncomfortable, especially if supplemented with ceiling fans, as stated by Atthajariyakul and Lertsatittanakorn (2008) and Vipavawanich (2008).

Within the scope of this study, perceived performance is more associated with thermal perception and overall environmental comfort than actual air temperatures (compare Figure 6.19, p. 275 and Figure 6.22, p. 280), corresponding to Leaman and Bordass's statement (1999). Based on self-reported learning performance, the use of actual temperature alone for specifying an effective learning environment neglects the personal backgrounds of occupants and other thermal factors, i.e. RH and air velocity which also contribute to the thermal performance of classrooms. According to the results and the scope of this study, effective learning environments and comfortable environments share the same principles. That is, they are not universal, and the thermal backgrounds of users should be taken into account. Notwithstanding this finding, this thesis does not conclude that perceived user performance and actual air temperature are not associated. The failure to find a perceived performance-air temperature relationship in this study is probably due to the temperature ranges observed, which mostly fell inside the comfort zone, particularly in the AC case (see Figure 6.22, p. 280); hence, these effects were not obvious.

Focusing on the findings of this thesis, the confirmation that self-reported learning performance of comfortable students in ANV and AC classrooms was not different offers an opportunity to use ANV in educational institutions for some periods of the year. However, the risk of reduced performance among uncomfortable ANV users should also be of concern as the percentage of uncomfortable students in ANV classrooms is likely to be higher than that within AC classrooms (see Figure 6.19, p. 275).

Overall, the challenge is for building designers and building operators to use ANV in the right place at the right time to mitigate the performance risks due to thermal discomfort. In hot-humid climates such as Thailand, it has to be accepted that the opportunity to use full natural ventilation for providing thermal comfort in enclosed multi-occupant spaces with few adaptive opportunities is relatively limited. In the field study, only 62% of occupants in ANV classrooms felt comfortable during the cool season (see Figure 6.20, p. 275), although it should be noted that this percentage was the average of the data for the whole period of the survey. In some classes, when the air temperature was not too high then the percentage of neutral-comfort votes was as high as 87% (see Figure 6.15, Case 11, p. 267). In contrast, during afternoon classes in the cool season, the comfort votes were reduced to as low as 21% (see Figure 6.15, Case 10, p. 267). Therefore, a mix of AC and ANV strategies is probably necessary, considering the need to balance both low energy consumption and high user performance.

The generalisation of the learning performance study is limited due to the scope and framework of the study, i.e. the range of indoor air temperatures during the observed period and the methods used for assessing learning performance and thermal comfort. Most importantly, ventilation rates and CO_2 concentrations in classrooms were not measured. Hence, their potential effects on students' perceived learning performance were not identified. Therefore, the findings from this study cannot be directly compared with studies that use an objective approach for evaluating user performance and environmental conditions. The percentages of comfortable, uncomfortable and neutral students in AC and ANV classrooms also cannot be generalised and cannot be compared to each other because a small number of AC and ANV classrooms were surveyed for a limited period of time and in different seasons. Additionally, the selected parameters for the learning performance assessment in this study focused only upon students' attention within the classroom, which may or may not significantly contribute to students' academic attainment in terms of grades. The interpretation of PLP requires further investigation in order to understand whether the differences in the PLP scores of students in different conditions, i.e. thermal mode and thermal comfort state, are meaningful in reality.

7.4 GAPS BETWEEN INDIVIDUAL AND ORGANISATIONAL THERMAL ADAPTABILITY

Based on the speculation resulting from the findings of the individual and organisational thermal adaptability investigations, there are gaps between the perceived individual and organisational thermal adaptability that need to be considered in order to decelerate the current trend for full-AC operation in MM non-residential buildings in hot-humid climates.

From the perspective of FMs, the way in which buildings are designed and operated today is potentially influenced by the increasing expectation of high-status users for constant air-conditioning and organisational motivation to remain responsive to users' requirements, which sometimes results in the overprovision of air-conditioning (i.e. pre-cooling). To be more precise, the FMs had experienced and believed that teachers and postgraduate students are not willing to reduce air-conditioning use and adapt to non-AC environments, regardless of the outdoor thermal conditions. This is probably because these individuals, particularly teachers, have a higher daily exposure to AC environments (i.e. AC office, private car and AC bedroom); hence, they are more accustomed to air-conditioning. This statement is also supported by the author's direct experiences during the pilot study – some teachers resisted to use ANV in classrooms if AC was available (see Subsection 4.4.4, p. 159). Even though teachers do not represent the whole organisation, they certainly have power to dominate the facilities management thermal comfort practice, which in turn affects the thermal experience and expectation of the majority of users. This perception towards teachers' and postgraduates' thermal preferences, associated with the notion about the fixed comfort temperature, i.e. 25°C, might result in the underuse of windows and the removal of fans, the two most significant behavioural adjustments. These minor changes during the lifetime of a building could then instantly shift the way in which buildings are thermally operated.

In contrast, although parts of the survey results (Studies 1 and 2) agree with some FMs' opinion that high-income users had low pro-environmental attitudes and were unlikely to accept ANV, the majority of students still perceived that they have the ability to maintain thermal comfort in ANV classrooms during the cool season, assuming that both fans and windows are sufficiently provided. If fans continue to be gradually removed from Thai HE buildings and are unlikely to be reinstalled, then this thermal adaptability of individuals becomes less perceptible by FMs. In the other case, although fans are available, it is unlikely that they would have been used once AC is available. The opportunity to reduce cooling energy by using fans to assist natural ventilation or air-conditioning has been diminished. In this regard, facilities management practice also affected the thermal adaptability of individuals. This could then explain why the adaptive comfort model and MM operations are invalid in some MM non-residential buildings. Additionally, it highlights the obvious point that MM operations in hot-humid climates would be possible only if MV is available. Once the majority of end-users have been acclimatised to constant AC environments, the improvement of design factors alone may only make the adaptive behaviours easier but might not be sufficiently effective to initiate behavioural and attitudinal changes, especially in the absence of strategies to foster adaptive actions. Moreover, the power of pro-environmental attitudes among non full-time AC students might be too weak, compared to the effects of climate, economics and other contextual constraints, to maintain efficient use of air-conditioning if they have no control over their thermal environments.

The findings highlight the weakness in applying adaptive thermal comfort theory to practice in non-residential buildings when end-users' thermal adaptability is neglected and probably weakened due to the current trend for constant air-conditioning. Gaps remain between what the majority of end-users can accept and what FMs deliver, and these should be considered in order to maintain the thermal adaptability of an individual and an organisation. Furthermore, the likelihood of being in a position to apply the adaptive comfort model for MM non-residential buildings or spaces seems to depend more on high-ranking people's attitudes and behaviour, rather than that of end-users.

7.5 LIMITATIONS

Apart from the specific limitations of the methods used for each study described above, this subsection discusses the limitations of the overall approach used for the data collection as utilised in this thesis and its implications on the findings.

Subjective approach – With regards to the behavioural adaptive opportunity assessment, the data obtained was solely based on users' own perceptions, which was the most practical approach for collecting the data from the occupants in existing MM buildings that were operated in full-time AC mode. Due to this limitation, the percentage of acceptance votes may deviate from reality if an interventional approach were applied. This finding only indicates the potential to use the ANV mode and potential adaptive behaviours in existing MM HE buildings, not the actual comfort votes for ANV in a real situation.

Non-integrated study – Each of the four studies was treated as an individual study. Different cohorts of students were chosen for Studies 1, 2 and 4. Some of the FMs who participated in Study 3 were not from the faculties and universities where the student surveys were conducted. This approach was considered the most practical for obtaining the sample size required for each study; however, it may have restricted speculation on the connections between the findings.

Non-cross organisational study – Only FMs were interviewed in Study 3. Despite their full insight into user behaviour and habits, some were unable to provide opinions on strategic questions such as future construction projects or refurbishment plans and energy policies. Their comments on an organisation's relevant policies and strategies might be based on their own speculation. Further interviews with relevant people at the strategic level would be beneficial in gaining a better understanding on the future trend of HE building design and operations.

Limited variations in ventilation systems – MM ventilation system focused upon in this research was limited to the combination of manually operated windows, ceiling fans and air-conditioning units. It should be noted that variations in ventilation systems in HE buildings in Thailand is also low. MM buildings that use a building envelope as an integral part of the MM ventilation system are very rare. The findings and discussion in relation to users' perceived adaptive opportunities and facilities management practices are therefore limited to this scope, and cannot be applied to advanced MM ventilated buildings.

The imbalance between female and male participants – In Studies 1 and 4, there were many more female participants (74% in Study 1 – see Table 5.2, p. 171 and 63% in Study 4 – see Table 6.5, p. 263) than male participants (26% in Study 1 – see Table 5.2, p. 171 and 36% in Study 4 – see Table 6.5, p. 263). These proportions partly reflect the high proportion of female to male HE students in Thailand as reported by NSO (p. 172). The implications on the findings of Studies 1 and 4 were that the percentage of disagree votes on the use of ANV (Study 1) and uncomfortable students in ANV classrooms (Study 4) might be higher than in the case that female and male participants are relatively equal because females are likely to be more sensitive to thermal variations.

The application of HE example findings to other non-residential buildings/ organisations must consider user activities in buildings and the relationships between organisations and end-users. The findings in this study could mostly apply to schools and offices. In schools, students may have more sense of belonging if they have their own permanent classroom. This possibly allows more interactions between users and classroom environments. Then adaptive behaviours such as opening windows and turning-on fans, in schools could be more probable than in HE buildings. It is also considered more possible, compared to HE institutions, for FMs to educate young children and even teachers in schools about thermal adaptations and pro-environmental attitudes and behaviour. In offices, a number of thermal adaptive actions such as adjusting clothes, drinking cold water and using a personal fan are probably more practical than in classrooms in HE buildings due to a lower space-sharing and a higher freedom of space utilisation.

7.6 SUMMARY

The findings from the student survey are generally consistent with past research studies; however, the following points were discussed:

- The use of ANV in existing classrooms was accepted in the cool season only when the mean outdoor air temperature was approximately 28°C (not exceeding 33°C, the upper boundary to which the adaptive comfort model applies); however, the overall acceptance votes were still lower than 80%. This could be partly due to high outdoor RH (79%), but it is inconclusive because there are no humidity limits for the adaptive comfort model.

- The negative impact of users' complaints and the demand for thermal pleasure of high-status or high-income users were probably more influential than other contextual factors (i.e. climate and building design) in shaping FMs' thermal operating practice in non-residential buildings.
- From FMs' experiences, users did not always adapt in a way that would reduce air-conditioning use probably because they seemed to be already addicted to quick cool air and had low control over their thermal environment as FMs said personal control in classrooms was not practical.
- Higher pro-environmental attitudes among non-full AC users could be considered as another parameter of psychological adaptation, but whether or not the pro-environmental attitudes were shaped-up through daily thermal experience was not confirmed.
- Performance drop among uncomfortable ANV students could be due to a higher degree of thermal discomfort in ANV classrooms, compared to AC classrooms.
- Negative perceptions of IAQ in ANV classrooms could be due to outdoor air and noise pollution, which might cause a decrease in perceived learning performance of students in ANV classrooms.
- The insignificant relationships between indoor air temperature and perceived learning performance could be due to limited variations in outdoor air temperature conditions during the observed period.

Main limitations of the study are:

- This thesis mainly employed a subjective approach for evaluating individual and organisational thermal adaptability as it was considered the most practical method for conducting the field studies; therefore, the results may deviate from reality.

- Each of the four studies was conducted individually; therefore, the connections between the results of the four studies were based on speculation.
- Regarding the organisational thermal adaptability, only FMs were interviewed; therefore, the results were mainly based on facilities management practices, not organisational energy policies or strategies.
- Limited variations in building design and ventilation systems of the chosen MM HE buildings may limit the variations in choices of adaptive behaviours and perceived effectiveness and probability of given adaptive options.
- High percentages of female participants obtained in Studies 1 and 4 may result in higher disagree votes on ANV use and higher uncomfortable votes in ANV classrooms than usual because females are normally more sensitive to thermal variations.

Due to the limitations of the data obtained, a generalisation of the findings should only be made with caution.

CHAPTER 8: CONCLUSIONS AND IMPLICATIONS

8.1 RESULTS SUMMARY

Thermal operating practice in non-residential buildings in certain hot-humid countries is heavily influenced by air-conditioning technology, which, through its energy demand and resulting carbon emissions, is considered one of the main contributors to climate change. The situation is getting worse as the evidence shows a growing tendency of air-conditioning addiction among people in hot-humid climates.

The research problem centres around the unnecessary use of air-conditioning, whereby many existing MM non-residential buildings in hot-humid climates with capabilities to operate in MM are operated in full AC mode, and how to alter this trend to reduce the over-consumption of air-conditioning. There is a high potential to reduce excessive air-conditioning use in MM non-residential buildings by maximising fan assisted natural ventilation or ANV whenever possible. This primarily requires an application of adaptive thermal comfort theory which in turn needs better knowledge of the influences of individual thermal adaptability, organisational thermal adaptability and the role of facilities managers, pro-environmental attitudes, and user performance on the acceptance of natural ventilation assisted with fans. Importantly, limitations of the application of the adaptive comfort model in hot-humid countries should be identified. There is not yet a solid body of knowledge for non-residential buildings in hot-humid climates of user attitudes, behaviour, and perceived effects on their productivity, or organisational policies and facilities management operating practice.

The aim of this thesis is to understand whether and how it is possible to support building design, operation, and energy policy development for maintaining and/or increasing the possibilities for using ANV to supplement air-conditioning in existing and future MM non-residential buildings in hot-humid climates, based on an understanding of individual and organisational thermal adaptability and the relevant factors. Based on a literature review, the thesis hypothesises that:

> *Acceptance of fan assisted natural ventilation in existing mixed-mode non-residential buildings in hot-humid climates is affected by users' perceived behavioural adaptive opportunities and psycho-physiological adaptation, as well as by facilities management practice.*

In order to test this hypothesis and achieve the research aim, four field studies that concern different aspects of ANV acceptance in MM non-residential buildings were designed and carried out. The HE sector in Thailand was selected as a case study for the non-residential building sector in a hot-humid climate. It is important to note here that the targeted MM HE buildings in Thailand are typically equipped with manually operable windows and air-conditioner units, with or without ceiling fans. The field studies involved a total 2,825 students in 11 Thai universities across six regions, interviewing with 25 facilities managers in four universities, and observing 39 classes, 14 of which were instrumented and monitored during the survey. Objectives, methods and results of the four field studies are summarised in the following.

Study 1: Thermal adaptive opportunity scoring system and acceptance of ANV survey

The purpose of this study was to identify the main factors affecting students' thermal adaptability and their contributions to students' acceptance of the ANV mode in existing MM HE buildings in a hot-humid climate. This study formulated a framework for evaluating the effects of perceived behavioural adaptive opportunities and psycho-physiological adaptation on students' acceptance of the ANV mode in selected MM classrooms during both the cool and hot seasons through use of a questionnaire. Focusing on behavioural adaptive opportunities, a method for evaluating adaptive opportunities, using perceived 'effectiveness' and 'probability' as the criteria, ten common adaptive behaviours for relieving warm discomfort were developed for identifying those adaptive options that are useful for students in the observed classrooms and have a significant contribution to their acceptance of the ANV mode. Furthermore, the influence of relevant contextual factors, particularly seasonal variation and design features, that affect these useful adaptive actions were also evaluated. The effects of psycho-physiological adaptation, directly and indirectly influenced by student's daily thermal experience (i.e. daily exposure to AC environments) and economic status (i.e. monthly income) on students' acceptance of ANV were also quantified.

According to the results, there is a reasonable chance that in multi-occupant spaces such as classrooms ANV will be used in existing MM buildings in the cool season in the change-over operational mode, as long as both operable windows and fans are in place and in sufficient numbers. In comparison, during the hot season, apart from the perceived opportunity to use fans, the influences of respondent's daily exposure to AC environments and income on their acceptance of ANV were recognisable. Despite this, the majority of students did not believe that they could adapt and maintain their comfort if using the ANV mode in the observed classrooms during the hot season.

Using fans and windows remains the most effective environmental adjustments, consistent with actual adaptive behaviours observed in NV buildings by other research studies in hot and hot-humid conditions. However, the role of windows was found to be insignificant in reducing heat discomfort during the hot season. This is possibly because outdoor air temperatures during the hot season are genuinely too extreme to endure comfortably. Remarkably, a lack of fans (use of full natural ventilation by window ventilation only) was not deemed acceptable for any season. The effects of daily exposure to AC environments on the acceptance of ANV were found to be consistent with the adaptive comfort theory. However, the effects of income have almost never been investigated before in the field. Therefore, this finding could be considered innovative.

With the application of a multinomial logistic regression, acceptance of ANV mode in existing MM HE buildings in a hot-humid climate and the contributions of the main factors relating to students' behavioural and psycho-physiological adaptability to students' acceptance of the ANV mode can be quantified.

- In the best scenario, when students perceived high opportunities to use windows and fans, the probability of students voting 'Agree' to using ANV in existing MM classrooms in the cool season was 76%.
- The probability to vote 'Agree' for the ANV mode during the hot season was still as low as 37% even in the best scenario – where low-income students had low daily exposure to air-conditioning (therefore they presumably had more tolerance of the heat) and perceived high opportunities to use fans.
- *Between seasons*: Students are 11.1 times more likely to vote 'Agree' versus 'Disagree' for the use of ANV in the cool season than during the hot season.
- *Cool season scenario – fans*: Students are 3.3 times more likely to vote 'Agree' rather than 'Disagree', if the opportunity to use fans is increased from a low to moderate-high level.
- *Cool season scenario – windows*: Students are 2.8 times more likely to vote 'Agree' rather than 'Disagree', if the opportunity to use windows is increased from a low to moderate-high level.
- *Hot season scenario – fans*: Students are 2.8 times more likely to vote 'Agree' rather than 'Disagree', if the opportunity to use fans is increased from a low to moderate-high level.
- *Hot season scenario – effect of daily exposure to NV environments*: Students are 1.8 times more likely to vote 'Agree' rather than 'Disagree', if the

students had more daily exposure to NV environments rather than full air-conditioning.

- *Hot season scenario – income effect*: Students are 1.5 times more likely to vote 'Agree' rather than 'Disagree', if the students had a low income rather than a high income.

With regards to the use of fans, the number of occupants sharing a fan could explain 67% of the variance in the level of opportunities to use fans. A multiple linear regression showed that students perceived a moderate-high opportunity to use fans when the number of students per fan was around 5-20 students. In the case of windows, the opportunity scores were affected by building location (Urban/Suburban), cross-ventilation (Yes/No) and view (Yes/No); however, the effects were too small and insignificant to explain the variance in the level of opportunities to use windows observed. The generalisation of these findings is not appropriate due to the limited variance in the design factors used in this analysis.

Study 2: Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey

The objective of this study was to compare the pro-environmental attitudes and behaviour of students with three different daily thermal experiences (i.e. full AC, full NV and mixed). A questionnaire was designed for assessing the pro-environmental attitudes and adaptive behaviour of students, and consisted of three scales: Adaptive behaviour at home, Acceptance of an air-conditioning reduction policy in university, and Pro-environmental attitudes. The questionnaire was administered to students in the main HE institutes in six regions of Thailand in order to obtain a sufficiently large sample size in the three comparative groups of daily thermal experience. The average scores for the pro-environmental attitudes and adaptive behaviour of students with full air-conditioning, full natural ventilation and mixed thermal backgrounds were then compared. The results of Study 2 showed that:

- Pro-environmental attitudes and adaptive behaviour were correlated with lower daily exposure to air-conditioning (in bedrooms, universities and transportation); however, the direction of causality was not established
- Students who had a lower exposure to air-conditioning reported a higher Adaptive behaviour at home, Acceptance of an air-conditioning reduction policy in university and Pro-environmental attitudes scores than those with full air-conditioning exposure
- The mean difference of the Adaptive behaviour at home scores between the two groups was the largest (Mixed versus Full AC group, r = 0.36; Full NV versus Full AC group, r = 0.70) followed by that of the Pro-environmental attitudes (Mixed versus Full AC group, r = 0.25; Full NV versus Full AC group, r = 0.27) and Acceptance of an air-conditioning reduction policy in university scores (Mixed versus Full AC group, r = 0.26; Full NV versus Full AC group, r = 0.19)
- Pro-environmental attitudes could be considered as one of many factors that influence students' acceptance of the ANV mode in the HE environment, but is not a dominant one (the relationship was weak, r = 0.14)
- Climate as well as income were also associated with pro-environmental attitudes (Climate and Pro-environmental attitudes, r = 0.39, Income and Pro-environmental attitudes, r = 0.32) and reported adaptive behaviour (Climate and Adaptive behaviour at home, r = 0.52, Income and Adaptive behaviour at home, r = -0.14).

Study 3: Facilities manager interviews

This study aimed to investigate the possibilities and the barriers to the implementation of three selected MM strategies (for increasing the use of the ANV mode) in existing MM non-residential buildings, based on the viewpoints of FMs. Semi-structured interviews were used as the main method for gathering data from FMs in various faculties in selected universities. The interviews focused on current thermal operating practice and relevant organisational factors that affect this practice. The perceived effectiveness and risks of the proposed MM strategies in FMs' HE buildings were examined. The proposed MM strategies were:

> Strategy 1: Concurrent - To use air-conditioners and fans together and set the thermostats 1 or 2 degrees higher than usual (from 25°C to 26-27°C) to save energy
>
> Strategy 2: Change-over - To use natural ventilation assisted with fans in the morning and evening classes and/or in the cool season, when the outdoor temperature is not too hot, in existing MM rooms
>
> Strategy 3: Zoned - To conserve and/or extend fully NV spaces (with or without fans) within faculty buildings in the future.

The interviews with FMs revealed that:

- FMs generally do not believe that MM operational strategies are possible
- The influence of the steady-state comfort model on the current thermal operating practice is apparently strong, as 25°C is currently held as the only main standard set-point in existing HE buildings
- If the organisation had no explicit energy policy, plans or targets, and there was little or no commitment on the part of senior executives or

administrators in relation to a reduction in air-conditioning, then the service providers have neither the motivation nor the incentive to change from the current full AC to MM operation

- The fear of complaints due to thermal discomfort and anticipation of adverse outcomes on user performance potentially prevented many facilities management staff from reducing air-conditioning use
- Thermal operating practice was also related to users' organisational status and power as teachers who had higher organisational status or postgraduate students who paid high tuition fees, usually expect quick constant air-conditioning
- Fans are becoming obsolete and being removed from many MM buildings which then makes it almost impossible to reverse the trend towards full air-conditioning.

Overall, the role of FMs in changing the current full-AC operation is not obvious because their daily routine mainly focuses on housekeeping whereas users are treated as customers (have little/no involvement in the energy reduction). If these findings can be applied to include thermal comfort practice in other non-residential organisations and the possibilities of improving it to become more energy efficient, then it is clear that practice depends heavily on high-ranking people (i.e. executive board or board of administration) within the relevant organisation.

Study 4: Learning and thermal performance survey

The objective of this study was to investigate whether students at the same state of self-reported thermal comfort (i.e. uncomfortable, neutral and comfortable), perceive their performance to be at the same level regardless of AC or ANV rooms. A questionnaire was administered to two groups of students; one in AC classrooms and another in ANV classrooms. Students rated their PLP and thermal comfort within the classrooms. The average PLP score of students between the two thermal conditions were then compared. The results showed that:

- Thermal comfort affected perceived learning performance but comfort was not necessarily achieved only within AC buildings
- Students' PLP was found to be affected less by objective thermal conditions than by perceived comfort, particularly in ANV classrooms, but this could be due to limited variations in the outdoor air temperature during the survey
- Some, though not the majority of students, in ANV classrooms felt neutral (32%) or comfortable (29%) and their self-reported performance was similar to those in AC classrooms in the same thermal comfort state
- Perceived performance of uncomfortable ANV students was slightly lower than the uncomfortable AC students (r = 0.17) because the degree of discomfort among uncomfortable ANV students was higher
- There was no significant reduction in performance among uncomfortable AC students (due to warmth), compared with neutral AC students, possibly because the degree of discomfort was small.

Based on the results of all four field studies, the evidence generally supported the hypothesis and additionally pointed to an important association between users' current daily exposure to AC environments and their economic status, in explaining their acceptance of the ANV mode and their environmental awareness. The findings also provide a mixed picture of the applicability of the thermal adaptation concept in non-residential buildings in Thailand and of the likelihood of greater use of NV and MV modes of operation in MM buildings. For example, as long as more AC buildings are built and more people spend more time in AC homes, transport and places of work or education, then it is likely that they will have a lower chance to practice their thermal adaptive skills, even though they have the ability to do so. For as long as users' thermal adaptability is not recognised, the more MM buildings will be operated in AC mode the majority of the time. Ceiling fans will then be removed as a result of underuse or may never be installed in new MM spaces; thus limiting still further the potential of non-AC operations because even during the cool season, both windows and MV are required to raise the likelihood of non-AC operations.

8.2 IMPLICATIONS FOR ENERGY POLICY MAKERS

The role of governmental organisations (i.e. EPPO and DEDE) in shaping thermal operating practice in the country is significant. The MOE should be aware that MM operation in non-residential buildings may become obsolete resulting in excessive air-conditioning use and an increase in air-conditioning addiction. Thus, suggestions for the MOE, Thailand, and energy policy makers are as follows:

- Data of MM buildings or spaces should be segregated from those with full air-conditioning based on the capabilities of their ventilation systems, rather than the presence of air-conditioning systems alone
- More attention must be paid to the MM non-residential building stock in relation to its actual thermal operation (not only design) and energy consumption, compared with other building types (full AC and full NV)
- Energy policy for MM buildings must be clearly differentiated from the policy for full AC buildings because the potential for air-conditioning reduction, levels or adaptive opportunities and thermal expectations are different
- Education is needed to help professional communities, university and other non-residential management, particularly those with large property

portfolios to understand the potential and limitations of using ANV in existing MM building stock and future buildings and the importance of thermal adaptability enhancement for air-conditioning reduction and user performance improvement.

Based on the crude data from one university observed in this thesis, MM classroom areas account for as much as 64% (26% with fans and 38% without fans) and 69% (55% with fans and 14% without fans) of the total classroom area in urban and suburban campuses, respectively. In these MM spaces, the availability of windows and fans (the most important adaptive features that contribute to users' acceptance of ANV) only shows that users have opportunities to adapt when not using air-conditioning; however, the actual use of windows and fans is dependent on the thermal operating practice within the organisation, which is most likely to be influenced by high-ranking people's concern for energy consumption within their organisation. Therefore, additional implications for the MOE, Thailand in relation to thermal operating practice in non-residential buildings are as follows:

- For existing MM non-residential buildings with high adaptive opportunities (operable windows and fans are available and adequate), the MOE should use a top-down approach targeting effective organisational behaviour change, alongside the technical assistance, in order to encourage ANV operation where possible to reduce air-conditioning consumption in these buildings
- For existing MM non-residential buildings with low adaptive opportunities (operable windows or fans are not available or inadequate), building improvements (focusing on thermal insulation or reinstating operable windows and/or fans) should be considered necessary in order to reduce air-conditioning waste due to poor insulated envelopes

- For both cases, the MOE should require senior executives or administrators within the organisation to demonstrate a commitment to reducing energy consumption (e.g. explicit goals, action plans and evaluation methods)
- Incentives for energy saving should be provided, but monetary incentives may not be very effective for people with high organisational status or income; hence, other behavioural change strategies should be applied to supplement monetary incentives.

Another important issue for thermal operating practice in existing MM non-residential buildings is the fact that 25°C is currently used as the only thermal comfort standard held by building operators, and this limits the possibility to use non-AC modes. Consequently, the main implication for the EIT, the establisher of the Thai thermal comfort standard, is that alternative thermal comfort standards for non-fully AC buildings should be developed and promoted to building designers and operators, in addition to the comfort standard for AC buildings. However, further research is needed prior to the establishment of alternative standards.

8.3 IMPLICATIONS FOR THE BUILDING DESIGN COMMUNITY

In the observed existing MM HE buildings in Thailand, the ANV mode could only provide thermal comfort for the majority of the building's occupants during milder seasons and only when adaptive opportunities for increasing air movement by fans and windows within the space are sufficient. Implications for the building design community are:

- It must be aware that neither fans nor windows alone are adequate for the majority of users, especially in multi-occupancy spaces, in order to maintain their comfort if the design strategy for this building type remains unchanged, e.g. low ceiling height, small opening area, single-sided windows, and low insulated windows and envelopes

- The Concurrent strategy (using fans to assist air-conditioning) is the most plausible option based on the opinion of FMs and should be further developed to suit MM buildings in hot-humid climates
- There might be a case for insisting that fans are installed in, and never removed from all occupied spaces whether or not they have air-conditioning because fans have a crucial role to play in reducing air-conditioning use in hot-humid climates
- Recommendations for more efficient air movement enhancement or detailed designs to support fan and window ventilation, for example, minimum opening areas and the number of occupants per fan or air velocity requirement for enhancing thermal comfort, should be developed to ensure high adaptive opportunities are incorporated at the design stage
- Alternative design strategies for HE building types should be developed to optimise the use of air-conditioning and ANV modes within buildings, as the current design typologies for MM spaces are unlikely to provide both energy-efficient and comfortable environments.

8.4 IMPLICATIONS FOR ORGANISATIONS

The potential for using the behavioural approach to reducing air-conditioning use in non-residential buildings is perceived as low, based on the FMs' perspective. This is because facilities management staff do not believe that users who are already accustomed to air-conditioning can adapt to non-AC environments. However, the findings regarding individual thermal adaptability do not fully agree with this assumption. In addition, a reduction in air-conditioning use does not necessarily reduce user performance. The absence of tools and mechanisms to evaluate the energy and thermal performance of buildings in a more integrative way also reduces the ability for FMs to gain relevant information to initiate ANV operation. This barrier is unlikely to be overcome without changing the way in which building performance is evaluated. The implications for organisations at both the strategic and operational levels are:

- An organisation's energy reduction targets and action plans must be clearly established and disseminated across the organisation
- The building and facilities management performance indicator should not focus on either user satisfaction or energy performance alone but rather the balance of these two aspects of building performance
- Users across the organisation should be educated about the environmental impact due to air-conditioning in order to reduce the tendency for air-conditioning over-consumption
- Thermal operating practice should be developed accordingly to optimise the energy and thermal performance of buildings as well as user performance
- Evaluation methods for assessing the success of behaviour change policies should be developed to support the implementation of this kind of policy.

For HE buildings, the recommendations resulting from the findings are:

- When using air-conditioning (with/without fans) use the upper limit of the air-conditioning comfort boundary (27-28°C for Thais) as the new temperature set point, assisted with fans if necessary, as this is unlikely to have significant adverse effects on users' comfort and self-reported performance

- To use ANV during the cool season if the opportunities to use fans and windows are high, because thermal discomfort and associated performance risks are relatively low
- To use thermal control technology to assist climate responsive thermal operations.

Aside from the thermal operating issues stated above, organisations should pay more attention to the design quality of the building in use and should be aware that the practice of removing fans causes MM buildings to revert to fully AC (in case that it is not the design intention). In fact, it may be impossible to preserve the building conditions throughout the building life cycle, and in such a case, this thesis suggests that buildings should be improved to suit the level of adaptive opportunity in order to retain energy performance.

8.5 CONTRIBUTION TO KNOWLEDGE

In order to understand the thermal operations in MM non-residential buildings in a hot-humid climate, this thesis applies the adaptive thermal comfort theory as a framework for the investigation. In the process, this thesis provides distinct contributions to the knowledge of adaptive thermal comfort, focusing on the relationships between users' and organisational thermal adaptability and the acceptance of non-AC operations in the specific context of MM non-residential buildings but which are operated as fully AC buildings. Main contributions to knowledge are stated below.

- Thermal adaptability of an organisation based on the service providers' viewpoint was firstly investigated in this thesis. The findings provide further understanding about the current AC-led thermal operating practice and its consequent psychological and organisational effects (e.g. sensitivity to complaints and concern about performance risks). This information has shed some light on the magnitude of organisational factors when studying individuals' thermal adaptation in non-residential buildings.

- A preliminary questionnaire technique modified from risk assessment methods was developed for quantifying perceived behavioural adaptive opportunities in non-residential buildings. This method did not only focus on the availability of adaptive options but also quantified user perceptions of their 'effectiveness' and 'probability' which then help provide more understanding about users' actual adaptive behaviour in different places and times.
- Multinomial logistic regression was initially applied in order to quantify the magnitude of the effect of climate, design, and particularly economic status and daily exposure to AC environments on users' acceptance of the ANV mode in existing MM buildings. This statistical technique produced logit models that can determine the percentages of total ANV votes of users as a group and compare the odds ratios of ANV votes in different scenarios.
- This thesis extends the scope of thermal adaptation studies to the examination of the association between daily thermal experience (i.e. AC, NV and mixed) and pro-environmental attitudes. Pro-environmental attitudes could be considered an additional factor of individuals' psychological adaptation and may explain the willingness of non-AC users to reduce AC use during the hot season, even they know it would be hot.

8.6 FUTURE RESEARCH DIRECTIONS

Thermal operations in MM non-residential buildings are complicated. Even though this thesis covers several aspects of the topic, it could not fully explain the current full AC operation in many MM non-residential buildings in hot-humid climates. Directions for future research are stated in this section in order to confirm the findings in this thesis and extend the body of existing knowledge.

Based on the limitations of this research stated in Section 7.5 (p. 307), there is still scope for further studies to confirm and clarify the findings and for methodology development. The following studies are needed:

- An investigation of actual thermal adaptability of MM buildings' occupants, the extent to which they can adapt, using an interventional or experimental approach (i.e. use of the ANV mode instead of the AC mode in existing MM buildings) to reduce the uncertainty in users' responses to ANV operation
- An investigation of the relationships between users' organisational status and their responses to a reduction in air-conditioning within the non-residential context, using in-depth cross organisational studies that include people at both the strategic and operational levels, and also end-users in other non-residential building types (to gain variations in MM ventilation systems that could not be obtained from Thai HE buildings) in order to provide a more holistic view on the practicality of adaptive thermal comfort mechanisms
- An examination of the cause-effect of daily exposure to air-conditioning and pro-environmental attitudes and its influence on acceptance of ANV to understand the role of thermal design and operation in shaping environmental attitudes
- An investigation of the relationship between user performance and thermal perceptions comparing users in AC and ANV environments, taking CO_2 levels and seasonal variations into account and controlling room location, surroundings and the degree of discomfort in both AC and ANV modes to

minimise bias in comparisons of overall environmental conditions and user performance

- The interpretation of perceived learning performance in practice should be studied further to determine whether the magnitude of perceived learning performance differences between ANV and AC groups as found in this study is significant or can be ignored in real life.

Finally, further organisational research should be undertaken to document the thermal operations capability of the Thai buildings stock and to track it over time. The thermal and energy performance of MM buildings under the scenario of climate change, if continuing with current practice (base case), should be monitored or simulated, so that the possible energy savings resulting from the application of various MM operational strategies for MM spaces during the cool season could be estimated. Given the conditions of existing MM building stock in Thailand, climate and facilities management practices, the most effective and practical MM operational strategy could then be identified in future research, and this would allow practical guidelines for MM building design and operation to be developed.

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APPENDIX A: QUESTIONNAIRES AND INTERVIEW

PRE-STUDY: LECTURE ROOM SURVEY

LECTURE ROOM SURVEY

Building Name ______________________ Room Number ______________________

Date | d | d | m | m | y | y | Surveyor Name ______________________

1. Location ☐ Urban ☐ Suburban

2. Floor level ________

3. Size
Width ________ m
Length ________ m
Height ________ m

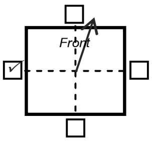
4. Capacity ________ seat

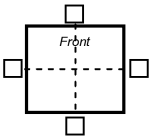
5. Ext. wall materials
☐ Heavyweight
☐ Medium-weight
☐ Lightweight
☐ Others____________

6. Exterior wall(s) facing to…, approximately

Tick ✓ at ext. wall and draw ↗ to the North

Ex.





7. Window area
☐ None or equivalent *(go to 14)*
☐ Small ▭ 1/4
☐ Medium ▭ 2/4
☐ Large ▭ 3/4
☐ Full ▭ 4/4

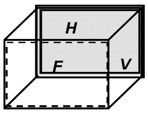
8. Cross-ventilation
☐ No
☐ Yes

9. Main window material (check only one)
☐ Clear glass
☐ Tint/filmed glass
☐ Others____________

10. Current view from window (check only one)
☐ Unseen
☐ Built elements
☐ Natural elements
☐ Others____________

11. Int. shading device (check only one)
☐ None
☐ Blind – horizontal
☐ Blind – vertical
☐ Curtain – horizontal
☐ Curtain – vertical
☐ Others__________________

12. Ext. shading device(s)



☐ None *(go to 14)*
☐ Horizontal
☐ Vertical
☐ Front plane

13. Device adjustable?
☐ No
☐ Yes

14. Thermal mode(s)
☐ NV
☐ AC – Type:
  ☐ Split units (local)
  ☐ VRF (local)
  ☐ Constant vol. (central)
  ☐ VAV (central)
  ☐ Others________________
☐ MV – Type:
  ☐ Ceiling fan_________units
  ☐ Wall fan___________units
  ☐ Exhaust fan________units
  ☐ Others________________

15. User control available?
→ for AC ☐ No or equivalent ☐ Yes
→ for MV ☐ No or equivalent ☐ Yes

STUDY 1: THERMAL ADAPTIVE OPPORTUNITY SCORING SYSTEM AND ACCEPTANCE OF ASSISTED NATURAL VENTILATION SURVEY

CASE		THERMAL ADAPTIVE OPPORTUNITY SCORING SYSTEM AND ACCEPTANCE OF ASSISTED NATURAL VENTILATION SURVEY	TIME	

This questionnaire is a part of PhD research carried out by Miss Darunee Mongkolsawat, Faculty of the Built Environment, University College London, UK. The aim of the survey is to estimate the quality of existing classroom environments and to improve the design of future learning environments. Please fill in this questionnaire as accurately as possible. Thank you for your cooperation.

Please check ✓on the one that is most appropriate

Part 1 Personal information

1.1 Gender ☐ Female ☐ Male

1.2 Age ____________ year

1.3 Monthly allowance, excluding your accommodation fees (Thai Baht)

- ☐ ≤ 2,500
- ☐ 2,501–5,000
- ☐ 5,001–7,500
- ☐ 7,501–10,000
- ☐ > 10,000

Part 2 Clothes worn

2.1 What are you wearing at the moment? **(Choose more than one if appropriate)**

- ☐ Vest
- ☐ T-shirt
- ☐ Short-sleeve shirt
- ☐ Long-sleeve shirt
- ☐ Long-sleeve blouse
- ☐ Jacket (thin)
- ☐ Jacket (thick)
- ☐ Knee-length skirt
- ☐ Ankle-length skirt
- ☐ Shorts
- ☐ Trousers
- ☐ Jeans
- ☐ Thin ankle socks
- ☐ Thick ankle socks
- ☐ Thin knee socks
- ☐ Thick knee socks
- ☐ Pantyhose/stocking
- ☐ Sandals/thongs
- ☐ Shoes (thin soled)
- ☐ Shoes (thick soled)
- ☐ Others______________

Part 3 Thermal experience

3.1 Do you use air-conditioning in your bedroom? ☐ No ☐ Yes

3.2 At present, do you usually use non-air-conditioned lecture rooms, laboratories, or studios (at least 2 hours/day)? ☐ No ☐ Yes

3.3 What is your main travelling mode to the university? **(Choose only one)**

- ☐ Taxi boat
- ☐ Cycling
- ☐ AC bus
- ☐ On foot
- ☐ AC van
- ☐ Sky train/Underground
- ☐ Non-AC bus
- ☐ Car/Taxi
- ☐ Others ___________

Part 4 Acceptance of assisted natural ventilation in this room

	Do you agree with these statements?	Disagree	Uncertain	Agree
4.1	In cool season, you still be able to maintain your comfort if using natural ventilation and fans (if available) instead of air-conditioning in this classroom.			
4.2	In hot season, you still be able to maintain your comfort if using natural ventilation and fans (if available) instead of air-conditioning in this classroom			

4.3 If you choose "Disagree" in 4.1 or 4.2, please state why

____

Part 5 Thermal Adaptive Opportunity

If this room is not air-conditioned, how would you rate the **EFFECTIVENESS** of these thermal adaptation methods to relieve the heat discomfort? (if all methods are possible)

Thermal adaptation methods	**1** **Very** **Low**	**2**	**3**	**4**	**5** **Very** **High**
5.1 Operate door(s)					
5.2 Operate window(s)					
5.3 Operate blind(s)/curtain(s)					
5.4 Operate external shading device(s)					
5.5 Operate electric fan(s)					
5.6 Change clothes					
5.7 Wash your face					
5.8 Consume cold drink					
5.9 Fan yourself (by hand or a handheld fan)					
5.10 Move your seat					

How would you rate the **PROBABILITY** of these thermal adaptation methods while you are studying in this room?

Thermal adaptation methods	**1** **Very** **Low**	**2**	**3**	**4**	**5** **Very** **High**
5.11 Operate door(s)					
5.12 Operate window(s)					
5.13 Operate blind(s)/curtain(s)					
5.14 Operate external shading device(s)					
5.15 Operate electric fan(s)					
5.16 Change clothes					
5.17 Wash your face					
5.18 Consume cold drink					
5.19 Fan yourself (by hand or a handheld fan)					
5.20 Move your seat					

-Thank you very much for your co-operation-

STUDY 2: PRO-ENVIRONMENTAL ATTITUDES, ADAPTIVE BEHAVIOUR AND DAILY THERMAL EXPERIENCE SURVEY

PRO-ENVIRONMENTAL ATTITUDES, ADAPTIVE BEHAVIOUR, AND DAILY THERMAL EXPERIENCE SURVEY

This questionnaire is a part of PhD research carried out by Miss Darunee Mongkolsawat, Faculty of the Built Environment, University College London, UK. The aim of the survey is to evaluate students' attitudes and behaviours toward air-conditioning and the environmental impact. The results from this survey can help with the future energy conservation policy. Please fill in this questionnaire as accurately as possible. All collected data will be anonymous, and please be assured that all data will be analysed so that it cannot be traced back to you.

*Please **check** ✓ **on the one** that is most appropriate*

Part 1 Personal information

1.1 Gender ☐ Female ☐ Male

1.2 Age __________________ year

1.3 Faculty ______________________

1.4 Monthly allowance, excluding your accommodation fees (Thai Baht)

☐ ≤ 2,500 ☐ 2,501 – 5,000 ☐ 5,001 – 7,500 ☐ 7,501 – 10,000 ☐ > 10,000

Part 2 Thermal experience

2.1 Do you use air-conditioning in your bedroom? ☐ No ☐ Yes

2.2 At present, do you usually use non-air-conditioned lecture rooms, laboratories, or studios (at least 2 hours/day)? ☐ No ☐ Yes

2.3 What is your main travelling mode to the university? **(Choose only one)**

☐ Taxi boat ☐ On foot ☐ Non-AC bus ☐ Cycling

☐ AC van ☐ Car/Taxi ☐ AC bus ☐ BTS/MRT ☐ Others ___________

Part 3 Thermal adaptive behaviour at home

When you are at <u>home</u>, how often do you...	Never	Occasionally	Sometimes	Often	Always
3.1 Use windows and/or fans, instead of air-conditioners, to save energy					
3.2 Use curtains/blinds to get natural light, to save energy					
3.3 Set air-conditioner thermostat higher than 25°C to save energy					
3.4 Adjust air-conditioner thermostat when I feel cold, rather than wearing more clothes					
3.5 Wear lighter clothes than usual, when not using air conditioners					

Part 4 Acceptance of potential university air-conditioning reduction policies

Would you find these university air-conditioning reduction policies acceptable?		Not acceptable at all	Not acceptable	Neither/ Uncertain	Acceptable	Very acceptable
4.1	Set air-conditioner thermostats in lecture rooms/lab/studio 1 or 2 degrees higher than usual to reduce the effect of global warming					
4.2	Use only windows and fans in some lecture rooms when the outdoor climate is pleasant for at least 2 hours per day in order to reduce the effect of global warming					
4.3	Use only windows and fans in some lab/studio for at least 2 hours per day when the outdoor climate is pleasant (morning or night classes) in order to reduce the effect of global warming					
4.4	Use only windows and fans in some lecture rooms all day in order to reduce the effect of global warming					
4.5	Use only windows and fans in some lab/studio all day in order to reduce the effect of global warming					

Part 5 Pro-environmental attitudes

How much would you agree with these statements?		Strongly disagree	Disagree	Neither/ Uncertain	Agree	Strongly agree
5.1	Humans are capable of finding ways to overcome the world's environmental problems					
5.2	Scientists will find a solution to global warming without people having to make big changes to their lifestyles					
5.3	Global warming is beyond control – it is too late to do anything about it					
5.4	I find it hard to change my habits to be more environmentally-friendly					
5.5	I do not believe my behaviour and everyday lifestyle contribute to global warming					
5.6	The environment is a low priority for me compared with a lot of other things in my life					
5.7	The effects of global warming are too far in the future to really worry me					
5.8	I believe that the increase of air-conditioning significantly contributes to global warming					
5.9	I do not pay much attention to the amount of electricity I use at home					
5.10	I do not pay much attention to the amount of electricity I use at my university					

-Thank you very much for your co-operation-

STUDY 3: FACILITIES MANAGER INTERVIEWS

THE INTERVIEW ABOUT THERMAL OPERATIONAL PRACTICES IN HIGHER EDUCATION SECTOR

This interview with facilities management staff is a part of PhD research entitled “Thermal Operations in Mixed-Mode Buildings, Higher Education Sector Case Study in a Hot-Humid Climate” carried out by Miss Darunee Mongkolsawat, Faculty of the Built Environment, University College London, UK.

The aim of the survey is to gather in-depth information about thermal operational practices in higher education sector in Thailand and to evaluate the possibilities and barriers to the implementation of adaptive thermal operation. The outline of the interview is enclosed herewith and will be explained further in details during the interview. The researcher may collect general data in relation to energy consumption and energy policy of the faculty from annual report or other secondary sources if you prefer. In order to gain the information from both strategic and operational levels, the interview will be conducted with senior facilities manager in your faculty. The conversation will be recorded if the interviewees are agree and used for academic purpose only. All information is confidential and will be presented anonymously and cannot be traced back to you. Each interview should not take longer than one hour at your convenience.

The results from this interview can help with the future building design-use policies and thermal operational practices in non-residential sector with the aim of climate change mitigation. Thank you very much in advance for your cooperation. If you have any questions, please do not hesitate to contact the researcher.

FACILITIES MANAGER INTERVIEW

University	________________	**Faculty**	________________
Date	d d m m y y	**Time**	h h m m
Interviewee Name	________________	**Position**	________________

Part 1 General background of the interviewee and the faculty

1.1 Work experience in the position

1.2 Number of facilities management staff in the faculty

1.3 Number of buildings you are responsible for

1.4 Are there any non-air-conditioned rooms in your faculty's building(s) at present?

1.5 What is buildings opening hour?

Part 2 Current energy reduction policies

2.1 Please describe the energy reduction policies currently implemented in your faculty

Part 3 Energy information system

3.1 Is there sub-meter(s) installed in your building(s)?

3.2 Does the facilities management staff/department have information about electricity consumption and costs?

3.3 Is the information about electricity consumption and costs disseminated to the faculty members?

3.4 Have you ever conducted an energy audit in your faculty?

3.5 Have you ever conducted a thermal comfort survey in your faculty?

Part 4 Air-conditioning installation

4.1 What kind of place in your faculty was firstly installed with air-conditioning system(s) or unit(s)?

4.2 Have rooms been improved or changed before or after the air-conditioning installation?

4.3 Does your faculty have any plan to install more air-conditioners in the future?

Part 5 Air-conditioning operation and user controls

5.1 Who are responsible for operating air-conditioners and setting thermostats?

5.2 What is the standard temperature set point in your faculty, if any?

5.3 Can users (teachers and students) adjust the thermostats?

Part 6 The possibilities and barriers to implementing mixed-mode strategies within the faculty

6.1 Please give an opinion on the following mixed-mode operational strategies, whether there is the possibility to implement these strategies in your faculty and what the barriers might be

Strategy 1 Concurrent: To use air-conditioners and fans together and set the thermostats 1 or 2 degrees higher than usual (from 25°C to 26-27°C) to save energy

Strategy 2 Change-over: To use natural ventilation assisted by fans in the morning and evening classes and/or in the cool season when the outdoor temperature is not too hot, in existing mixed-mode rooms

Strategy 3 Zoned: To conserve and/or extend fully naturally ventilated spaces (with or without fans) within faculty buildings in the future

STUDY 4: LEARNING AND THERMAL PERFORMANCE SURVEY

CASE		**LEARNING AND THERMAL PERFORMANCE SURVEY**	AC / NV	AM / PM

This questionnaire is a part of PhD research carried out by Miss Darunee Mongkolsawat, Faculty of the Built Environment, University College London, UK, and is supported by Deans of your faculty. The aim of the survey is to estimate the quality of existing classroom environments and to improve the design of future learning environments. Please fill in this questionnaire as accurately as possible. All collected data will be anonymous, and please be assured that all data will be analysed so that it cannot be traced back to you.

Please ***check*** ✓ ***on the one*** *that is most appropriate*

Part 1 Personal information

1.1 Gender ☐ Female ☐ Male
1.2 Age ______________ year
1.3 Monthly allowance, excluding your accommodation fees (Thai Baht)
☐ ≤ 2,500 ☐ 2,501 – 5,000 ☐ 5,001 – 7,500 ☐ 7,501 – 10,000 ☐ > 10,000

Part 2 Clothes worn

2.1 What are you wearing at the moment? **(Choose more than one if appropriate)**

☐ Vest
☐ T-shirt
☐ Short-sleeve shirt
☐ Long-sleeve shirt
☐ Long-sleeve blouse
☐ Jacket (thin)
☐ Jacket (thick)
☐ Knee-length skirt
☐ Ankle-length skirt
☐ Shorts
☐ Trousers
☐ Jeans
☐ Thin ankle socks
☐ Thick ankle socks
☐ Thin knee socks
☐ Thick knee socks
☐ Pantyhose/stocking
☐ Sandals/thongs
☐ Shoes (thin soled)
☐ Shoes (thick soled)
☐ Others ______________

Part 3 Perceived learning performance

How likely did the environmental conditions (temperature, lighting, noise, cleanliness, and odour) in this lecture room affect your learning performance (3.1-3.5) throughout this lecture?

Learning performance	**Much lower than normal**	**Moderately lower than normal**	**Normal**	**Moderately higher than normal**	**Much higher than normal**
3.1 Attention					
3.2 Freshness					
3.3 Alertness					
3.4 Environmental tolerance					
3.5 Overall learning performance					

Part 4 Indoor environmental comfort

How **COMFORTABLE** are you with given environmental conditions (4.1-4.5) of the current classroom throughout this lecture?

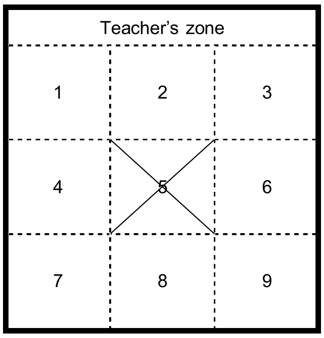
Environmental conditions	**Very uncomfortable**	**Mildly uncomfortable**	**Neutral**	**Mildly comfortable**	**Very comfortable**
4.1 Thermal comfort					
4.2 Visual comfort					
4.3 Hearing comfort					
4.4 Indoor air quality (air freshness and odour)					
4.5 Overall environmental comfort					

Part 5 Seating zone

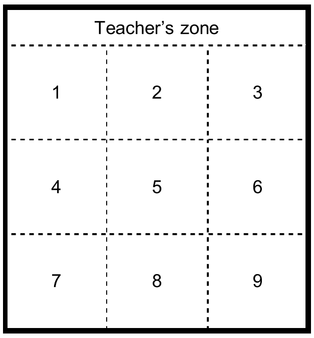
*Please **check X on the one** that is most appropriate*

Example: Your seat is in the middle of the room

In front of the room



In front of the room



-Thank you very much for your co-operation-

APPENDIX B: STATISTICAL CONCEPTS

This appendix explains the main statistical concepts used in this thesis. There are three parts describing the statistical techniques for the data analysis in Study 1: Thermal adaptive opportunity scoring system and acceptance of assisted natural ventilation survey, Study 2: Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey and Study 4: Learning and thermal performance survey respectively. Each details the concept, relevant model(s), what to report, assumptions and sample size determination.

PART 1 - STUDY 1

There are two main statistical techniques used for examining the data in this study; logistic regression (appeared in Subsection 5.2.2.4, Chapter 5, p. 183) and multiple linear regression (appeared in Subsection 5.2.2.5, Chapter 5, p. 198). The concepts behind these two methods are explained in the following sections.

1.1 LOGISTIC REGRESSION: MULTINOMIAL LOGISTIC REGRESSION

1.1.1 Concept

Logistic regression is used for building a model to predict the outcome variable that is a categorical scale where the independent variables can be continuous or a categorical scale or both. There are three methods for logistic regression analyses: binary logistic regression (outcome variable is dichotomous), ordinal logistic regression (outcome variable has more than two categories and is an ordinal scale) and multinomial logistic regression – MloR (outcome variable is a nominal scale with more than two categories and unordered).

In Study 1, MLoR was employed because the outcome variable has three possible responses (i.e. Agree, Uncertain and Disagree). Therefore, the following parts focus on the MLoR model.

1.1.2 Model

A logit model for predicting the 'log odds' of the outcome being *j* rather than *R* is:

$$\text{Log}\,(\pi_j/\pi_R) = \alpha_j + B_j\,x, \qquad j = 1, ..., J-1 \qquad \textbf{Equation B.1}$$

where: π_j/π_R = the probability of the outcome being *j* rather than *R*

α = intercept

B = parameter estimates

Then, in order to invert the response logarithm odds to actual probabilities, the exponential function is employed to remove the logarithm of both sides of the equation above first. Therefore, the odds of the event of interest are (Agresti, 2007, p. 176):

$$\pi_j / \pi_R = \exp(\alpha_j + B_j\,x), \qquad j = 1, ..., J \qquad \textbf{Equation B.2}$$

For the example of the outcome with three categories and the third category is set as a baseline, the odds ratio of outcome $j = 1$ and $j = 2$ versus $j = 3$ are:

$$\pi_1 / \pi_3 = \exp(\alpha_1 + B_1\,x_1),$$

$$\pi_2 / \pi_3 = \exp(\alpha_2 + B_2\,x_2), \text{ and}$$

$$\pi_3 / \pi_3 = 1$$

Eventually, the actual probabilities of the event of interest can be calculated as follows:

$$\pi_j = \frac{\exp(\alpha_j + B_j\,x_j)}{\Sigma^J{}_{j=2} \exp(\alpha_j + B_j\,x_j) + 1} \qquad \textbf{Equation B.3}$$

Therefore; $$\pi_1 = \frac{(\pi_1/\pi_3)}{(\pi_1/\pi_3) + (\pi_2/\pi_3) + 1}$$

$$= \frac{\exp(\alpha_1 + B_1\,x_1)}{\exp(\alpha_1 + B_1\,x_1) + \exp(\alpha_2 + B_2\,x_2) + 1}$$

$$\pi_2 = \frac{(\pi_2/\pi_3)}{(\pi_1/\pi_3) + (\pi_2/\pi_3) + 1}$$

$$= \frac{\exp(\alpha_2 + B_2\,x_2)}{\exp(\alpha_1 + B_1\,x_1) + \exp(\alpha_2 + B_2\,x_2) + 1}$$

(as the sum of the probabilities of all events = 1)

$$\pi_3 = 1 - \pi_1 - \pi_2$$

Finally, the probabilities of all three events (all possible outcome), given particular values for the independent variable(s), can be computed from the logit model(s). These probabilities are expressed as 0 – 1 (Koutoumanou and Wade, 2010, p. 16). The highest probability predicts the outcome category to which an individual case belongs (Hosmer and Lemeshow, 2000, p. 156). Furthermore, if the probabilities are multiplied by 100 then they can be used for estimating the cell frequencies or cell percentages of cases classified by outcome and independent variables.

1.1.3 What to report

This part includes the main output of the MLoR and explanations of them.

Coefficient estimates

Like the linear regression model, the function of MLoR consists of an intercept (α) and coefficient values (B) of the variables included in the model. According to Koutoumanou and Wade (2010, p. 6) α does not have any meaningful interpretation, but instead shows where to locate the origin of a regression line. The term B in MLoR indicates how the outcome variable will be changed when a particular independent variable (x) changes for one unit whilst other independent variables are constant (Koutoumanou and Wade, 2010, p. 6). The B values should be reported with their 95% confidence interval in order to show the precision of the estimation (Koutoumanou and Wade, 2010, p. 6).

Odds and odds ratios

MLoR is often used in clinical and social science research, and within these fields it is sometimes more meaningful to interpret the outcome in terms of odds and odds ratios, for example, the odds of having cancer or not. The odds of an event can be calculated by dividing the probability of the event occurring by the probability of the event not occurring (Koutoumanou and Wade, 2010, p. 11). When the outcome has more than two categories, a researcher is always interested in the odds of the event of interest against the event set as a reference category. In PASW, odds are represented by $Exp(B)$. The interpretation of B and $Exp(B)$ values is described as follows (Koutoumanou and Wade, 2010, p. 11).

If $B > 0$, $Exp(B) > 1$: As a particular independent variable increases one unit the odds of the event of interest compared with the reference event increase.

If $B < 0$, $Exp(B) < 1$: As a particular independent variable increases one unit the odds of the event of interest compared with the reference event decrease.

If B = 0, Exp(B) = 1: A particular independent variable does not have an effect on the event of interest.

The odds ratio is the odds of an event in one group divided by the odds of the event in another group (Koutoumanou and Wade, 2010, p. 12).

Goodness of fit

Once the MLoR model(s) has been constructed, it is normal to check the goodness of fit of the model, i.e. how the estimation of the model based on selected independent variables fits the observed values. There are a number of tests for evaluating the goodness of fit, although the interpretation of these tests may be different. Pearson (X^2) and the deviance (G^2, calculated from -2log likelihood) measures are the two most common methods utilised for comparing the estimated and observed cell frequencies (Hosmer and Lemeshow, 2000, p. 145). Significant results for X^2 and G^2 indicate a lack-of-fit, i.e. the observed and estimated cell frequencies are significantly different. Notably, Agresti (2007, p. 147) stated that both X^2 and G^2 apply to grouped data or fitness of the estimation of total data only and they do not assess the fitness of the estimation of an individual case.

Hosmer-Lemeshow test

The Hosmer-Lemeshow test is a test for the overall fit. A non-significant statistic implies that the model adequately fits the data, while significance could mainly be due to the lack of other predictors included in the model (Koutoumanou and Wade, 2010, p. 25). In addition, the Hosmer-Lemeshow test works well when independent variables are continuous, because it deals directly with the number of covariate patterns within the data (O'Connell, 2006, p. 43).

Classification table

A classification table shows the frequencies of cells categorised by the probabilities of the event of interest. Actual against predicted events are compared so that the percentage of correct predictions by logit model(s) can be estimated. However, Hosmer and Lemeshow (2000, p. 157) remark that classification is very sensitive to group size and "*always favours classification into the larger group, a fact that is independent of the fit of the model.*" For a model to fit, the results of the omnibus likelihood ratio test and the Wald tests for the contribution of each independent variable in the model is preferred (O'Connell, 2006, p. 43).

Pseudo R^2

Other measures of goodness of fit are known as pseudo R^2. There are three measurements for R-squares computed by PASW; Cox and Snell R^2, Nagelkerke R^2 and McFadden R^2. However, the pseudo R^2 values do not actually measure the true fitness of the prediction of the MLoR model and are not equal to the R^2 in a linear regression (Koutoumanou and Wade, 2010, p. 25). In fact, pseudo R^2 measures are based on a comparison of estimated values from the fitted model and those from the intercept-only or no model (i.e. guessing). These measures are useful when comparing models only, and consequently, Hosmer and Lemeshow (2000, p. 167) do not recommend reporting the pseudo R^2 values with the results since they may be mistakenly interpreted.

1.1.4 Assumptions of logistic regression

Assumptions of logistic regression are presented below based on Field (2009, p. 273).

1) Linearity: As the logistic regression model uses logarithms to transform the outcome from a categorical to continuous scale. The assumption of linear regression about linear relationships between the outcome and the predictors also applies.
2) Independence of errors: The data must be independent or are not drawn from the same people.
3) Multicollinearity: All the predictors, i.e. independent variables, should not be highly correlated.

1.1.5 Sample size for logistic regression

Hosmer and Lemeshow (2000, pp. 339-346) suggest two approaches for estimating the sample size for logistic regression; prospective and retrospective. When a researcher needs to know whether a new treatment has significant effects on participants with a certain level of power, the prospective method is used to calculate the sample size required. If a researcher needs to know how many subjects are needed to fit a logistic model, the retrospective method is more relevant.

For the second approach, Peduzzi, Concato, Kemper, Holford and Feinstein (1996) (cited in Hosmer and Lemeshow, 2000, p. 346) recommended that at least 10 events per parameter (p) should be obtained. Otherwise, there may be problems of variance estimation leading to a poor test of coefficients and their confidence intervals. The rule of 10 should apply to the frequency of the least frequent outcome. For example, if the outcome has three categories and the total number of participants is 100 (30, 20 and 50 participants in each category), there should be no more than 2 (= 20/10) parameters included in the logit model.

Study 1 is interested in whether the data is sufficient to generate a model for predicting the acceptance of ANV as a function of a set of variables (i.e. perceived behavioural adaptive opportunities and personal variables), which corresponds to the retrospective approach. According to the retrospective concept, an estimate of the minimum number of events is required. In this case, there are three possible events – Agree, Uncertain and Disagree with the use of ANV. There is no previous research indicating the odds of an occupant accepting ANV in a given room. In order to estimate the sample size, let say that in a typical room 80% of occupants accept the thermal conditions in an air-conditioned room and 20% do not. This assumption is arbitrary; however, it is derived from a general thermal design rule of thumb which stipulates that an acceptable thermal design should provide thermal comfort for at least 80% of the occupants. In contrast, given the ANV scenario for existing air-conditioning users, these figures could be the other way around. That is, only 20% of the users may accept the use of ANV where the majority of them do not or are uncertain.

Based on this assumption, out of 100 participants, the estimated number of students agreeing with the use of ANV is 20 while the other 80 participants vote otherwise. This allows for only two parameters in the logit model according to the rule of 10. According to the research framework, 12 parameters were expected to be included in the model (i.e. 10 adaptive opportunity scores, 1 economic status and 1 daily thermal experience – these were all variables that may have a direct relationship with acceptance of ANV). In fact, the overall possible number of independent variables should be 26 when considering the levels within each variable (i.e. 10×2 levels of adaptive opportunity scores[1], 1×4 levels of economic status[2] and 1×2 levels of daily thermal experience[3]). However, in practice, this was too many for building a logit model and hence 12

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[1] Levels of adaptive opportunity scores = 3 (Low, Moderate and High), but one category is set as a reference category; therefore, there are only two levels counted.

[2] Levels of economic status = 5 (1 = ≤ 2,500, 2 = 2,501-5,000, 3 = 5,001-7,500, 4 = 7,501-10,000 and 5 = > 10,000 Baht/Month). One category is treated as a reference category; therefore, only four categories are included as independent variables.

[3] Levels of daily thermal experience = 3 (Fully AC, Mixed-mode and Fully NV). Similarly, only two categories are included as independent variables since one category is set as the reference category.

parameters were adopted instead. Therefore, Study 1 required at least 120 participants in the minimum category. Consequently, a total of at least 600 participants (minimum category = 120 and other categories altogether = 480) were needed for Study 1. Assuming the response rate was 80%, the target sample size was increased to 750. Since there were 23 classrooms used as case studies, in each classroom 32 (= 750/23) participants were needed. Therefore this sample size was rounded up to 30. During the data analysis, the actual number of participants in the minimum category was also investigated before drawing any conclusions.

1.2 MULTIPLE LINEAR REGRESSION: CATEGORICAL PREDICTORS

1.2.1 Concept

MLiR is generally used for defining the relationships between dependent and independent variables where the dependent variable is continuous and the independent variables can be a continuous or categorical scale or both (Field, 2009, p. 220). The purposes of using MLiR are various, for example, predicting the outcome, investigating correlations, comparing sizes of the relationship of dependent and independent variables between groups, and comparing the outcome between groups (when the independent variables are categorical) (Cohen et al., 2003, pp. 1-3). In Study 1 MLiR was applied for comparing the levels of adaptive opportunities (dependent variable) perceived by students in different classrooms (independent variables were the configurations of the rooms – number of fans, window area, location, etc.). Furthermore, the independent variables included in the MLiR model were all categorical. Therefore, the explanation of MLiR modelling in the following parts will focus on categorical independent variables.

1.2.2 Dummy coding

When the independent variable(s) is categorical, it needs to be coded using 0 and 1 (Field, 2009, p. 253). If the independent variable has two categories, one is coded as 0 and another one is coded as 1 (Field, 2009, p. 253); however, when there are more than two categories, other coding methods are necessary (Field, 2009, pp. 253-254). There are many methods of coding: dummy coding, unweighted effects coding, weighted effects coding, contrast coding and nonsense coding (Cohen et al., 2003, p. 303). Each method is used for a different purpose and interpreted in a different way. In Study 1, dummy coding was employed for generally comparing students' perceived adaptive opportunities in different classroom environments.

If an independent variable has three categories, then two dummy variables need to be created (the number of all categories minus one) (Field, 2009, p. 254). One category must be chosen as a reference or baseline group and coded as 0 (Cohen et al., 2003, p. 303). The selection of the reference group depends on the researcher, but it should be the group that yields the benefit of comparison (Field, 2009, p. 254). Field (2009, p. 254) provides a useful instruction for dummy coding as quoted below.

1) Count the number of groups you want to recode and subtract 1.
2) Create as many new variables as the value you calculated in step 1. These are your dummy variables.
3) Choose one of your groups as a baseline (i.e. a group against which all other groups should be compared). This should usually be a control group, or, if you don't have a specific hypothesis, it should be the group that represents the majority of people (because it might be interesting to compare other groups against the majority).
4) Having chosen a baseline group, assign that group values of 0 for all of your dummy variables.
5) For your first dummy variable, assign the value 1 to the first group that you want to compare against the baseline group. Assign all other groups 0 for this variable.
6) For the second dummy variable assign the value 1 to the second group that you want to compare against the baseline group. Assign all other groups 0 for this variable.
7) Repeat this until you run out of dummy variables.
8) Place all of your dummy variables into the regression analysis.

1.2.3 Model

Cohen et al. (2003, p. 313) provides an example of how to create MLiR models for comparing the outcome between groups. If a researcher needs to compare the attitude toward abortion (Y) between participants in four different religious groups (x_i), i.e. Protestant (x_0 – reference group), Catholic (x_1), Jewish (x_2) and other (x_3), three dummy variables are created as follows (Table B.1).

Table B.1 Dummy coding

Dummy variables Religion	x_1	x_2	x_3
Protestant (reference group)	0	0	0
Catholic	1	0	0
Jewish	0	1	0
Other	0	0	1

The MLiR model for estimating Y with given x is:

$$Y = \alpha + B_1(x_1) + B_2(x_2) + B_3(x_3) \quad \textbf{Equation B.4}$$

where: α = constant

B = unstandardised regression coefficient

1.2.4 What to report

Basically, a MLiR model can be built and some general statistics about the model should be reported: the coefficient values (B) of the independent variables, the standardised coefficient (β), their significance value and 95% confidence interval (Field, 2009, p. 252). The multiple correlation coefficient (R) between the independent and dependent variables may also be reported. More importantly, R^2 and adjusted R^2 are always reported with MLiR results as these show how much of the variation in the outcome is explained by the independent variables input into the model (Field, 2009, p. 235).

1.2.5 Assumptions of multiple linear regression

This part lists the assumptions of MLiR (Field, 2009, pp. 220-221).

1) Variable types: The outcome variable must be continuous and not constrained within a certain range. Independent variables can be continuous or categorical (recoded as 0 and 1).
2) Non-zero variance: The variance of independent variables should not be 0.
3) Multicollinearity: All independent variables must not be highly correlated.
4) Influence of 'external variables': Independent variables must not be influenced by external variables (i.e. variables not included in the model).
5) Homoscedasticity: The residuals at each level of the independent variable(s) should have the same variance.

6) Independent errors: The residuals of any two observations should not be correlated (or independent) and a Durbin-Watson test can be used for analysing this. If the size of the Durbin-Watson statistic is close to 2, the residuals are not correlated. In contrast, if the values are less than 1 or higher than 3 there should be concern.
7) Normally distributed errors: The residuals in the model should be normally distributed with a mean of 0.
8) Independence: The values of the outcome variable are independent, i.e. the data are obtained from different participants or from a separate entity.
9) Linearity: the relationship between the outcome and independent variables are assumed to be in a linear term.

The assumptions mentioned above are important if a researcher needs to generalise the findings to a wider population. However, if the researcher only needs to explain the sample data obtained only, it is not necessarily to follow all the assumptions (Cohen et al., 2003, pp. 41-42). Therefore, if some assumptions are violated, the model can still be used to generate useful findings although the generalisation of the findings may be restricted.

1.2.6 Sample size for multiple linear regression

There are recommendations available for determining the sample size for MLiR. Some researchers have suggested that the number of cases per independent variable should not be less than ten, otherwise the model may be overfitted and it is difficult to generalise (Bartlett et al., 2001). Other less simple methods have also been proposed for calculating the sample size. Green (1991) (cited in Field, 2009, p. 222) recommended that if a researcher needs to test the model overall, then the minimum sample size should be $50 + 8k$, where k is the number of independent variables. If the researcher wants to test the B values of the independent variables, then the minimum sample size should be $104 + k$. Both methods should be computed and the largest value chosen. Alternatively, the sample size can be estimated based on the power and effect of the model required. In cases where the number of independent variables are as yet unknown, Field (2009, p. 223) cited Cohen (1988) and stated that to detect a small effect size with 80% power, which is common, at least 600 cases of data should be collected.

For Study 1, the number of independent variables for MLiR was not known beforehand; therefore, they were not used for estimating the sample size. However, the sample size estimation methods recommended above were used for checking whether the number of data input into the analysis was adequate or not.

PART 2 - STUDY 2

In Study 2, the main objective of the data analysis is to compare the scores of pro-environmental attitudes and the behaviour of students between the three thermal experience groups, i.e. full air-conditioning, MM and full natural ventilation. The relevant tests are the analysis of variance (ANOVA) and the Kruskal-Wallis test, a non-parametric test equivalent to the ANOVA test (appeared in Subsection 5.3.2.3, Chapter 5, p. 218).

2.1 ANOVA TEST

2.1.1 Concept

ANOVA is a method used to compare several means. It produces an *F*-statistic to compare the systematic variance of the data and unsystematic variance (Field, 2009, p. 349). Assumptions of the ANOVA test are (Field, 2009, pp. 359-360):

1) Data within groups are normally distributed.
2) The variances in each group are relatively similar (PASW also provides alternative statistical results if the variances in the data are significantly different).
3) Data are independent, i.e. collected from different participants.
4) The dependent variable should be an interval scale.

The ANOVA only detects whether means of comparative groups are significantly different or not and it does not show where the differences lie. Post-hoc tests to determine how the means of several groups are different are required. Additionally, the effect size of the overall ANOVA can be calculated; however, it is not usually reported. Most studies are more interested in the effect size of two contrasted groups and this is presented in Part 3.

2.1.2 Post-hoc tests

As stated above, post-hoc tests are necessary for clarifying where the differences of means between several groups are located. PASW offers several post-hoc tests to choose from, but only some were appropriated for use in Study 2 and their conditions are presented here (Field, 2009, p. 375).

1) REGWQ or Tukey: when you have equal sample sizes and the group variances are similar
2) Bonferroni: if you want guaranteed control over the Type I error rate
3) Gabriel's: if the sample sizes are slightly different
4) Hochberg's GT2: if the sample sizes are very different
5) Games-Howell: if the group variances are not equal

The results of the post-hoc tests are based on comparisons of the means of every two groups of the dataset. For example, if there are three groups – A, B and C, three comparisons are run – A versus B, A versus C and B versus C. Significant statistical values indicate that the means of the two comparative groups are significantly different. The tests also show the direction of the differences, i.e. higher or lower means.

2.1.3 Sample size for ANOVA test

The sample size for Study 2 was calculated using Power and Precision V.4 software, which uses algorithms for the computation based on publications by Cohen (1977). By inputting the power of analysis required and the effect size intended to detect, the software generates the total sample size as well as the sample size for each comparative group. The results are explained below.

Daily thermal experience was the main factor of the analysis and consisted of three groups, i.e. Full AC, MM and Full NV. The criterion for significance (α) of the ANOVA was set at 0.05, which is common. In order to detect the small effect size ($f = 0.10$), and to achieve a power of 0.80, the software suggested at least 323 cases per group in a balanced design. Assuming a response rate of 80% (arbitrary), 404 cases should be obtained for each thermal experience group to ensure the minimum sample size required. In total, 1,212 (= 404×3) participants were targeted.

2.2 KRUSKAL-WALLIS TEST

The Kruskal-Wallis test is a non-parametric ANOVA test. In cases where the assumptions of ANOVA are violated, a Kruskal-Wallis test is performed instead. The principle of the Kruskal-Wallis test is similar to a Mann-Whitney U test, in that it compares mean ranks of the data not means (Field, 2009, p. 560). If the test statistic is significant, then the null hypothesis that mean ranks of the comparative groups are not significantly different is rejected. Similar to ANOVA, the Kruskal-Wallis test only detects the existence of the difference and it is necessary to follow-up by running a series of Mann-Whitney U tests to examine which group differs from which group. Since the concept of a Mann-Whitney U test and the calculation of the effect size has already been described earlier, it is not repeated here.

PART 3 - STUDY 4

The objective of Study 4 is mainly to compare the PLP of students in two thermal conditions, i.e. AC and NV conditions. Consequently, this part focuses on statistical techniques used for comparing means; the independent t-test and Mann-Whitney U test, and an equivalent non-parametric t-test (appeared in Subsection 6.3.2.3, Chapter 6, p. 271). The concept of these statistical methods is explained in only in brief since equations and the processes of these methods are not very complicated and available in general statistical textbooks. Consequently, only sample size determination is explained in details.

3.1 INDEPENDENT T-TEST

3.1.1 Concept

An independent t-test is a parametric test used for comparing two means. Basically, it tests whether the differences of the means between two groups are significantly different from zero (Field, 2009, p. 795). The assumptions of an independent t-test are (Field, 2009, p. 326):

1) Data must be normally distributed.
2) Data are an interval scale.
3) Variances in the data of two sample groups are not significantly different (PASW also provides alternative statistical results if the variances in the data are significantly different).

4) Data are independent, i.e. collected from different participants.

If the t-statistic is significant, then the null hypothesis that the means of the two different sample groups are not significantly different is rejected. Aside from the general statistics of the test, it is also useful to report the effect size (r). The effect size is a standardised measure of the magnitude of the difference. The effect size for a t-test is computed using Equation B.5 expressed below (Field, 2009, p. 332).

$$r = \mathrm{sqr}[t^2/(t^2 + df)] \qquad \textbf{Equation B.5}$$

Effect sizes of 0.2, 0.5 and 0.8 are considered as small, medium and large, respectively (Cohen 1988).

3.1.2 Sample size for t-test

In order to determine the sample size for Study 4, formulae proposed by Bartlett, Kotrlik and Higgins (2001) were used. Equation B.6 shows a method for calculating the sample size when the data collected are a continuous scale whilst Equation B.7 is used for categorical data.

For continuous data:

$$n_0 = \frac{(t)^2 \times (s)^2}{(d)^2} \qquad \textbf{Equation B.6}$$

where: n_0 = required return sample size according to Cochran's formula

t = value for the selected alpha level of 0.025 in each tail = 1.96 (the alpha level of 0.05 indicates the level of risk the researcher is willing to take that the true margin of error may exceed the acceptable margin of error)

s = estimate of standard deviation in the population

d = acceptable margin of error for the mean being estimated (acceptable margin of error = 0.05, error the researcher is willing to except)

For categorical data:

$$n_0 = \frac{(t)^2 \times (p)(q)}{(d)^2} \qquad \textbf{Equation B.7}$$

where: n_0 = required return sample size according to Cochran's formula

t = value for the selected alpha level of 0.025 in each tail = 1.96

$(p)(q)$ = estimate of the population dispersion (this value can never exceed 0.25 as $q = 1 - p$; therefore, the maximum possible $(p)(q)$ value is gained when $p = 0.5$ and $q = 0.5$)

d = acceptable margin of error for proportion being estimated

For Study 4, the main data collected are thermal comfort votes using a 5-point rating scale; therefore, Equation B.7 was more relevant. As the possibility of a student voting for any one of the five choices of thermal comfort was one-fifth, (p) was 0.2 and (q) was 0.8. Given $d = 0.05$, the sample size for Study 4 was:

$$n_0 = \frac{(1.96)^2 \times (0.2)(0.8)}{(0.05)^2}$$

$$= 246 \text{ (in each condition)}$$

Assuming the response rate or the percentage of valid questionnaires is 80% (arbitrary), the adjusted sample size was 308 for each condition. Consequently, the total number required for the learning performance survey was 616 (= 308×2) where the minimum sample size was 492 (= 246×2).

3.2 NON-PARAMETRIC MANN-WHITNEY U TEST

The Mann-Whitney U test is the non-parametric equivalent of the independent t-test. In cases where the data violates the assumptions of an independent t-test, this statistical method is used instead. This test compares mean ranks of the data in two different groups. The significant statistical value, the Z-score, indicates that the mean ranks of the two comparative groups are significantly different. The effect size of the observation can be estimated by Equation B.8 (Field, 2009, p. 550).

$$r = Z/\mathrm{sqr}(N) \qquad \textbf{Equation B.8}$$

Effect sizes of 0.1, 0.3 and 0.5 are considered as small, medium and large, respectively (Field, 2009, p. 550).

Apart from comparing two means, Study 4 also involved a comparison of means between more than two groups. Statistical methods used for this purpose have already been described previously, i.e. ANOVA or Kruskal-Wallis test.

APPENDIX C: PERCEPTIONS OF THERMAL COMFORT AND PERCEIVED LEARNING PERFORMANCE – A PILOT STUDY IN A THAI UNIVERSITY

SUMMARY

In order to provide evidence to support decision making with regards to the introduction of natural ventilation in the higher education sector in hot-humid climates, this pilot study investigated the relationships between thermal conditions and perceived learning performance (PLP), comparing air-conditioned (AC) and natural-ventilated (NV) environments. A survey of PLP and thermal comfort was conducted in four typical lecture rooms in a Thai university (354 responses: AC: NV = 287: 67). The overall environmental comfort in NV cases was found to be greatly influenced by thermal and indoor air quality (IAQ) perceptions. Thermal perception was a more useful PLP indicator than measured temperature. The PLP of students who reported to be 'uncomfortable' was higher (ρ = 0.021) in the AC than in the NV group. Due to a limited sample size, it cannot be excluded that students in the 'comfortable' group may have the same PLP regardless of thermal operating modes. However, this study suggests that the introduction of natural ventilation in existing AC environments may negatively affect students' performance.

INTRODUCTION

Due to the increasing global warming concern there is a tremendous effort to reduce unnecessary use of air-conditioning and to utilise natural ventilation strategies for ensuring user thermal comfort. From an organisational viewpoint, reducing air-conditioning might affect thermal comfort and hence user satisfaction and productivity. A study on the relationships between thermal environments and user performance is needed, particularly in hot-humid climates where the demand for air-conditioning use is increasing dramatically. The higher education (HE) sector in Thailand has been chosen as the case study. Although the HE sector is not the biggest consumer of electricity, more attention should be paid to the effectiveness of electricity consumption in this sector. HE buildings use air-conditioning to provide comfortable environments that support learning/teaching activities, which is important for the growth and development of future generations. However, the HE sector also has a social responsibility to reduce its energy consumption and carbon dioxide (CO_2) emissions. Therefore, facilities managers (FMs) need balance energy saving with user performance. Additionally, a large proportion of HE buildings in Thailand are designed to be operable in both AC and NV modes, yet air-conditioning is the main choice in practice. Therefore, there is a great potential to save electricity by encouraging natural ventilation in HE buildings, although facilities managers may be reluctant to introduce natural ventilation due to a lack of understanding of its effects on learning performance.

There are a few studies available which investigate the direct relationship between thermal perception and self-reported learning performance. In a survey of teachers conducted in 1958, 75% thought the performance and behaviour of pupils improved with air-conditioning (Pepler and Fabrijio 1958 cited in Parsons, 2003, p. 331). For office environments, the productivity of office workers due to environmental comfort perceptions have been heavily studied by Building Use Studies (BUS) and William Bordass Associates since 1985. According to the results of their studies, which were mostly based in the UK, perceptions of comfort and productivity are positively correlated. They stated that comfortable users perceived productivity as up to 25% higher than uncomfortable groups (Leaman and Bordass, 1999). Remarkably, although measurements of indoor temperatures suggested that NV spaces were less comfortable than the AC ones, if explicit control of their working environments was provided, occupants of many NV buildings perceived greater thermal comfort and higher productivity than people in AC buildings (Leaman, 2003). Although these findings raised the opportunity to provide productive environments with low-energy strategies, the link between perceived and actual thermal condition was not emphasised. Therefore, it is difficult to apply these findings to support decision making on natural ventilation introduction in other climate zones.

The relationship between indoor air temperatures and objectively-measured learning performance has been investigated mostly within school contexts. The main cognitive performance assessment method used in these studies is fully or semi-psychological tests, for example, numerical and language-based tasks where speed and accuracy are the two main indicators used in performance evaluation. According to a number of field and laboratory experimental studies in cold climates, student performance, accuracy and average speed was significantly improved when the temperature was reduced from 25°C to 20°C (Wargocki and Wyon, 2007a, Fisk and Seppänen, 2007). However, a study in Shanghai, a humid subtropical region, showed that office workers performed better at 24°C than at 19°C (Lan et al., 2008). It was also noted that using different types of cognitive tasks gave different results (Lan et al., 2008). The main implications of these objective-based studies are that air temperature alone could not be used as a reliable productivity indicator.

McCartney and Humphreys (2002) suggested that perceived productivity is more affected by perceived thermal condition, i.e. thermal comfort rather than actual air temperature. According to the adaptive thermal comfort theory, the perception of thermal comfort is affected by thermal adaptive behaviour, thermal experience, and thermal expectation (Brager and de Dear, 1998). Consequently, people with different thermal backgrounds would be expected to perform better in different thermal ranges. If this assumption is true, people in NV or AC environments would perform equally, as long as their ‘perception’ of the thermal condition is maintained at the same level. Conceptually, this provides the chance to provide an effective learning environment in hot and hot-humid regions without relying solely on air-conditioning. However, the practicality and limitations of this theory need to be examined.

In order to provide evidence to support decision making on the introduction of natural ventilation in the HE sector in hot-humid climates, this pilot study compared the learning performance of students in different room conditions, i.e. AC and NV. In reality, both thermal and non-thermal conditions, i.e. light, noise, and IAQ, are different between AC and NV rooms. Therefore, the associations between perceptions of overall environmental comfort (OEC) and other environmental factors were also investigated. The following research questions/hypotheses were addressed.

Q: *How are perceptions of overall environmental comfort associated with other environmental factors, comparing AC and NV environments?*

H1: *Learning performance is more influenced by ‘perception’ than by the ‘actuality’ of thermal conditions.*

H2: *Students who perceive similar thermal comfort levels perceive similar levels of performance, regardless of the thermal operating mode, i.e. AC or free-running buildings.*

METHODS

This study conducted an intervention study in existing Thai lecture rooms to compare the learning performance of students in AC and NV environments in order to take into account real HE learning contexts (e.g. class size, dress code, teaching/learning methods) which are influential in thermal perception. Self-assessment was chosen as the main method with which to evaluate learning performance, defined here as PLP because it is easily applicable and can potentially increase the sample size of the study. A questionnaire on environmental comfort and PLP was conducted in conjunction with objective measurements of environmental conditions. Since this is a pilot study, one of the aims of this study was to test these proposed methods and approaches I preparation for a larger study.

In reality, perceived or objective learning performance can be affected by a number of variables; mainly psychological, physiological and environmental factors (Parsons, 2003). In order to reduce the differences in psychological and physiological factors (e.g. motivations and attitudes towards teachers), an intervention approach was utilised whereby the same student cohort and rooms which are normally AC were studied under air-conditioning and natural ventilation modes. In this manner it was possible to minimise the impact of confounding variables such as room size and configurations, furniture type and arrangement, topic of the classes, etc. Lecture rooms were assessed before distributing the questionnaire in order to select representative rooms for this study.

Based on the main physical characteristics of the lecture rooms, four typical rooms were chosen in which to conduct the survey. In order to gain variation in the thermal conditions for natural ventilation, two rooms in each location, i.e. in urban and rural areas, were selected. A room with single-sided ventilation and another room with cross ventilation were chosen in each location since this factor contributes substantially to thermal conditioning within NV rooms, and this is a common technique in this building type in Thailand. Unfortunately, the chosen cross-ventilated room in the rural area was not accessible, so was substituted by another room with single-sided ventilation. Once the rooms had been selected, the equipment for environmental measurements was installed before commencing the survey.

Intervention study rooms were operated in AC mode in the first week and in NV mode in the second week during the hot season (June-July) and students were not aware of this intervention. The NV mode in this case was assisted by ceiling fans. The questionnaire was conducted at the end of each lecture in every accessible class so that students had time to adjust to the thermal conditions in the rooms before answering the questions. The questionnaire was divided into four main parts consisting of: 1) Personal data; 2) Clothes worn; 3) Perceptions of environmental comforts and the importance of each environmental factor to learning performance; and 4) Perceptions of learning performance. The subjects were asked to rate their perceptions of comfort in each environmental factor on a 5-point scale ranging from 1 (Very Uncomfortable) to 5 (Very Comfortable), with 3 being Neutral. The factors were air temperature, humidity, air velocity, visual comfort, hearing comfort, cleanliness and freshness of indoor air, and overall environment. The term 'IAQ' is used to represent students' perception of 'cleanliness and freshness of indoor air'. From the same list of factors, users rated how important each factor is to their learning performance using a rating scale ranging from 1 (Very Unimportant) to 5 (Very Important), with 3 being Neutral.

In parallel with the survey, measurements of the environmental conditions, indoor and outdoor, were carried out. These parameters were air temperature, relative humidity, air velocity, room's surface temperature (for mean radiant temperature calculations), light intensity, ambient noise level, and CO_2 concentrations. Due to a limitation in the instrument capability, air velocity, surface temperature, light intensity, and ambient noise level were measured on a one-off basis in each class whilst the other parameters were continuously measured and recorded at 3-minute intervals for the whole-class period.

RESULTS

The questionnaire was distributed to fourteen classes during occupied periods, with twelve classes being operated in air-conditioning mode and two classes in NV mode. The number of questionnaires returned was 354, with 287 from the AC mode and 67 from the NV mode. Respondents were predominantly female (78%) and ages ranged from 17-26. The average clothing value was 0.38 clo and was not significantly different between the AC and NV groups. The difference in clothing levels between the two cases is not surprising since participants were expecting to attend AC classes. A major problem experienced during this study was that some chosen rooms could not be operated in the NV mode due to excessive air and noise pollution in urban areas. After the first two NV classes, some resistance was exhibited by students who were reluctant to accept the NV mode. Therefore, the questionnaire for the NV case was not continued and consequently, there were only two cases conducted in NV mode.

Environmental Conditions

Data for the indoor and outdoor environments during the survey is summarised in Table C.1. During the observation period the set point temperatures in AC rooms varied from 22°C to 28°C; however, 25°C was the predominant set point temperature. In NV cases, only approximately 50% of the window area was opened due to the limitation of the sliding window type. When operating in NV mode, fans were always turned on at the maximum rate.

Table C.1 The measured environmental conditions (mean min. – mean max.) experienced during the survey

Environmental Factor	**AC Mode (12 classes)**		**NV Mode (2 classes)**	
	Indoors	**Outdoors**	**Indoors**	**Outdoors**
Air Temperature (°C)	25.7-27.5	31.1-33.0	28.0-30.3	31.1-32.7
Relative Humidity (%)	48-60	59-66	58-65	61-68
Air Velocity (m/s)	0.1-0.3	NA[a]	0.2-0.5	NA[a]
Light Intensity (lux)	389-770	NA[b]	136-984	NA[b]
Ambient Noise Level (dBA)	55-64	58-74	51-65	53-73
CO_2 Concentrations (ppm)	>2,500[c]	362-380	806-2,049	362-378

a. The outdoor air velocity was not recorded.

b. The outdoor light intensity was over the recordable range (exceeded 32,292 lux).

c. The indoor CO_2 concentrations were over the recordable range (exceeded 2,500 ppm).

In Table C.2, a Mann-Whitney U test was utilised to compare the mean ranks of environmental comfort ratings of students in AC and NV environments. According to the results of this test, respondents voted that all other environmental factors in the AC mode were significantly more comfortable than in the NV mode. Overall, the thermal conditions in AC rooms were more attractive than in NV rooms, both objectively and subjectively. Notably, although the average air velocity in NV rooms was higher than in AC rooms, it did not appear to reduce thermal discomfort sufficiently. For non-thermal factors, the light intensity levels in both cases were within acceptable levels; however, students perceived lower visual comfort in the NV case than in the AC case. This may be due to glare and uneven distribution of natural lighting. The average CO_2 level in NV rooms was much lower than in AC rooms, yet students rated the IAQ in NV rooms lower than in AC rooms. This is because the questionnaire asked students to score the IAQ based on their perceptions of ‘cleanliness and freshness of indoor air’. Outdoor air pollution may possibly explain the lower IAQ rating in NV case.

Table C.2 The comparisons of the mean ranks of environmental comfort votes

Environmental Factor	Air Temp.	Relative Humidity	Air Velocity	Visual Comfort	Hearing Comfort	IAQ	Overall
Mann-Whitney U	2795.5	3786.5	4631	7526	8191.5	7422	4131
Z^*	-9.488	-8.154	-7.152	-2.738	-1.87	-2.927	-7.796
Sig. (2-tailed)	0.000	0.000	0.000	0.006	0.061	0.003	0.000
n(AC) = 282, n(NV) = 67							
* A Z-score is a measure of effect size expressed in standard deviation units. In this analysis, the confidence level is set at 95% (α = 0.05); if the calculated Z-scores fall between -1.96 and +1.96, the mean ranks of the comfort ratings between AC and NV cases are **not** significantly different.							

Figure C.1 shows the percentage of temperature comfort (ComfAir) ratings, and compares the AC and NV cases. The graph also shows the average operative temperature (T_{op})[4] in each comfort group and the thermal mode, as well as the comfort boundary levels (calculated by adaptive thermal comfort models stated in ASHRAE, 2001) corresponding to the average outdoor temperature of 32.35°C.

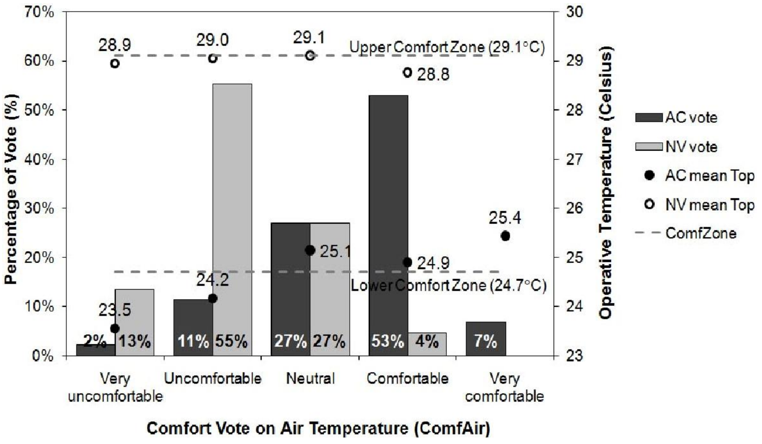

Figure C.1 Percentage of ComfAir votes broken down by thermal mode

From the graph, the majority of NV respondents were ‘Uncomfortable’ (55%), whilst in contrast, 53% of AC students were ‘Comfortable’. These results are unsurprising since most NV cases were at the top boundary of the comfort range.

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[4] Operative temperature (T_{op}): the uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat through radiation plus convection as in the actual non uniform environment. T_{op} is a function of dry-bulb temperature, air velocity, and mean radiant temperature (ASHRAE, 2004, p.3).

Kendall's tau-b test was utilised to further investigate the correlations between the perceptions of OEC and each individual environmental comfort parameter. Table C.3 shows the correlation strength between each relationship broken down by thermal mode. In the AC case, the correlation strengths (tau-b value) between OEC and individual environmental factors did not differ greatly (22%-39%). In contrast, in the NV case OEC was greatly influenced by perceptions of air temperature (61%) and IAQ (52%), whereas hearing and visual comforts were found to be only weakly correlated to OEC. This was contradicted by students' ratings on the importance of each environmental factor to their PLP, where hearing and visual comfort were perceived as the two most important factors to their learning performance in general. Air velocity was voted the least important in both the AC and NV cases. However, the results on the influence of individual environmental factors on perception of OEC should be viewed with caution. In this study noise and lighting were always set at acceptable levels, otherwise lectures could not be given. Therefore, the conditions for these two factors were too narrow to affect students' perceptions. Consequently, these results only show that when the rooms were manipulated from AC to NV mode, students then perceived the greatest change in thermal factors, particularly air temperature and IAQ.

Table C.3 The correlations between perceptions of OEC and individual environmental comforts

Environmental Factor		**Air Temp.**	**Relative Humidity**	**Air Velocity**	**Visual Comfort**	**Hearing Comfort**	**IAQ**
AC	Kendall's tau-b	0.393	0.269	0.219	0.307	0.245	0.315
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
NV	Kendall's tau-b	0.611	0.471	0.405	0.089	0.254	0.524
	Sig. (2-tailed)	0.000	0.000	0.000	0.405	0.010	0.000

Learning Performance, Thermal Conditions, and Perceived Thermal Comfort

The relationships between PLP and perceived air temperature were examined. The percentage of PLP within the same ComfAir groups, comparing AC and NV cases is shown in Figure C.2 (no sample for the NV-Very Comfortable group). According to Kendall's tau-b test, ComfAir and PLP were moderately correlated (n = 351, $tau\text{-}b$ = 0.43, $\rho < 0.001$). This means that the perception of indoor air temperature could explain approximately 43% of the variation in students' PLP. When comparing the AC and NV cases, the correlation strengths in both were not much different (AC: n = 284, *tau-b* = 0.348, $\rho < 0.001$; NV: n = 67, *tau-b* = 0.315, $\rho = 0.003$).

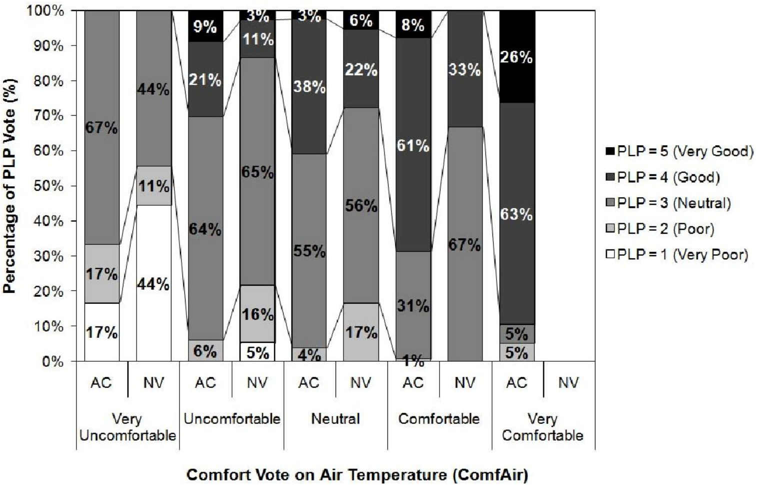

Figure C.2 The percentage of PLP votes within the same ComfAir groups (AC versus NV)

In addition, the associations between PLP and measured air temperature were also analysed using Kendall's tau-b test. In this investigation T_{op} was used since it is closer to how people really feel than the actual air temperature. The T_{op} were categorised into five ranges running from 21°C to 31°C. No correlation was found between the T_{op} range and PLP in both the AC and NV cases (AC: n = 266, *tau-b* = 0.04, $\rho = 0.478$; NV: n = 61, *tau-b* = 0.181, $\rho = 0.118$).

Perceived Learning Performance in AC and NV Environments

A comparison of the mean ranks of students' PLP in AC and NV environments was performed. Based on a Mann-Whitney U test, overall students in AC environments rated a significantly higher PLP than those in NV conditions (AC: n = 285; NV: n = 67, U = 4978, z = -6.652, $\rho < 0.001$). Students were then categorised into five groups according to their ComfAir votes. The PLP of students within the same ComfAir groups was compared between AC and NV cases (Table C.4). In the 'Uncomfortable' group, students' PLP was greater ($\rho = 0.021$) in the AC than in the NV case. In the other ComfAir groups no statistically significant difference in PLP was found between AC and NV cases. Due to a lack of sample size for the 'Very Comfortable' group in the NV case, the test was not performed.

Table C.4 Comparisons of PLP within the same ComfAir group between AC and NV cases

ComfAir Group	**Very Uncomfortable**		**Uncomfortable**		**Neutral**		**Comfortable**	
Mode	**AC**	**NV**	**AC**	**NV**	**AC**	**NV**	**AC**	**NV**
n	6	9	33	37	76	18	150	3
Mann-Whitney U	19.5		443.5		557.5		140.5	
Z	-0.981		-2.301		-1.37		-1.283	
Sig. (2-tailed)	0.388[a]		0.021		0.171[b]		0.2[b]	

a. Exact Sig. (not corrected for ties due to a small sample size)
b. The observed control group span is smaller than its theoretical minimum due to ties in the data.

While PLP and ComfAir of individual students was presented in Figure C.2 and analysed in Table C.4 using the Mann-Whitney U test, Figure C.3 compares the average PLP of students in each ComfAir group for the AC and NV cases using the independent t-test. The results confirm that the only statistically significant difference in PLP is for the 'Uncomfortable' group (AC > NV, $\rho = 0.017$).

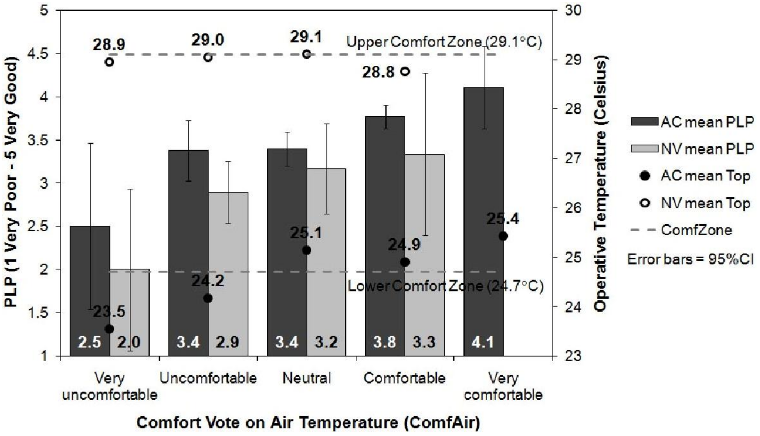

Figure C.3 Average PLP categorised by ComfAir group

DISCUSSION

The moderate correlation of PLP and thermal comfort found in this pilot study agrees with the results of studies by Leaman and Bordass (Leaman, 2003) on the relationship between perceived productivity and occupant comfort within an office environment. That is, the higher the perceived comfort, the greater the self-reported productivity. The results also confirm the hypothesis that PLP varied more with 'perception of' rather than measured air temperature. However, conclusions that people perform better or worse at some temperature set points should be applied with caution.

Students in AC environments rated their PLP significantly higher than those in NV conditions. The main explanation for this is that the majority of students in AC settings perceived almost all the environmental conditions as more comfortable than students in NV rooms resulting in them perceiving a higher performance. Furthermore, since the rooms examined in this study are usually air-conditioned, altering the thermal environments against user expectation might negatively affect users' responses to natural ventilation (Brager and de Dear, 2003, Brager and de Dear, 1998) and PLP accordingly. Additionally, since the questionnaire was conducted twice using the same subjects, first with air-conditioning and then in natural ventilation without a crossover, repetition might result in boredom and decreased enthusiasm for the second survey.

When comparing the PLP within the same thermal comfort group, the only statistically significant difference in PLP between AC and NV mode was found in the 'Uncomfortable' group (AC > NV). Therefore, it might be concluded that the introduction of natural ventilation in existing AC environments may negatively affect students' learning performances. However, this partial conclusion should be taken with extreme caution due to the limitations in sample size. The intervention study approach was selected to reduce some confounding factors (e.g. room layout, student cohort), as well as to take advantage of the MM design of the selected HE spaces. However, natural ventilation operation in reality was more difficult than anticipated and this was due to: a) students' objections and b) noise and air pollution. Consequently, the NV sample size achieved in this study was small. In addition, the study was performed during the hot season and the students expected an AC environment; as a result, the majority of NV respondents were uncomfortable. Whilst the intervention approach presents some advantages, it also has the disadvantage of potentially reducing the students' 'tolerance' of NV environments. Therefore, further studies with a cross-over approach should be conducted during the mild season with a greater sample size to assess whether these results can be confirmed.

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APPENDIX D: NORMALITY TESTS

This appendix is dedicated to normality tests of the data input into all the statistical analyses, as the distribution of data is one of the most important conditions for selecting appropriate statistical methods. Incidentally, the explanations of the statistics in this appendix may refer to the output of PASW package used in this thesis.

CONCEPT

This section presents the results of the normality tests for all the datasets used in this thesis. The objective of these tests is to identify whether the data were normally distributed, the main assumption for parametric tests, so that the appropriate statistical techniques for data analyses can be chosen.

First of all, the attributes of normally distributed data are described. There are two characteristics of the data distribution to examine, the symmetry (known as skewness) and the pointyness (known as kurtosis) of the distribution (Field, 2009, p. 19). The values of skewness and kurtosis of normally distributed data are zero. Highly positive and negative skewness and kurtosis values indicate that the data are unlikely to be normal (Field, 2009, p. 138). In order to test whether the values of skewness and kurtosis are statistically significant, it is more practical to convert the values to a Z-score. The benefit of using Z-scores is that skewness and kurtosis values of the data using different measures can be compared. Equations D.1 and D.2 are used to transform skewness and kurtosis scores to Z-scores (Field, 2009, p. 139).

$$Z_{\text{skewness}} = \frac{S - 0}{SE_{\text{skewness}}} \qquad \textbf{Equation D.1}$$

where: S = skewness

SE_{skewness} = standard error of skewness

$$Z_{\text{kurtosis}} = \frac{K - 0}{SE_{\text{kurtosis}}} \qquad \textbf{Equation D.2}$$

where: K = kurtosis

SE_{kurtosis} = standard error of kurtosis

In order to indicate whether the Z-scores are significant, it should first be determined what values should be set as a threshold for comparing different ρ-values (Field, 2009,

p. 139). In general, if absolute values of Z_{skewness} or Z_{kurtosis} are greater than 1.96, this means that the distribution of the data is significantly different from normal at $\rho < 0.05$. If the absolute values are above 2.58 and 3.29, then the data distribution differs from normal significantly at $\rho < 0.01$ and $\rho < 0.001$, respectively. However, Field (2009, p. 139) mentions that if the sample size is larger than 200, it is natural to have a significant statistical value although the data may be considered normally distributed. Therefore, he recommends using a visual investigation and looking at the skewness and kurtosis values themselves instead of comparing the Z-scores.

In the following sections, the output of normality tests based on Equations D.1 and D.2 are presented. The statistical results are also compared with visual observations if necessary.

PART 1 - STUDY 1

In this part, both visual and statistical tests of data distributions carried out prior to multiple regression analyses in Study 1: Thermal adaptive opportunity scoring system and acceptance of assisted natural ventilation survey are presented.

1.1 Normality tests prior to multiple regression analyses

This section presents the results of the normality tests as normality distributed data is one of the assumptions for multiple regression analysis (see Subsection 5.2.2.5, Chapter 5, p. 198). The implications of the results can support or limit the generalisation of the outcome of the multiple regression analysis.

Two variables were analysed, adaptive opportunity scores of window (OPPwindow) and fan (OPPfan) operations. The valid sample sizes were 874 and 873 for the OPPwindow and OPPfan tests, respectively. Table D.1 shows the statistical results including Z_{skewness} and Z_{kurtosis} values. According to these Z-scores, the distribution of OPPwindow and OPPfan were not normally distributed since the Z_{kurtosis} exceeded ±3.29 (Z_{kurtosis} of OPPwindow = -5.76 and Z_{kurtosis} of OPPfan = -9.68, $\rho < 0.001$). However, as the sample sizes were larger than 200 in both cases, Field (2009, p. 139) suggests that a visual investigation and a direct consideration of the skewness and kurtosis values should also be performed to confirm the results.

Table D.1 Descriptive data of adaptive opportunity scores and *Z*-values of skewness and kurtosis

Statistics	Opportunity for Window Operation	Opportunity for Fan Operation
Valid N	874	873
Mean	14.80	13.06
Median	15.00	15.00
Std. Deviation	6.889	8.485
Variance	47.458	71.999
Skewness (Std. Error)	-0.081 (0.083)	0.094 (0.083)
Z_{skewness}	-0.98	1.13
Kurtosis (Std. Error)	-0.951 (0.165)	-1.598 (0.165)
Z_{kurtosis}	**-5.76**	**-9.68**

A histogram and normal curve for the OPPwindow and OPPfan data are exhibited in Figure D.1. In general, the data were sparsely distributed as a result of how the opportunity scores were calculated. That is, the score is based on the multiplication of a rating of 1-5 by another rating of 1-5; therefore, some numbers are missing (i.e. 7, 11, 13, 14, 17, 18, 19, 21, 22, 23 and 24) from the data. Notwithstanding this fact, the skewness and Z_{skewness} values of both datasets were normal according to the statistics. However, the kurtosis values of both graphs show that the distributions seemed flatter than normal. Therefore, the Z_{kurtosis} values and visual investigations agreed that the data were not normally distributed.

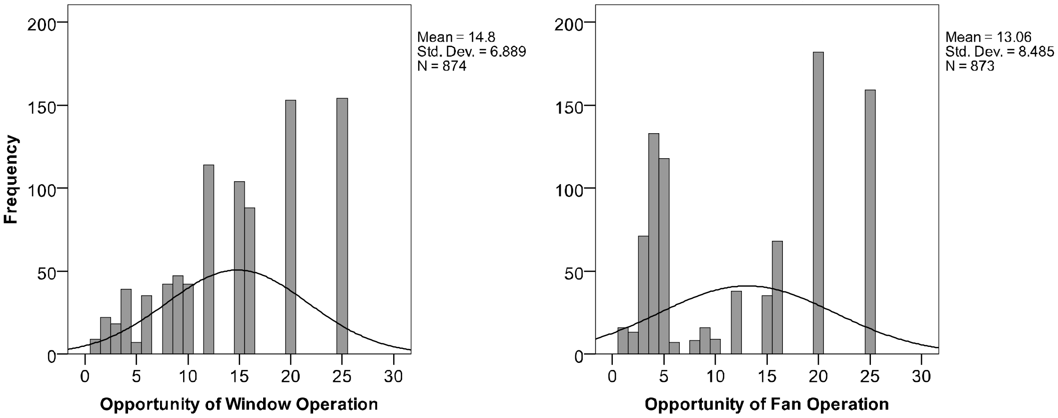


Figure D.1 Histograms with a normal curve of the opportunity scores of window and fan operations

Even though the data were not normally distributed, it is possible to conduct a multiple regression (Field, 2009, p. 251). However, the interpretation of the regression results should be made with caution, as in the case of non-normality, the generalisation of the regression model beyond the sample is restricted.

PART 2 - STUDY 2

The distribution of data input into the statistical analyses for Study 2: Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey, was tested beforehand. The results of the normality tests are presented in this section.

2.1 Normality tests prior to correlation tests

The pro-environmental attitude and behaviour scores collected were tested to determine whether they were normally distributed. This process is needed before the correlation tests in order to choose the correct method, i.e. parametric Pearson or non-parametric Spearman's rho correlation test.

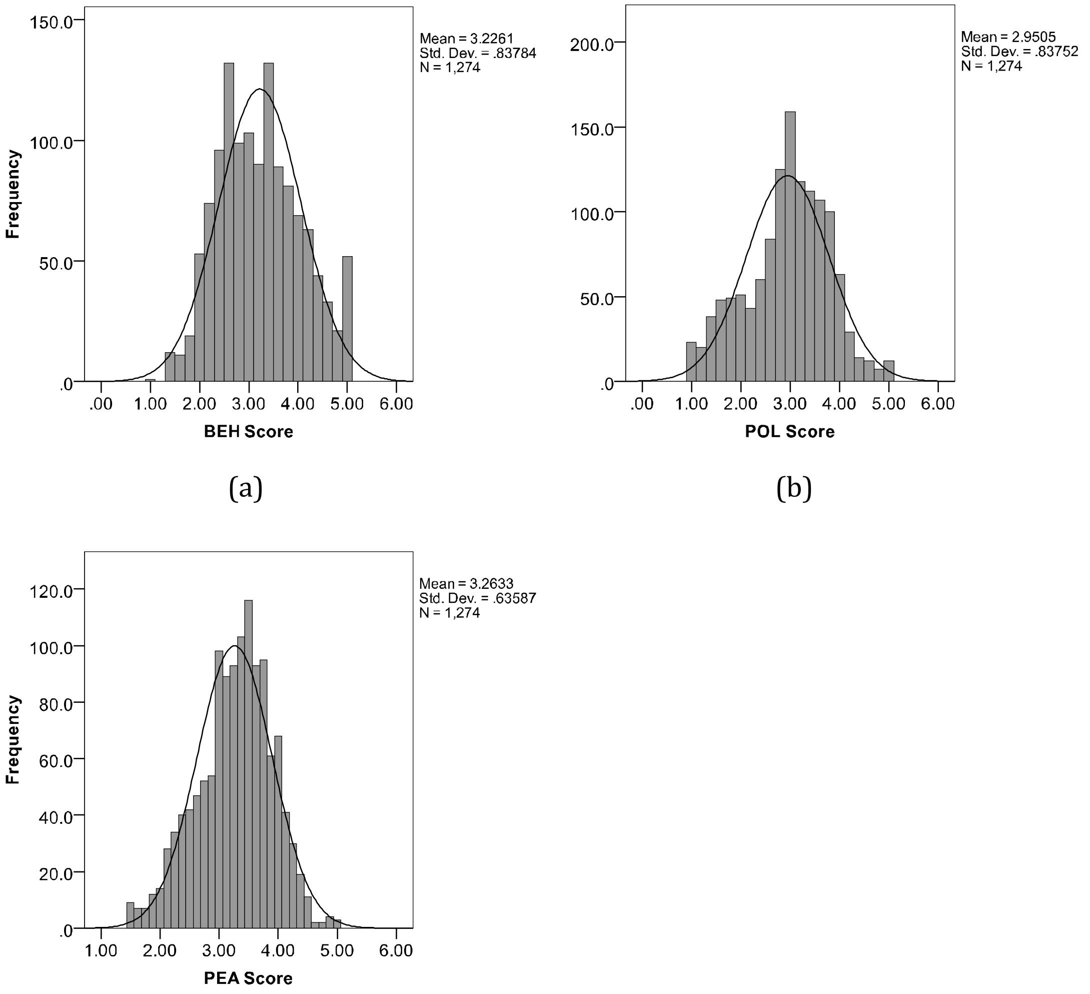
In Study 2, the correlation tests (see Subsection 5.3.2.2, Chapter 5, p. 211) were comprised of three main variables: Adaptive behaviour at home (BEH), Acceptance of an air-conditioning reduction policy in university (POL) and Pro-environmental attitudes (PEA) scores, which were treated as a continuous interval scale. Hence, the normality tests also involved all these variables. The sample size was 1,274 in all sets of data. The statistical results are presented in Table D.2.

Table D.2 Descriptive data of pro-environmental attitude and behaviour scores and *Z*-values of skewness and kurtosis

Statistics	**Adaptive Behaviour at Home (BEH Score)**	**Acceptance of AC Reduction Policy (POL Score)**	**Pro-Environmental Attitudes (PEA Score)**
Valid N	1,274	1,274	1,274
Mean	3.2261	2.9505	3.2633
Median	3.2000	3.0000	3.3750
Std. Deviation	0.83784	0.83752	0.63587
Variance	0.702	0.701	0.404
Skewness (Std. Error)	0.241 (.069)	-0.285 (0.069)	-0.332 (0.069)
$Z_{skewness}$	**3.49**	**-4.13**	**-4.81**
Kurtosis (Std. Error)	-0.571 (.137)	-0.255 (0.137)	-0.100 (0.137)
$Z_{kurtosis}$	**-4.17**	1.86	-0.73

As shown in this table, the computed Z-scores of skewness and kurtosis in some datasets were significant at $\rho < 0.001$. That is, the absolute Z values were higher than 3.29 (BEH $Z_{\text{skewness}} = 3.49$, BEH $Z_{\text{kurtosis}} = -4.17$, POL $Z_{\text{skewness}} = -4.13$ and PEA $Z_{\text{skewness}} = -4.81$) indicating that the data were not normally distributed. However, as the sample size was considered very large the results of these statistical tests can easily be significant and so inspection of the histograms was more appropriate.

Figure D.2 shows the histograms for the BEH, POL and PEA scores with a normal curve. From the visual observation, there was no sign of non-normality as the data distribution in all cases was neither too pointy nor flat. In addition, the data did not heavily cluster at either end of the distribution. At this stage, it was able to conclude that the data in all sets were normally distributed.



(a) (b)

(c)

Figure D.2 Histograms with a normal curve for the three variables: (a) BEH score, (b) POL score and (c) PEA score

As the data were considered normal, a Pearson correlation test was suitable for the correlation analyses.

2.2 Normality tests of three comparative groups

In this section the data for the BEH, POL and PEA scores were categorised into three sub-groups according to daily thermal experience as the data for students with different daily thermal experiences were to be compared in Study 2 (see Subsection 5.3.2.3, Chapter 5, p. 218). The sample sizes of the comparative groups are presented in Table D.3.

Table D.3 Frequencies and percentages of respondents in comparative groups

	Dependent Variables	Group						Row Total	
		Full AC		Mixed-mode		Full NV			
		Count	N%	Count	N%	Count	N%	Count	N%
1st Comparison	Adaptive Behaviour at Home (BEH)	269	21.1%	893	70.1%	112	8.8%	1,274	100%
2nd Comparison	Acceptance of AC Reduction Policy (POL)	269	21.1%	893	70.1%	112	8.8%	1,274	100%
3rd Comparison	Pro-Environmental Attitudes (PEA)	269	21.1%	893	70.1%	112	8.8%	1,274	100%

In order to select the proper statistical tool for comparing the means of the BEH scores between the three sub-groups (i.e. Full AC, MM and Full NV groups), the normality of the data distributions was tested. If the data are normally distributed then an ANOVA test can be used, if not, then the non-parametric Kruskal-Wallis test is more appropriate.

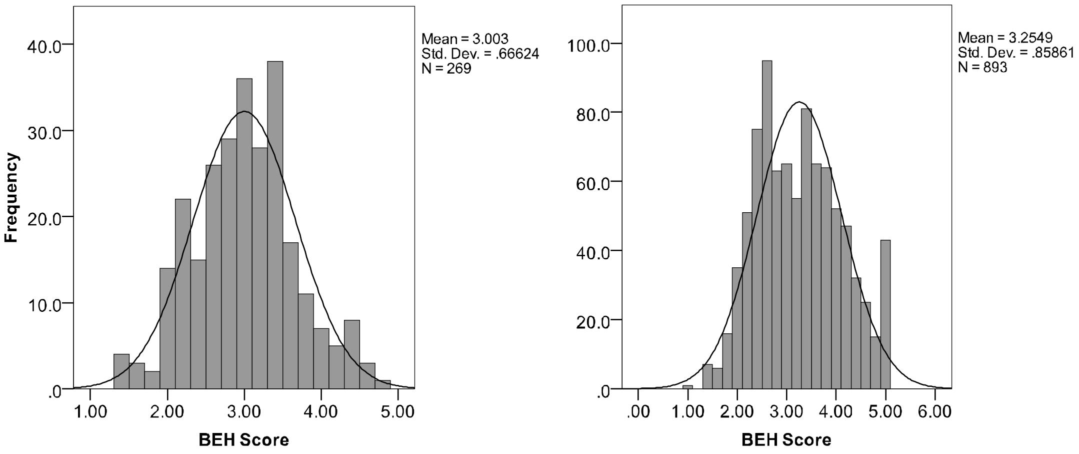
2.2.1 Adaptive behaviour at home (BEH)

The first step was to test the distribution of the BEH scores. The sample sizes obtained in each sub-group, i.e. Full AC, MM and Full NV groups, were 269, 893 and 112, respectively, and the results of the normality test are presented in Table D.4. According to the statistics, the BEH scores of students in the MM group were not normally distributed at $\rho < 0.001$ and the Z_{kurtosis} was as great as -4.23. As the sample size was large, histogram analyses were undertaken.

Table D.4 Descriptive data for the BEH scores and *Z*-values of skewness and kurtosis classified by daily thermal experience

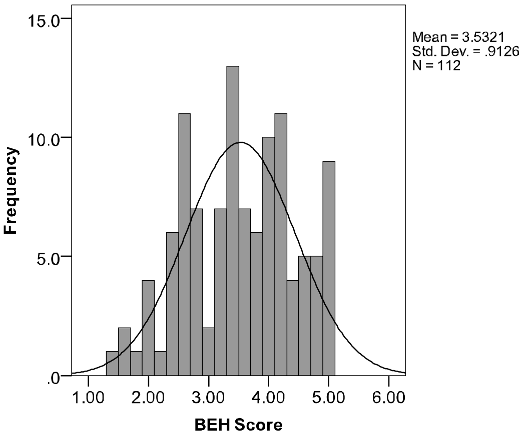
Statistics (BEH Score)	**Daily Thermal Experience**		
	Full AC	**Mixed-mode**	**Full NV**
Valid N	269	893	112
Mean	3.0030	3.2549	3.5321
Median	3.0000	3.2000	3.6000
Std. Deviation	0.66624	0.85861	0.91260
Variance	0.444	0.737	0.833
Skewness (Std. Error)	0.103 (0.149)	0.222 (0.082)	-0.184 (0.228)
$Z_{skewness}$	0.69	2.71	-0.81
Kurtosis (Std. Error)	-0.062 (0.296)	-0.690 (0.163)	-0.761 (0.453)
$Z_{kurtosis}$	-0.21	**-4.23**	-1.68

From Figure D.3, the distribution of BEH scores in mixed-mode group seemed to be normal. Therefore, it was possible to use ANOVA test for the first comparison.



(a) Full AC

(b) Mixed-mode



(c) Full NV

Figure D.3 Histograms with normal curves for the BEH scores of students in three daily thermal experience groups: (a) Full AC, (b) MM and (c) Full NV

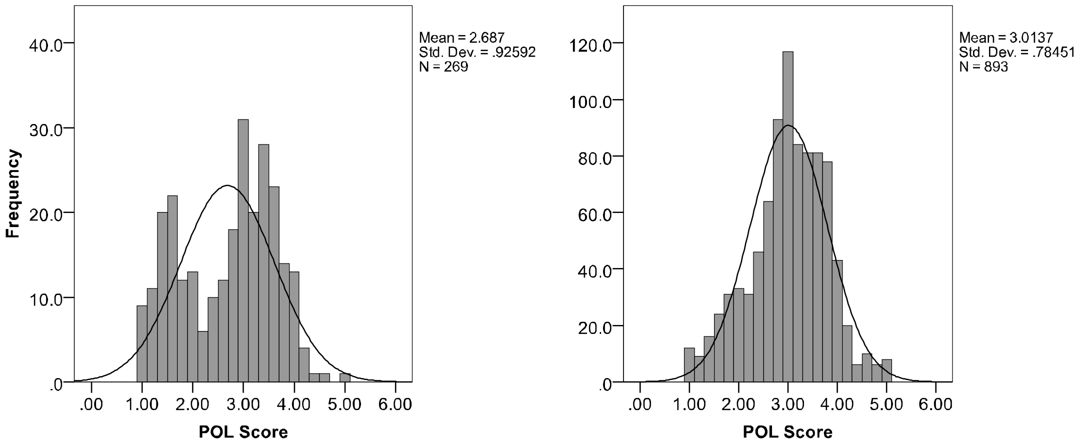
2.2.2 Acceptance of an air-conditioning reduction policy in university (POL)

Next, the data distribution of POL scores was analysed and Table D.5 presents the statistical results. The data in the Full AC and Full NV groups were proved to not differ significantly from normal at $\rho < 0.001$. The POL scores of MM group, however, were not normally distributed as the Z_{skewness} was outside the ±3.29 range.

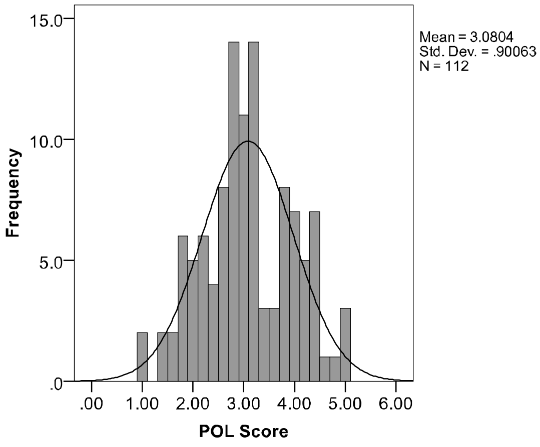
Table D.5 Descriptive data of POL scores and *Z*-values of skewness and kurtosis classified by daily thermal experience

Statistics (POL Score)	Daily Thermal Experience		
	Full AC	**Mixed-mode**	**Full NV**
Valid N	269	893	112
Mean	2.6870	3.0137	3.0804
Median	3.0000	3.0000	3.0000
Std. Deviation	0.92592	0.78451	0.90063
Variance	0.857	0.615	0.811
Skewness (Std. Error)	-0.215 (0.149)	-0.285 (0.082)	0.031 (0.228)
$Z_{skewness}$	-1.44	**-3.48**	0.14
Kurtosis (Std. Error)	-1.063 (0.296)	0.017 (0.163)	-0.449 (0.453)
$Z_{kurtosis}$	-3.59	0.10	-0.99

The histograms were then analysed to supplement the statistical test results. In Figure D.4 (b), the shape of data distribution in the MM group seemed to be normal; therefore, an ANOVA test could be used for the second comparison.



(a) Full AC (b) Mixed-mode



(c) Full NV

Figure D.4 Histograms with a normal curve for the POL scores of students in three daily thermal experience groups: (a) Full AC, (b) MM and (c) Full NV

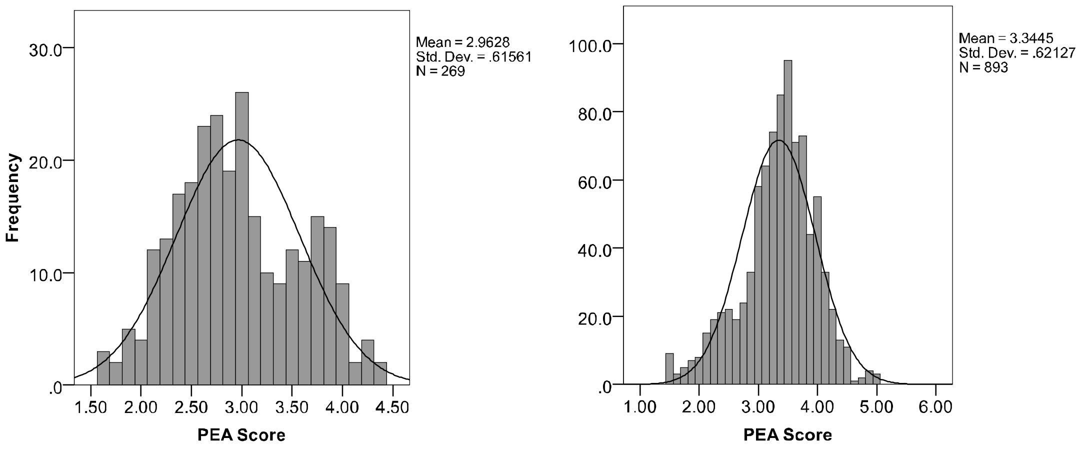
2.2.3 Pro-environmental attitudes (PEA)

The data distribution of PEA scores in each sub-group was analysed and Table D.6 shows the basic statistics and *Z*-values for skewness and kurtosis. The results were similar to the previous analyses for BEH and POL scores. That is, statistically, the data in the MM group were not normally distributed as the Z_{skewness} (-6.23) was significant at $\rho < 0.001$, which is assumingly due to the size of the sample.

Table D.6 Descriptive data of PEA scores and *Z*-values of skewness and kurtosis classified by daily thermal experience

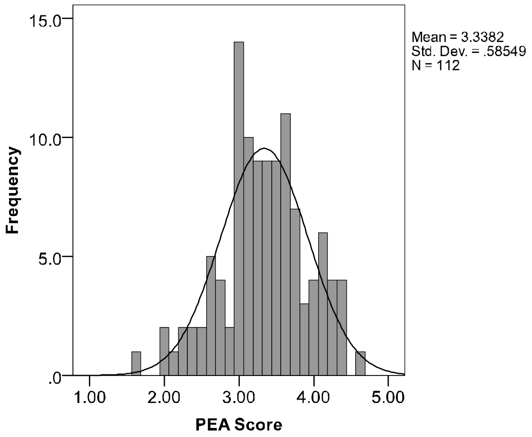
Statistics (PEA Score)	Daily Thermal Experience		
	Full AC	**Mixed-mode**	**Full NV**
Valid N	269	893	112
Mean	2.9628	3.3445	3.3382
Median	2.8750	3.3750	3.3750
Std. Deviation	0.61561	0.62127	0.58549
Variance	0.379	0.386	0.343
Skewness (Std. Error)	0.199 (0.149)	-0.511 (0.082)	-0.259 (0.228)
$Z_{skewness}$	1.34	**-6.23**	-1.14
Kurtosis (Std. Error)	-0.676 (0.296)	0.435 (0.163)	0.033 (0.453)
$Z_{kurtosis}$	-2.28	2.67	0.07

Therefore, a visual investigation was necessary to examine the statistical outcomes. Figure D.5 shows the histograms of the PEA scores for the three groups of daily thermal experience. As can be seen, the data distribution of the MM group was normal.



(a) Full AC

(b) Mixed-mode



(c) Full NV

Figure D.5 Histograms with a normal curve for the PEA scores of students in three daily thermal experience groups: (a) Full AC, (b) MM and (c) Full NV

According to the graphs, the conclusion was reached that the PEA scores of all sub-groups were normally distributed. As a result, a parametric ANOVA test was suitable for comparing the means of the PEA scores of students in the three different daily thermal experience groups.

PART 3 - STUDY 4

The normality tests conducted prior to the various statistical analyses, for example, correlation, independent t-tests and ANOVA tests, in Study 4: Learning and thermal performance survey are presented in this part.

3.1 Normality tests prior to correlation tests

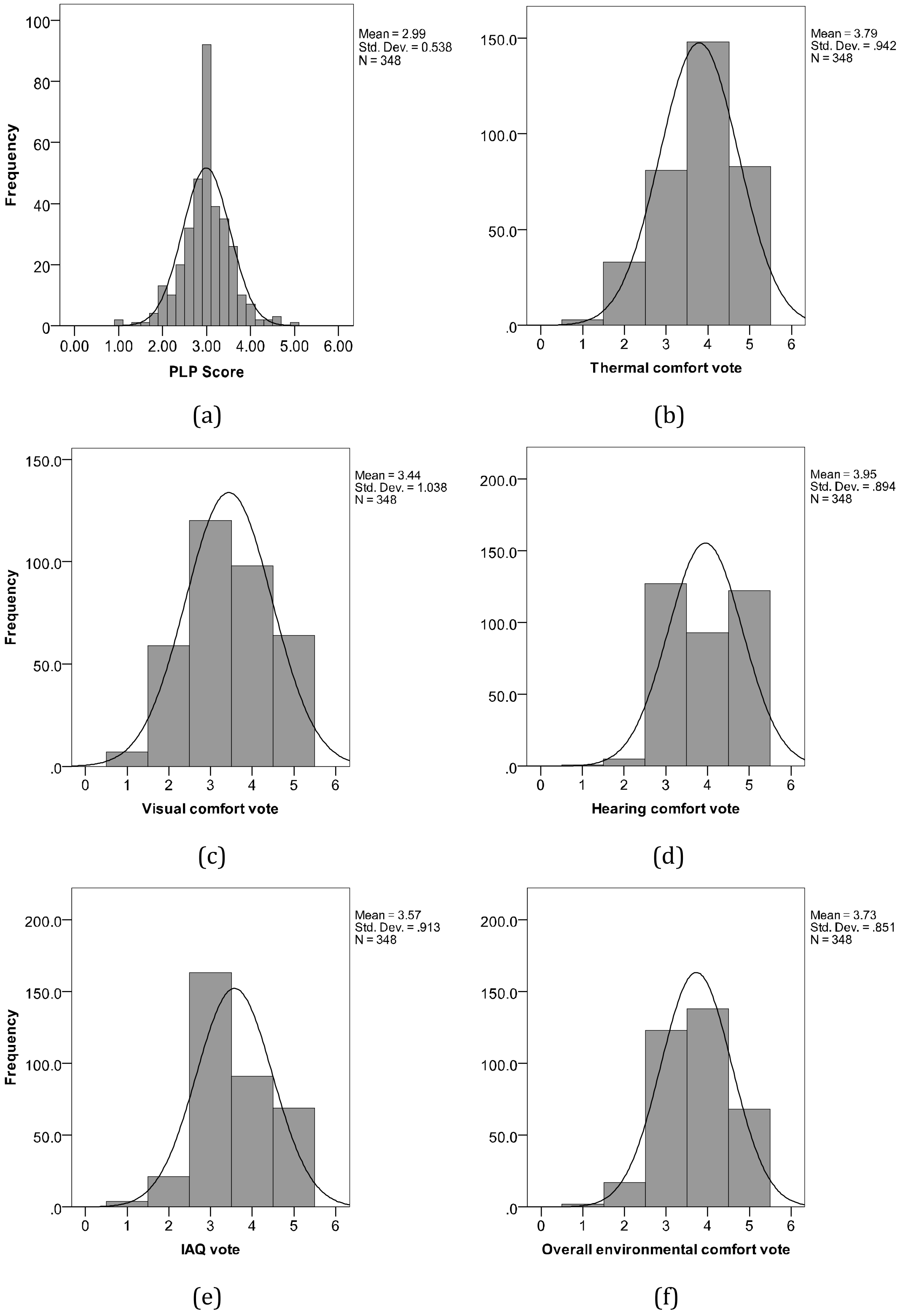
This section provides the results of the normality tests showing whether the data were drawn from a normally distributed population of scores. This procedure was carried out prior to the correlation tests (see Subsection 6.3.2.2, Chapter 6, p. 269) in order to select the appropriate statistical tool (i.e. Pearson or Spearman's rho correlation test).

The data for the AC case were analysed first, which had a valid sample size of 348. The variables accounted for in the correlation tests were PLP score, thermal comfort vote, visual comfort vote, hearing comfort vote, IAQ (indoor air quality) vote and overall environmental comfort vote. Therefore, the normality of all these variables was examined. It should be noted that the five environmental comfort votes were treated as a discrete interval scale in this investigation. Table D.7 describes the statistical results of the normality tests. According to these statistics, the Z_{kurtosis} values of the PLP score (5) and hearing comfort vote (-4.56) and Z_{skewness} of the thermal comfort vote (-3.87) were significantly different from a normal distribution, $\rho < 0.001$.

Table D.7 Descriptive data of environmental comfort votes and PLP scores and *Z*-values of skewness and kurtosis in AC case

Statistics	**PLP Score (5 items)**	**Thermal Comfort**	**Visual Comfort**	**Hearing Comfort**	**IAQ**	**Overall Comfort**
Valid N	348	348	348	348	348	348
Mean	2.992	3.79	3.44	3.95	3.57	3.73
Median	3.0000	4.00	3.00	4.00	3.00	4.00
Std. Deviation	0.53763	0.942	1.038	0.894	0.913	0.851
Variance	0.289	0.887	1.077	0.798	0.833	0.724
Skewness (Std. Error)	-0.050 (0.131)	-0.507 (0.131)	-0.071 (0.131)	-0.118 (0.131)	0.097 (0.131)	-0.152 (0.131)
Z_{skewness}	-0.38	**-3.87**	-0.54	-0.90	0.74	-1.16
Kurtosis (Std. Error)	1.679 (0.261)	-0.302 (0.261)	-0.764 (0.261)	-1.189 (0.261)	-0.447 (0.261)	-0.363 (0.261)
Z_{kurtosis}	**6.43**	-1.16	-2.93	**-4.56**	-1.71	-1.39

As the sample size was large, i.e. higher than 200, a visual inspection of the histograms was carried out. Figure D.6 shows the frequency charts with normal curves for all the data. The data distribution of the PLP scores seemed to be pointy while the data distribution of hearing comfort vote appeared to be fairly bimodal. The remaining variables, thermal comfort, visual comfort, IAQ and overall environmental comfort, seemed to be normally distributed. Since the correlations between PLP scores and five environmental comfort votes were to be compared, Spearman’s rho was considered a proper test for all the datasets because not all the data were normally distributed.



(a) (b)

(c) (d)

(e) (f)

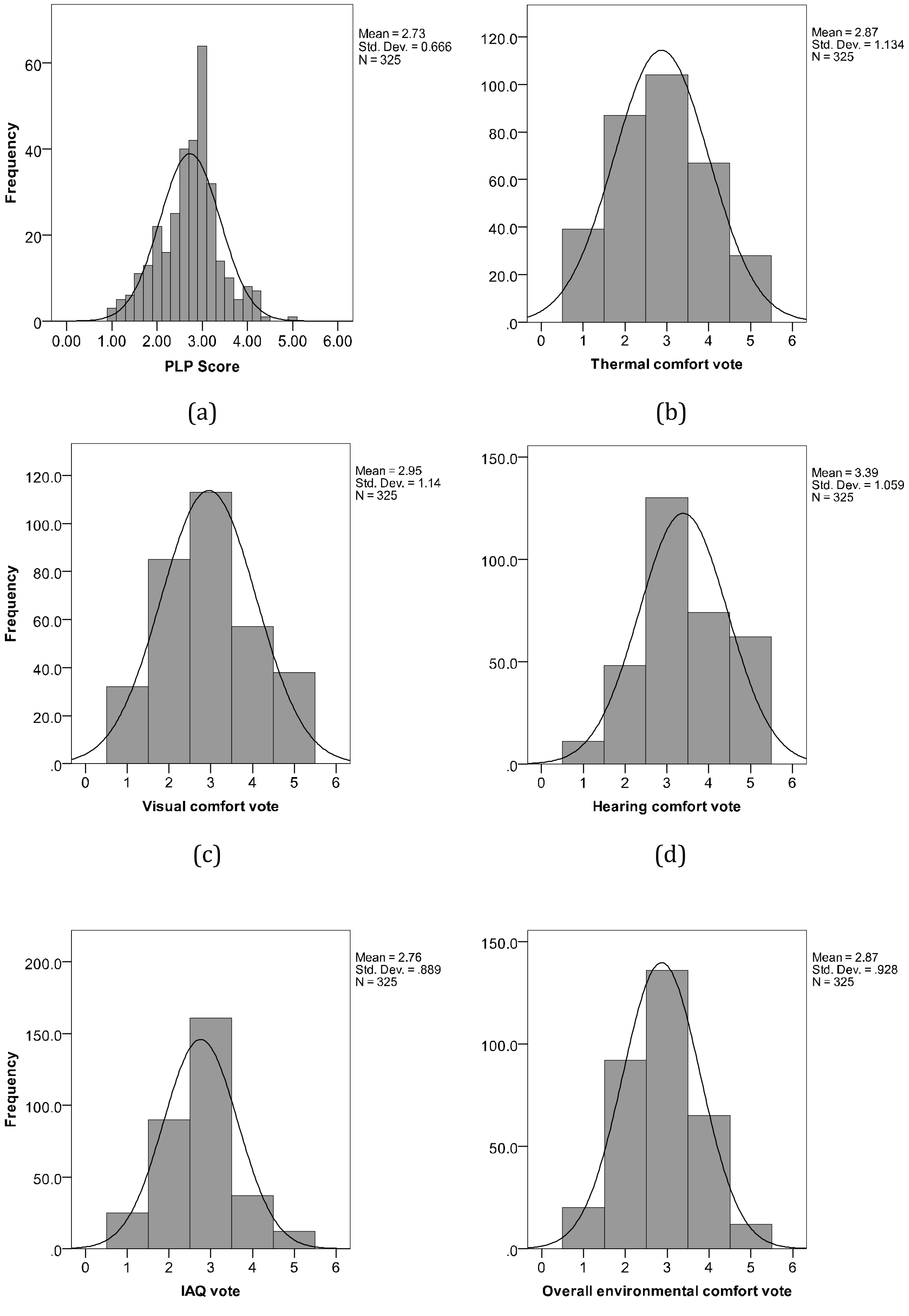
Figure D.6 Histograms with a normal curve for the variables in the AC case: (a) PLP score, (b) thermal comfort vote, (c) visual comfort vote, (d) hearing comfort vote, (e) IAQ vote and (f) overall environmental comfort vote

Next, the data collected for the ANV case were tested, where the valid sample size was 325. As before, PLP scores and five environmental comfort votes were included in the normality tests and Table D.8 presents the statistical results. Absolute values of Z_{skewness} or Z_{kurtosis} for all the data were not significant at $\rho < 0.001$. In other words, the data distribution was not significantly different from a normal distribution.

Table D.8 Descriptive data of environmental comfort votes and PLP scores and *Z*-values of skewness and kurtosis in ANV case

Statistics	PLP Score	Thermal Comfort	Visual Comfort	Hearing Comfort	IAQ	Overall Comfort
Valid N	325	325	325	325	325	325
Mean	2.7292	2.87	2.95	3.39	2.76	2.87
Median	2.80	3.00	3.00	3.00	3.00	3.00
Std. Deviation	0.66595	1.134	1.140	1.059	0.889	0.928
Variance	0.443	1.286	1.300	1.122	0.789	0.862
Skewness (Std. Error)	-0.094 (0.135)	0.115 (0.135)	0.172 (0.135)	-0.040 (0.135)	0.151 (0.135)	0.080 (0.135)
Z_{skewness}	-0.70	0.85	1.27	-0.30	1.12	0.59
Kurtosis (Std. Error)	0.382 (0.270)	-0.722 (0.270)	-0.662 (0.270)	-0.611 (0.270)	0.303 (0.270)	-0.276 (0.270)
Z_{kurtosis}	1.41	-2.67	-2.45	-2.26	1.12	-1.02

Figure D.7 shows histograms for the ANV data which were used to confirm the statistical results. However, as mentioned earlier, the correlations of the variables were to be compared, not only within the AC group but also between the AC and ANV groups. Therefore, using the same test was necessary to make the results comparable. Therefore, Spearman's rho correlation was still more appropriate since the data distribution of some variables in the AC case was not normal.



(a)

(b)

(c)

(d)

(e)

(f)

Figure D.7 Histograms with a normal curve for the variables in the ANV case: (a) PLP score, (b) thermal comfort vote, (c) visual comfort vote, (d) hearing comfort vote, (e) IAQ vote and (f) overall environmental comfort vote

3.2 Normality tests for the two comparative groups

In this part, the normality of the PLP scores categorised by thermal mode and thermal comfort vote were tested. The objective of the tests is to choose the most suitable statistical tool, i.e. independent t-test or Mann-Whitney U test, for comparing the two means of the PLP scores of students in AC and ANV environments (see Subsection 6.3.2.3, Chapter 6, p. 271). As shown in Table D.9, there were three separate comparisons: 1) Uncomfortable AC and ANV students, 2) Neutral AC and ANV students and 3) Comfortable AC and ANV students.

Table D.9 Frequencies and percentages of respondents in the three-paired comparative groups

	Thermal Comfort Vote	**Thermal Mode**				**Row Total**	
		AC		**ANV**			
		Count	**N %**	**Count**	**N %**	**Count**	**N %**
1st Comparison	Uncomfortable	36	22.2%	126	77.8%	162	100%
2nd Comparison	Neutral	81	43.8%	104	56.2%	185	100%
3rd Comparison	Comfortable	231	70.9%	95	29.1%	326	100%

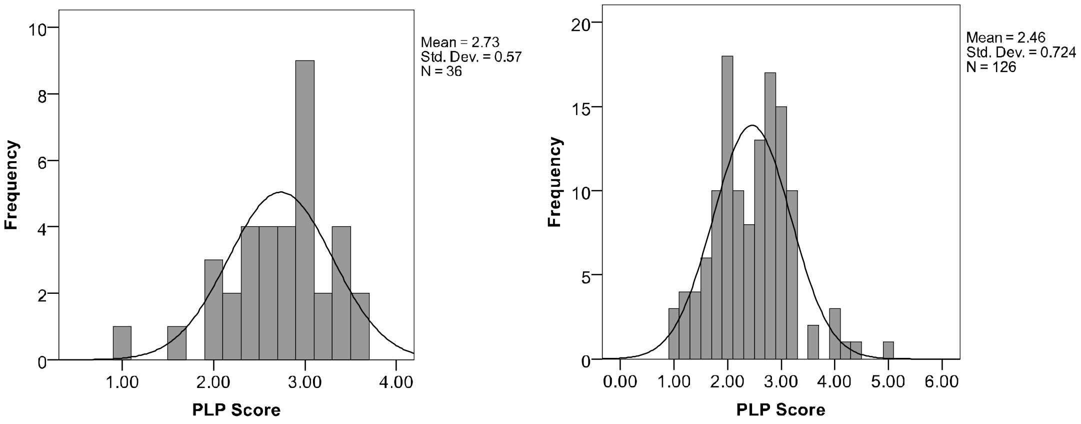
3.2.1 Uncomfortable AC versus uncomfortable ANV group

Table D.10 shows the descriptive data for the PLP scores of students in the uncomfortable group. The valid sample size of the AC and ANV cases were 36 and 126, respectively. According to the *Z*-scores for skewness and kurtosis, it can be concluded with certainty that the data in both sub-groups were normally distributed as neither of the absolute *Z*-scores exceeded 3.29.

Table D.10 Descriptive data of PLP scores of uncomfortable group and *Z*-values of skewness and kurtosis classified by thermal mode

Statistics (PLP Score)	Thermal Mode	
	AC	ANV
Valid N	36	126
Mean	2.7333	2.4556
Median	2.8000	2.5000
Std. Deviation	0.56971	0.72427
Variance	0.325	0.525
Skewness (Std. Error)	-0.891 (0.393)	0.431 (0.216)
$Z_{skewness}$	-2.27	2.00
Kurtosis (Std. Error)	1.173 (0.768)	0.735 (0.428)
$Z_{kurtosis}$	1.53	1.72

Histograms of the PLP scores for the AC and ANV cases are presented in Figure D.8 to confirm the statistical results. Consequently, the data were deemed suitable for use in a parametric independent t-test to compare the PLP scores of students in the AC and ANV uncomfortable groups.



(a) AC

(b) ANV

Figure D.8 Histograms with a normal curve of the PLP scores of students in uncomfortable group in two thermal conditions: (a) AC mode and (b) ANV mode

3.2.2 Neutral AC versus neutral ANV group

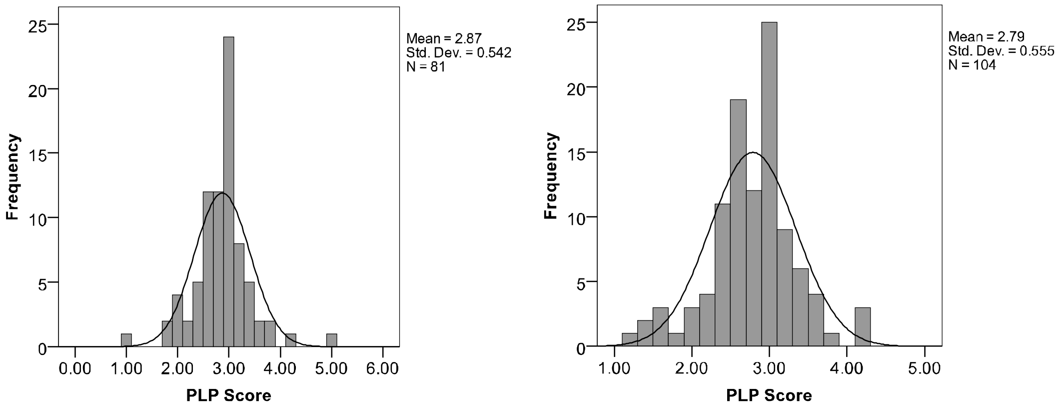
In Table D.11, the statistics of PLP scores of neutral group are presented comparing AC and ANV modes. The valid N for AC and ANV conditions were 81 and 104 respectively.

Considering the Z-values, the normality tests show that the kurtosis of PLP scores in AC mode was highly significantly different from normal ($Z_{\text{kurtosis}} = 6.39$, $\rho < 0.001$). Since the sample size was not large, the statistical test was sufficient to draw a conclusion.

Table D.11 Descriptive data of PLP scores of neutral group and Z-values of skewness and kurtosis classified by thermal mode

Statistics (PLP Score)	**Thermal Mode**	
	AC	**ANV**
Valid N	81	104
Mean	2.8691	2.7865
Median	3.0000	2.8000
Std. Deviation	0.54237	0.55478
Variance	0.294	0.308
Skewness (Std. Error)	0.206 (0.267)	-0.255 (0.237)
Z_{skewness}	0.77	-1.07
Kurtosis (Std. Error)	3.756 (0.529)	1.089 (0.469)
Z_{kurtosis}	**7.10**	2.32

Figure D.9 shows histograms with a normal curve of the data. In AC case, the data appeared to be pointy which are consistent with the statistical results.



(a) AC (b) ANV

Figure D.9 Histograms with a normal curve of the PLP scores of students in neutral group in two thermal conditions: (a) AC mode and (b) ANV mode

In summary, it was more appropriate to use non-parametric Mann-Whitney U test for the comparison of PLP scores of students in neutral groups.

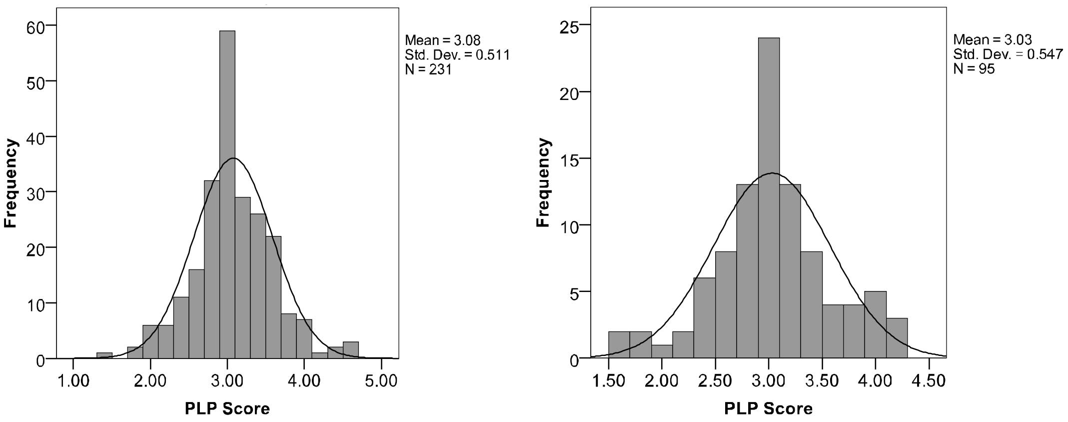
3.2.3 Comfortable AC versus comfortable ANV group

In the third comparison, the distribution of the PLP scores of students who felt comfortable was tested. The sample sizes of the AC and ANV cases were 231 and 95, respectively. Table D.12 shows the descriptive statistics as well as *Z*-values of skewness and kurtosis. From the *Z*-values there was no sign of non-normal distribution of the data in both the AC and ANV cases.

Table D.12 Descriptive data of PLP scores of comfortable group and *Z*-values of skewness and kurtosis classified by thermal mode

Statistics (PLP Score)	**Thermal Mode**	
	AC	**ANV**
Valid N	231	95
Mean	3.0753	3.0295
Median	3.0000	3.0000
Std. Deviation	0.51147	0.54653
Variance	0.262	0.299
Skewness (Std. Error)	0.107 (0.160)	-0.110 (0.247)
$Z_{skewness}$	0.67	-0.44
Kurtosis (Std. Error)	0.955 (0.319)	0.499 (0.490)
$Z_{kurtosis}$	2.99	1.02

The histograms in Figure D.10 also confirm the statistical results. Therefore, in the third comparison an independent t-test can be used.



(a) AC

(b) ANV

Figure D.10 Histograms with normal curves for the PLP scores of students in the comfortable group in two thermal conditions: (a) AC mode and (b) ANV mode

APPENDIX E: COMPLETE RESULTS OF ALL THE STATISTICAL OUTPUTS FROM PASW

This appendix presents the complete results of all the statistical analyses performed in Study 1: Thermal adaptive opportunity scoring system and acceptance of assisted natural ventilation survey, Study 2: Pro-environmental attitudes, adaptive behaviour and daily thermal experience survey and Study 4: Learning and thermal performance survey respectively. PASW was the statistical package used for these analyses.

PART 1 - STUDY 1

1.1 Multinomial logistic regression

The results of MLoR for predicting students' acceptance of ANV (see Subsection 5.2.2.4, Chapter 5, p. 183) are divided into two subsections: Subsection 1.1.1 for the cool season and Subsection 1.1.2 for the hot season. Then, the comparison of the acceptance of ANV mode between the two seasons is shown in Subsection 1.1.3.

1.1.1 Acceptance of assisted natural ventilation in the cool season

The MLoR analysis for predicting the acceptance of the ANV mode in the cool season was performed for three trials.

Cool Season: Trial 1

Table E.1 Code sheet for the variables in the multinomial logistic regression analysis, ANVcool – Trial 1

Variable	Description (scale)	Codes/Values	Name
1. DV	Do you agree that you would still be able to maintain your comfort if using natural ventilation and fans (if available) instead of air-conditioning within this classroom in the cool season? (nominal)	1 = Disagree (ref.) 2 = Uncertain 3 = Agree	ANVcool
2. IV	Adaptive opportunity for door operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPdoor
3. IV	Adaptive opportunity for window operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPwindow
4. IV	Adaptive opportunity for fan operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPfan

Table E.2 Case processing summary for the multinomial logistic regression analysis, ANVcool – Trial 1

Variables		N	Marginal Percentage
Acceptance of ANV in the cool season	Disagree	61	7.0%
	Uncertain	259	29.9%
	Agree	546	63.0%
Opportunity for door operation	Low	357	41.2%
	Moderate	324	37.4%
	High	185	21.4%
Opportunity for window operation	Low	218	25.2%
	Moderate	346	40.0%
	High	302	34.9%
Opportunity for fan operation	Low	380	43.9%
	Moderate	149	17.2%
	High	337	38.9%
Valid		866	100%
Missing		12	
Total		878	
Subpopulation		26[a]	

a. The dependent variable has only one value observed in 4 (15.4%) subpopulations.

Table E.3 Model fitting information of the multinomial logistic regression model, ANVcool – Trial 1

Model	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	258.843	268.370	254.843			
Final	187.322	254.016	159.322	95.521	12	0.000

Table E.4 Goodness-of-fit tests for the multinomial logistic regression model, ANVcool – Trial 1

	Chi-Square	df	Sig.
Pearson	40.210	38	0.373
Deviance	45.632	38	0.185

Table E.5 Likelihood ratio tests for the multinomial logistic regression model, ANVcool – Trial 1

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Chi-Square[b]	df	Sig.
Intercept	187.322	254.016	159.322[a]	0.000	0	.
OPPdoor	190.152	237.791	170.152	10.830	4	0.029
OPPwindow	206.978	254.617	186.978	27.656	4	0.000
OPPfan	215.413	263.052	195.413	36.092	4	0.000

a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.

b. The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

Table E.6 Parameter estimates of the multinomial logistic regression model, ANVcool – Trial 1

Acceptance of ANV in the Cool Season[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% CI for Exp(B)	
								Lower Bound	Upper Bound
Uncertain	Intercept	1.428	0.409	12.211	1	0.000			
	[OPPdoor =1]	1.562	0.574	7.397	1	0.007	4.767	1.547	14.689
	[OPPdoor =2]	0.881	0.531	2.755	1	0.097	2.413	0.853	6.831
	[OPPdoor =3]	0[b]	.	.	0	.	.	.	.
	[OPPwindow =1]	-1.403	0.580	5.851	1	0.016	0.246	0.079	0.766
	[OPPwindow =2]	-0.554	0.534	1.076	1	0.300	0.575	0.202	1.637
	[OPPwindow =3]	0[b]	.	.	0	.	.	.	.
	[OPPfan =1]	-0.357	0.387	0.850	1	0.356	0.700	0.327	1.495
	[OPPfan =2]	0.016	0.516	0.001	1	0.975	1.016	0.370	2.796
	[OPPfan =3]	0[b]	.	.	0	.	.	.	.
Agree	Intercept	2.977	0.382	60.597	1	0.000			
	[OPPdoor =1]	1.784	0.558	10.214	1	0.001	5.956	1.994	17.790
	[OPPdoor =2]	1.068	0.511	4.378	1	0.036	2.911	1.070	7.919
	[OPPdoor =3]	0[b]	.	.	0	.	.	.	.
	[OPPwindow =1]	-2.369	0.566	17.500	1	0.000	0.094	0.031	0.284
	[OPPwindow =2]	-1.047	0.517	4.105	1	0.043	0.351	0.128	0.966
	[OPPwindow =3]	0[b]	.	.	0	.	.	.	.
	[OPPfan =1]	-1.297	0.369	12.352	1	0.000	0.273	0.133	0.563
	[OPPfan =2]	-0.425	0.494	0.739	1	0.390	0.654	0.248	1.723
	[OPPfan =3]	0[b]	.	.	0	.	.	.	.
a. The reference category is: Disagree.									
b. This parameter is set to zero because it is redundant.									

Note: R^2 = 0.10 (Cox and Snell), 0.13 (Nagelkerke), 0.05 (McFadden). Model $\chi^2(12) = 95.52$, $\rho < 0.001$. * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.

Cool Season: Trial 2

Table E.7 Code sheet for the variables in the multinomial logistic regression analysis, ANVcool – Trial 2

Variable	Description (scale)	Codes/Values	Name
1. DV	Do you agree that you would still be able to maintain your comfort if using natural ventilation and fans (if available) instead of air-conditioning within this classroom in the cool season? (nominal)	1 = Disagree (ref.) 2 = Uncertain 3 = Agree	ANVcool
2. IV	Adaptive opportunity for window operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPwindow
3. IV	Adaptive opportunity for fan operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPfan

Table E.8 Case processing summary for the multinomial logistic regression analysis, ANVcool – Trial 2

Variables		N	Marginal Percentage
Acceptance of ANV in the cool season	Disagree	61	7.0%
	Uncertain	259	29.8%
	Agree	548	63.1%
Opportunity for window operation	Low	218	25.1%
	Moderate	346	39.9%
	High	304	35.0%
Opportunity for fan operation	Low	380	43.8%
	Moderate	149	17.2%
	High	339	39.1%
Valid		868	100%
Missing		10	
Total		878	
Subpopulation		9	

Table E.9 Model fitting information of the multinomial logistic regression model, ANVcool – Trial 2

Model	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	170.478	180.011	166.478			
Final	100.763	148.425	80.763	85.715	8	0.000

Table E.10 Goodness-of-fit tests for the multinomial logistic regression model, ANVcool – Trial 2

	Chi-Square	df	Sig.
Pearson	9.936	8	0.270
Deviance	10.426	8	0.236

Table E.11 Likelihood ratio tests for the multinomial logistic regression model, ANVcool – Trial 2

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Chi-Square[b]	df	Sig.
Intercept	100.763	148.425	80.763[a]	0.000	0	.
OPPwindow	114.622	143.219	102.622	21.858	4	0.000
OPPfan	131.056	159.653	119.056	38.292	4	0.000
a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.						
b. The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.						

Table E.12 Parameter estimates of the multinomial logistic regression model, ANVcool – Trial 2

Acceptance of ANV in the Cool Season[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% CI for Exp(B)	
								Lower Bound	Upper Bound
Uncertain	Intercept	1.747	0.385	20.562	1	0.000			
	[OPPwindow =1]	-0.259	0.380	0.465	1	0.495	0.772	0.366	1.626
	[OPPwindow =2]	0.158	0.390	0.164	1	0.686	1.171	0.545	2.515
	[OPPwindow =3]	0[b]	.	.	0	.	.	.	.
	[OPPfan =1]	-0.400	0.387	1.070	1	0.301	0.670	0.314	1.430
	[OPPfan =2]	0.008	0.514	0.000	1	0.988	1.008	0.368	2.759
	[OPPfan =3]	0[b]	.	.	0	.	.	.	.
Agree	Intercept	3.396	0.363	87.324	1	0.000			
	[OPPwindow =1]	-1.099	0.366	9.018	1	0.003	0.333	0.163	0.683
	[OPPwindow =2]	-0.234	0.371	0.397	1	0.529	0.791	0.382	1.638
	[OPPwindow =3]	0[b]	.	.	0	.	.	.	.
	[OPPfan =1]	-1.355	0.368	13.539	1	0.000	0.258	0.125	0.531
	[OPPfan =2]	-0.440	0.491	0.802	1	0.371	0.644	0.246	1.687
	[OPPfan =3]	0[b]	.	.	0	.	.	.	.

a. The reference category is: Disagree.

b. This parameter is set to zero because it is redundant.

Note: R^2 = 0.09 (Cox and Snell), 0.11 (Nagelkerke), 0.06 (McFadden). Model $\chi^2(8) = 85.72$, $\rho < 0.001$. * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.

Cool Season: Trial 3

Table E.13 Code sheet for the variables in the multinomial logistic regression analysis, ANVcool – Trial 3

Variable	Description (scale)	Codes/Values	Name
1. DV	Do you agree that you would still be able to maintain your comfort if using natural ventilation and fans (if available) instead of air-conditioning within this classroom in the cool season? (nominal)	1 = Disagree (ref.) 2 = Uncertain 3 = Agree	ANVcool
2. IV	Adaptive opportunity for window operation (dichotomous)	1 = Low 0 = Moderate-High	OPPwindow
3. IV	Adaptive opportunity for fan operation (dichotomous)	1 = Low 0 = Moderate-High	OPPfan

Table E.14 Case processing summary for the multinomial logistic regression analysis, ANVcool – Trial 3

Variables		N	Marginal Percentage
Acceptance of ANV in the cool season	Disagree	61	7.0%
	Uncertain	259	29.8%
	Agree	548	63.1%
Opportunity for window operation	Low	218	25.1%
	Moderate-High	650	74.9%
Opportunity for fan operation	Low	380	43.8%
	Moderate-High	488	56.2%
Valid		868	100%
Missing		10	
Total		878	
Subpopulation		4	

Table E.15 Model fitting information of the multinomial logistic regression model, ANVcool – Trial 3

Model	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	120.677	130.209	116.677			
Final	52.894	81.491	40.894	75.783	4	0.000

Table E.16 Goodness-of-fit tests for the multinomial logistic regression model, ANVcool – Trial 3

	Chi-Square	df	Sig.
Pearson	2.119	2	0.347
Deviance	2.260	2	0.323

Table E.17 Likelihood ratio tests for the multinomial logistic regression model, ANVcool – Trial 3

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Chi-Square[b]	df	Sig.
Intercept	52.894	81.491	40.894[a]	0.000	0	.
OPPwindow	69.747	88.811	61.747	20.853	2	0.000
OPPfan	83.971	103.036	75.971	35.078	2	0.000

a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.

b. The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

Table E.18 Parameter estimates of the multinomial logistic regression model, ANVcool – Trial 3

Acceptance of ANV in the Cool Season[a]		B	Std. Error	Wald	df	Sig.	Exp (B)	95% CI for Exp(B)	
								Lower Bound	Upper Bound
Uncertain	Intercept	1.839	0.260	49.899	1	0.000			
	[OPPwindow =1]	-0.348	0.298	1.358	1	0.244	0.706	0.394	1.267
	[OPPwindow =0]	0[b]	.	.	0	.	.	.	.
	[OPPfan =1]	-0.398	0.314	1.603	1	0.205	0.672	0.363	1.244
	[OPPfan =0]	0[b]	.	.	0	.	.	.	.
Agree	Intercept	3.128	0.248	159.68	1	0.000			
	[OPPwindow =1]	-1.022	0.292	12.280	1	0.000	0.360	0.203	0.637
	[OPPwindow =0]	0[b]	.	.	0	.	.	.	.
	[OPPfan =1]	-1.196	0.301	15.736	1	0.000	0.303	0.168	0.546
	[OPPfan =0]	0[b]	.	.	0	.	.	.	.
a. The reference category is: Disagree.									
b. This parameter is set to zero because it is redundant.									

Note: R^2 = 0.08 (Cox and Snell), 0.10 (Nagelkerke), 0.05 (McFadden). Model $\chi^2(4) = 75.78$, $\rho < 0.001$. * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.

Table E.19 Observed and predicted outcome based on the multinomial logistic regression model, ANVcool – Trial 3

Observed	Predicted			
	Disagree	Uncertain	Agree	Percent Correct
Disagree	0	25	36	.0%
Uncertain	0	69	190	26.6%
Agree	0	54	494	90.1%
Overall Percentage	.0%	17.1%	82.9%	64.9%

Table E.20 Observed and predicted cell frequencies and percentages of ANV votes based on the multinomial logistic regression model, ANVcool – Trial 3

Opportunity for Fan Operation	Opportunity for Window Operation	Acceptance of ANV for the Cool Season	Frequency			Percentage[a]	
			Observed	Predicted	Pearson Residual	Observed	Predicted
Low	Low	Disagree	25	22.876	0.483	16.9%	15.5%
		Uncertain	69	68.242	0.125	46.6%	46.1%
		Agree	54	56.882	-0.487	36.5%	38.4%
	Moderate-High	Disagree	17	19.124	-0.507	7.3%	8.2%
		Uncertain	80	80.758	-0.105	34.5%	34.8%
		Agree	135	132.118	0.382	58.2%	56.9%
Moderate-High	Low	Disagree	3	5.124	-0.975	4.3%	7.3%
		Uncertain	22	22.758	-0.193	31.4%	32.5%
		Agree	45	42.118	0.704	64.3%	60.2%
	Moderate-High	Disagree	16	13.876	0.580	3.8%	3.3%
		Uncertain	88	87.242	0.091	21.1%	20.9%
		Agree	314	316.882	-0.329	75.1%	75.8%
a. The percentages are based on total observed frequencies in each subpopulation.							

Based on the MLoR output in this trial, two logit models were generated to estimate the odds of students' votes on the use of the ANV mode during the cool season. The levels of adaptive opportunity for window and fan operations are the independent variables. The equations are:

1) The log odds of voting Agree versus Disagree (π_A/π_D) for ANVcool

$$\text{Log}\ (\pi_A/\pi_D) = 3.128 + (1.022)(\mathit{LowOPPwindow}) + (1.196)(\mathit{LowOPPfan})$$

Equation E.1

If OPPwindow = Low and OPPfan = Low;

$$\begin{aligned} \text{Log}\ (\pi_A/\pi_D) &= 3.128 + (-1.022)(\mathit{1}) + (-1.196)(\mathit{1}) \\ &= 0.91 \\ \pi_A/\pi_D &= \exp(0.91) \\ &= 2.48 \end{aligned}$$

2) The log odds of voting Uncertain versus Disagree (π_U/π_D) for ANVcool

$$\text{Log}\ (\pi_U/\pi_D) = 1.839 + (-0.348)(\mathit{LowOPPwindow}) + (-0.398)(\mathit{LowOPPfan})$$

Equation E.2

If OPPwindow = Low and OPPfan = Low;

$$\begin{aligned} \text{Log}\ (\pi_U/\pi_D) &= 1.839 + (-0.348)(\mathit{1}) + (-0.398)(\mathit{1}) \\ &= 1.093 \\ \pi_U/\pi_D &= \exp(1.093) \\ &= 2.98 \end{aligned}$$

The probabilities of the outcomes (Agree, Uncertain and Disagree) when OPPwindow and OPPfan are low can be estimated by Equations E.3 – E.5;

$$\pi_A = \frac{(\pi_A/\pi_D)}{(\pi_A/\pi_D) + (\pi_U/\pi_D) + 1}$$

Equation E.3

$$\begin{aligned} &= 2.48 / (1 + 2.48 + 2.98) \\ &= 0.38 \end{aligned}$$

$$\pi_U = \frac{(\pi_U/\pi_D)}{(\pi_A/\pi_D) + (\pi_U/\pi_D) + 1}$$

Equation E.4

$$= 2.98 / (1 + 2.48 + 2.98)$$

$$= 0.46$$

$$\text{thus,} \quad \pi_D = 1 - \pi_A - \pi_U \qquad \textbf{Equation E.5}$$

$$= 1 - 0.38 - 0.46$$

$$= 0.16$$

According to the estimated probabilities, it can be interpreted that – giving low OPPwindow and OPPfan, the probabilities of a student to vote 'Agree', 'Uncertain', or 'Disagree' on ANV mode for the cool season were 38%, 46% and 16% respectively. Therefore, if a student perceive low opportunities to use windows and fans, the equations predict that the student is more likely to vote 'Uncertain' rather than 'Agree' or 'Disagree' to the use of ANV mode during the cool season.

From Table E.21, the models predicted that students are likely to agree to the use of ANV during the cool season, but they would be uncertain about it if they perceive low opportunities to use windows and fans.

Table E.21 Estimated probabilities of votes on the acceptance of the ANV mode in the cool season

OPPwindow	**OPPfan**	**ANVcool**		
		Disagree	**Uncertain**	**Agree**
Low	**Low**	0.15	**0.46**	0.38
	Moderate-High	0.07	0.33	**0.60**
Moderate-High	**Low**	0.08	0.35	**0.57**
	Moderate-High	0.03	0.21	**0.76**

1.1.2 Acceptance of assisted natural ventilation in the hot season

The MLoR analysis for predicting the acceptance of ANV mode in the hot season was performed for three trials.

Hot Season: Trial 1

Table E.22 Code sheet for the variables in the multinomial logistic regression analysis, ANVhot – Trial 1

Variable	Description (scale)	Codes/Values	Name
1. DV	Do you agree that you would still be able to maintain your comfort when using natural ventilation and fans (if available) instead of air-conditioning within this classroom during the hot season? (nominal)	1 = Disagree (ref.) 2 = Uncertain 3 = Agree	ANVhot
2. IV	Adaptive opportunity for door operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPdoor
3. IV	Adaptive opportunity for window operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPwindow
4. IV	Adaptive opportunity for fan operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPfan
5. IV	Participant's daily thermal experience (nominal)	1 = Full AC 2 = Mixed-mode 3 = Full NV	TExp
6. IV	Participant's income (Baht/Month) (ordinal)	1 ≤ 2,500 2 = 2,501-5,000 3 = 5,001-7,500 4 = 7,501-10,000 5 > 10,000	Income

Table E.23 Case processing summary for the multinomial logistic regression analysis, ANVhot – Trial 1

Variables		N	Marginal Percentage
Acceptance of ANV in the hot season	Disagree	282	33.3%
	Uncertain	338	39.9%
	Agree	227	26.8%
Opportunity for door operation	Low	350	41.3%
	Moderate	318	37.5%
	High	179	21.1%
Opportunity for window operation	Low	216	25.5%
	Moderate	339	40.0%
	High	292	34.5%
Opportunity for fan operation	Low	372	43.9%
	Moderate	148	17.5%
	High	327	38.6%
Daily thermal experience	Full AC	230	27.2%
	Mixed-mode	586	69.2%
	Full NV	31	3.7%
Participant's income (Baht/Month)	</= 2,500	70	8.3%
	2,501-5,000	440	51.9%
	5,001-7,500	204	24.1%
	7501-10,000	112	13.2%
	> 10,000	21	2.5%
Valid		847	100%
Missing		31	
Total		878	
Subpopulation		178[a]	
a. The dependent variable has only one value observed in 78 (43.8%) subpopulations.			

Table E.24 Model fitting information of the multinomial logistic regression model, ANVhot – Trial 1

Model	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	773.022	782.506	769.022			
Final	733.819	857.103	681.819	87.203	24	0.000

Table E.25 Goodness-of fit tests for the multinomial logistic regression model, ANVhot – Trial 1

	Chi-Square	df	Sig.
Pearson	327.873	330	0.523
Deviance	368.126	330	0.073

Table E.26 Likelihood ratio tests for the multinomial logistic regression model, ANVhot – Trial 1

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Chi-Square[b]	df	Sig.
Intercept	733.819	857.103	681.819[a]	0.000	0	.
OPPdoor	734.336	838.653	690.336	8.517	4	0.074
OPPwindow	727.678	831.995	683.678	1.858	4	0.762
OPPfan	753.149	857.466	709.149	27.330	4	0.000
TExp	735.855	840.172	691.855	10.036	4	0.040
Income	738.841	824.192	702.841	21.022	8	0.007

a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.

b. The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

Table E.27 Parameter estimates for the multinomial logistic regression model, ANVhot – Trial 1

Acceptance of ANV in the Hot Season[a]		B	Std. Error	Wald	df	Sig.	Exp (B)	95% CI for Exp(B)	
								Lower Bound	Upper Bound
Uncertain	Intercept	-0.794	0.732	1.176	1	0.278			
	[OPPdoor =1]	0.289	0.295	0.955	1	0.328	1.334	0.748	2.380
	[OPPdoor =2]	0.538	0.281	3.675	1	0.055	1.713	0.988	2.969
	[OPPdoor =3]	0[b]	.	.	0	.	.	.	.
	[OPPwindow =1]	-0.377	0.295	1.636	1	0.201	0.686	0.385	1.222
	[OPPwindow =2]	-0.242	0.247	0.954	1	0.329	0.785	0.484	1.275
	[OPPwindow =3]	0[b]	.	.	0	.	.	.	.
	[OPPfan =1]	-0.480	0.199	5.838	1	0.016	0.619	0.419	0.913
	[OPPfan =2]	0.228	0.260	0.766	1	0.381	1.256	0.754	2.092
	[OPPfan =3]	0[b]	.	.	0	.	.	.	.
	[TExp=1]	0.190	0.506	0.140	1	0.708	1.209	0.448	3.259
	[TExp=2]	0.093	0.492	0.036	1	0.850	1.098	0.418	2.881
	[TExp=3]	0[b]	.	.	0	.	.	.	.
	[Income=1]	1.164	0.594	3.838	1	0.050	3.204	0.999	10.273
	[Income=2]	1.191	0.518	5.289	1	0.021	3.290	1.192	9.078
	[Income=3]	0.807	0.532	2.305	1	0.129	2.241	0.791	6.353
	[Income=4]	0.374	0.551	0.460	1	0.498	1.454	0.493	4.285
	[Income=5]	0[b]	.	.	0	.	.	.	.
Agree	Intercept	-0.726	0.936	0.603	1	0.438			
	[OPPdoor =1]	-0.009	0.331	0.001	1	0.977	0.991	0.517	1.896
	[OPPdoor =2]	0.568	0.308	3.392	1	0.066	1.764	0.964	3.229
	[OPPdoor =3]	0[b]	.	.	0	.	.	.	.
	[OPPwindow =1]	-0.132	0.336	0.154	1	0.695	0.877	0.454	1.693
	[OPPwindow =2]	-0.154	0.272	0.321	1	0.571	0.857	0.503	1.462
	[OPPwindow =3]	0[b]	.	.	0	.	.	.	.
	[OPPfan =1]	-1.021	0.224	20.867	1	0.000	0.360	0.232	0.558
	[OPPfan =2]	-0.057	0.279	0.042	1	0.837	0.944	0.547	1.631
	[OPPfan =3]	0[b]	.	.	0	.	.	.	.
	[TExp=1]	-0.939	0.508	3.426	1	0.064	0.391	0.145	1.057
	[TExp=2]	-0.463	0.479	0.934	1	0.334	0.630	0.246	1.609
	[TExp=3]	0[b]	.	.	0	.	.	.	.
	[Income=1]	1.946	0.839	5.382	1	0.020	6.999	1.352	36.224
	[Income=2]	1.539	0.786	3.835	1	0.050	4.659	0.999	21.733
	[Income=3]	1.342	0.797	2.838	1	0.092	3.829	0.803	18.254
	[Income=4]	0.977	0.815	1.439	1	0.230	2.657	0.538	13.122
	[Income=5]	0[b]	.	.	0	.	.	.	.
a. The reference category is: Disagree.									
b. This parameter is set to zero because it is redundant.									

Note: R^2 = 0.10 (Cox and Snell), 0.11 (Nagelkerke), 0.05 (McFadden). Model $\chi^2(24)$ = 87.20, $\rho < 0.001$. * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.

Hot Season: Trial 2

Table E.28 Code sheet for the variables in the multinomial logistic regression analysis, ANVhot – Trial 2

Variable	Description (scale)	Codes/Values	Name
1. DV	Do you agree that you would still be able to maintain your comfort when using natural ventilation and fans (if available) instead of air-conditioning within this classroom during the hot season? (nominal)	1 = Disagree (ref.) 2 = Uncertain 3 = Agree	ANVhot
2. IV	Adaptive opportunity for fan operation (ordinal)	1 = Low 2 = Moderate 3 = High	OPPfan
3. IV	Participant's daily thermal experience (nominal)	1 = Full AC 2 = Mixed-mode 3 = Full NV	TExp
4. IV	Participant's income (Baht/Month) (ordinal)	1 ≤ 2,500 2 = 2,501-5,000 3 = 5,001-7,500 4 = 7,501-10,000 5 > 10,000	Income

Table E.29 Case processing summary for the multinomial logistic regression analysis, ANVhot – Trial 2

Variables		N	Marginal Percentage
Acceptance of ANV in the hot season	Disagree	284	33.4%
	Uncertain	339	39.8%
	Agree	228	26.8%
Opportunity for fan operation	Low	373	43.8%
	Moderate	148	17.4%
	High	330	38.8%
Daily thermal experience	Full AC	232	27.3%
	Mixed-mode	588	69.1%
	Full NV	31	3.6%
Participant's income (Baht/Month)	</= 2,500	70	8.2%
	2,501-5,000	442	51.9%
	5,001-7,500	205	24.1%
	7501-10,000	113	13.3%
	> 10,000	21	2.5%
Valid		851	100%
Missing		27	
Total		878	
Subpopulation		38[a]	
a. The dependent variable has only one value observed in 2 (5.3%) subpopulations.			

Table E.30 Model fitting information of the final multinomial logistic regression model, ANVhot – Trial 2

Model	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	314.870	324.363	310.870			
Final	272.397	357.832	236.397	74.473	16	0.000

Table E.31 Goodness-of-fit tests for the multinomial logistic regression model, ANVhot – Trial 2

	Chi-Square	df	Sig.
Pearson	54.768	58	0.596
Deviance	62.881	58	0.308

Table E.32 Likelihood ratio tests for the multinomial logistic regression model, ANVhot – Trial 2

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Chi-Square[b]	df	Sig.
Intercept	272.397	357.832	236.397[a]	0.000	0	.
OPPfan	295.888	362.337	267.888	31.491	4	0.000
TExp	275.403	341.853	247.403	11.006	4	0.026
Income	275.647	323.111	255.647	19.250	8	0.014

a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.

b. The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.

Table E.33 Parameter estimates of the multinomial logistic regression model, ANVhot – Trial 2

Acceptance of ANV in the Hot Season[a]		B	Std. Error	Wald	df	Sig.	Exp(B)	95% CI for Exp(B)	
								Lower Bound	Upper Bound
Uncertain	Intercept	-0.600	0.713	0.708	1	0.400			
	[OPPfan =1]	-0.545	0.187	8.518	1	0.004	0.580	0.402	0.836
	[OPPfan =2]	0.190	0.252	0.569	1	0.451	1.209	0.738	1.982
	[OPPfan =3]	0^b	.	.	0	.	.	.	.
	[TExp=1]	0.143	0.504	0.081	1	0.776	1.154	0.430	3.097
	[TExp=2]	0.098	0.491	0.040	1	0.842	1.103	0.422	2.886
	[TExp=3]	0^b	.	.	0	.	.	.	.
	[Income=1]	1.163	0.591	3.874	1	0.049	3.200	1.005	10.189
	[Income=2]	1.132	0.514	4.848	1	0.028	3.103	1.133	8.503
	[Income=3]	0.772	0.527	2.146	1	0.143	2.164	0.770	6.078
	[Income=4]	0.387	0.547	0.500	1	0.480	1.472	0.504	4.299
	[Income=5]	0^b	.	.	0	.	.	.	.
Agree	Intercept	-0.548	0.916	0.358	1	0.550			
	[OPPfan =1]	-1.048	0.210	24.977	1	0.000	0.351	0.232	0.529
	[OPPfan =2]	-0.078	0.269	0.084	1	0.771	0.925	0.546	1.567
	[OPPfan =3]	0^b	.	.	0	.	.	.	.
	[TExp=1]	-1.003	0.502	3.993	1	0.046	0.367	0.137	0.981
	[TExp=2]	-0.466	0.474	0.965	1	0.326	0.627	0.248	1.590
	[TExp=3]	0^b	.	.	0	.	.	.	.
	[Income=1]	1.948	0.836	5.425	1	0.020	7.013	1.362	36.119
	[Income=2]	1.485	0.784	3.590	1	0.058	4.414	0.950	20.501
	[Income=3]	1.279	0.794	2.594	1	0.107	3.592	0.758	17.030
	[Income=4]	1.033	0.810	1.627	1	0.202	2.811	0.574	13.754
	[Income=5]	0^b	.	.	0	.	.	.	.

a. The reference category is: Disagree.

b. This parameter is set to zero because it is redundant.

Note: $R^2 = 0.08$ (Cox and Snell), 0.10 (Nagelkerke), 0.04 (McFadden). Model $\chi^2(16) = 74.47$, $\rho < 0.001$. * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.

Hot Season: Trial 3

Table E.34 Code sheet for the variables in the multinomial logistic regression analysis, ANVhot – Trial 3

Variable	Description (scale)	Codes/Values	Name
1. DV	Do you agree that you would still be able to maintain your comfort when using natural ventilation and fans (if available) instead of air-conditioning within this classroom during the hot season? (nominal)	1 = Disagree (ref.) 2 = Uncertain 3 = Agree	ANVhot
2. IV	Adaptive opportunity for fan operation (dichotomous)	1 = Low 0 = Moderate-High	OPPfan
3. IV	Participant's daily thermal experience (dichotomous)	1 = Full AC 0 = Non-full AC	TExp
4. IV	Participant's income (Baht/Month) (dichotomous)	1 ≤ 5,000 0 > 5,000	Income

Table E.35 Case processing summary for the multinomial logistic regression analysis, ANVhot – Trial 3

Variables		N	Marginal Percentage
Acceptance of ANV in the hot season	Disagree	284	33.4%
	Uncertain	339	39.8%
	Agree	228	26.8%
Opportunity for fan operation	Low	373	43.8%
	Moderate-High	478	56.2%
Daily thermal experience	Full AC	232	27.3%
	Non-full AC	619	72.7%
Participant's income (Baht/Month)	</=5,000	512	60.2%
	>5,000	339	39.8%
Valid		851	100%
Missing		27	
Total		878	
Subpopulation		8	

Table E.36 Model fitting information of the multinomial logistic regression model, ANVhot – Trial 3

Model	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC	BIC	-2 Log Likelihood	Chi-Square	df	Sig.
Intercept Only	146.360	155.853	142.360			
Final	95.275	133.246	79.275	63.085	6	0.000

Table E.37 Goodness-of-fit tests for the multinomial logistic regression model, ANVhot – Trial 3

	Chi-Square	df	Sig.
Pearson	5.750	8	0.675
Deviance	5.825	8	0.667

Table E.38 Likelihood ratio tests for the multinomial logistic regression model, ANVhot – Trial 3

Effect	Model Fitting Criteria			Likelihood Ratio Tests		
	AIC of Reduced Model	BIC of Reduced Model	-2 Log Likelihood of Reduced Model	Chi-Square[b]	df	Sig.
Intercept	95.275	133.246	79.275[a]	0.000	0	.
OPPfan	122.754	151.233	110.754	31.479	2	0.000
TExp	100.831	129.310	88.831	9.556	2	0.008
Income	102.817	131.296	90.817	11.542	2	0.003
a. This reduced model is equivalent to the final model because omitting the effect does not increase the degrees of freedom.						
b. The chi-square statistic is the difference in -2 log-likelihoods between the final model and a reduced model. The reduced model is formed by omitting an effect from the final model. The null hypothesis is that all parameters of that effect are 0.						

Table E.39 Parameter estimates of the multinomial logistic regression model, ANVhot – Trial 3

Acceptance of ANV in the Hot Season[a]		B	Std. Error	Wald	df	Sig.	Exp (B)	95% CI for Exp(B)	
								Lower Bound	Upper Bound
Uncertain	Intercept	0.157	0.160	0.960	1	0.327			
	[OPPfan=1]	-0.625	0.168	13.793	1	0.000	0.535	0.385	0.744
	[OPPfan=0]	0[b]	.	.	0	.	.	.	.
	[TExp=1]	0.039	0.181	0.045	1	0.832	1.039	0.728	1.483
	[TExp=0]	0[b]	.	.	0	.	.	.	.
	[Income=1]	0.547	0.167	10.793	1	0.001	1.729	1.247	2.396
	[Income=0]	0[b]	.	.	0	.	.	.	.
Agree	Intercept	0.120	0.171	0.487	1	0.485			
	[OPPfan=1]	-1.038	0.193	28.934	1	0.000	0.354	0.243	0.517
	[OPPfan=0]	0[b]	.	.	0	.	.	.	.
	[TExp=1]	-0.581	0.225	6.672	1	0.010	0.559	0.360	0.869
	[TExp=0]	0[b]	.	.	0	.	.	.	.
	[Income=1]	0.437	0.187	5.442	1	0.020	1.548	1.072	2.236
	[Income=0]	0[b]	.	.	0	.	.	.	.

a. The reference category is: Disagree.

b. This parameter is set to zero because it is redundant.

Note: R^2 = 0.07 (Cox and Snell), 0.08 (Nagelkerke), 0.03 (McFadden). Model $\chi^2(6) = 63.09$, $\rho < 0.001$. * $\rho < 0.05$, ** $\rho < 0.01$, *** $\rho < 0.001$.

Table E.40 Observed and predicted outcome based on the multinomial logistic regression model, ANVhot – Trial 3

Observed	**Predicted**			
	Disagree	**Uncertain**	**Agree**	**Percent Correct**
Disagree	82	202	0	28.9%
Uncertain	57	282	0	83.2%
Agree	27	201	0	0%
Overall Percentage	19.5%	80.5%	0%	42.8%

Table E.41 Observed and predicted cell frequencies and percentages of ANV votes based on the multinomial logistic regression model, ANVhot – Trial 3

Participant's Income (Baht/Month)	Daily Thermal Experience	Opportunity for Fan Operation	Acceptance of ANV in Hot Season	Frequency			Percentage[a]	
				Observed	Predicted	Pearson Residual	Observed	Predicted
</=5,000	Full AC	Low	Disagree	31	29.954	0.248	41.9%	40.5%
			Uncertain	34	33.688	0.073	45.9%	45.5%
			Agree	9	10.358	-0.455	12.2%	14.0%
		Moderate-High	Disagree	14	12.509	0.485	27.5%	24.5%
			Uncertain	24	26.284	-0.640	47.1%	51.5%
			Agree	13	12.208	0.260	25.5%	23.9%
	Non-full AC	Low	Disagree	51	49.252	0.314	38.3%	37.0%
			Uncertain	50	53.297	-0.583	37.6%	40.1%
			Agree	32	30.451	0.320	24.1%	22.9%
		Moderate-High	Disagree	49	53.285	-0.660	19.3%	21.0%
			Uncertain	113	107.732	0.669	44.5%	42.4%
			Agree	92	92.983	-0.128	36.2%	36.6%
>5,000	Full AC	Low	Disagree	39	37.888	0.265	54.9%	53.4%
			Uncertain	24	24.651	-0.162	33.8%	34.7%
			Agree	8	8.461	-0.169	11.3%	11.9%
		Moderate-High	Disagree	9	12.650	-1.274	25.0%	35.1%
			Uncertain	18	15.377	0.884	50.0%	42.7%
			Agree	9	7.973	0.412	25.0%	22.1%
	Non-full AC	Low	Disagree	43	46.906	-0.802	45.3%	49.4%
			Uncertain	33	29.364	0.807	34.7%	30.9%
			Agree	19	18.730	0.070	20.0%	19.7%
		Moderate-High	Disagree	48	41.557	1.197	35.0%	30.3%
			Uncertain	43	48.607	-1.001	31.4%	35.5%
			Agree	46	46.836	-0.151	33.6%	34.2%

a. The percentages are based on total observed frequencies in each subpopulation.

Based on the MLoR output in this trial, two logit models were generated to estimate odds of students' votes on the use of the ANV mode during the hot season. The levels of adaptive opportunity for fan operation, students' daily thermal experience and income are the independent variables. The equations are:

1) The log odds of voting Agree versus Disagree (π_A/π_D) for ANVhot

$$\text{Log}\,(\pi_A/\pi_D) = .120 + (-1.038)(\mathit{LowOPPfan}) + (-.581)(\mathit{FullAC}) + (.437)(\mathit{Income} \leq 5{,}000) \qquad \textbf{Equation E.6}$$

If OPPfan = Low, TExp = Full AC and Income ≤ 5,000 Baht/Month;

$$\begin{aligned} \text{Log}\,(\pi_A/\pi_D) &= .120 + (-1.038)(\mathit{1}) + (-0.581)(\mathit{1}) + (0.437)(\mathit{1}) \\ &= -1.062 \\ \pi_A/\pi_D &= \exp(-1.062) \\ &= 0.35 \end{aligned}$$

2) The log odds of voting Uncertain versus Disagree (π_U/π_D) for ANVhot

$$\text{Log}\,(\pi_U/\pi_D) = .157 + (-0.625)(\mathit{LowOPPfan}) + (0.039)(\mathit{FullAC}) + (0.547)(\mathit{Income}\leq 5{,}000) \qquad \textbf{Equation E.7}$$

If OPPfan = Low, TExp = Full AC and Income ≤ 5,000 Baht/Month;

$$\begin{aligned}\text{Log}\,(\pi_U/\pi_D) &= .157 + (-0.625)(\mathit{1}) + (0.039)(\mathit{1}) + (0.547)(\mathit{1})\\ &= 0.118\\ \pi_U/\pi_D &= \exp(0.118)\\ &= 1.13\end{aligned}$$

The probabilities of the outcomes (Agree, Uncertain and Disagree) when OPPfan is low; TExp is full AC; and Income is not more than 5,000 Baht/Month can be calculated by Equations E.8 – E.10.

$$\pi_A = \frac{(\pi_A/\pi_D)}{(\pi_A/\pi_D) + (\pi_U/\pi_D) + 1} \qquad \textbf{Equation E.8}$$

$$\begin{aligned}&= 0.35 / (1 + 0.35 + 1.13)\\ &= 0.14\end{aligned}$$

$$\pi_U = \frac{(\pi_U/\pi_D)}{(\pi_A/\pi_D) + (\pi_U/\pi_D) + 1} \qquad \textbf{Equation E.9}$$

$$\begin{aligned}&= 1.13 / (1 + 0.35 + 1.13)\\ &= 0.46\end{aligned}$$

thus, $\pi_D = 1 - \pi_A - \pi_U$ **Equation E.10**

$$\begin{aligned}&= 1 - 0.14 - 0.46\\ &= 0.40\end{aligned}$$

For this example, if a student has full AC daily thermal experience, monthly income lower than or equal to 5,000 Baht, and perceives low opportunity to use fans, the equations estimate that the probabilities of the student to vote ‘Agree’, ‘Uncertain’, or ‘Disagree’ on the use of ANV mode during the hot season are 14%, 46% and 40% in respective. Under these circumstances, the logit models predict that the student is more likely to vote ‘Uncertain’ rather than ‘Agree’ or ‘Disagree’ to the ANV use in the hot season.

Table E.42 shows estimated probabilities of votes on the acceptance of the ANV mode in the hot season based on different values of the independent variables in the final models (Equations E.6 and E.7).

Table E.42 Estimated probabilities of votes for the acceptance of the ANV mode in the hot season

OPPfan	TExp	Income (Baht/Month)	ANVhot		
			Disagree	Uncertain	Agree
Low	**Full AC**	**≤5,000**	0.40	**0.46**	0.14
		>5,000	**0.53**	0.35	0.12
	Non-full AC	**≤5,000**	0.37	**0.40**	0.23
		>5,000	**0.49**	0.31	0.20
High	**Full AC**	**≤5,000**	0.24	**0.52**	0.24
		>5,000	0.35	**0.43**	0.22
	Non-full AC	**≤5,000**	0.21	**0.42**	0.37
		>5,000	0.30	**0.36**	0.34

1.1.3 Acceptance of assisted natural ventilation between seasons

The odds of 'Agree' versus 'Disagree' votes and of 'Uncertain' versus 'Disagree' votes for the use of ANV mode during the cool and hot seasons are compared in this subsection. This is to show the effect of perceived seasonal variations on students' votes.

Table E.43 Cross table for assisted natural ventilation votes by season (count)

		ANV votes for the hot season			Total
		Disagree	Uncertain	Agree	
ANV votes for the cool season	**Disagree**	36	20	6	62 (a)
	Uncertain	116	120	26	262 (b)
	Agree	140	207	201	548 (c)
Total		292 (d)	347 (e)	233 (f)	872

Calculation of odds ratio:

$$\text{Odds ratio} = \frac{\text{Odds of 'Agree' vs 'Disagree' in cool season}}{\text{Odds of 'Agree' vs 'Disagree' in hot season}} \qquad \textbf{Equation E.11}$$

$$= (c/a) \,/\, (f/d)$$

From Table E.43,

Odds ratio = (548/62) / (233/292)
= 11.08

Calculation of 95%CI of the odds ratio:

Upper limit OR = exp(upper limit lnOR) **Equation E.12**
Lower limit OR = exp(lower limit lnOR) **Equation E.13**

where:

Upper limit lnOR = lnOR + [1.96 × SE (lnOR)] **Equation E.14**
Lower limit lnOR = lnOR – [1.96 × SE (lnOR)] **Equation E.15**
SE (lnOR) = sqr(Variance of lnOR) **Equation E.16**
Variance of lnOR = (1/a) + (1/c) + (1/d) + (1/f) **Equation E.17**

From Table E.43,

Variance of lnOR = (1/62) + (1/548) + (1/292) + (1/233)
= 0.016 + 0.002 + 0.003 + 0.004
= 0.026

SE (lnOR) = sqr(0.026)
= 0.16

Upper limit lnOR = ln(11.1) + (1.96 × 0.16)
= 2.4 + 0.31
= 2.71

Lower limit lnOR = ln(4.64) - (1.96 × 0.1)
= 2.4 – 0.31
= 2.09

Upper limit OR = exp(2.71)
= 15.0

Lower limit OR = exp(2.09)
= 8.1

Calculation of odds ratio:

$$\begin{aligned}\text{Odds ratio} &= \frac{\text{Odds of 'Uncertain' vs 'Disagree' in cool season}}{\text{Odds of 'Uncertain' vs 'Disagree' in hot season}} \qquad \textbf{Equation E.18}\\ &= (b/a) / (e/d)\end{aligned}$$

From Table E.43,

$$\begin{aligned}\text{Odds ratio} &= (262/62) / (347/292)\\ &= 3.56\end{aligned}$$

Calculation of 95%CI of the odds ratio (based on Equations E.12 – E.17):

$$\begin{aligned}\text{Variance of lnOR} &= (1/62) + (1/262) + (1/292) + (1/347)\\ &= 0.016 + 0.004 + 0.003 + 0.003\\ &= 0.026\end{aligned}$$

$$\begin{aligned}\text{SE (lnOR)} &= \text{sqr}(0.026)\\ &= 0.16\end{aligned}$$

$$\begin{aligned}\text{Upper limit lnOR} &= \ln(3.56) + (1.96 \times 0.16)\\ &= 1.27 + 0.31\\ &= 1.58\end{aligned}$$

$$\begin{aligned}\text{Lower limit lnOR} &= \ln(3.56) - (1.96 \times 0.1)\\ &= 1.27 - 0.31\\ &= 0.96\end{aligned}$$

$$\begin{aligned}\text{Upper limit OR} &= \exp(1.58)\\ &= 4.9\end{aligned}$$

$$\begin{aligned}\text{Lower limit OR} &= \exp(0.96)\\ &= 2.6\end{aligned}$$

1.2 MULTIPLE LINEAR REGRESSION

This section presents the complete results of MLiR for estimating the opportunity for fan and window operations based on building design (see Subsection 5.2.2.5, Chapter 5, p. 198).

1.2.1 Opportunity for fan operation

Table E.44 Code sheet for the variables used in the multiple linear regression analysis for the opportunity scores of fan operation

Variable	Description (scale)	Codes/Values	Name
1. DV	Opportunity scores of fan operation (interval)	1-25	ANVhot
2. IV	Number of fan/student: dummy variable 1 (dichotomous)	1 = Low Nfan 0 = Otherwise	Low Nfan
3. IV	Number of fan/student: dummy variable 2 (dichotomous)	1 = Moderate Nfan 0 = Otherwise	Moderate Nfan
4. IV	Number of fan/student: dummy variable 3 (dichotomous)	1 = High Nfan 0 = Otherwise	High Nfan

Table E.45 Descriptive statistics for OPPfan analysis

Variables	Mean	Std. Deviation	N
Opportunity for fan operation	13.06	8.485	873
Number of fan per student	0.05050	0.044873	873

Table E.46 Model summary of the multiple linear regression model for OPPfan

Model[a]	R	R^2	Adjusted R^2	S.E. of the Estimate	Change Statistics					Durbin-Watson
					R^2 Change	F Change	df_1	df_2	Sig. F Change	
1	0.819[b]	0.671	0.670	4.875	0.671	591.085	3	869	0.000	1.885
a. Dependent Variable: Opportunity for fan operation										
b. Predictors: (Constant), Low Nfan, Moderate Nfan, High Nfan										

Table E.47 Coefficients of the variables in the multiple linear regression model for OPPfan estimation

Model[a]		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	95% CI for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	3.889	0.274		14.183	0.000	3.351	4.427
	NfanLow	10.071	1.013	0.198	9.944	0.000	8.083	12.058
	NfanModerate	14.574	0.365	0.858	39.984	0.000	13.859	15.290
	NfanHigh	14.577	0.523	0.592	27.889	0.000	13.552	15.603
a. Dependent Variable: Opportunity for fan operation								

Table E.48 Coefficients of the variables in the multiple linear regression model for OPPfan estimation (continued)

Model[a]		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)					
	NfanLow	0.018	0.320	0.193	0.954	1.048
	NfanModerate	0.602	0.805	0.778	0.822	1.217
	NfanHigh	0.255	0.687	0.543	0.840	1.190
a. Dependent Variable: Opportunity for fan operation						

1.2.2 Opportunity for window operation

Table E.49 Code sheet for the variables used in the multiple linear regression analysis for the opportunity scores of window operation

Variable	Description (scale)	Codes/Values	Name
1. DV	Opportunity scores of window operation (interval)	1-25	OPPwindow
2. IV	Building location (dichotomous)	1 = Suburban 0 = Urban	Loc
3. IV	Cross ventilation (dichotomous)	1 = Yes 0 = No	Vent
4. IV	Current view (dichotomous)	1 = Built/Natural environments 0 = No view/Unseen	View

Table E.50 Descriptive statistics for OPPwindow analysis

Variables	Mean	Std. Deviation	N
Opportunity for window operation	14.80	6.889	874
Building location	0.51	0.500	874
Current view	0.49	0.500	874
Cross ventilation	0.44	0.497	874

Table E.51 Model summary of the multiple linear regression model for OPPwindow

Model^a	R	R^2	Adjusted R^2	S.E. of the Estimate	Change Statistics					Durbin-Watson
					R^2 Change	F Change	df_1	df_2	Sig. F Change	
1	0.219^b	0.048	0.045	6.733	0.048	14.676	3	870	0.000	1.827
a. Dependent Variable: Opportunity for window operation										
b. Predictors: (Constant), Cross ventilation, Building location, Current view										

Table E.52 Coefficients of the variables in the multiple linear regression model for OPPwindow estimation

Model^a		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	95% CI for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	12.633	0.428		29.542	0.000	11.793	13.472
	Building location	2.178	0.510	0.158	4.272	0.000	1.177	3.178
	Current view	1.279	0.520	0.093	2.458	0.014	0.258	2.301
	Cross ventilation	0.968	0.470	0.070	2.062	0.040	0.046	1.890
a. Dependent Variable: Opportunity for window operation								

Table E.53 Coefficients of the variables in the multiple linear regression model for OPPwindow estimation (continued)

Model[a]		Correlations			Collinearity Statistics	
		Zero-order	Partial	Part	Tolerance	VIF
1	(Constant)					
	Building location	0.197	0.143	0.141	0.799	1.252
	Current view	0.149	0.083	0.081	0.766	1.305
	Cross ventilation	0.046	0.070	0.068	0.954	1.048
a. Dependent Variable: Opportunity for window operation						

PART 2 - STUDY 2

2.1 ONE-WAY ANOVA TEST

One-way ANOVA tests were performed by PASW statistical package to compare the levels of pro-environment attitudes and adaptive behaviour, i.e. Adaptive behaviour at home (BEH), Acceptance of air-conditioning reduction policy in university (POL) and Pro-environmental attitudes (PEA), of students with different daily thermal experiences, i.e. Full AC, Mixed-mode and Full NV (see Subsection 5.3.2.3, Chapter 5, p. 218). The comparative groups and sample size of each are presented in Table E.54.

Table E.54 Frequencies and percentages of respondents in three comparative groups

	Dependent Variables	Group						Row Total	
		Full AC		Mixed-mode		Full NV			
		Count	N%	Count	N%	Count	N%	Count	N%
1st Comparison	Adaptive Behaviour at Home (BEH)	269	21.1%	893	70.1%	112	8.8%	1,274	100%
2nd Comparison	AC Policy Acceptance (POL)	269	21.1%	893	70.1%	112	8.8%	1,274	100%
3rd Comparison	Pro-Environmental Attitudes (PEA)	269	21.1%	893	70.1%	112	8.8%	1,274	100%

2.1.1 Adaptive behaviour at home (BEH)

Table E.55 Descriptive statistics for the BEH scores categorised by daily thermal experience groups

Daily Thermal Experience	N	Mean BEH Score	Std. Deviation	Std. Error	95% CI for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Full AC	269	3.0030	0.66624	0.04062	2.9230	3.0830	1.40	4.80
Mixed-mode	893	3.5153	0.97489	0.03262	3.4513	3.5794	1.00	5.00
Full NV	112	4.4393	0.68856	0.06506	4.3104	4.5682	1.80	5.00
Total	1,274	3.4884	0.96467	0.02703	3.4354	3.5414	1.00	5.00

Table E.56 Test of homogeneity of variances in the BEH scores

Levene Statistic	**df_1**	**df_2**	**Sig.**
68.446	2	1,271	0.000

Table E.57 Welch and Brown-Forsythe tests of equality of the BEH scores

	Statistic[a]	**df_1**	**Adjust df_2**	**Sig.**
Welch	177.606	2	308.145	0.000
Brown-Forsythe	154.951	2	509.726	0.000
a. Asymptotically F distributed.				

Table E.58 Test of linear trend of the BEH scores

			Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	(Combined)		165.303	2	82.652	103.057	0.000
	Linear Term	Unweighted	163.133	1	163.133	203.408	0.000
		Weighted	**155.412**	**1**	**155.412**	**193.780**	**0.000**
		Deviation	9.892	1	9.892	12.334	0.000
	Quadratic Term	Unweighted	9.892	1	9.892	12.334	0.000
		Weighted	9.892	1	9.892	12.334	0.000
Within Groups			1019.345	1271	0.802		
Total			1184.648	1273			

Table E.59 Games-Howell test for comparing the BEH scores between the three different daily thermal experience groups

(I) Daily Thermal Experience	**(J) Daily Thermal Experience**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% CI**	
					Lower Bound	**Upper Bound**
Mixed-mode	**Full AC**	**0.51237***	**0.05210**	**0.000**	**0.3900**	**0.6348**
	Full NV	-0.92394*	0.07278	0.000	-1.0960	-0.7519
Full NV	**Full AC**	**1.43631***	**0.07670**	**0.000**	**1.2552**	**1.6174**
	Mixed-mode	**0.92394***	**0.07278**	**0.000**	**0.7519**	**1.0960**
*. The mean difference is significant at the ρ = 0.05 level.						

A series of independent t-tests for comparing means of the BEH scores between any pairs of thermal experience groups were performed to identify the effect size of the differences.

Table E.60 Independent t-test statistics for comparing the BEH scores of the students in Full NV and Full AC groups

t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% CI of the Difference**	
					Lower	**Upper**
18.982	379	0.000	1.43631	0.07567	1.28754	1.58509

Effect size: r = sqr[$t^2/(t^2 + df)$] **Equation E.19**

= sqr[18.982^2 / (18.982^2 + 379)]

= 0.70

Table E.61 Independent t-test statistics for comparing the BEH scores of the students in MM and Full AC groups

t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% CI of the Difference**	
					Lower	**Upper**
9.834	644.632	0.000	0.51237	0.05210	0.41006	0.61467

Effect size: r = sqr[$t^2/(t^2 + df)$]

= sqr[9.834^2 / (9.834^2 + 644.6)]

= 0.36

Table E.62 Independent t-test statistics for comparing the BEH scores of the students in Full NV and MM groups

t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**Std. Error Difference**	**95% CI of the Difference**	
					Lower	**Upper**
12.694	172.473	0.000	0.92394	0.07278	0.78028	1.06761

Effect size: r = sqr[$t^2/(t^2 + df)$]

= sqr[12.694^2 / (12.694^2 + 172.5)]

= 0.69

2.1.2 Acceptance of air-conditioning reduction policy in university (POL)

Table E.63 Descriptive statistics for the POL scores categorised by daily thermal experience groups

Daily Thermal Experience	**N**	**Mean POL Score**	**Std. Deviation**	**Std. Error**	**95% CI for Mean**		**Min.**	**Max.**
					Lower Bound	**Upper Bound**		
Full AC	269	2.6870	0.92592	0.05645	2.5758	2.7981	1.00	5.00
Mixed-mode	893	3.0137	0.78451	0.02625	2.9621	3.0652	1.00	5.00
Full NV	112	3.0804	0.90063	0.08510	2.9117	3.2490	1.00	5.00
Total	1,274	2.9505	0.83752	0.02346	2.9045	2.9966	1.00	5.00

Table E.64 Test of homogeneity of variances in the POL scores

Levene Statistic	**df_1**	**df_2**	**Sig.**
16.254	2	1,271	0.000

Table E.65 Welch and Brown-Forsythe tests of equality of the POL scores

	Statistic[a]	df_1	Adjusted df_2	Sig.
Welch	14.724	2	256.056	0.000
Brown-Forsythe	15.079	2	383.572	0.000
a. Asymptotically F distributed.				

Table E.66 Test of linear trend of the POL scores

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		24.130	2	12.065	17.650	0.000
	Linear Term	Unweighted	12.236	1	12.236	17.901	0.000
		Weighted	**20.183**	**1**	**20.183**	**29.527**	**0.000**
		Deviation	3.947	1	3.947	5.774	0.016
	Quadratic Term	Unweighted	3.947	1	3.947	5.774	0.016
		Weighted	3.947	1	3.947	5.774	0.016
Within Groups			868.795	1,271	0.684		
Total			892.925	1,273			

Table E.67 Games-Howell test for comparing the POL scores between the three different daily thermal experience groups

(I) Daily Thermal Experience	(J) Daily Thermal Experience	Mean Difference (I-J)	Std. Error	Sig.	95% CI	
					Lower Bound	Upper Bound
Mixed-mode	**Full AC**	**0.32667***	**0.06226**	**0.000**	**0.1802**	**0.4732**
	Full NV	-0.06670	0.08906	0.735	-0.2778	0.1444
Full NV	**Full AC**	**0.39337***	**0.10212**	**0.000**	**0.1523**	**0.6344**
	Mixed-mode	0.06670	0.08906	0.735	-0.1444	0.2778
*. The mean difference is significant at the ρ = 0.05 level.						

A series of independent t-tests for comparing means of POL scores between any pairs of thermal experience groups were performed to identify the effect size of the differences.

Table E.68 Independent t-test statistics for comparing the POL scores of the students in Full NV and Full AC groups

t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
					Lower	Upper
3.808	379	0.000	0.39337	0.10330	0.19026	0.59648

Effect size: $r = \mathrm{sqr}[t^2/(t^2 + df)]$

$= \mathrm{sqr}[3.808^2 / (3.808^2 + 379)]$

$= 0.19$

Table E.69 Independent t-test statistics for comparing the POL scores of the students in MM and Full AC groups

t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
					Lower	Upper
5.247	390.950	0.000	0.32667	0.06226	0.20427	0.44908

Effect size: r = sqr[$t^2/(t^2 + df)$]

= sqr[5.247^2 / (5.247^2 + 391)]

= 0.26

Table E.70 Independent t-test statistics for comparing the POL scores of the students in Full NV and MM groups

t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
					Lower	Upper
0.749	132.982	0.455	0.06670	0.08906	-0.10946	0.24285

Effect size: r = sqr[$t^2/(t^2 + df)$]

= sqr[0.749^2 / (0.749^2 + 133)]

= 0.06

2.1.3 Pro-environmental attitudes (PEA)

Table E.71 Descriptive statistics for the PEA scores categorised by daily thermal experience groups

Daily Thermal Experience	N	Mean PEA Score	Std. Deviation	Std. Error	95% CI for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Full AC	269	2.9628	0.61561	0.03753	2.8889	3.0367	1.63	4.38
Mixed-mode	893	3.3445	0.62127	0.02079	3.3037	3.3853	1.50	5.00
Full NV	112	3.3382	0.58549	0.05532	3.2285	3.4478	1.63	4.63
Total	1,274	3.2633	0.63587	0.01781	3.2284	3.2983	1.50	5.00

Table E.72 Test of homogeneity of variances in the PEA scores

Levene Statistic	df_1	df_2	Sig.
0.688	2	1,271	0.503

Table E.73 Test of linear trend of the PEA scores

			Sum of Squares	df	Mean Square	F	Sig.
Between Groups	(Combined)		30.800	2	15.400	40.449	0.000
	Linear Term	Unweighted	11.141	1	11.141	29.261	0.000
		Weighted	**22.011**	**1**	**22.011**	**57.811**	**0.000**
		Deviation	8.790	1	8.790	23.086	0.000
	Quadratic Term	Unweighted	8.790	1	8.790	23.086	0.000
		Weighted	8.790	1	8.790	23.086	0.000
Within Groups			483.910	1,271	0.381		
Total			514.711	1,273			

Table E.74 Hochberg's GT2 test for comparing the PEA scores between the three different daily thermal experience groups

(I) Daily Thermal Experience	(J) Daily Thermal Experience	Mean Difference (I-J)	Std. Error	Sig.	95% CI	
					Lower Bound	Upper Bound
Mixed-mode	**Full AC**	**0.38166***	**0.04292**	**0.000**	**0.2791**	**0.4843**
	Full NV	0.00632	0.06185	0.999	-0.1416	0.1542
Full NV	**Full AC**	**0.37534***	**0.06939**	**0.000**	**0.2095**	**0.5412**
	Mixed-mode	-0.00632	0.06185	0.999	-0.1542	0.1416
*. The mean difference is significant at the ρ = 0.05 level.						

A series of independent t-tests for comparing means of PEA scores between any pairs of thermal experience groups were performed to identify the effect size of the differences.

Table E.75 Independent t-test statistics for comparing the PEA scores of the students in Full NV and Full AC groups

t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
					Lower	Upper
5.499	379	0.000	0.37534	0.06825	0.24114	0.50955

Effect size: r = sqr[$t^2/(t^2 + df)$]
= sqr[5.499^2 / (5.499^2 + 379)]
= 0.27

Table E.76 Independent t-test statistics for comparing the PEA scores of the students in MM and Full AC groups

t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
					Lower	Upper
8.851	1160	0.000	0.38166	0.04312	0.29706	0.46626

Effect size: r = sqr[$t^2/(t^2 + df)$]

= sqr[8.851^2 / (8.851^2 + 1160)]

= 0.25

Table E.77 Independent t-test statistics for comparing the PEA scores of the students in Full NV and Mixed-mode groups

t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
					Lower	Upper
-0.102	1003	0.919	-0.00632	0.06189	-0.12777	0.11513

Effect size: r = sqr[$t^2/(t^2 + df)$]

= sqr[-0.102^2 / (-0.102^2 + 1003)]

= 0

PART 3 - STUDY 4

3.1 INDEPENDENT T-TEST AND MANN-WHITNEY U TEST

This part presents the results of independent t-tests or, alternatively, Mann-Whitney U tests, for comparing means of PLP scores of students in AC and ANV environments (see Subsection 6.3.2.3, Chapter 6, p. 271). A list of the comparative groups and the numbers of valid respondents in each group are presented in Table E.78.

Table E.78 Frequencies and percentages of respondents in three comparisons of PLP scores

	Thermal Comfort Vote	Thermal Mode				Row Total	
		AC		ANV			
		Count	N %	Count	N %	Count	N %
1st Comparison	Uncomfortable	36	22.2%	126	77.8%	162	100%
2nd Comparison	Neutral	81	43.8%	104	56.2%	185	100%
3rd Comparison	Comfortable	231	70.9%	95	29.1%	326	100%

3.1.1 Uncomfortable AC versus uncomfortable ANV group

Table E.79 Descriptive statistics of the PLP scores of students in the Uncomfortable group categorised by thermal mode

Thermal Mode	N	Mean	Std. Deviation	Std. Error Mean
AC	36	2.7333	0.56971	0.09495
ANV	126	2.4556	0.72427	0.06452

Table E.80 Independent t-test statistics for comparing the PLP scores of students in the AC and ANV Uncomfortable groups

t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
					Lower	Upper
2.120	160	0.036	0.27778	0.13104	0.01898	0.53657

Effect size: r = sqr[$t^2/(t^2 + df)$]

= sqr[2.120^2 / (2.120^2 + 160)]

= 0.17

3.1.2 Neutral AC versus neutral ANV group

Table E.81 Ranks of the PLP scores of students in the Neutral group

Thermal Mode	N	Mean Rank	Sum of Ranks
AC	81	97.53	7900.00
ANV	104	89.47	9305.00
Total	185		

Table E.82 Mann-Whitney U test statistics for comparing the PLP scores of students in the AC and ANV Neutral groups

	PLP Score[a]
Mann-Whitney U	3845.000
Wilcoxon W	9305.000
Z	-1.030
Asymp. Sig. (2-tailed)	0.303
a. Grouping Variable: Thermal mode	

Effect size: r = Z/sqr(N) **Equation E.20**

= -1.030/sqr(185)

= -0.08

3.1.3 Comfortable AC versus comfortable ANV group

Table E.83 Descriptive statistics of the PLP scores of students in the Comfortable group

Thermal Mode	N	Mean	Std. Deviation	Std. Error Mean
AC	231	3.0753	0.51147	0.03365
ANV	95	3.0295	0.54653	0.05607

Table E.84 Independent t-test statistics comparing the PLP scores of students in the AC and ANV Comfortable groups

t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% CI of the Difference	
					Lower	Upper
0.721	324	0.472	0.04585	0.06361	-0.07929	0.17099

Effect size: r = sqr[$t^2/(t^2 + df)$]

= sqr[0.721^2 / (0.721^2 + 324)]

= 0.04

3.2 CORRELATION TESTS

This section shows the results of Pearson correlation tests between indoor air temperatures and PLP scores of students in AC and ANV classrooms (see Subsection 6.3.3, Chapter 6, p. 279).

Table E.85 Correlations test between indoor air temperatures and PLP scores of students in AC classrooms

		PLP Score	Indoor air temperature
PLP Score	Pearson Correlation	1	-0.050
	Sig. (2-tailed)		0.352
	N	348	348

Table E.86 Correlations test between indoor air temperatures and PLP scores of students in ANV classrooms

		PLP Score	Indoor air temperature
PLP Score	Pearson Correlation	1	0.023
	Sig. (2-tailed)		0.677
	N	325	325

3.3 CROSS TABLE

This section shows the frequencies and percentages of students in AC and ANV classrooms classified by their thermal comfort group and PLP score group (see Subsection 6.3.3, Chapter 6, p. 279).

Table E.87 Frequencies and percentages of students by thermal comfort votes and PLP score groups

Thermal Comfort Group		**PLP Score Group**			**Total**
		Low (1-2.4)	**Medium (2.5-3.4)**	**High (3.5-5)**	
AC					
Uncomfortable	Count	11	23	2	36
	% within Thermal comfort group	30.6%	**63.9%**	5.6%	100%
Neutral	Count	14	61	6	81
	% within Thermal comfort group	17.3%	**75.3%**	7.4%	100%
Comfortable	Count	26	162	43	231
	% within Thermal comfort group	11.3%	**70.1%**	18.6%	100%
ANV					
Uncomfortable	Count	63	55	8	126
	% within Thermal comfort group	**50.0%**	43.7%	6.3%	100%
Neutral	Count	25	71	8	104
	% within Thermal comfort group	24.0%	**68.3%**	7.7%	100%
Comfortable	Count	13	66	16	95
	% within Thermal comfort group	13.7%	**69.5%**	16.8%	100%